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Abstract

Standards and specifications apply a rule of thumb when determining the distance of two adjacent weld joints, but they rarely give any clear technical justification for the predetermined values. It is vital to understand the implications it has on mechanical and material properties of the weld joint when exceeding these set requirements. The objective of this thesis was aimed at obtaining quantifiable data regarding the implications of having two adjacent weld joints in close proximity.

An experimental analysis was designed where the resulting material behavior was analyzed and documented. The test consisted of six welded 500x300x15 mm S420G2+M steel plates, each having two adjacent parallel butt welds along its full length. The distances between two adjacent welds were 50, 15 and 5 mm in order to analyze the effect a variation in distance have on the properties of the initial weld pass.

All plates were welded at KIWA in Stavanger, and subsequently mechanically tested at Quality Lab in Forsand in accordance with NS-EN ISO 15614-1:2017. A WPQ was established in order to maintain conformance in all subsequent welding operations and ensure replicability of the experiment. Fatigue test and microstructural analysis (optical microscope) was conducted at the Department of Mechanical and Structural Engineering and Materials Science at the University of Stavanger. Residual stress analysis was conducted at Veqter in Bristol using ultrasound (US), Incremental Centre-Hole Drilling (ICHD) and X-ray Diffraction (XRD) technique.

The mechanical testing results from Qlab showed no reduction in the material properties from the tested specimens based on tensile tests, Charpy V Impact toughness test and Vickers hardness test. This was despite that the closest adjacent weld toes were 1.3 mm. There was no clear difference between the different results from the tests.

An optical microscope was used during the microstructural examination of three specimens with different weld to weld distances; 44 mm, 12 mm and 1.3 mm. Based on the observed microstructure in the WM and HAZ the welds at 44 mm and 12 mm between the weld toes had no visible microstructural effect. The weld that had 1.3 mm between the weld toes had a clear HAZ overlap. It did not seem to be any harmful microstructural changes in the HAZ and the heat from the secondary weld appeared to have had a normalizing effect on the initial HAZ. The results from the mechanical testing supported this observation. Because of the limitations in magnification of the optical microscope, further testing should be conducted in order to assure that this is the case. This also requires the addition of SEM and TEM results.

The objective of the fatigue test was to assess if any reduction in fatigue strength had occurred due to the weld proximity situation. The fatigue test specimens were prepared with the intention to isolate and study the microstructure. The preparation of the sample were conducted in accordance with ASTM E466-15 for a homogenous material subjected to high-cycle fatigue. Weld discontinuities was avoided in order to isolate and focus on the HAZ microstructure, and any geometrical and angular weld stress concentrations was removed. The result from the test was that the specimen at 5 mm distance with overlapping welds seemed to have failed in the

secondary weld. The reason for the crack initiation was not possible to determine. Important to note though, was that the failure did not occur in the first weld, which was the focus of the study, but the secondary overlapping weld. In the absence of stress concentrations, the remaining fatigue specimens failed in the parent metal. The sample size was limited, but the results indicated that at 12 mm between two weld toes, the weld has the higher fatigue strength.

The majority of ultrasonic (US) residual stress tests that were performed showed longitudinal tensile and a compressive transverse residual stress in both the weld cap and the root of tested specimens. It was surprising to find compressive transverse residual stress in the weld, but all the subsequent residual stress test methods performed supported this result. This included XRD and ICHD. A Contour measurement planned in the future will provide the longitudinal residual stress and will be used as an additional source for calibration.

The findings in this report can assist in the assessment of a weld proximity or weld-on-weld scenarios. The welding operation did not seem to introduced any degradation of the material properties in the WM and HAZ. The mechanical properties of similar weld joints in the field could be assumed to be unaffected due to the welding of an adjacent weld.

Important to note is that this is for this type of method and materials. More testing has to be performed in other to ascertain the findings. The results can be used as a baseline for further research.

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Abbreviations

AF	Acicular Ferrite
AWS	American Welding Society
BM	Base Material
CE, CET	Carbon equivalent [%]
CGHAZ	Coarse Grain Heat-Affected Zone
FGHAZ	Flux-Cored Arc Welding
GF	Grain boundary Ferrite
GMAW	Gas Metal Arc Welding
HAZ	heat-affected zone
HV	Vickers Hardness
ICHAZ	Inter-Critical Heat-Affected Zone
ICHD	Incremental Hole-Drilling
ISO	The International Organization for Standardization
IWE	International Welding Engineer
J	Joule
MAG	Metal Active Gas
MIG	Metal Inert Gas
MMA	Manual Metal Arc
MT, MPI	Magnetic-Particle Testing
PT	Penetrant Testing
pWPS	preliminary Welding Procedure Specification
SCHAZ	Sub Critical Heat-Affected Zone
SEM	Scanning Electron Microscope
$T_{8/5}$	Cooling time (from 800 °C to 500 °C)
TEM	transmission electron microscope or Transmission electron microscopy
UTS	Ultimate Tensile Strength
WF	Widmanstätten Ferrite
WPS	Welding Procedure Specification
XRD	X-Ray Diffraction

1 Introduction

1.1 Motivation and background

Restrictions have been set on weld proximity and overlapping welds during the fabrication of steel structures in most industrial codes, standards and specifications. Two weld joints are required to have a minimum required distance between each other to comply with the design requirements. However, no technical explanation has been given in the literature for the predetermined distances. The reasoning behind the set distance is to avoid the adverse effects weld proximity or weld overlapping has on a weld joint, also known as weld-on-weld. However, during the fabrication stage this issue may be unavoidable and can also be found on existing structures. It is vital to maintain code compliance in both these scenarios in order to make an informed decision for the appropriate course of action.

Weld-on-welds are a frequent occurrence in the industry. For instance, a multi-pass weld is just several weld passes on top of each other. There is a clear difference between weld-on-welds and multi-pass welds. A multi-pass weld has been tested and approved, while a weld-on-weld scenario is when two, separately approved welds, conflict with each other by physically overlapping. An initial weld could experience unsatisfactory changes in the HAZ due to the secondary weld. Especially if the weld has been performed under controlled conditions. There are several accepted procedures for weld-on-welds that have been tested and approved. In pipelines, the overlapping of a longitudinal seam weld and a circumferential girth weld have been thoroughly documented and welding procedures have been developed for the specific cases. The nozzles in pressure containing vessels, must sometimes be in an area with several butt welds. Weld overlapping is also common in split tee connections.

We need to differentiate between weld-on-welds and weld proximity. Weld proximity issues arise when two initially approved welds do not physically overlap, but conflicts with the required minimum design distance. This is covered in several international standards. BS 2633 “Class I arc welding of ferritic steel pipework for carrying fluids”, states that the toes of adjacent butt welds shall, whenever possible, be no closer than four times the nominal thickness of the pipe [1]. BS 4515 ‘Specification for welding of steel pipelines on land and offshore’ (Section 11), states that the proximity of weld toe-to-toe distance shall not be less than four times the pipe thickness [2]. BS 2971 ‘Class II arc welding of carbon steel pipework for carrying of fluids’ (Section 10), states that if design factors are such that the meeting of more than two welded seams cannot be avoided, then appropriate precautions shall be taken which shall be agreed between the contracting parties [3]. PD5500 ‘Specification for Unfired fusion welded pressure vessels’ (Section 4.1.3), states that where any part of a vessel is made in two or more courses, the longitudinal seams shall be completed before commencing the adjoining circumferential seam(s) and, where practicable, the longitudinal seams of the adjacent courses shall be staggered by four times the nominal thickness or 100 mm, whichever is the greater, measured from the toe of the welds [4].

It is vital to have a good understanding of the implications on the material properties in a weld-on-weld and weld proximity scenario in a weld joint. In this area there is a lack of clear guidance in structural standards, codes and specifications, which has led to uncertainties on how to address the specific scenarios. Being able to identify the specific affected material properties is essential when determining what precautions to take in the assessment of a structure.

1.2 Problem statement

Predetermined distances for weld proximity have been set in most standards, codes and specifications in the industry today. There is still a lack of information regarding the implications when divergences from the requirements are necessary or have been detected in the service-life of a structure. More information is needed regarding the consequences on the material properties.

1.3 Scope of the thesis

Design an experimental procedure to test and analyze the effect two parallel adjacent welds have on each other at varying distances.

Approve a WPS for the weld configuration.

Mechanical testing in accordance with ISO 15614-1:2017:

- Visual testing
- Radiographic or ultrasonic testing
- Surface crack detection
- Vickers Hardness Test
- Charpy V Impact Test
- Transverse Tensile test
- Bending test
- Macroscopic examination

In addition, the following tests will be performed:

- Fatigue test
- Microscopic analysis
- Residual stress measurement

1.4 Organization of this thesis

The organisation of the chapters are presented in following figure. Every box corresponds to a certain chapter. A dashed line sorrounding several chapters serves the purpose of grouping the chapters into the categories "Part I: Theory" and "Part II: Experimental Investigation". Each chapter in category "Part II: Experimental Investigation" consists of a methodology, result and conclusion. In the end, a main conclusion summarizes the conclusions from the chapters. The results section of each chapter remains in each sub-chapter.

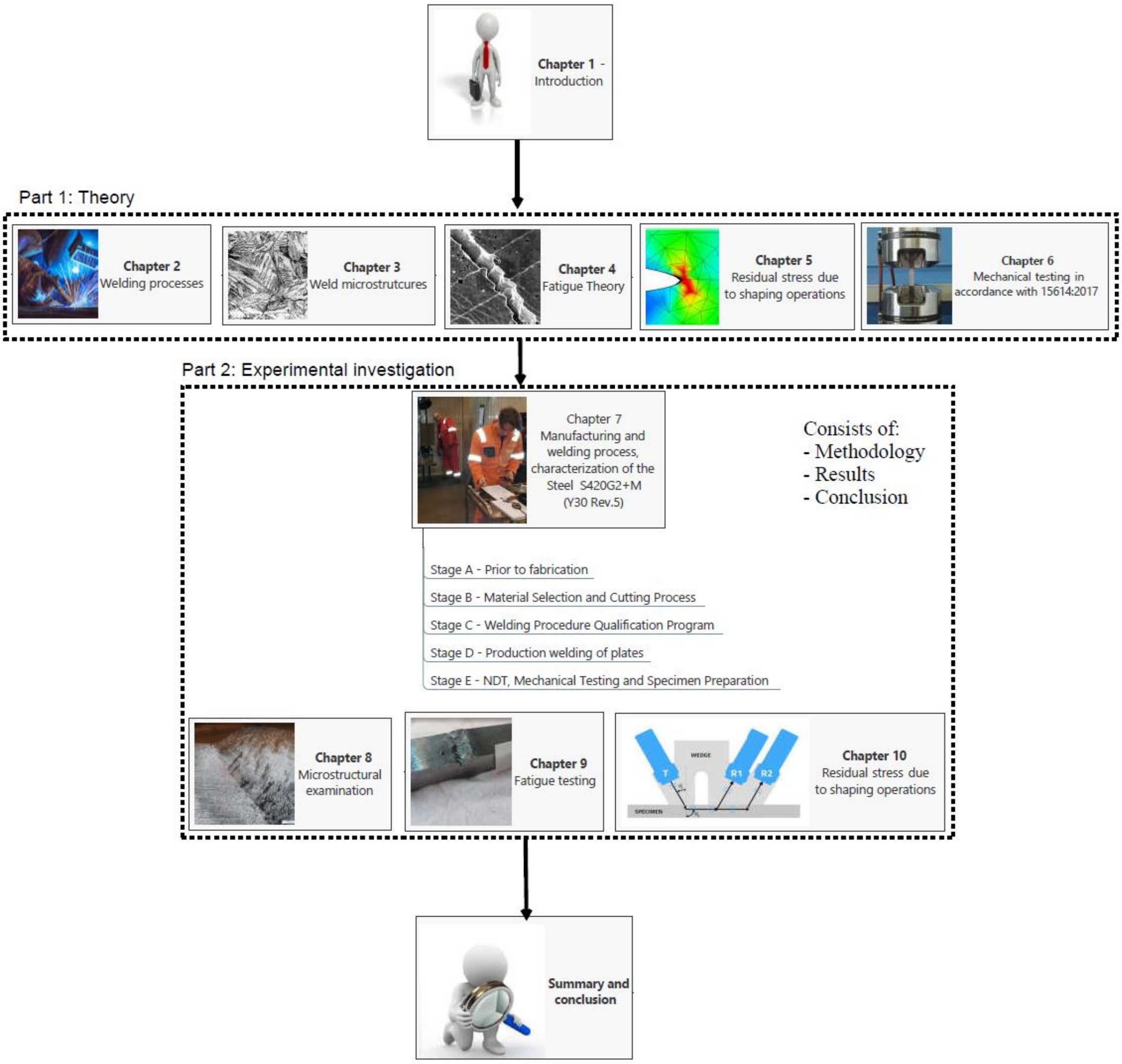


Figure 1-1 - Organisation diagram

1.5 Main challenges

- Develop a viable model for physical testing.
- Involve external partners in the project.
- Develop a welding procedure specification. In order to achieve this a preliminary welding procedure specification must be developed and tested to make sure all parameters are correct.
- Maintain control over all variables by having a systematic and careful working process. This is especially important since the margin of error is very small and there are a lot of uncertainties.
- Conduct extensive testing on finished weldment.

Part I:
Theory

2 Welding processes

A large variety of different welding methods exists today but the most important is arc welding. Arc welding is a process that joins two materials by heating them above the melting point and thereby fusing them together [5].

2.1 Manual Metal Arc welding (MMA)

Manual Metal Arc, method nr 111 in EN-ISO is often refered to as stick welding. The MMA method establishes an arc between a sticklike fluxcovered electrode and the base material as seen in Figure 2-1.

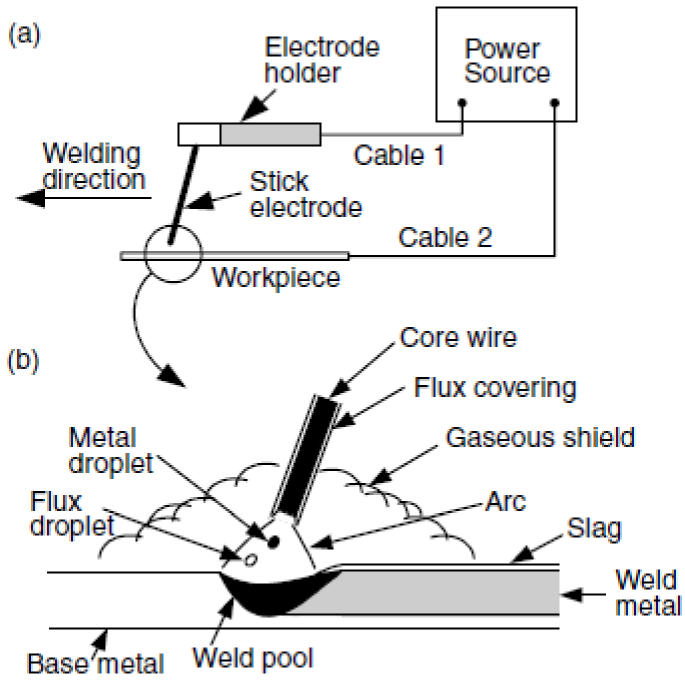


Figure 2-1 – Schematic diagram of Manual Metal Arc welding [5]

The benefits of this method is that it is relatively easy to set up, meets high quality requirements, is suited for outdoor use due to less weather sensitivity and has a high selection of additives.

The negative aspects of the method is that it is slow compared to MIG/MAG welding, and requires regular breaks for electrode replacement. It also requires a relatively skilled welder. It tends to generate more smoke than other methods, which places higher demands on the ventilation system. Basic electrodes are moisture sensitive, which requirets extra good storage and handling.

2.2 Gas-metal arc welding (GMAW)

Gas-metal arc welding is the method of joining two metals by heating them with an arc established between a continuously fed filler wire electrode and a weld pool. The shielding mechanism is obtained by using an externally supply of inter gas, such as argon and helium, hence why it's called metal-inert gas (MIG) welding. Since CO_2, which isn't inert, is also sometimes used the more suitable name is gas-metal arc welding (GMAW). The method can be used to fuse almost all metals of all thicknesses. Since GMAW doesn't use any flux, it can be used to weld aluminum [5].

Gas-metal arc welding was introduced in the 1920s, but didn't become commercially available until 1948. It was initially implemented as a high-current-density, small-diameter, bare-metal-electrode process using an inert gas for arc shielding. MIG was initially used to weld aluminum, but further progression in the industry offered an alternative with reactive gas welding [6].

2.3 Flux-Core Arc Welding (FCAW)

Flux-Core Arc Welding is similar to Gas-Metal Arc Welding in the sense that it uses a continuous filler material in the welding process as seen in Figure 2-2 [5]. The key difference is that the filler electrode has a flux core similar to manual metal arc welding, which combined with gas in the welding process [5].

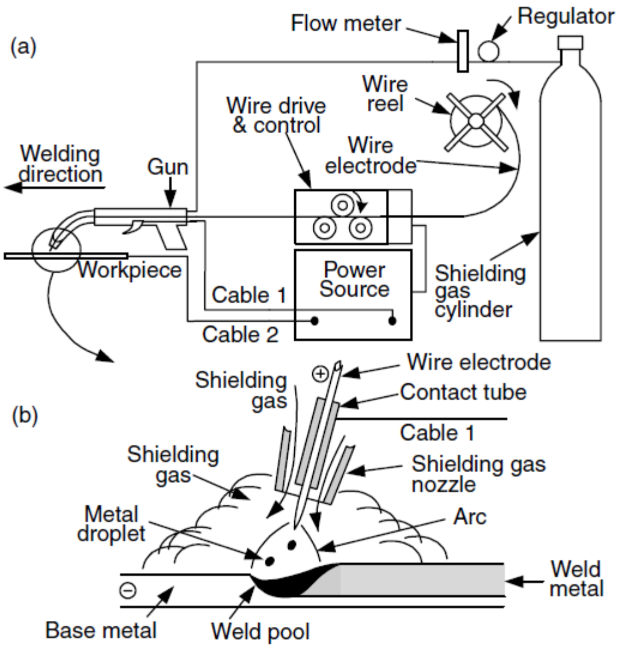


Figure 2-2 – Flux-Core Arc welding: (a) overall process; (b) welding area enlarged

[5].

3 Weld microstructures

3.1 Introduction

The weld joint is divided into two major regions: the fusion zone and the heat-affected zone (HAZ). The fusion zone includes the melt of both deposited weld and adjacent base material. The heat-affected zone is the area around the fusion zone that has not melted, but whose microstructure and mechanical properties has transformed. The area outside the HAZ is called the base material (BM). In this region the temperature does not reach the levels that result in tempering of the base material [7].

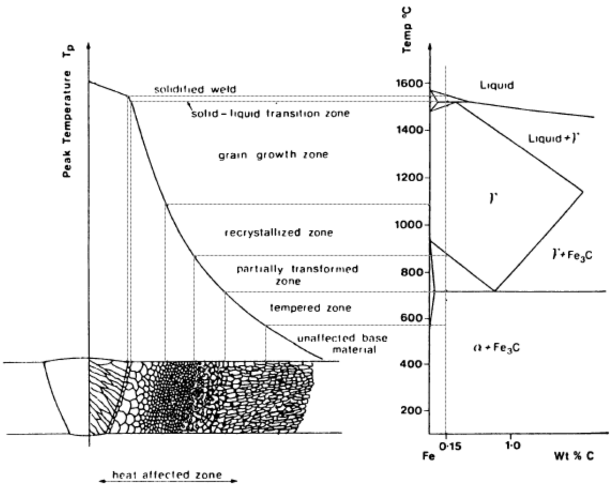


Figure 3-1 – Schematic diagram of the various sub-zones of the heat-affected zone approximately corresponding to 0.15 weight % C [8].

3.2 Fusion zone

The microstructure of the weld metal in the fusion zone is called the as-deposited or primary microstructure. Figure 3-2 illustrates the major microstructural constituents in the primary microstructure. These are grain boundary (or allotriomorphic) ferrite (GF), Widmanstätten ferrite (WF), and acicular ferrite (AF). There are also traces of martensite, retained austenite and degenerate pearlite in the deposited weld microstructure, but due to its limited occurrence, these are referred to as microphases [7].

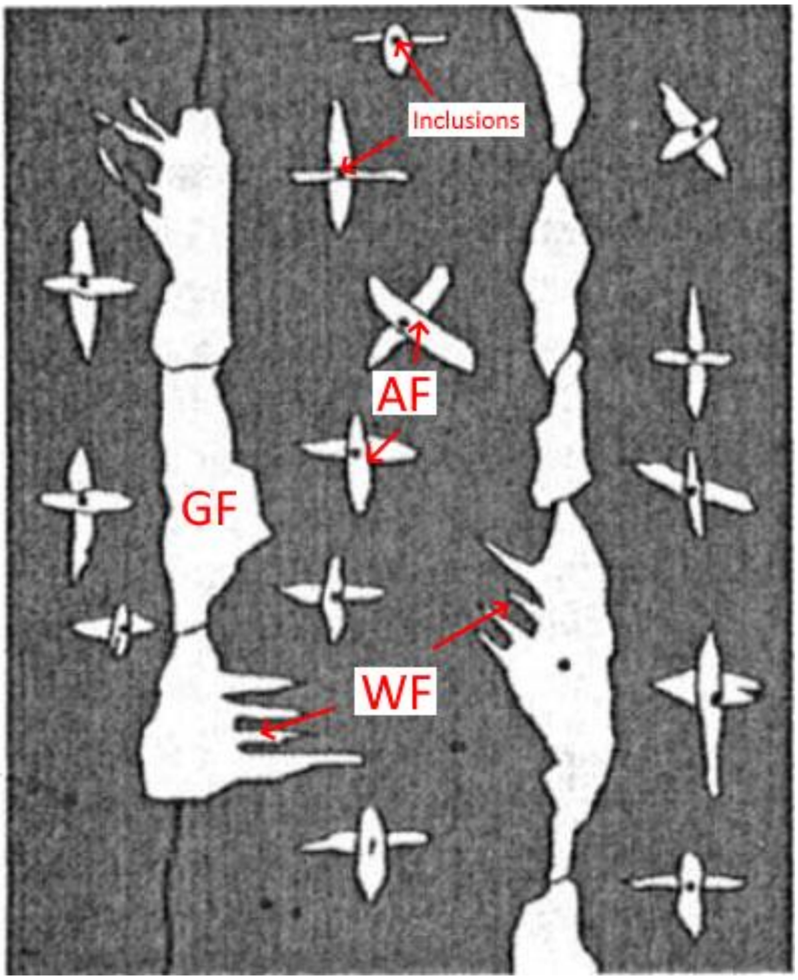


Figure 3-2 – Schematic diagram of the primary microstructure in the columnar austenite grains of a steel weld deposit. The terms $GF, WF\ and\ AF$refers to allotriomorphic ferrite, Widmanstätten ferrite and acicular ferrite, respectively. Modified from Bhadeshia [7].

Hardenability is the ability in a steel to form martensite. The two most significant variables which effect hardenability are austenite grain size, carbon composition and alloying elements. The hardenability of a microstructure increases with growing grain size due to the ratio of grain boundary per unit volume decreases. Locations for ferrite and pearlite nucleation is slowed down which increases the hardenability. The importance of alloying elements is often expressed by its carbon equivalence (CE). An increase in CE promotes the forming of a martensitic grain structure since it retards the austenite to ferrite transformation [7]. A steel is considered weldable if $CE < 0.4$ [8].

Ito and Besseyo formulated an expression for carbon equivalence at carbon weight < 0.18 % C

$$CE = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

This expression is more suitable for steels with a lower carbon content since the carbon sensitivity increases at lower carbon content levels.

3.3 The heat-affected zone (HAZ)

The HAZ is the region adjacent to the weld that has not melted, but instead has undergone a solid-state transformation or been tempered. The microstructure and mechanical properties in these regions have been altered due to various degrees of temperature and has therefore been divided into the various subzones illustrated in Figure 3-1 [7].

3.3.1 Heat flow

The effect of the heat input decreases as a function of distance from the fusion boundary, but the cooling rate on the other hand is not as affected. The formula Δt_{8-5} is the time it takes to cool from $800°C$ to $500°C$, which is the temperature where many weldable steels experience a solid-state phase transformation from austenite to ferrite [7].

The thermal cycle within any location within the HAZ can be described with the two parameters; peak temperature T_p and the time period Δt_{8-5}. Both are dependent on the heat input q.

$$T_p \propto \frac{q}{r}$$

$$\Delta t_{8-5} \propto q^n$$

Where r is the distance from the fusion boundary and n depends on the nature of the heat dispersion into the material. The dispersion is dictated by the thickness of the weld bead compared to the base material and whether the heat flow is two- or three-dimensional [7].

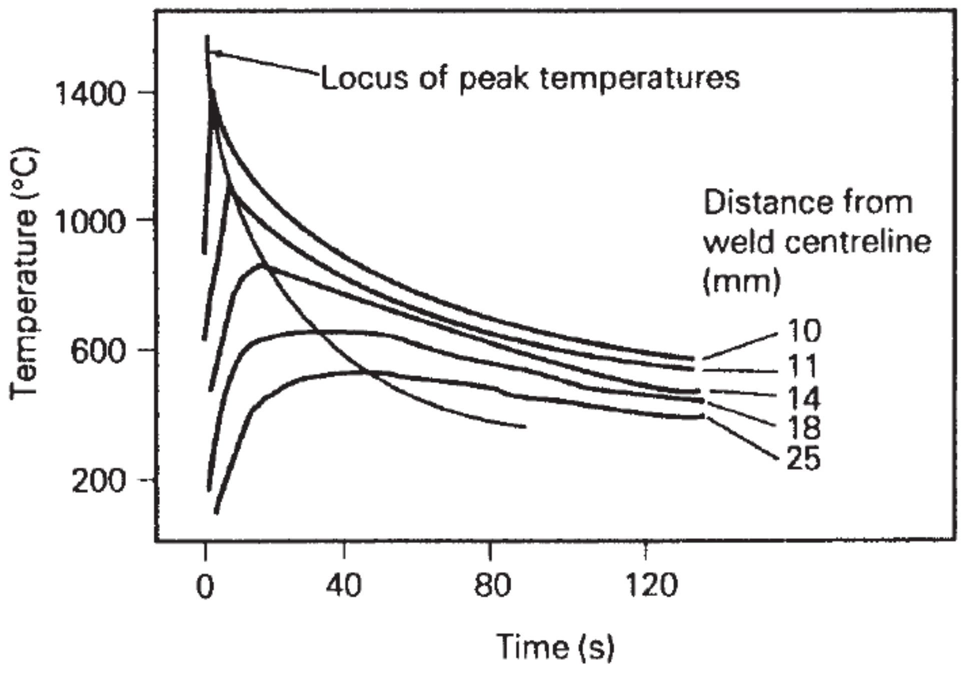


Figure 3-3 – Temperature changes over time depending on the distance from the weld zone [7].

3.3.2 *Phase transformations in the HAZ*

The phase transformations that occur during the welding process are as Bhadeshia and Honeycomb [7] describes. The subsequent microstructural regions after the fusion boundary has a distinct characteristic dependent on the nature of the peak temperature and duration as seen in Figure 8-5.

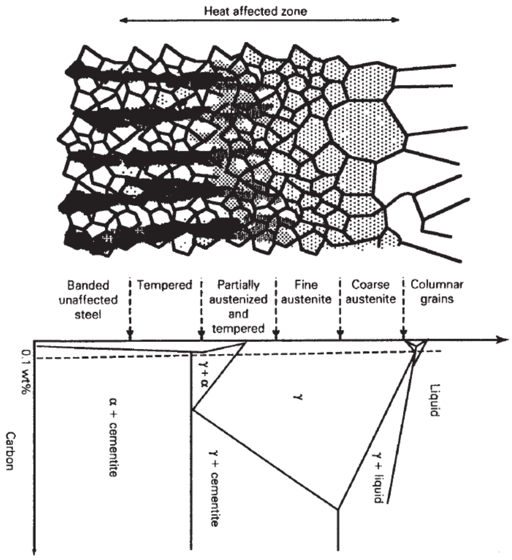


Figure 3-4 – Schematic diagram of the heat-affected zone [7].

1. The region adjacent to the fusion boundary is heated to temperatures that has allowed for complete austenitization of the grain structure (CG HAZ). The temperature for complete austenitization during rapid heating is different from a quasistatic heating rate. In order to achieve full austenitization the temperatures need go above the $A_{c3} = 950\ °C$, and begins to form at $A_{c1} = 800\ °C$. The peak temperatures in the fusion boundary is well above this temperature that results in a very coarse-grained austenitic microstructure. The forming temperature which is usually defined above 1100 °C.
2. The grain-size decreases rapidly when moving away from the fusion boundary resulting in a fine-grained microstructure (FG HAZ). The mechanical properties in this zone tends to be higher than in the coarse-grained zone. The temperature here is defined as being between 1100 °C and Ac3.
3. Further away from the fusion boundary the temperatures drop to the region in between the A_{c1} and A_{c3} curve called the intercritical heat-affected zone (IC HAZ). The microstructure in this region experiences a partially austenitizing process with a rather high carbon content. The grains that do not transform into austenite experiences a tempering effect instead.
4. At temperature below A_{c1} the microstructure only experiences tempering. This zone is called the subcritical heat-affected zone (SC HAZ).

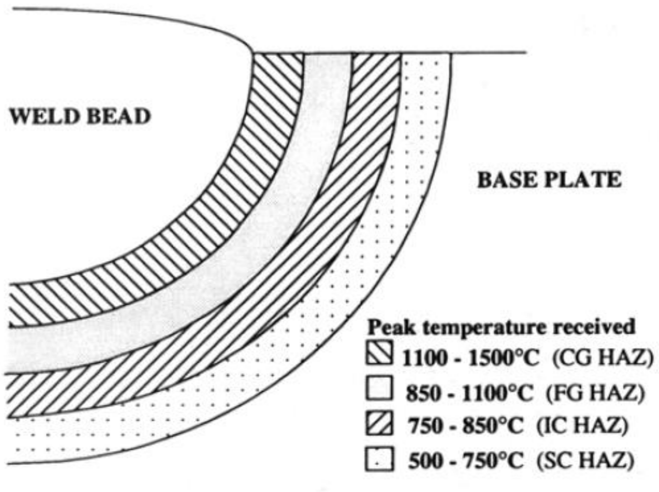


Figure 3-5 - Schematic diagram of a single pass weld [9].

3.3.3 *Multipass welds*

Each weld pass heat-treats the underlying microstructure in a multirun weld. This results in a very complicated microstructure where the layers can be fully austenitised and transformed into a different microstructure. Areas further away might only experience a tempering process. These microstructures are called secondary or reheated microstructures [9].

Extra zones are identified regarding the CG-HAZ as seen in Figure 3-6.

- Unaltered CG HAZ (U CG HAZ) is the region where the CG HAZ has been reheated to a region above 1100 °C.
- Supercritical reheated CG HAZ (SC CG HAZ) that has been reheated to a temperature between Ac3 and 1100 °C.
- Intercritical reheated CG-HAZ (IC CG HAZ) is the zone that has been reheated to a temperature between Ac1 and Ac3.
- Subcritical reheated CG-HAZ (S CG HAZ) defined as the zone heated to a temperature below Ac1.

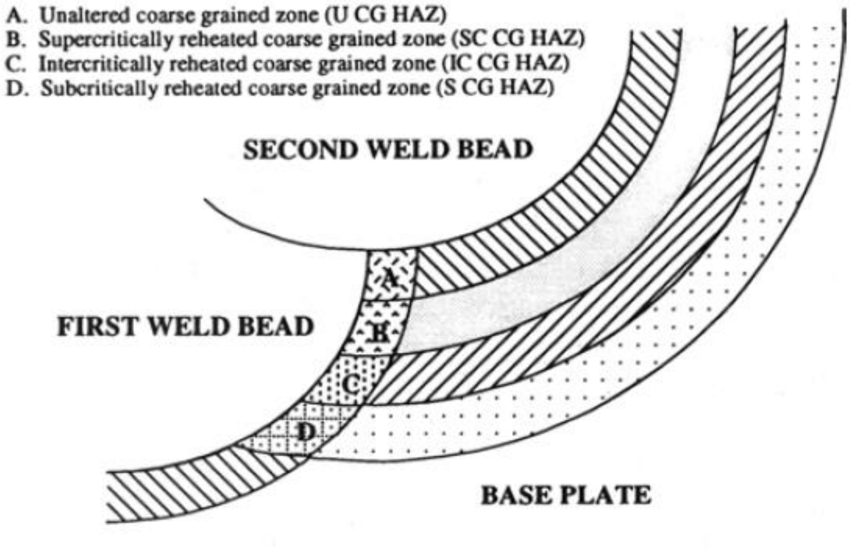


Figure 3-6 - Schematic diagram of a multipass weld [9].

3.3.4 *Intercritical reheated coarse grained heat-affected zone (IC CG HAZ)*

A reverted austenitization occurs in the CG HAZ when it is reheated to the temperatures between Ac1 and Ac3. The austenite grows from the former austenite grain boundaries and the composition of this phase has a high carbon content due to the high solubility of carbon in austenite. Under these conditions the reverted austenite can transform back to either retained austenite or martensite. This localized transformation requires a sufficiently high carbon content and high cooling rate in order to occur. These localized areas are hard and brittle due to the inherent properties of martensite [9].

4 Fatigue Theory

4.1 General fatigue theory

Fatigue is the progressive, localized and permanent structural change that occurs in a material after a certain number of loading cycles have been reached. Unless cyclic stress, tensile stress or plastic stress are acting simultaneously in the material neither crack initiation nor crack propagation will take place.

The three stages of fatigue are [10]:

- Initial fatigue damage leading to crack initiation.
- Progressive cyclical growth of a crack (crack propagation) until the remaining uncracked cross section of a part becomes too weak to sustain the loads imposed.
- Final, sudden fracture of the remaining cross section.

The total number of cycles required for a material to fail is called its fatigue life. The term failure here is different from fracture and damage. A part can be damaged but still usable. Failure on the other hand is when a part is damaged to such a degree that it isn't viable for service. Fracture is when the failed part physically splits in two. The fatigue life depends on several variables such as stress level, stress state, cyclical wave form, fatigue environment and the metallurgical condition of the material [10].

Laboratory fatigue tests can be divided into crack initiation and crack propagation. Crack initiation testing is the study of the time it takes for a crack to initiate and result in a failure. In crack propagation testing an initial crack is introduced in the surface of the material in order to study the growth rate [10].

The crack initiation phase is defined by the creation of a crack or by the sharpening of a rounded imperfection into a crack. This process can account for over half of the life of a fatigue specimen with a smooth surface, but is generally not relevant for welded structures because welds contain flaws that are sufficiently sharp to eliminate the entire crack initiation phase [11].

There are two common stress ratios in a stress cycle

$$R = \frac{Minimum\ stress}{Maximum\ stress} = \frac{S_{min}}{S_{max}} \tag{4-1}$$

and

$$A = \frac{Alternating\ stress\ amplitude}{Mean\ stress} = \frac{S_a}{S_m} \tag{4-2}$$

The variable S_{min} and S_{max} is the minimum and maximum stress respectively. In the second stress ratio formula the variable S_m is the mean stress and S_a is the alternating stress amplitude. The mean stress is the average of maximum and minimum stress

$$S_m = \frac{S_{max} + S_{min}}{2} \tag{4-3}$$

And the formula for the alternating stress amplitude

$$S_a = \frac{S_r}{2} = \frac{S_{max} - S_{min}}{2} \tag{4-4}$$

S_r is the stress range and $S_a$is the stress range amplitude. When running a constant amplitude fatigue test a normal cyclical range is $S_m \pm S_a$.

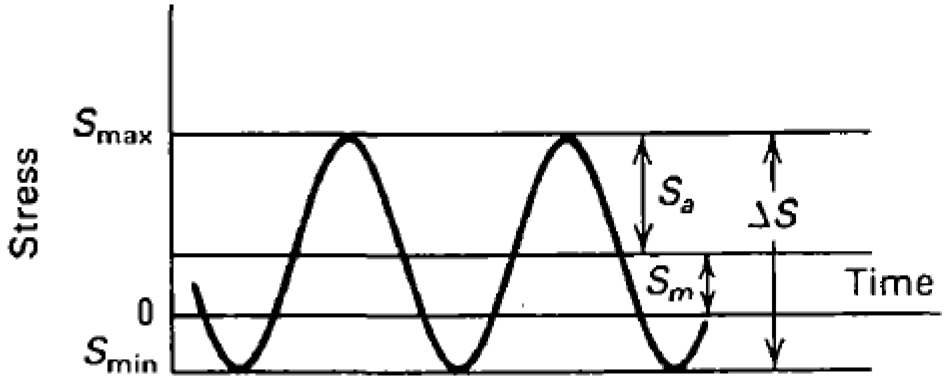


Figure 4-1 – Constant amplitude stress cycle [10].

Table 4-1 - Stress ratios

Stress ratios $R = S_{min}/S_{max}$	
$R = 0$	The stress range is between maximum stress and 0 stress.
$0 < R < 1$	Cycled between two tensile or two compressive stresses.
$R = -1$	The stresses are fully reversed. Mean = 0.
$-1 < R < 0$	Partially reversed.
$R = 1$	Fully tensile.

4.2 Fatigue test regimens

Two common methods that are used during fatigue testing are high- and low-cycle. The low-cycle fatigue testing regime is characterized by high overstress in the plastic stress range, while the high-cycle fatigue test is usually characterized by being in the elastic stress range. The dividing line is approximated to be around about $10^4 - 10^5$ cycles [10].

4.3 Fatigue mechanisms in solids

Fatigue cracks initiate at locations with maximum local stress and minimum local strength and has been observed to nucleate due to a variety of crystallographic features. During a certain number of loading cycles, dislocations as seen in Figure 4-2, pile up and form persistent slip bands (PSB) [10].

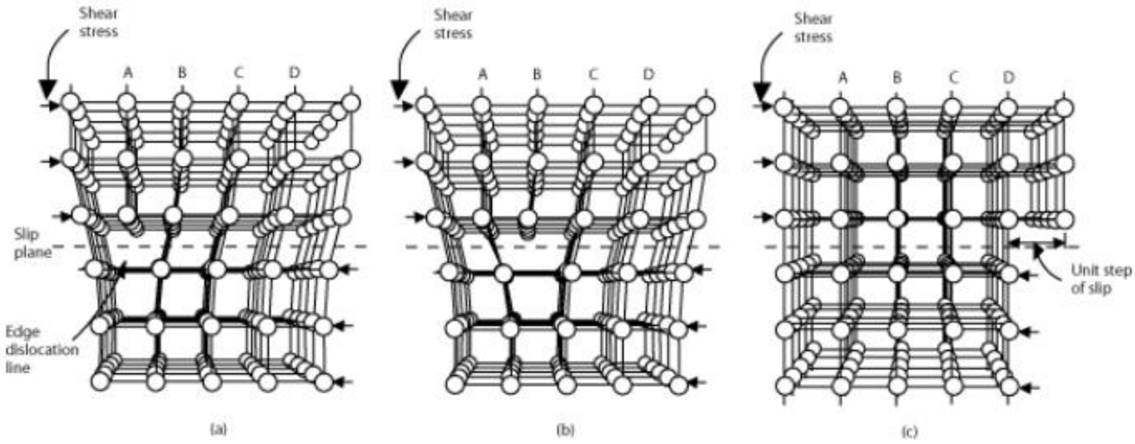


Figure 4-2 – Dislocations [12].

These PSBs, as seen in Figure 4-3, serves as the nucleation point for fatigue cracks. Crack initiations always nucleate in zones with high plastic deformation concentration where the main contributing factor is the surface roughness.

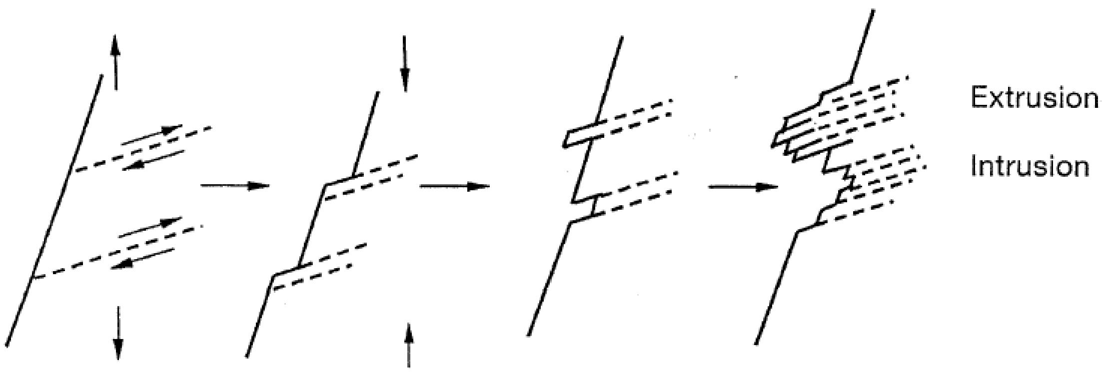


Figure 4-3 – Persistent Slip Bands (PSB) [13].

Cracks initiate at the surface except for instances where internal defects, or particular surface hardening treatments are applied [10].

4.4 Fatigue failure in welded joints

During design of a component or structure the avoidance of fatigue failure is a factor which limits the design stresses. This is especially true in weldments due to the reduced fatigue strength compared to unwelded components. Figure 4-4 shows a comparison of the fatigue strengths between unwelded and welded components. While the endurance life of a component may be around 0.5xUTS, a welded component may be around 30 MPa in some cases. In addition, fatigue failure can occur during compressive stresses [11].

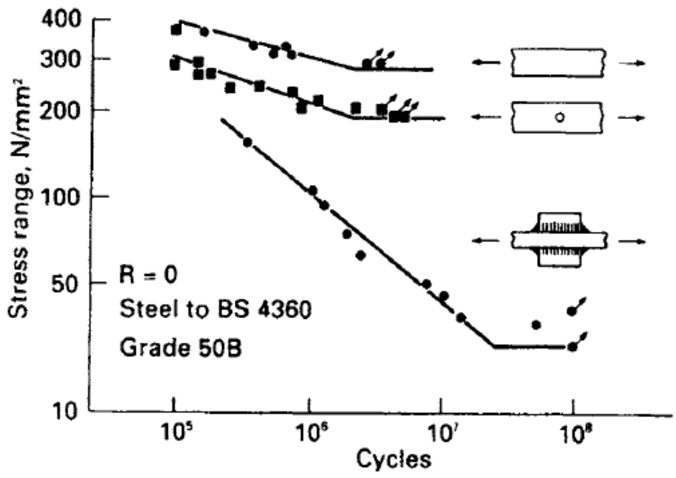


Figure 4-4 – Comparison of fatigue strengthsof plain steel plate, notched plate and with fillet welded attachments [11].

Stress concentrations are introduced in a weldment due to a sudden change in geometry in the weld toe. The severity is dependent on the shape of the weld bead and the type of joint. If the weld joint is smooth, then the stress concentration is lower. The opposite is mostly true for normal weld joints though and should be accounted for in the design. The weld itself does not have to be load carrying for a stress concentration to occur, and just the change in the geometry introduces a stress concentration [11].

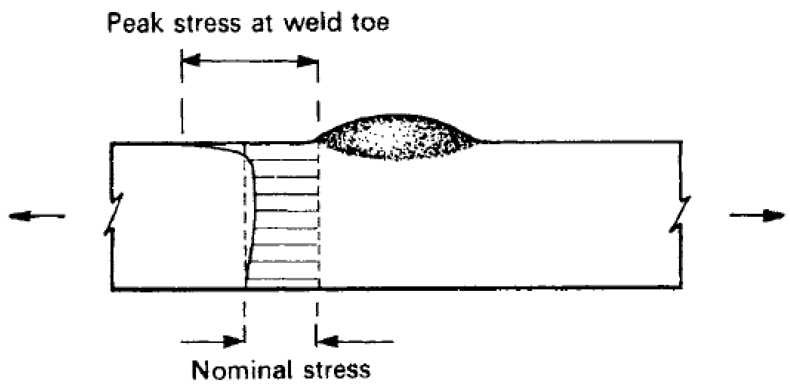


Figure 4-5 - Stress Concentration due to weld geometry [11] .

Inherent flaws called weld intrusions increase the stress concentrations drastically. These intrusions are very small crack-like discontinuities and exist in the weld toe with varying depth. In addition, undercutting of the weld toe and residual stresses are also an issue with welding. All these issues are considered when determining the representative SN-curve for the weld joint. It is important though that care is taken to follow the welding procedure in order to avoid other issues in the weld [11].

4.5 Residual stresses

Residual stresses can be induced in a material from various processes such as casting, forging and rolling. These "locked-in" stresses are independent of external loading, balanced out by each other and the system of compressive and tensile forces is thus in equilibrium. In a welded structure there are two types of stresses – reaction stresses and residual stresses. The reaction stresses are the overall distribution of compressive and tensile forces throughout the welding structure assembly and are sometimes called "long range residual stresses". Residual stresses on the other hand is a form of localized stress in the sense that it occurs in each weld joint. The residual stresses arise due to the restraining effect the adjacent material has on the weld as seen in the buttweld of two plates in Figure 4-6. During the weld heating and cooling cycles, the weld metal wishes to contract and expand, but since the surrounding material inhibits this process it results in "locked-in" residual stresses [11].

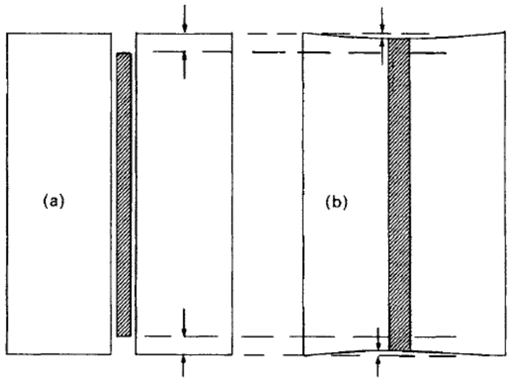


Figure 4-6 – Residual stress in buttwelded plate showing a) the preferred size of the weld bead and b) the size of the weld bead after welding. This results in tensile stresses in the weld as well as compressive stresses in the plate [11].

The longitudinal stresses reaches yield point level are distributed as shown in Figure 4-7 with tensile residual stresses counteracted by compressive stresses further out in the plate where the area A is equal to $B_1 + B_2$. The transverse stresses may vary from the figure but does include high stress areas coincident with the weld zone.

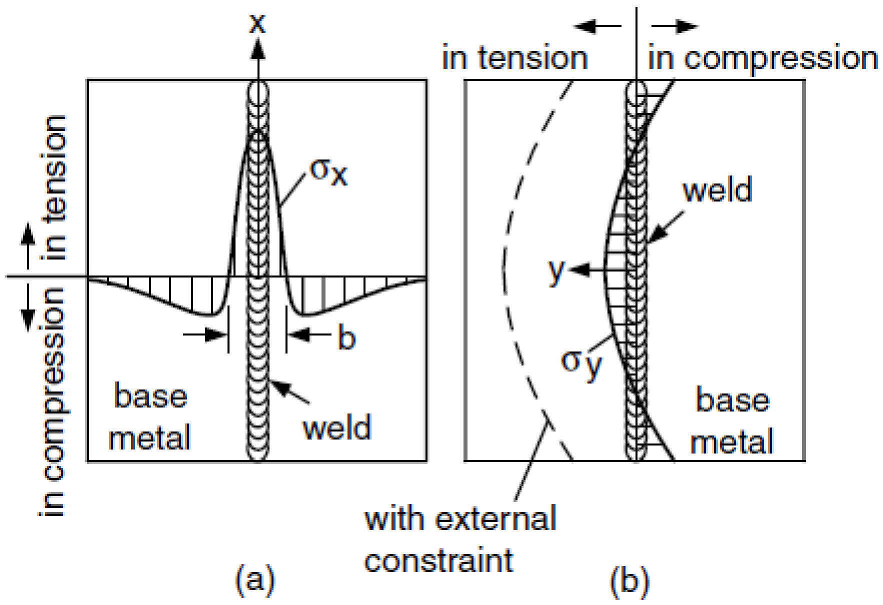


Figure 4-7 - Residual stress distribution in a welded plate [5].

When a plate is loaded above the yield point level due to a high load and a high mean residual stress, the location of highest stress starts to yield. The load is then redistributed to the adjacent material, which in turn starts to yield as well. When the loading is removed, the former residual stress level is reduced. The residual stress in this area has been relaxed. No plastic straining occurs when a compressive loading is applied, but the stress range is equal. This emphasizes the importance of residual stresses of yield point magnitude. Fracture is possible during both compressive and tensile loading conditions, and that the fatigue strength of a welded joint is mainly governed by the stress range and not the nominal stress level. The formation of a crack might redistribute the residual stresses such that it offers stress relief. This could stop the crack growth in a fully or partially compressive load scenario due to the requirements for a crack to grow is tensile stresses. In the same sense that tensile residual stresses facilitate crack initiation, compressive residual stresses could do the opposite [11].

4.6 Stress relief

According to Maddox [11], the need for stress relief is only necessary for welded joints under partly or fully compressive loading. This is due to the significance of crack propagation and that crack growth is marginally influenced by mean stress level. The stress range must still increase when the mean stress is lower.

4.7 Material properties

One of the most distinct differences between a welded joint and a solid component is that the fatigue strength of a solid component normally increases with increasing tensile strength, whereas a welded joint doesn’t. This is due to the significance of the crack initiation stage in the fatigue life of an unwelded component. In a welded component it is assumed that a preexisting crack already exist, so the fatigue life primarily consists of crack propagation. The crack growth doesn't vary significantly with material tensile strength [11].

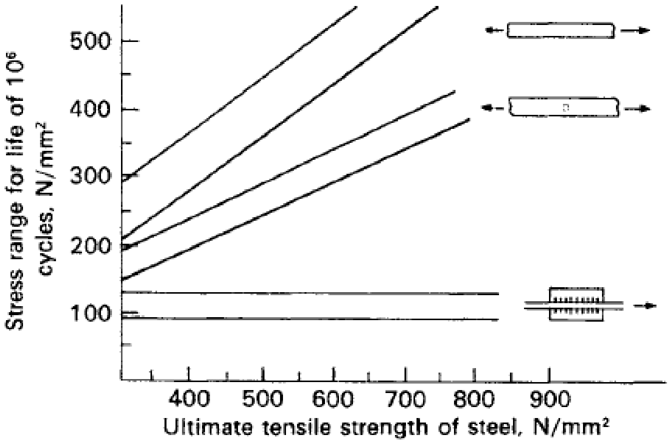


Figure 4-8 - Effect of increasing tensile strength between welded and unwelded components [14].

4.8 Weld quality

Weld flaws in a weld joint, such as porosity, slag inclusions, lack of fusion and incomplete weld root penetration, provide additional stress concentrations. If these are more severe than the weld toe, they will act as alternative sources for crack initiation. In dressed flush butt welds these are the critical crack initiation locations [11].

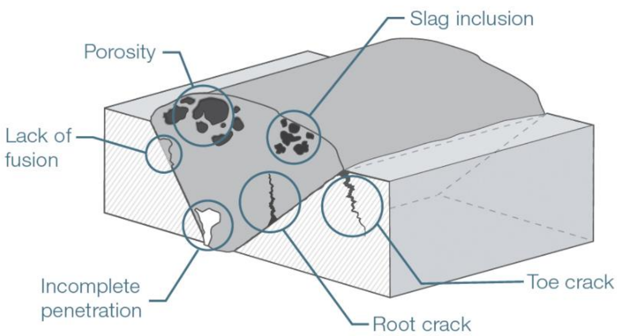


Figure 4-9 - Weld flaws [15].

In addition, weld misalignment increases the local secondary stress concentration by bending, either by axial eccentric misalignment or angular misalignment. The distinction between misalignment and weld flaws is that the former does not introduce an alternative crack initiation site, but rather enhances existing stress concentrations. Due to the bending being higher in the top surface, this is especially true in the weld toe [14].

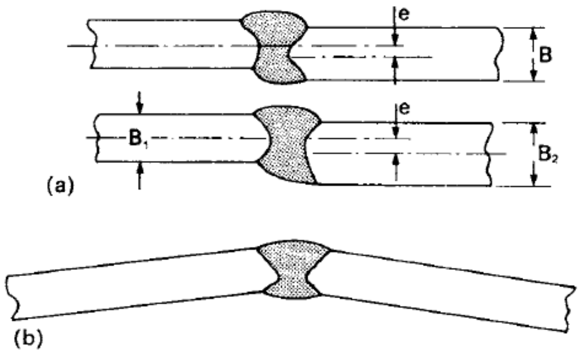


Figure 4-10 - Weld axial and angular misalignment [11].

5 Residual stresses due to shaping operations

Operations such as grinding, cutting, milling, turning, drilling and processes such as shot peening and blasting, involves local plastic deformation. Residual stresses from shaping can be compressive or tensile and can also have additional large shear components [16].

Grinding is an abrasive method used to remove small portions of material on a surface. Machines that are used are grindstones, angle grinder, grinding machines, etc. There are similarities between the methods mentioned in the previous section and grinding. The energy from the cutting operation results in temperature increase and plastic deformation. Compressive stresses in the surface tend to be the results of plastic deformation due to smearing. Tensile stresses tend to appear when the heat from the operation expands the material, which in turn is constrained by the adjacent material. The subsequent cooling of this area results in tensile residual stresses. A third factor is the forming of martensitic microstructure due to rapid cooling, which causes compressive residual stresses. The resulting residual stresses depends on the balance between these three factors as seen in Figure 5-1.

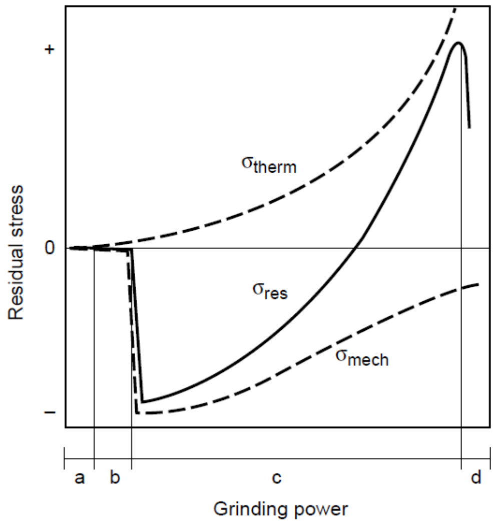


Figure 5-1 - Residual stresses during shaping operation. The higher the grinding power the higher the tensile residual stresses [16].

Important parameters during grinding is the cutting speed, depth of cut and feed rate, the mechanical properties of the workpiece and the heat conductivity of the grinding wheel and workpiece. Normally, the affected depth is relatively small; less than 100 µm. The level of the residual stresses can reach values below the yield point [16].

Milling removes material by using rotary cutters. The factors that control the resulting residual stresses are the same as for grinding; the smearing effect, temperature and martensitic formation process. The mechanism is divided into chip formation and smearing of the workpiece surface. The chip formation process tends to induce tensile residual stresses, while the smearing process results in compressive stresses. Most of the heat generated during the cutting process is stored in the removed chip. The affected depth is usually thicker than grinding [16].

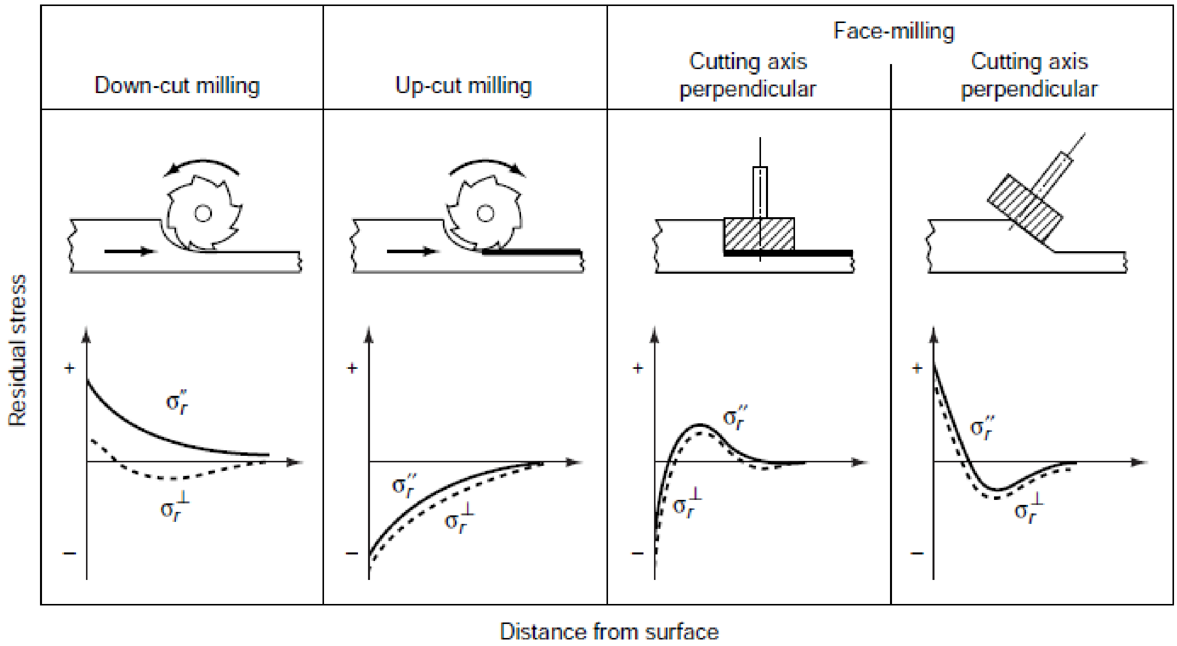


Figure 5-2 - Residual stress distribution depending on the cutting process. The longitudinal stress is the solid line while the dashed line is the transverse stress [16].

6 Mechanical testing in accordance with 15614-1:2017

All new welding procedures were to be carried out in accordance with 15614-1:2017 Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys [17]. The main objective of welding qualification is to validate that the joining process intended for construction is capable of producing joints having the necessary mechanical properties for proposed application. The standard consists of two levels; level 1 and 2. Level 1 is based on requirements of ASME IX and level 2 is based on the previous issues of standard 15614-1:2017. The extent of testing is greater in level 2 and the ranges of qualification are more restrictive than in level 1. Procedural tests for level 2 automatically qualify level 1 requirements.

There are two main categories of testing – non-destructive testing and destructive testing. As the names imply, the different methods either destroy or has no lasting effect on the test sample.

Table 6-1 - Extent of mechanical testing procedures and corresponding acceptance criterias in order to approve WPS.

Activity Description	Specification/ Procedure	Acceptance Criteria
Visual testing	ISO 17637:2016	EN ISO 5817:2014
Radiographic	ISO 17636-2:2013	ISO 10675-1:2016
Surface Crack Detection Test (Magnetic particle inspection)	NS-EN ISO 17638:2016, NS-EN ISO 3452-1:2013	ISO 23278:2015 Level B
Macro examination	NS-EN 17639:2013	EN ISO 5817:2014 (quality level B)
Transverse Tensile Test	ISO 4136:2012, ISO 6892-1:2016 Method A1	NS-EN 15614-1: 2017, NS-EN 10225:2009
Charpy V Impact Test	NS-EN ISO 148-1:2016, ISO 9016:2012	NS-EN 15614-1, NS-EN 10225:2009
Side bend test	NS-EN ISO 5173:2010	NS-EN 15614-1:2017
Vickers hardness test	NS-EN ISO 9015:2011	NS-EN 15614-1:2017

6.1 Visual testing

The procedural steps for visual testing is documented in NS-EN ISO 17637:2016 [18]. The inspection and testing is performed after the initial joint preparation before welding, during the welding operation and on the finished weld. The examiner shall have access to the necessary inspection and product documentation required. Several weld discontinuities can be detected by the examiner in this stage.

The finished weld shall be examined to determine whether it meets the requirements of the application or product standards or other agreed acceptance criterias. The acceptance criterias in this project was NS-EN ISO 5817:2014 [19] and NS-EN ISO 15614-1:2017.

6.2 Radiographic testing

A non-destructive test performed in accordance with Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (NS-EN ISO 5817:2014) [19] and acceptance criterias in Non-destructive testing of welds - Acceptance levels for radiographic testing - Part 1: Steel, nickel, titanium and their alloys (NS-EN ISO 10675-1) [20].

An X-ray tube sends out radioactive waves that penetrates the tested specimen and hits a photographic film. Cracks and pores in the weld let more X-rays through, which results in more exposed areas on the film.

6.3 Magnetic particle inspection testing (MT)

A non-destructive test performed in accordance with Non-destructive testing of welds - Magnetic particle testing NS-EN ISO 17638:2016 [21] and acceptance criteria Non-destructive testing of welds - Magnetic particle testing - Acceptance levels (NS-EN ISO 23278:2015) [22].

This method is used to detect surface flaws in magnetic materials. The test specimen is magnetized, and an iron powder is distributed on the surface. Cracks in the metal surface and 2 mm into the surface disturbs the magnetic field and attract the iron powder. The cracks become visible as dark stripes on the surface.

6.4 Penetrant testing (PT)

A non-destructive test performed in accordance with Non-destructive testing - Penetrant testing - Part 1: General principles (NS-EN ISO 3452-1:2013) [23] in accordance with acceptance criterias in Non-destructive testing of welds - Magnetic particle testing - Acceptance levels (NS-EN ISO 23278:2015) [22].

The testing method is used to exclusively detect surface defects, such as pores and cracks, not large enough to be visible in the visual inspection. The method uses a liquid penetrant that is sprayed on the surface in combination with an absorbing component that reveals weld discontinuities.

6.5 Macroscopic and microscopic examination

Macroscopic examination is the analysis of a test specimen by the naked eye, or under low magnification (generally less than x 50), with or without etching. Microscopic examination is the analysis of a test specimen with a magnification of x50 to x500 with or without etching [24].

A destructive test performed in accordance with Destructive tests on welds in metallic materials - Macroscopic and microscopic examination of welds (NS-EN ISO 17639:2003) [24] and acceptance criteria's in Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (NS-EN ISO 5817:2014) [19].

An optical microscope can be used to assess the weld and base material microstructure (including grain structure, morphology and orientation, precipitates and inclusions), with several thousand times magnification. The test piece is initially prepared by being cut into small pieces, and then grinded and treated with acid in order to reveal grain structure, precipitations and microscopic flaws. The difference between macroscopic and microscopic examination is the level of magnification. A macroscopic examination studies the fusion zone, the heat-affected zone and the weld passes in a low magnification. In a microscopic examination the magnification is increased such that it's possible to study the grain structure itself in both the weld and HAZ [25].

6.6 Tensile test

A destructive test performed in accordance with Destructive tests on welds in metallic materials - Transverse tensile test (NS-EN ISO 4136:2012) [26] and acceptance criterias in Metallic materials - Tensile testing - Part 1: Method of test at room temperature (NS-EN ISO 6892-1:2016) [27].

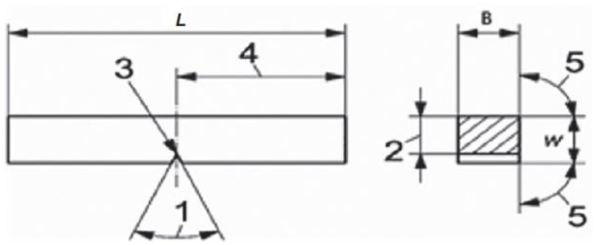
The tensile test demonstrates the static strength of a specimen. The usual characteristic data that is obtained from the test is the yield point, ultimate tensile strength and total elongation. The test result is presented in a stress-strain diagram.

6.7 Charpy V Impact Toughness test

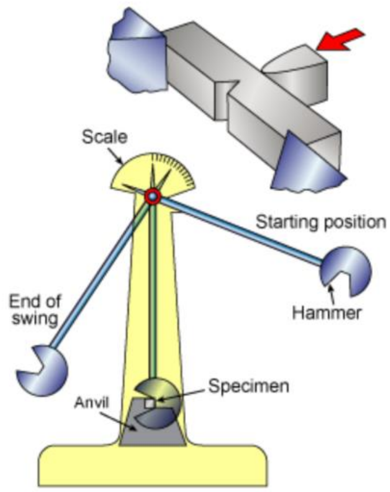
A destructive test performed in accordance with Metallic materials - Charpy pendulum impact test - Part 1: Test method (NS-EN ISO 148-1:2016) [28] and Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination (NS-EN ISO 9016:2012) [29]. Acceptance criteria's are presented in Specification and qualification of welding procedures for metallic materials Welding procedure test Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (NS-EN ISO 15614-1) [17] and Weldable structural steels for fixed offshore structures - Technical delivery conditions - Part 1: Plates (NS-EN 10225-1) [30].

A Charpy impact test is a standardized high strain-rate test to measure a materials toughness, which is the ability to absorb energy from an impact before fracturing. The test specimen is designed according to ISO 148-1:2016 and ISO 9016:2012. There are different designs, but the most conservative one is where a V-notch is introduced in the surface. A standard V-notch geometry shall have an included angle of 45°, a depth of 2 mm and a root radius of 0.25 mm, see Figure 6-1(c) [28].

The Charpy test is about hitting a notched test piece with a swinging pendulum. The notched test piece is placed in a test bit support, Figure 6-1 (c). The notch should be placed in the middle between two anvils, see Figure 6-1 (b), so that the center of strike is positioned on the opposite side of the notch. From the test you can find out how much energy was absorbed in the impact and the appearance of the shear fracture.

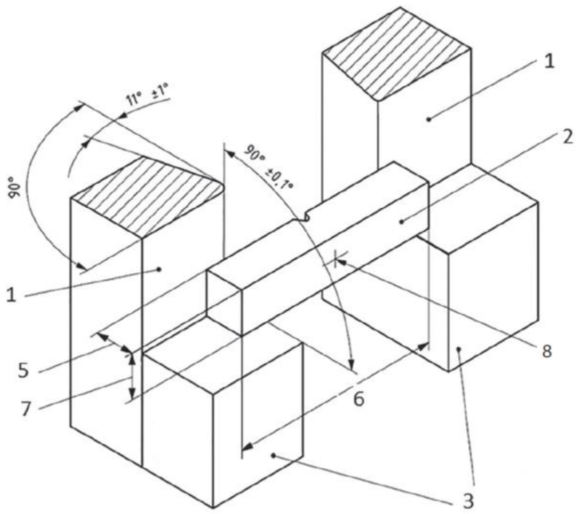


(a) Charpy pendulum impact test piece,V-notch geometry



(b) Charpy testing machine

Thickness, B = 10mm
Width, W = 10mm
Length, L = 55mm
Angle of notch, 1 = 45°
Ligament, 2 = 8mm
Notch radius, 3 = 0.25mm



(c) Test piece terminology showing configuration of test piece support and anvils of a pendulum impact testing machine

1. Anvil
2. Standardized test piece
3. Test piece support
4. Shroud
5. Width of test piece, W
6. Length of test piece, L
7. Thickness of test piece, B
8. Centre of strike
9. Direction of pendulum swing

Figure 6-1 - Charpy test

As seen in Figure 6-2 the energy absorption is very temperature dependent. A decrease in temperature negatively affects the materials ability to absorb an impact and decreases the amount of energy needed to fracture the specimen. The ductile to brittle transition phase is in a relatively small window called the Impact Transition Temperature. The energy absorbed around the Impact Transition Temperature for steel is normally around 27 J (40 J for high strength steel). The thickness of the specimen also affects the toughness of the material whereas a thinner specimen has a higher toughness [25].

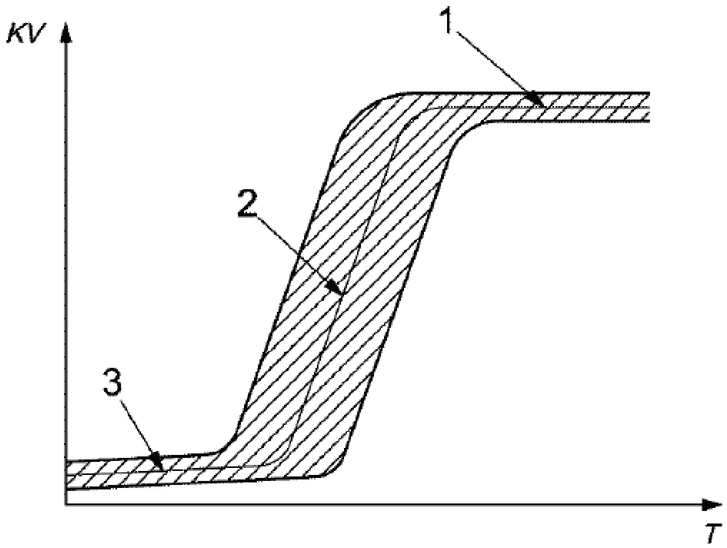


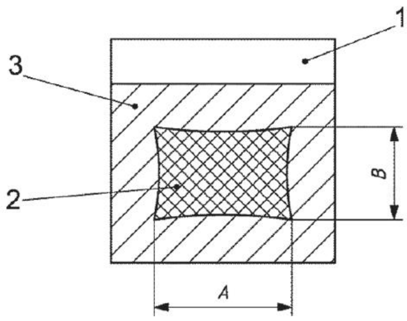
Figure 6-2 - Absorbed energy/temperature curve. The Impact Transition Temperature is a relatively narrow window [28].

Three Charpy specimens are tested at a certain design temperature and at the same location; WM, FL,FL+2 mm and FL+5 mm. The average of these values need to meet a set minimum value that is dependent on the strength value of the material and is typically 27 J or 40 J of absorbed energy.

Fracture appearance

The Charpy tests fracture area is mostly evaluated by the shear fractures that occur. The greater the amount of shear fracture, the greater the toughness. The fracture surface of a Charpy specimen has a mixture of shear and planar fracture areas. The shear areas are concidered to be fully ductile, but the planar fracture area tends to be more ductile, brittle in a combination of fracture modes. Since the classification is very subjective, it is advised not to be used it in specifications.

According to NS-EN ISO 148-1: 2016 [28], there are several methods for assessing the proportion of shear fractures. One of the methods compare the fracture with an appearance chart. Another method measures the length and width of the cleavage section, see Figure 6-3.



(a) Cross section

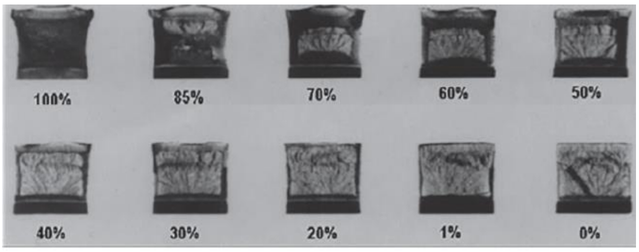
1. notch
2. cleavage area (brittle)
3. shear area (dull)

A. dimension measured to estimate the cleavage area
B. dimension measured to estimate the cleavage area

B mm	A mm																		
	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10
	Per cent shear																		
1,0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1,5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2,0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2,5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3,0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3,5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4,0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4,5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5,0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5,5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6,0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6,5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7,0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7,5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8,0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0

NOTE 100 % shear shall be reported when *A* and *B* are zero.

(a) Percent shear for measurement in mm



a) Fracture appearance charts and per cent shear fracture comparator

(c) Guide for estimating fracture appearance

Figure 6-3 – Methods for determining percentage of shear fracture

6.8 Bending test

The bending test is a destructive test performed in accordance with Destructive tests on welds in metallic materials - Bend tests (NS-EN ISO 5173:2010) [31] and acceptance criterias in Specification and qualification of welding procedures for metallic materials Welding procedure test Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (NS-EN ISO 15614-1:2017) [17].

Bending tests are conducted in order to assess the ductility and the presence of imperfections in the weld. ISO 5173:2010 specifies various methods of testing the welded buttjoint by performing transverse root, face and side bend test. A standard test is transverse across the weld, but in cases where there is a significant difference in the filler and base material’s physical and mechanical properties a longitudinal test may be performed.

6.9 Vickers hardness test

Hardness test performed in accordance with the procedure in Destructive tests on welds in metallic materials Hardness testing Part 1: Hardness test on arc welded joints (NS-EN ISO 9015-1:2011) [32] and acceptance criterias in Specification and qualification of welding procedures for metallic materials Welding procedure test Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (NS-EN ISO 15614-1:2017) [17].

A materials ability to resist deformation from a harder object is defined as its hardness. The size of the resulting imprint is larger the softer the material is. There are three main hardness testing methods, Brinell, Rockwell and Vickers. Vickers is the method used in the majority of cases.

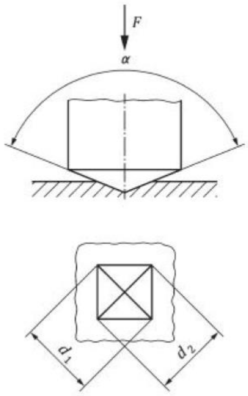


Figure 6-4 - The pyramide diamond indenter of a Vickers hardness tester [33].

The Vickers hardness test is performed by applying a diamond cone tip into the surface of the material. After the load has been applied the diagonals of the imprint is measured and the hardness is calculated with the formulas:

$$Vickers\ hardness = \frac{Test\ force\ (kgf)}{Surface\ area\ of\ indentation\ (mm^2)}$$

$$= \frac{1}{g_n} * \frac{Test\ force\ (N)}{Surface\ area\ of\ indentation\ (mm^2)}$$

$$= \frac{1}{g_n} * \frac{F * 2 * \sin(\alpha/2)}{d^2}$$

$$= \frac{1}{g_n} * \frac{2 * F * \sin(\alpha/2)}{d^2}$$

Where α is the angle in 136°, d is the arithmetic mean of the two diagonal lengths and g_n is the gravitational constant in 9.80665 m/s^2 which results in

$$Vickers\ hardness \approx 0.1891 * F/d^2$$

Part II:
Experimental Investigation

7 Manufacturing and welding process, characterization of the Steel S420G2+M (Y30 Rev.5)

The following experimental chapter describes the process of developing a WPQ for S420G2+M steel plates and subsequent mechanical testing. It aims to provide information on the manufacturing process and the mechanical testing that has been carried out.

The test data obtained from the mechanical testing in this chapter is necessary in order to form a conclusion in the following chapters:

- Experimental Investigation: Microstructure
- Experimental Investigation: Fatigue
- Experimental Investigation: Residual Stress Measurements

This chapter is divided into five sub-chapters that describe the different steps that have been completed during the project. All sub-chapters have a corresponding appendix. This chapter and the following chapters in experimental work should be read together with the document, Inspection & Test Plan (I&TP). The I&TP is a quality management document that describes all activities, procedures, acceptance criteria in the project.

To see a summary of all documents that have been produced during the project, see the document list in the beginning in the appendices.

7.1 Introduction: Strategy and objectives

Initially, an experimental investigation was performed in order to test and analyze parallel welds at various distances. The choice of test setup and material was two parallel buttwelds in a S420G2+M (Y30 Rev.5) offshore steel plate.

A common minimum distance between two adjacent welds are 50 mm or 4x the material thickness. This minimum distance is set for them to be regarded as independent and to ensure that the two welds do not adversely affect each other. The interests of the project were therefore to see if the material properties were affected when the welds were closer than this minimum distance. Three sets of two steel plates with parallel buttwelds with different distances were manufactured and assessed – 50 mm, 15 mm and 5 mm.

In order to maintain conformity of all welded plates a welding procedure qualification record (WPQR) was initially established. This was achieved by welding an initial qualifying plate that was tested and qualified in accordance with the requirements in NS-EN ISO 15614-1:2017 [17]. Following welding procedures were then subsequently based of the approved welding procedure qualification (WPQ).

The manufactured plates were subjected to both destructive and non-destructive testing; visual testing, radiographic, hardness testing, Charpy V Impact testing, tensile testing, fatigue testing, ultrasonic measurement, macro and microscopic examination.

7.2 Experimental program

The experimental program was conducted in five stages. Every stage is presented in a dedicated sub-chapter as seen below:

Stage A - Prior to fabrication
Stage B - Material Selection and Cutting Process
Stage C - Welding Procedure Qualification Program
Stage D - Production welding of plates
Stage E – NDT, Mechanical Testing and Specimen Preparation

7.3 Stage A - Prior to fabrication

A test plate was welded prior to the manufacturing of the production plates. It served the purpose to act as a concept plate, before the actual test began. By doing this it was possible to gather some experience before the actual welding was started.

7.3.1 *Objective*

- Weld and test an initial "prior to fabrication plate" before the main "production plates" were welded.
- Develop an "Inspection and Test Plan" based the results and conclusions from this stage.

7.3.2 *Fabrication and welding process of Test Plate*

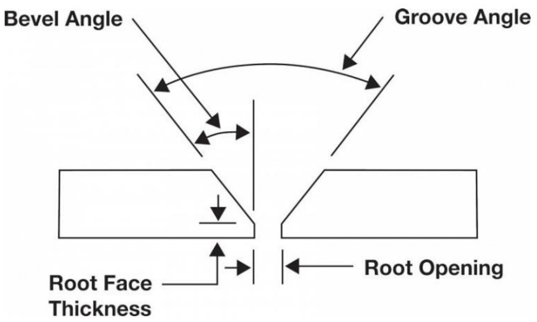
The main objective with the initial welding that was performed at Vest Norge Doors AS in Sandnes, was to determine if the weld joint chosen for the experiment was functional. This included factors such as welding method, if machining was possible on a deformed plate due to weld distortion and if it was possible to conduct mechanical testing on the finished plate. Weld logging was performed due to the necessary equipment to measure the weld parameters was not available.

7.3.2.1 Welding process

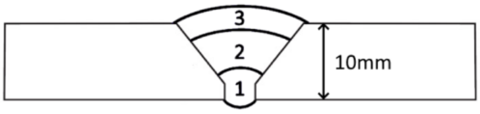
First, three plates were cut from a Flat bar P-150X10. An angle grinder was used to bevel angles of 30 degree. These plates were joined together and welded to a frame, see Table 7-1.The joints had a groove angle of 60° with a root face thickness of 0.5 mm and between the plates was a root opening of 2.5 mm. Welding was performed in PF position (rising) and without a welding procedure specification. The full penetration weld was made by using the shield metal arc welding (SMAW) technique and a consumable electrode covered in flux, type SPEZIAL. All welding was done indoors, and the welding machine used was a KEMPPI - Minarc Evo 180.

Table 7-1 - Welding procedure characteristics.

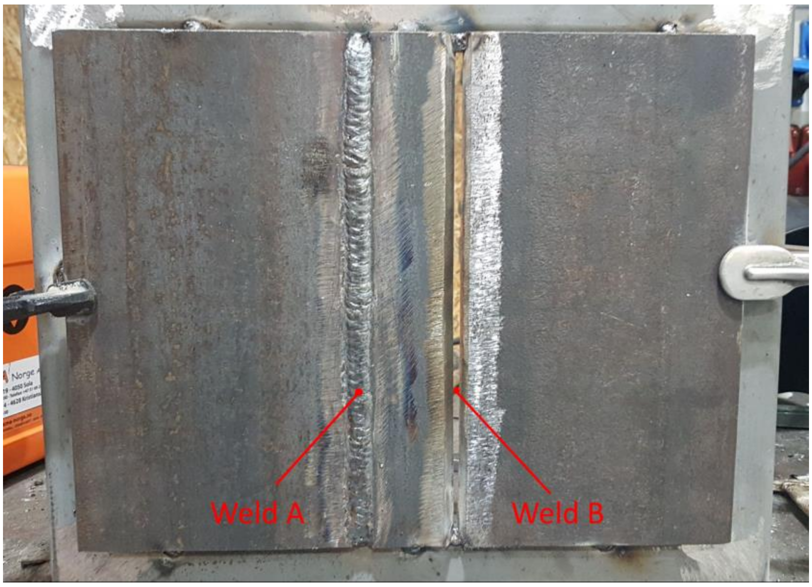
Welding process	111 - SMAW (Shielded Metal Arc Welding)
Base material	S355J2+M
Filler metal	Consumable electrode covered in flux. Type SPEZIAL - 2.50X0350XVPMD.
Welding Current (A)	70-80
Interpass Temperature (° C)	≤ 250
Number of Passes	3



(a) – This shows our V-groove butt weld with two beveled edges.



(b) Number of passes.

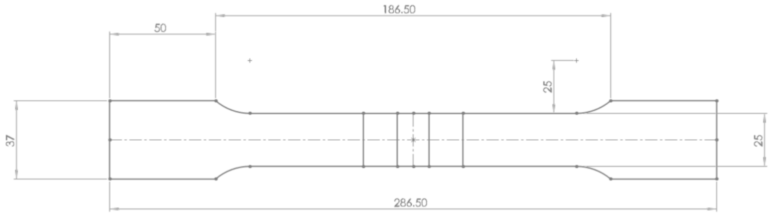


(c) - The distance between weld toes is 50 mm. The left weld is called A and is performed first. Weld number two is seen as a repair weld and is called B.

Figure 7-1 – V- groove butt weld for Prior To Fabrication Test Plate).

After welding, the plate was transported to the University in Stavanger (UIS) for preparation. The plates were cut into 6 pieces and the sides of the specimen was machined, see Figure 7-2. When the specimens were finished, they got an ID.

(a) The test plate was cut into 6 parts and each specimen received a ID. The plate thickness was 10mm. What is missing in the picture is the letter F (fatigue) on specimen F1-F5 and the letter T (Tensile) on specimen T6.



(b) Test specimen drawing.

(c) The sides of the specimen are milled out.

Figure 7-2 –Test Specimens for the “Prior To Fabrication Test Plate”.

7.3.3 *Material properties of the S355J2+N and filler metal*

The base material used for fabrication of ”Prior To Fabrication Test Plate” was steel grade S355J2+M. This is a commonly used high strength structural steel and in critical components or major structural members. S355J2+M is an unalloyed fully killed structural steel with good weldability and machinability [34]. The yield point of the steel in room temperature is 355 MPa, with a minimum impact energy value of 27 J at -20 °C (J2) and thermomechanically rolled (M) delivery condition. The final rolling process in thermomechanically rolled steel is performed in a certain temperature range. This results in material properties that can’t be achieved by normal cooling conditions [34].

The filler metal that was chosen for welding was an electrode from OERLIKON by the name SPEZIAL. SPEZIAL is a basic, double coated multi-purpose MMA electrode meant for welding of S235 to S355.

7.3.3.1 Identification of base material and filler metal

Identification of base material and filler metal are given in Table 7-2 and Table 7-3.

Table 7-2 - Identification of base material, S355J2+M

Identification of base material S355J2+M					
Heat No. and Plate No.	Type	Name/Grade	Standard	Group	Delivery condition
43831-9133182	Flat bar P-150X10	S355J2+M	NS-EN 10025-2:2004	1.2	M

Table 7-3 - Identification of filler metal, SPEZIAL.

Identification of filler metal	
Brand name	Specification/Classification
SPEZIAL Electrodes 2.50X0350XVPMD	EN ISO 2560-A: E 38 3 B 1 2 H10 AWS A5.1: E 7016-H8

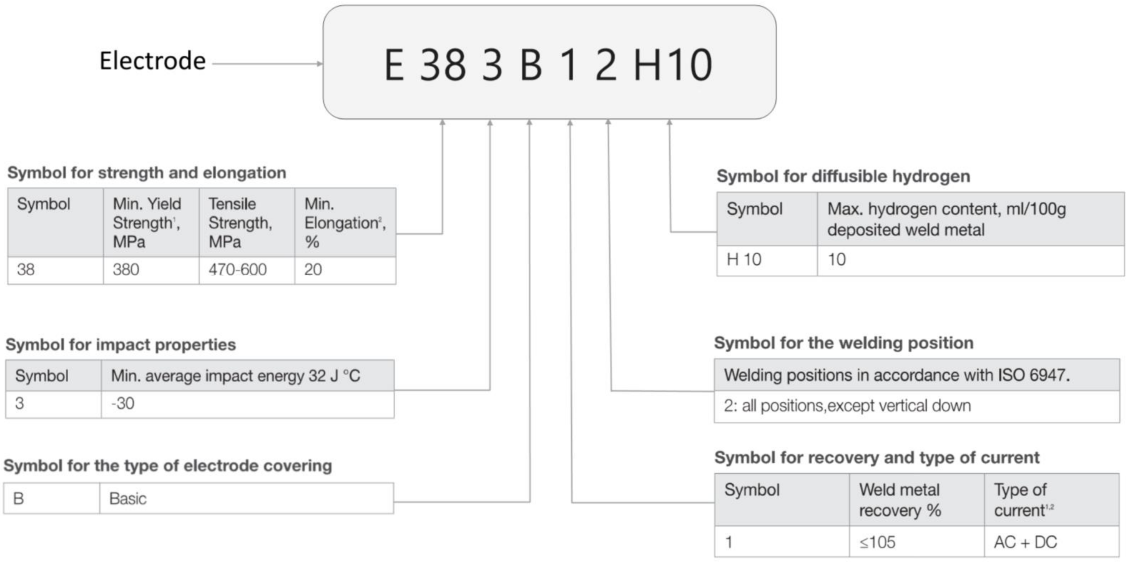


Figure 7-3 – Specification NS-EN ISO 2560:2009 - Welding consumables -
Covered electrodes for manual metal arc welding of non-alloy and fine grain steel.

7.3.3.2 Chemical composition

The chemical composition of the base material is presented in Table 7-4. It shows the maximum allowed composition in accordance with NS-EN 10025-2:2004 [34], and the chemical composition from the ladle analysis.

The chemical composition for the filler metal, SPEZIAL, is given in Table 7-5.

The MDS for base material and filler metal is included in Appendix A.

Table 7-4 – Chemical content of base material, Steel S355J2+M.

Elements	**Requirements** EN 10025:2004:2005 [%]	**Ladle analysis** [%]
Carbon C	≤0.20	0.15
Silicon Si	≤0.55	0.190
Manganese Mn	≤1.60	1.29
Phosphors P	0.025	0.026
Sulfur S	≤0.025	0.012
Nitrogen N	No spec.	0.005
Aluminum Al	No spec.	0.003
Copper Cu	≤0.55	0.04
Chromium Cr	No spec.	0.07
Nickel Ni	No spec.	0.02
Vanadium V	No spec.	0.05
Titanium Ti	No spec.	<0.001
Niobium Nb	No spec.	<0.001
Boron B	No spec.	0.0004
Molybdenum Mo	No spec.	0.01
Arsenic As	No spec.	0.002
Tin Sn	No spec.	0.002
Lead Pb	No spec.	-
Calcium Ca	No spec.	0.0010

Antimony Sb	No spec.	-
Bismuth Bi	No spec.	-
EV2 (CEV)	0.45	0.39
EV2: CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15		

Table 7-5 - Filler metal composition, SPEZIAL.

Elements	**Requirements** MDS – OERLIKON [%]
Carbon C	0.06
Silicon Si	0.7
Manganese Mn	0.9
Phosphors P	≤0.020
Sulfur S	≤0.015

The composition of steel provides important information in order to determine the transformation behavior. Carbon, manganese and nickel below 1 %, silicon below 1.1/2 % and copper move the transformation curve to the right, but do not change the slope.

Chromium, molybdenum, vanadium and other strong carbide forming elements move the curve to the right as well, but they do not change the shape of the curve.

According to NS-EN 10025:2005, the carbon equivalence value, CEV, in the ladle analysis for S355J2 in % with a plate thickness ≤ 30 mm should be less than 0.45.

One of the easiest ways to improve the strength of a steel, is to increase the carbon content. The weldability of the steel limits the amount of carbon to 0.25 % [25]. Based on the composition we can see that S355J2+M is a low carbon steel since the carbon content is lower than 0.30 %. The risk of forming brittle martensite increases with higher carbon content. The higher the carbon content, the more brittle and harder the formed martensite will become during rapid cooling or quenching.

Steel that contains between 0.9-1.7 % manganese is called carbon-manganese steels (C-MN Steel). It can be desirable to increase the manganese content due to increased depth of hardening, improved strength and toughness. Manganese also assists during the production process, when it bonds with impurities such as oxygen and sulfur [25].

7.3.3.3 Mechanical properties

The mechanical properties and the requirements for S355J2+M and filler metal that’s presented below, is from NS-EN 10025:2-2005, EN ISO 2560:2009 and MDS S355J2+M [34, 35].

In order to make sure that the choice of filler metal was correct and the weld was quality sufficient, a tensile test had to be performed on specimen T6, Figure 7-4. Fracture occurred in the base material. The result is shown Table 7-6. The five specimens left, F1-F5, was later used for fatigue testing.

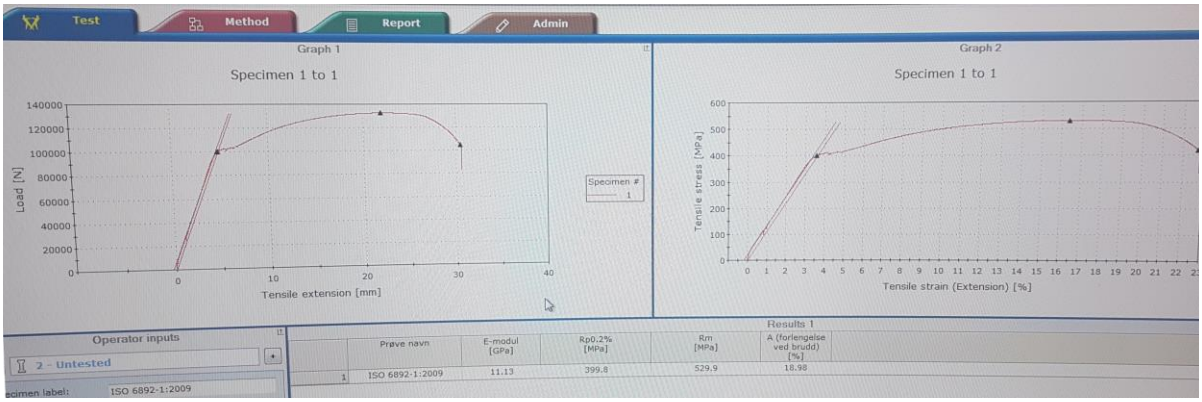


Figure 7-4 - Tensile test of specimen T6. The test results are presented below in the "Tensile test" table.

Table 7-6 - Tensile test data for base material, S355J2+M.

Tensile test Base material - S355J2+M						
Code / certificate / test	Specimen No.	Heat No.	Yield stress, R_{eH} [N/mm^2]	Tensile strength, R_m [N/mm^2]	R_{eH}/R_m	Elongation, A [%]
Requirements in NS-EN 10025:2:2004 $_{1)}$			>355	470-630		>22
MDS - S355J2+M $_{1)}$		86336Y	414	541	0.77	30.8
Test results $_{1)\ 2)}$	T6	86336Y	ca. 410	529.9	0.77	-

1) Tensile test acc. to EN ISO 6892-1:2009.
2) The test was for the welded "Prior to fabrication test plate". Fracture was in the base material.

Table 7-7 - Tensile test data for MMA electrodes, SPEZIAL

Tensile test Filler metal – OERLIKON SPEZIAL			
Code / Certificate	Yield stress, R_{eH} [N/mm^2]	Tensile strength, R_m [N/mm^2]	Elongation [%]
Requirements in EN ISO 2560-A: E 38 3 B 1 2 H10	Min. 380	470-600	≥ 20
Requirements acc. to MDS-OERLIKON SPEZIAL (as welded)	Min 380	470-600	≥ 25

Table 7-8 - Charpy test data for base material (S355J2+M)

Charpy Impact test Base material - S355J2+M				
Code / Certificate	Heat No.	Test temp	Single values [J]	

		(C °)	1	2	3	Avarage [J]
Requirements in NS-EN 10025:2:2004 1)		-20	Min. 27	Min. 27	Min. 27	
Inspection certificate 1)	86336Y	-20	118	132	104	118
1) Tensile test acc. to EN ISO 148-2010						

Table 7-9 - Charpy test data for MMA electrodes SPEZIAL

Charpy Impact test Filler metal – OERLIKON SPEZIAL					
Code / Certificate	Test temp (C °)	Single values [J]			Avarage [J]
		1	2	3	
Requirements acc. to EN ISO 2560-A: E 38 3 B 1 2 H10	-30	32	32	32	
Requirements acc. to MDS-OERLIKON SPEZIAL (as welded)	+20	≥150	≥150	≥150	
	-30	≥60	≥60	≥60	
1) Tensile test acc. to EN ISO 148-2010					

7.3.4 *Inspection and test plan*

After the “Prior To Fabrication Test Plate” was completed and tested, an I&TP was developed. The I&TP was implemented in order to keep track of all the steps in the project. All activities in the project was carried out according to the "I&TP". An I&TP is a tool used for planning a project and maintaining control of responsibilities and relevant documents.

The I&TP is divided into the various steps of the project. The document should be read together with "Experimental work" as it describes in detail all the activities that have been carried out.

The “I&TP” can be found in Appendix A.

7.3.5 *Appendix A*

In step A-Prior to fabrication the following documents have been created. See Appendix A.

- I&TP
- MDS Base material - S355 J2+M
- MDS Filler metal – OERLIKON SPEZIAL

7.3.6 *Summary*

- The initial test of the prior to fabrication showed that the test setup was viable for further experimentation with some modifications:

- This test plate was welded prior to the manufacturing of the productions plates. It served the purpose to act as a concept plate and by doing this it was possible to gather some experience before the start of the production welding.

- The cutting operation was performed using a metal cutting band saw and an angle grinder. The operation was done in two stages, the plate was first cut then subsequently grinded with a flap disk. After this experience we choose to find another method, due to that the operation was very time consuming, unprecise and unrepeatable.

  Oxy-fuel cutting was a viable method, but the microstructural implications from the high temperature that is induced in the material might also apply unwanted effects. A more favorable alternative was waterjet cutting. This method doesn't introduce significant heat into the material since it uses an abrasive high-pressure cutting process. It is also very efficient when cutting several plates in a series.

- We discussed the choice of steel for the base material and decided to choose S420G2+M. This is a steel that is often used for critical constructions and therefore very interesting for the offshore industry. The steel is more complex than S355J2+M as it is higher alloyed, which makes it more challenging to weld as the risk for cracks increases. We also wanted a steel that is more likely to be sensitive to weld-on-weld or weld proximity interference.
- We decided to use the FCAW welding method due to it being more productive and more common in offshore welding operations as it is cost effective. This method also makes it possible to use a thicker material.
- As we changed the base material and welding method, we also needed to change to a different filler metal. The choice was NSSW SF-3AM as it is commonly used offshore, has preferable properties and works well with the chosen base material.
- Important to note is that post weld heat treatment can lower the strength values of a thermomechanically rolled steel [36].
- The weld joint in this chapter was visually tested and subjected to tensile testing. More extensive testing will be performed on future plates in order to develop a WPQ.

7.4 Stage B – Material Selection and Cutting Process

The manufacturing and delivery conditions of the steel and filler metal used in the project will be discussed in this sub-chapter. It also includes the process of casting the designated steel and the subsequent waterjet cutting operation.

7.4.1 *Objective*

- Order materials and prepare for welding.

7.4.2 *Introduction (Stage B)*

The choice of steel was chosen based on its commonality in the offshore industry and its potential sensitivity to the following welding operations. S420G2+M (NORSOK Y30 Rev. 5) is one of the most commonly sold steels from Norsk Stål AS. It is included in the European Standard NS-EN 10225:2009 [30, 37] and is a high strength plate used for offshore platforms, wind-power installations, pressure vessels and FPSO:s where high strength and corrosion resistance is a requirement. NS-EN 10225:2009 is applicable to steels for offshore structures, designed to operate in the offshore sector, but not to steels supplied for the fabrication of subsea pipelines, risers, process equipment, process piping and other utilities. It is primarily applicable to the North Sea Sector, but may also be applicable in other areas provided that due consideration is given to local condition e.g. temperature [36].

The dimension of the plates was 15x300x500 mm which were waterjet cut from a heavy plate with dimensions of 15x2500x12000 mm at Smed T. Kristiansen in Randaberg. The waterjet cutting method does not introduce any adverse heating that could affect the base material due to it being a cold working process. This is wanted for the future analysis of the microstructure. The intention to analyze the changes the microstructure experiences from the welding operation heat source.

Welding method 13, gas-shielded metal arc welding was chosen as the welding process. The filler metal was one of Norsk Sveiseteknikk AS main products from Nippon Steel & Sumikin Welding, NSSW SM-47A and NSSW SF-3AM. This filler metal is common both offshore and in ship construction.

7.4.3 *Material properties of the S420G2+M and filler material*

The base material used for welding of qualification and production plates was the steel type S420G2+M (MDS-Y30 Rev. 5). It is classified according to NS-EN 10225:2009 and EN 10020:2000 [38] as an special steel alloy in group 3 and steel number 1.8857+M. The construction steel has a specified minimum yield point in room temperature at 420 MPa, and a minimum average impact energy value of 60 J at -40 °C. The steel is of grade 2 and delivery condition thermomechanically rolled (M) [36].

Method 13 was chosen for welding, gas-shielded metal arc welding and the filler metal was the following:

- For root passes method 138 was used. MAG welding with metal cored electrode (Gas Metal Arc Welding using active gas and metal cored electrode). The filler metal used was NST:s NSSW SM-47A. A metal cored wire for low temperature pipe and steel applications down to -60 °C.
- For the hot, fill and cap passes, welding method 136 was used. This is MAG welding with flux cored electrode (gas metal arc welding using active gas and flux cored electrode). Filler metal used was NST:s SF-3AM, flux cored wire for low-alloyed steel, offshore applications, piping, etc.

7.4.3.1 Identification of base material and filler metal

Identification of base material and filler metal are presented in Table 7-10 and Table 7-11.

Table 7-10 - Identification of base material (S420G2+M)

Heat No. and Plate No.	Type	Name/Grade	Standard	Group	Delivery condition
43831-9133182	Heavy Plate 15X2500X12000	S420G2+M (MDS-Y30 Rev.5)	NS-EN 10025-2: 2004	2.1	M

Table 7-11 - Identification of filler material (NSSW SM-47A and NSSW SF-3A)

Brand name	Specification/Classification
NSSW SM - 47A	EN ISO 17632-A-T 46 6 1Ni M M 1 H5 AWS A5.36 E80T15-M21A8-Ni1-H4
NSSW SF - 3AM	EN ISO 17632-A-T 46 4 Z P M 2 H5 EN ISO 17632-A-T 46 6 Z P M 2 H5 AWS A5.36 E81T9-M21A8-Ni1-H4

7.4.3.2 Chemical composition

The chemical composition of the base material is presented in Table 7-12. The table shows the maximum allowed value according to NS-EN 1025:2005 and the chemical composition from the ladle analysis. The chemical composition of the filler metal is presented in Table 7-13, Table 7-14 and Table 7-15.

Table 7-12 – Chemical content of base material (Steel S420G2+M)

Elements (Base material)	Requirements (% by mass), EN 10025:2004:2005	Ladle analysis (% by mass), MDS
Carbon C	≤0.14	0.10
Silicon Si	0.15-0.55	0.28
Manganese Mn	≤1.65	1.49
Phosphors P	≤0.020	0.011
Sulfur S	≤0.005	0.002
Nitrogen N	≤0.010	0.005

Aluminum Al	0.015-0.055	0.041
Copper Cu	≤0.30	0.02
Chromium Cr	≤0.25	0.05
Nickel Ni	≤0.70	0.04
Vanadium V	≤0.080	0.003
Titanium Ti	≤0.025	0.002
Niobium Nb	≤0.040	0.026
Boron B	0.0005	0.0001
Molybdenum Mo	≤0.25	0.002
Arsenic As	≤0.030	0.002
Tin Sn	0.020	0.005
Lead Pb	0.010	0.001
Calcium Ca	0.005	0002
Antimony Sb	0.010	0.000
Bismuth Bi	0.010	0.001
Nb+V	0.09	0.03
EV1 (P_{cm})	≤0.22	0.19
EV2 (CEV)	≤0.42	0.36
EV3	≤0.11	0.03
EV4	≤0.90	0.11

The levels of the residual elements arsenic, antimony, tin, lead, bismuth and calcium shall not exceed 0.03% As, 0.010% Sb, 0.020% Sn, 0.010% Pb, 0.010% Bi and 0.005% Ca. Boron (B) shall not exceed 0.0005%. These elements shall be checked at least once every 5000 tones at each manufacturing location and shall be reported as a cast analysis [36].

EV1: Pcm=C+Mn/20+Mo/15+Ni/60+Cr/20+V/10+Cu/20+Si/30+5*B
EV2: CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15
EV3: V+Nb+Ti
EV4: Cr+Cu+Mo+Ni

Table 7-13 - Chemical content of filler material.

Elements (Filler material NSSW SM-47A)	Requirements (% by mass), spec.	Chemical composition (%), Manuf.No.7U341AW996
Carbon C	0.04-0.10	0.07
Silicon Si	0.40-0.80	0.59
Manganese Mn	1.1-1.4	1.26
Phosphors P	≤0.020	0.009
Sulfur S	≤0.020	0.008
Copper Cu	≤0.3	0.25
Nickel Ni	0.80-1.10	1.02
Chromium Cr	≤0.15	0.02
Molybdenum Mo	≤0.15	0.01
Vanadium V	≤0.05	0.01
Niobium Nb	≤0.05	0.01

Hydrogen Content of Deposited Metal (Acc. To ISO 3690)		
HDM (ml/100g)	Ave.	Spec Max.
1.0, 1.7, 1.0	1.2	5 Max

Table 7-14 - Filler metal composition for NSSW SF-3AM Manuf.No.7S041MP960 (% of weight), only nominal values are available, see Appendix B.

Elements (Filler material)	Requirements (% by mass), spec.	Chemical composition for NSSW SF-3AM (%), Manuf. No. S041MP960
Carbon C	0.03-0.07	0.06
Silicon Si	0.25-0.60	0.31
Manganese Mn	1.0-1.5	1.22
Phosphors P	≤0.020	0.010
Sulfur S	≤0.020	0.005
Copper Cu	≤0.40	0.26
Nickel Ni	0.80-1.10	1.02
Chromium Cr	≤0.15	0.02
Molybdenum Mo	≤0.35	0.01
Vanadium V	≤0.05	0.01
Niobium Nb	Ref.	0.01

Hydrogen Content of Deposited Metal (Acc. To ISO 3690)		
HDM (ml/100g)	Ave.	Spec.
1.4, 1.2, 1.3	1.3	5 Max

Table 7-15 - Filler metal composition for NSSW SF-3AM Manuf.No.8X221MP996 (% of weight), only nominal values are available, see Appendix B.

Elements (Filler material)	Requirements (% by mass), spec.	Chemical composition for NSSW SF-3AM (%), Manuf. No. 8X221MP996
Carbon C	0.03-0.07	0.05
Silicon Si	0.20-0.55	0.27
Manganese Mn	1.0-1.5	1.15
Phosphors P	≤0.020	0.010
Sulfur S	≤0.020	0.004
Copper Cu	≤0.40	0.30
Nickel Ni	0.80-1.10	1.03
Chromium Cr	≤0.15	0.03
Molybdenum Mo	≤0.35	0.01
Vanadium V	≤0.05	0.01
Niobium Nb	Ref.	0.02
Boron B	Ref.	0.003

Hydrogen Content of Deposited Metal (Acc. To ISO 3690)		
HDM (ml/100g)	Ave.	Spec.
1.8, 1.2, 1.0	1.3	5 Max

The easiest way to increase the strength of a steel is to increase the carbon content. A too high amount of carbon can decrease the weldability and increases the risk for solidification cracking in the weld and cold cracking in the fusion boundary in the HAZ. By comparing the chemical composition of S420G2+M and S355J2+M, used for welding of the previous plate, we can see that the carbon content has been reduced from 0.15 % to 0.10 %, while Mn has increased from 1.29 % to 1.49 %, Al has increased from 0.003 % to 0.041 % and Nb has increased from 0.001 % to 0.026 %.

Higher strength of pure carbon steel is achieved by increasing the manganese content. Both carbon and manganese increases the strength, while also reducing the weldability. When a steel is alloyed with manganese it can go from being a carbon steel to becoming a carbon-manganese steel at 0.9-1.7% [25]. The microstructure will still be ferritic-perlitic up to 1.7 % where it changes to a bainitic microstructure. The increase in aluminum and niobium content raises the yield point. Steel that has been treated with Al and Nb is called microtreated steels. Microtreated steels are a special type of microalloyed steels. Micro alloying means that small amounts of bonding elements is introduced in the steel melt. Micro alloying elements are Vanadium (V) and Titanium (Ti) with a higher density than steel. These elements react with C and N and forms carbides, nitrides and carbonnitrides, which forms small precipitations in the austenite.

When these particles become large enough, they lock the grain boundaries and prevent grain growth in the austenite during hot rolling and during the cooling period after hot rolling a more fine-grained ferrite structure is formed. All this means that the material has a better impact resistance but also a lower transtition temperature.

S420G2 + M has less Boron than S355J2 + M. For residual element control, Boron (B) shall not be intentionally added to the steel. Nor are any other elements listed in Table 7-12 allowed.

7.4.3.3 Mechanical properties

The mechanical properties of S420G2 + M and filler materials presented below are from the material certificates and the requirements from NS-EN 10225: 2009.

Table 7-16 - Tensile test data for base material – S420G2+M

Tensile test For base material – S420G2+M					
Code / certificate / test	Heat &plate No.	Yield stress (N/mm^2), R_{eH}	Tensile strength (N/mm^2) R_m	R_{eH}/R_m	Elongation %
Requirements in NS-EN 10225:2:2004 1)	-	420-540	500-660	≤0.93	≥19
Inspection certificate 1)	43831-9133182	489	557	0.88	31

Table 7-17 - Tensile test data for NST filler material

Tensile test Filler material – OERLIKON SPEZIAL			
Code / Certificate	Yield stress (N/mm^2), R_{eH}	Tensile strength (N/mm^2) R_m	Elongation %
Requirements in EN ISO 2560-A: E 38 3 B 1 2 H10	Min. 380	470-600	20
Electrode SPEZIAL (As welded)	≥380	470-600	20

Table 7-18 - Charpy test data for base material S420G2+M

Charpy Impact Test For base material – S420G2+M						
Code / Certificate	Heat No.	Test temp (C °)	Single values [J]			Avarage [J]
			1	2	3	
Requirements in NS-EN 10025:2:2004 1)	-	-40	Min. 42	Min. 42	Min. 42	Min. 60
Inspection certificate 1)	43831-9133182	-40	118	111	114	114

Table 7-19 - Charpy test data for NST filler material

Charpy Impact test, Condition: As welded Filler material – NSSW SM-47A and NSSW SF-3AM					
Code / Certificate	Test temp (C °)	Single values [J]			Average [J]
		1	2	3	
Requirements according to material test report (as welded)	-40	Min. 32	Min. 32	Min. 32	Min. 47
	-60	Min. 32	Min. 32	Min. 32	Min. 47
NSSW SM-47A, Manuf. No. U341AW996 (as welded)	-60	93	104	115	104
NSSW SF-3AM, Manuf. No. 7S041MP960 (as welded)	-40	112	126	142	127
	-60	82	80	87	83
NSSW SF-3AM, Manuf. No. 8X221MP996 (as welded)	-40	137	151	162	150
	-60	115	95	74	95

7.4.4 *Plate manufacturing process*

The steel used has been made by the basic oxygen process. It is a steel making process where the carbon-rich molten pig iron is made into low carbon steel. The plate has been manufactured at Salzgitter Flachstahl GmbH and later mill rolled at Ilsenburger Grobblech. In Figure 7-5 we can see the manufacturing procedure for the plate. The material presented below on the manufacturing process comes from the I&TP Manufacturing Procedure for Plate S420G2 +M. I&TP is manufactured by Salzgitter Flachstahl and Ilsenbruger Grobblech.

General information:

Steel making: Basic oxygen steelmaking process Continuous casting Vacuum

treatment by ladle degassing

Rolling: Quattro mill stand with 36 m length
Descaling at several passes with 180 bar water pressure
Radiometric thickness control
TMCP

Plate Stacking: Stock cooling for hydrogen effusion (min. 12 hours)

Inspection: Surface inspection on both sides of plates
Marking of defects and grinding if necessary
After grinding a thickness test will be performed to assure min. wall thickness

Ultrasonic testing:	Automatic UT-Application will be applied to ascertain soundness of the plates. Acceptance criteria S1/E2 acc. To EN 10160
Plate Marking:	Low stress die stamping
Cutting:	Flame cutting

Manufacturing Procedure for Plate S420G2+M

Salzgitter Flachstahl

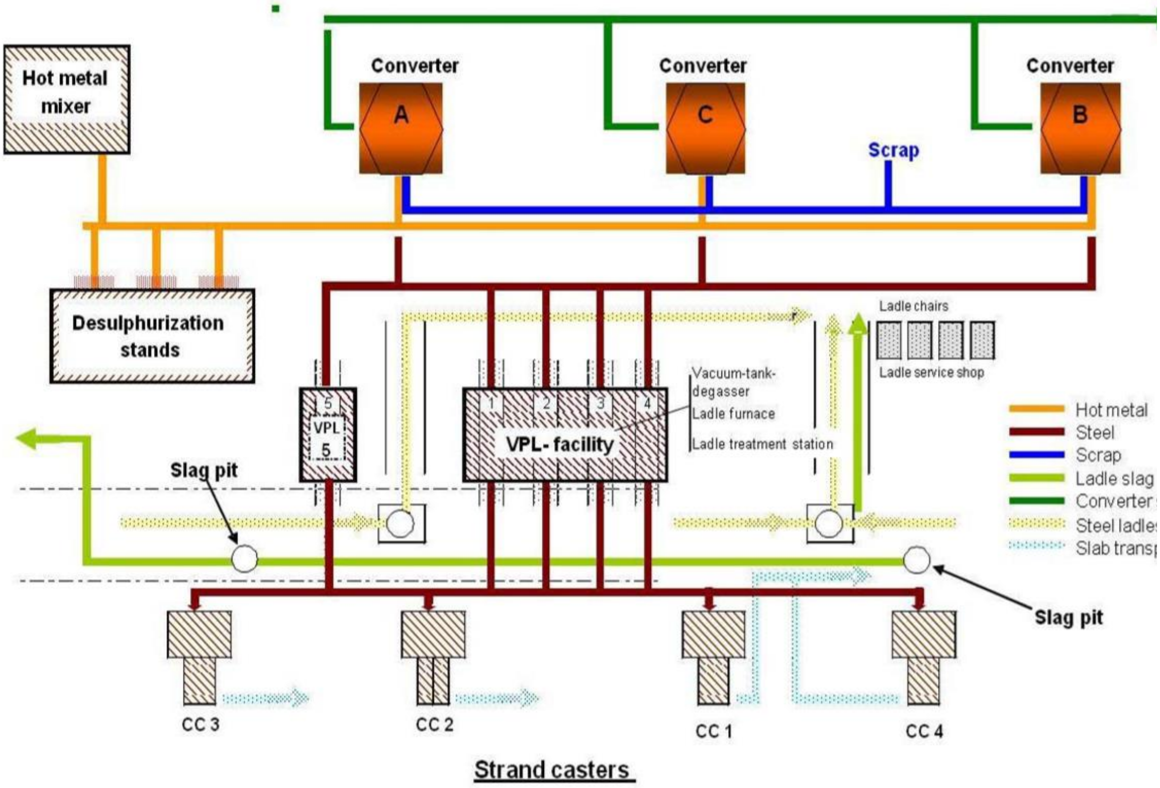


Figure 7-5 - Schematic overview of equipment and material flow in Salzgitter steel plant

1) Pig Iron Production (Blast furnace): Pig iron is first melted into a blast furnace and then transported to the steel works.
2) Desulphurisation (Pig Iron): Pig iron is desulphurised in a ladle by injection of a mixture of CaC2 and Mg powder.
3) Steel Production (Converter A, B and C): The converter is loaded with pig iron and scrap. The steel used during the project was fully killed and this is done through the addition of Al and Si. This is the precondition of a fine-grained microstructure. Pure oxygen is blown into the iron bath through a water-cooled lance and inert gas (argon) is blown through bottom. The red hot molten pig iron is further heated until the desired carbon content is reached. The process is called carbon drop. At the end of the process the pig iron has been converted into crude steel. Heat number is allocated. After completion of the production process, crude steel is transferred into a casting ladle.

4) Degassing (VPL 1-5 facilities): Here vaccum treatment is performed by ladle degassing. This is done according to NS-EN 10225: 2009. Vacuum is used to extract the gases from the steel. Gas that is not removed becomes like frozen gas bubbles in the material. Alloying elements are also added to this station. This is done to give the steel its unique character. Before sending, a ladle check is made for alloying correction. A CA-SI treatment for inclusion shape control and desulphuristation is also performed.
5) Continuous Casting (CC 1-4): These have a bow type with a radius of 10.5 m. The steel is transferred from teeming ladle to tundisched in the plant. Continuous casting occurs in sequence and all process parameters are continuously monitored. Before a new casting campaign, a centerline segregation control is implemented. The continuous casting lines create slabs for the liquid steel. The liquid steel is protected against re-oxidation by slag covering, intert gas and mold powder. The casting has a solid shell a few centimeters thick while most of the cross-section is still liquid. A slab dimension control and transverse cutting by automatic flame cutting equipment is then carried out. Generally the first and last slab of one sequence will be rejected by key quality change.
6) Flame Scarfing (Scarfing workshop): The slab is transferred to the Scarfing Shop. Here identification of the incoming slabs and visual inspection of surface and edges is carried out. Slab is cut into mother slabs and automatic paint marking with heat resistant paint with heat and slab number.
7) Transport: The S420G2 + M sheet is transported to sister company Ilsenburger Grobblech GMbH where it will be rolled into steel plates.

Ilsenbruger Grobblech

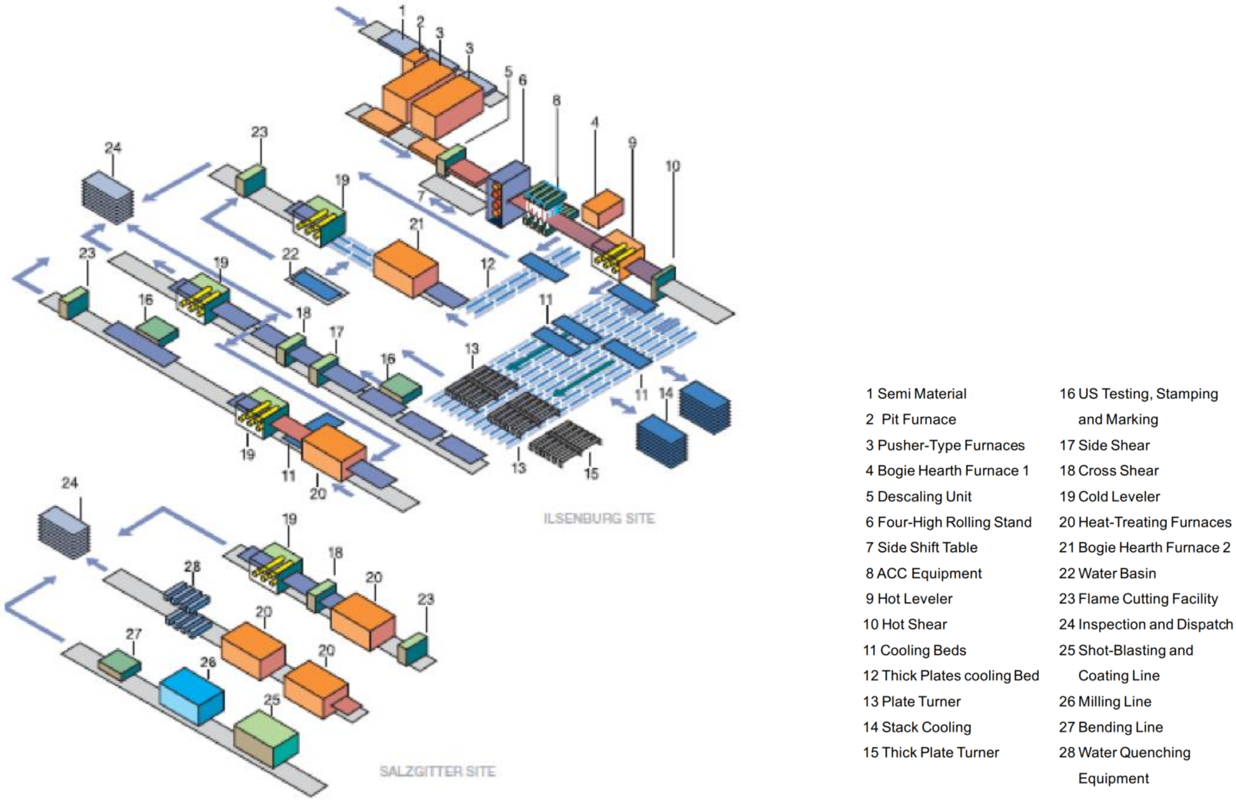


Figure 7-6 - Schmatic overview of equipment and material flow (Ilsenbrug and Salzgitter facilities) - rolling mill

8) Slab Reheating (pos. 3): The slab is transported to a pusher type furnace. In the furnace the plate is heated a temperature between 1100-1200 °C.
9) Descaling (pos.5): Descaling in 2x2 lanes with water pressure of 200 bar.
10) Plate rolling (pos. 6&8): The material is exclusively TMCP processed. No accelerated cooling is done on the project plates. Accelerated cooling is only done on plates with a thickness over 25 mm. The sense of TMCP is to roll the plate in a temperature frame, where due to Nb/ Ti or V as micro alloying elements no recrystallisation takes place. Den first rolling är i intervallet 950-800 °C and the second rolling is done in the interval of 780-700 °C and cools in still air. Figure 7-7 and Figure 7-8 illustrates the rolling procedure in a schematic diagram.

Information about the rolling process:

- Quattro mill stand with 36 m length
- Thermo mechanical controlled process
- Finish temperature: 700-800° C

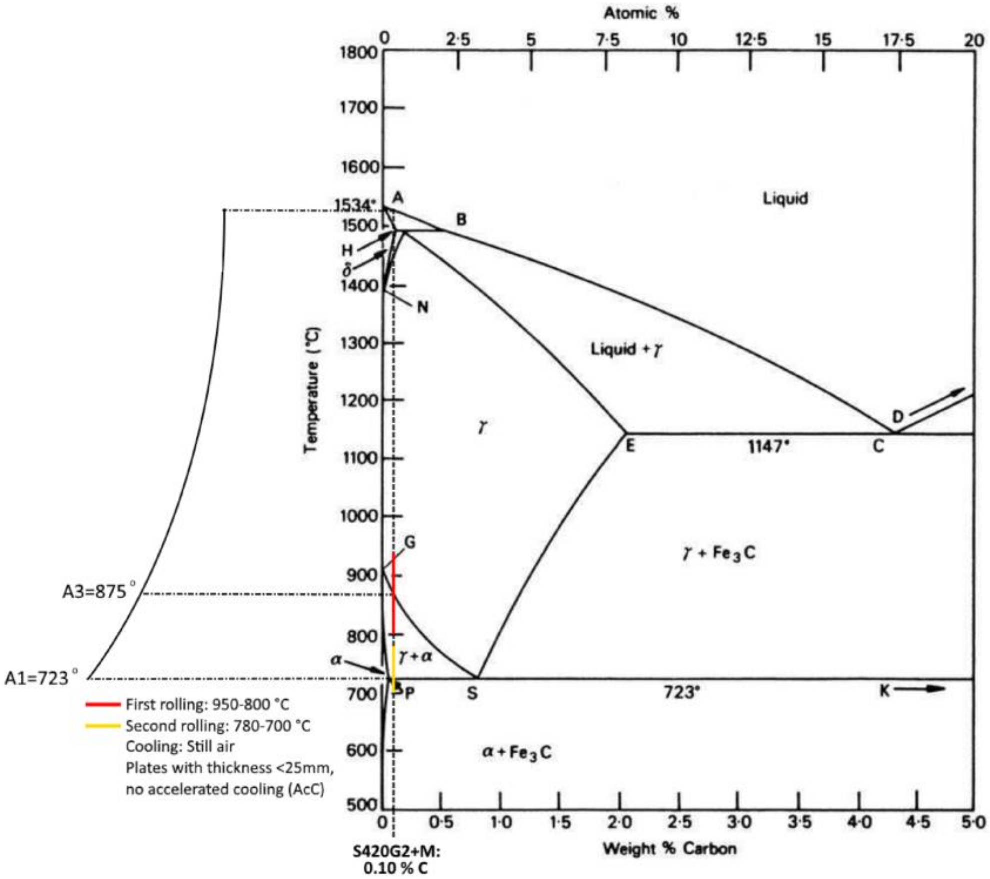


Figure 7-7 - Phase diagram for S420G2 + M 0.10% C showing the temperature interval for rolling. The Iron -Carbon Diagram is only valid for a state of equilibrium condition. During the rolling we have a more dynamic behavior so the temperature is not transferable, but the figure shows the general idea.

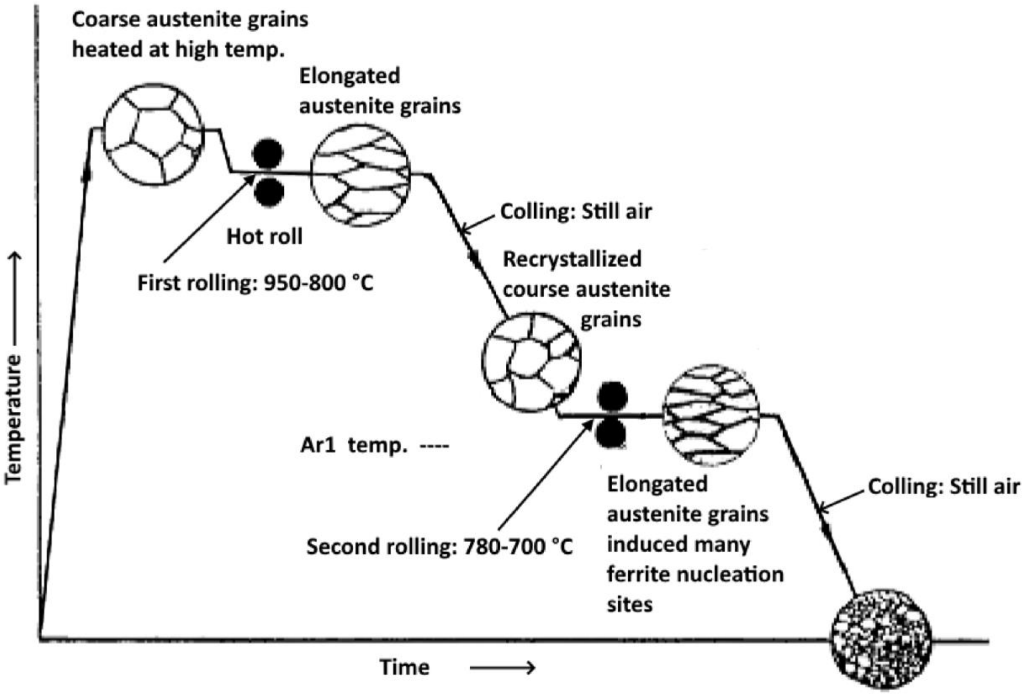


Figure 7-8 - Schematic representation of thermomechanically rolled steel plate S420G2+M

11) Thickness Control (pos. 6): A radiometric thickness control is conducted.
12) Hot Levelling, Plate Cutting and Hot Marking (pos. 9, 10 &11)
13) Plate Stacking (pos. 12): The plates will be stocked for hydrogen effusion.
14) Non-Destructive testing (pos. 11, 16): Visually Inspection and Automatic Ultrasonic Testing. All plates shall be 100% visually controlled and approved according to EN 10163-2. Acceptance criteria for the Ultrasonic Test is EN 10160.
15) Marking (pos. 16): Paint marking and low stress die stamping.
16) Cutting (pos. 18, 17): Sampling and preparation of test coupons and cutting to final plate dimensions and final dimension check.
17) Material testing and final inspection: Product analysis, transverse tensile test and impact test. Final inspection is according to NS-EN 10225:2009.
18) Dispatch and Certification: The preparation of the mill test certificate commences as soon as the order has started production. The certificate is finally printed in parallel with the release for dispatch.

7.4.5 *Waterjet cutting*

The breakthrough for water cutting came with the fact that you started to cut diapers. At the start of water cutting, you only cut with water. The materials that could be cut were only softer materials such as diapers, paper, plastic and thin plywood. Just over 20 years ago, the water jet began to add an abrasive in the form of sand [39].

A little later, the idea came to mix abrasive agents in the form of sand in the jet stream and then materials such as metal, stone and hard plastic could also be cut [39].

Abrasive water cutting works so that a high pressure pump provides a water pressure of about 4000 bar which is pressed against a jewel orifice. The jewel has a hole and a thin water jet with a diameter of 0.1 mm is created. To get the abrasive into the water, the stream passes through a chamber shaped like a tunnel, where the abrasive is picked up by the water stream and accelerated. The water stream, now carrying abrasive particles, then goes through a focusing tube, or nozzle, which gets all of the abrasive fully involved in the water stream and moving in the same direction. Once it has the focusing tube, you have a supersonic stream of water and abrasive that will quickly be its way through virtually any material [39].

Some advantages of abrasive water cutting versus competitive methods are that it is a cold-working method that does not give rise to internal stresses, straightness of the cut, the lack of a heat affect zone, giving no residual stress, melting edges or curing of the material [39].

Figure 7-9 - Waterjet Garnet

Equipment specifications
Kimtech Water-jet Machine
Type: XY-2560
Year: 1012

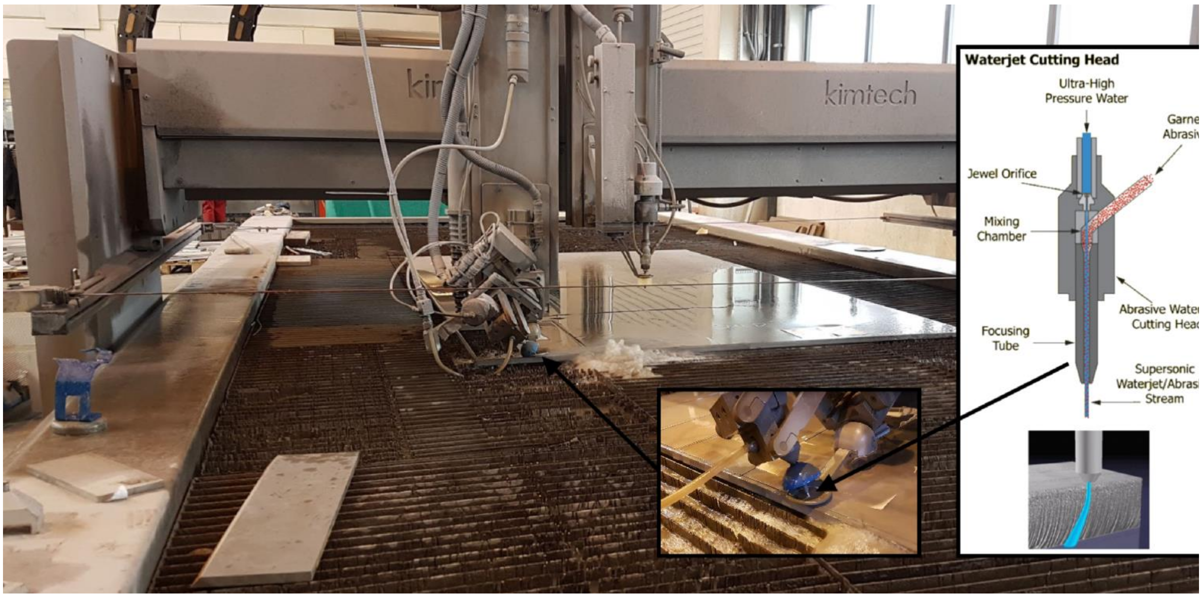
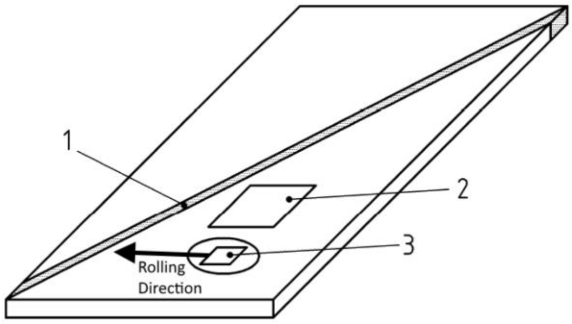


Figure 7-10 - Water-jet cutting på Smedtkristiansen i Dusavik, Stavanger.

Cutting process

All cutting was done with waterjet cutting. The reason why this method was chosen was to not add any extra heat that could affect the material and the end result.

Waterjet cutting was performed at Smed T Kristiansen on a 2.5x3 m sheet metal. The cutting done on this plate was according to "Drawing - Joint preparation 1", see Appendix A. The roller direction has to be perpendicular to the welding direction according to NS-EN ISO 15614: 2017- Specification and qualification of welding procedures for metallic materials. One can find the rolling direction through the heat number, see Figure 7-11 - Waterjet cutting process. In Figure 7-10(c) the cut pieces and the heat numbers are shown.



(a) Marking of plate according to NS-EN 10225:2009. 1. Colour of band according to steel type; 2. Marking; 3. Die stamp (ringed with white paint), text line to be 90 ° to rolling direction.

(b) Heat and plate number.

(c) Here we see the finished sheet and heat the number.

(d) Qualification plate, PL1.

Figure 7-11 - Waterjet cutting process.

7.4.6 *Appendix B*

I Stage B-Material Selection and Cutting Process the following documents have been produced. See Appendix B.

- Mill test report - Base Material S420G2+m - HT43831-9133182
- Certified Material Test Report - Filler material NSSW SM-47-A Manuf.No. 7U341AW996 MIT 9118
- Certified Material Test Report - Filler material NSSW SF-3AM Manuf.No. 7S041MP960 MIT 9188
- Certified Material Test Report - Filler material NSSW SF-3AM Manuf.No. 8X221MP996 MIT 9588

7.4.7 *Summary*

- The objective in this stage was to decide on the suitable steel, filler metal and preparation process before initial welding.
    - The steel type is a commonly used offshore steel. It is thermomechanically rolled, which gives it material properties that cannot be achieved by heat treatment alone.
    - Waterjet cutting was an efficient method that doesn’t introduce any adverse heat into the material. This is beneficial due to the interest of the project is to analyze the adverse effect a secondary weld has on the primary weld. The effect oxy-fuel The operation was also able to cut several plates at a single operation. Due to the welding operation is conducted in two stages, the waterjet cutting operation also has to be conducted after the first weld.

7.5 Stage C – Welding Procedure Qualification Program

In this section, the qualification process of the project's WPQ will be presented. The WPQ is backed by a WPQR that is manufactured and tested in accordance with NS-EN 15614:2017. The chapter will begin with a presentation of the material handling and the standard we used to produce welding procedures. The qualification program we produced will then be described and all of the project's WPS's will be presented. Two different types of WPS's were produced. A WPS for the original weld, weld A, and a repair WPS for weld B. The repair WPS was based on the original WPS and was produced in accordance with NORSOK M-101: 2011 (Rev. 5). The results of non-destructive and destructive testing for the qualification plate will be presented at the end of the work together with results from the production plate.

7.5.1 *Objective*

Develop and approve a WPS.

7.5.2 *Material handling*

Cold cracking, also called hydrogen cracking, can occur after welding unalloyed steel. Basic theory of how cold crack formation occurs is described in NS-EN 17642-1: 2004 and NS-EN 10025-2: 2005 [34, 40]. Hydrogen cracks are usually formed in the coarse-grained part of the heat-affected zone of HAZ, as a result of a critical combination of microstructure, applied stresses and hydrogen [30].

Important factors affecting the risk of hydrogen cracks are:

- The alloy composition of the steel
- Cooling rate
- Tensile stress concentrations in the welded joint
- The amount of diffused hydrogen in the weld metal [34]

The danger of hydrogen cracks in an unalloyed steel can be expressed with the so-called carbon equivalent CEV, generally used for normal solid C / Mn steels [41].

The cooling rate determines how hard the HAZ will be. The faster the cooling, the harder the structure, and thus the greater danger of hydrogen cracks. The cooling rate is dependent on welding parameters, plate thickness and preheating [41]. The welding parameters can be set to the so-called Heat Input. Heat input is often described with two different concepts, in ISO / TR 18491: 2015 [42] and these terms are defined as arc energy and heat input. Heat input uses a unitless thermal efficiency factor which arc energy does not. Arc energy is determined as shown in equation (7-1). We have used the method for Arc Energy in ISO / TR 18491:2015 [42] when preparing WPQ and logging.

$$E = (U * I)/v * 10\text{^}(-3) \qquad (7\text{-}1)$$

E Arc energy [kJ/mm]

U Arc voltage [V]

I Arc welding current [A]
v Traveling speed [mm/s]

Increased heat supply and / or increased preheating results in slower cooling at the same plate thickness, which reduces the risk of hydrogen cracks. This means that thicker sheets have a greater risk of hydrogen cracks.

Moisture is always present in small amounts during welding and this is a prerequisite for hydrogen cracks to occur.

The most common cause of moisture (hydrogen) is [41]:

- Water bound to the filler metal.
- Lubricants in the electrodes.
- Moisture in air or in the protective gas.
- Condensate, rust, oil or coating in the weld zone.

By proper storage, handling and drying procedures, the content of moisture can be minimized and thus reduce the risk of hydrogen cracks.

The hydrogen content is measured in ml H2 / 100 g. The content of the weld varies and is commonly used is <10, <5 and <3 ml / 100g. The hydrogen content for the filler metal of the project can be found in MDSs in Appendix B. The toughest requirement of <3 ml H2 / 100 g comes from the offshore industry. With low hydrogen values one can greatly reduce the heating requirements when welding in thicker materials.

In welding, it is important to understand the relationship between heat input, material thickness, CE / CET, maximum hydrogen content in filler metal and minimum preheating to avoid hydrogen cracks, described in NS-EN 1011-2: 2001 [41]. We will present below how we have gone about counteracting hydrogen cracks.

7.5.3 *Material, welding consumable and specimens handling plan*

All materials and specimens used have been handled according to the material handling plan below.

Base material - S420G2+M (MDS Y30 Rev 5)
The material was stored indoors in a dry environment to avoid corrosion. All material was also stored on a pallet to prevent material from disappearing and being damaged.

Filler Wire (NSSW-SM47A and NSSW SF-3AM)
Storage and handling of filler material was done in accordance with supplier NST recommendations. Unopened packages of filler material were stored indoors in a heating cabinet to ensure optimal performance during use. After welding, the filler material was stored in a heating cabinet until it was used again. The manufacturer has presented hydrogen content of Deposited Metal on MDS filler metal see Chemical composition 7.4.3.2.

Electrode – ESAB OK48.08 E7018-G, Low Hydrogen Welding Rod

The electrodes used for welding strongbacks were ESAB OK48.08. These were taken from unopened vacuum-packed packages and before use, dates were checked.

Prior to all welding, the filler material was checked against the stated filler material in the welding procedure. We also checked that the filler material had not begun to corrode or had defects.

Test specimens

- Test specimens for mechanical testing were taken care of by Qlab.
- Test specimens for fatigue testing were taken care of at UIS. Finished prepared fatigue specimens were lubricated in anti-rust oil and stored in a dry environment. Fatigue specimens had undergone thorough surface preparation and were handled with great care. Specimens were rolled into towels in anticipation of testing. Installation of specimens in the fatigue machine was done with nitrile gloves so as not to apply grease or moisture to the surface which could cause surface corrosion.

7.5.4 *Production flow of Welding Procedure Test*

The figure below shows the different steps the qualification plate (PL1) went through. When we picked up the plate after waterjet cutting, we were on step 2 Figure 7-12. The plate was then transported to KIWA TI. where welding and logging would be carried out.

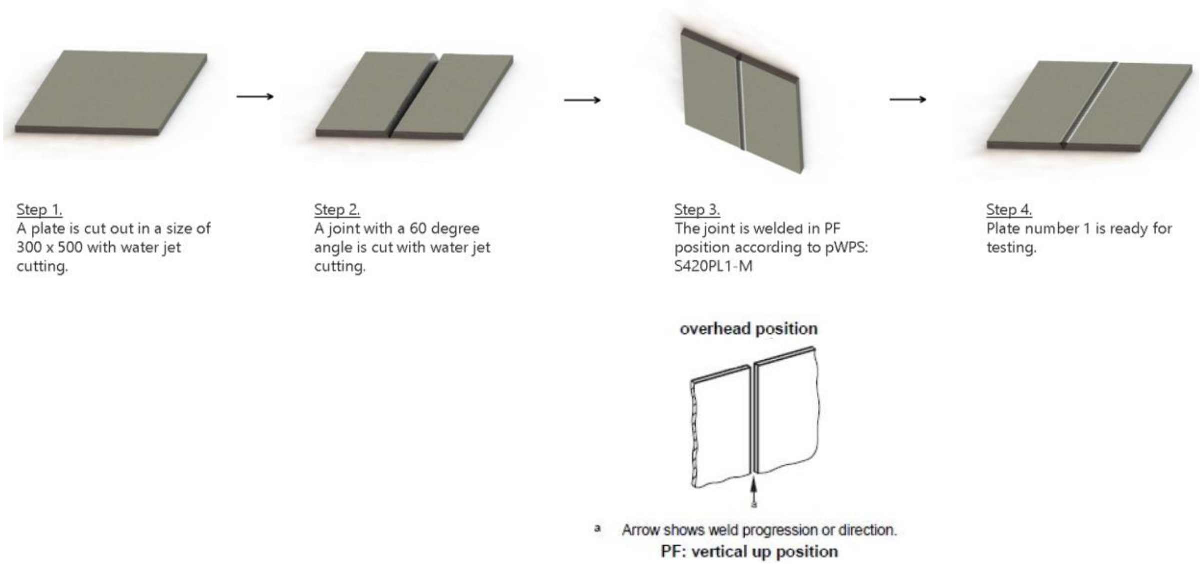


Figure 7-12 - Production flow of Welding Procedure Test

Before welding, strong backs were installed on the back for fixing the plates. The strong backs were formed so that after installation, during and after welding, it was possible to examine the weld joint and the weld root side. Three strongbacks were welded. According to standard for manufacturing welding procedure, NS-EN 15614: 2017, the discard shall be 25 mm at the beginning and end of the plate. Two strongbacks were welded in areas that would later be discarded and the last strongbacks installed in the middle of the plate. Tack weld was carried out in accordance with guidelines in NS-EN 1011-1: 2009, where the recommended minimum length of a tack weld should be 50 mm [41]. For easier disassembly the tack welds were only welded on one side Figure 7-13.

In the following steps 3 and 4 in Figure 7-12, welding in ascending position (PF) as well as non-destructive and destructive testing was performed to look at the mechanical properties. After welding and dismantling of stongbacks, a visual check was made where deformation and defects were noted.

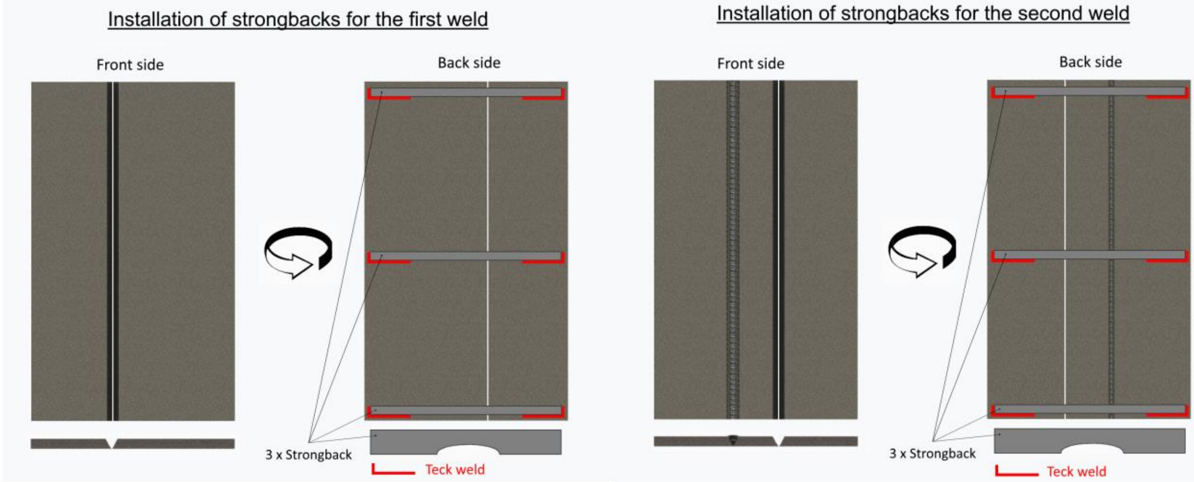


Figure 7-13 - Installation of Strongbacks

7.5.5 *Welding Procedure Qualification Program*

Welding procedures are the necessary basis for planning the welding operation and the quality control during welding. Qualification of welding procedures must be carried out prior to actual welding production and can be done according to several methods mentioned in NS-EN ISO15607.2007 [43].

The method used was "Qualification based on a welding procedure test", see Figure 7-14.

There was no pWPS or WPS when the project started, so first a pWPS is produced, this one is shown in Figure 7-15. Plate 1 (PL1-SW) was the qualifying plate and welded according to the pWPS-S420PL1-M.

All new welding procedure tests shall be carried out in accordance with NS-EN ISO 15614: 2017-Specification and qualification of welding procedures for metallic materials Welding procedure test Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys. Two levels of welding procedures tests are given in order to permit application to a wide range of welded fabrication and they are desginated by level 1 and 2. Level 1 is based on the requirements of ASME Section IX and level 2 based on the previous edition of NS- EN ISO 15614.2017. Testing was carried out in accordance with the level 2 regulations, which also qualify for lower level 1. During testing it was demonstrated that the used joining process is capable of producing joints that meet standard requirements.

Testing results were used as the basis for the establishment of the Welding Procedure Qualification Record, WPQR. The qualification program was used for the production of WPQR. The tests from the qualification plate had to be approved before the project's WPS's became valid.

The project's WPS is based on WPQR: S420PL1-M. We can see the whole manufacturing process of WPS in Figure 7-14.

Repair WPS is based on original WPS according to NORSOK M-101: 2011 Rev.5. According to NORSOK M-101: 2011 Rev.5, the preheat temperatures used during repair welding was minimum 50 °C higher than the preheat used for the original weld. Preheating was achieved by propane.

The activities in the qualification program was carried out according to the I&TP. The I&TP shows the activities, acceptance criteria, verifying documents that was followed and who carried out the approval.

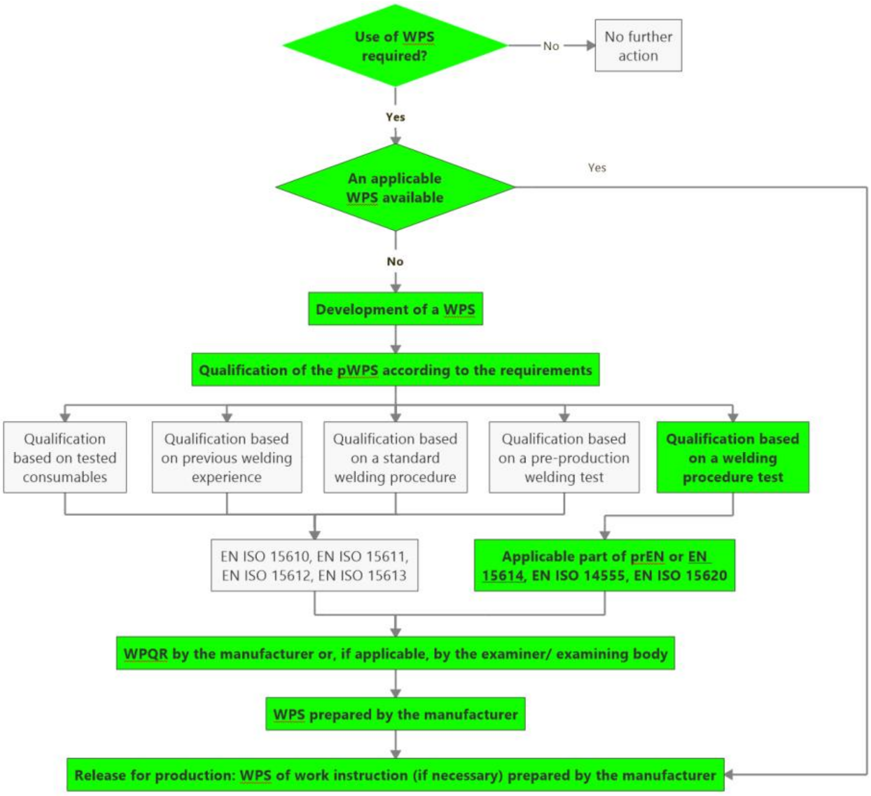


Figure 7-14 - Flow diagram for the development and qualification of a WPS

Welding Procedure Qualification Overview

Table 7-20 - Welding Procedure Qualification Overview shows how the different welding procedures are linked together. Here you can see that PL1 was a qualification plate welded with pWPS-S420PL1-M. Welding, logging and testing done on this sheet resulted in WPQR-S420PL1-M, as previously mentioned, this became the basis for future WPS's.

In Table 7-20 we also see Qlabs Cert. No., these are Qlabs materials reports.

Table 7-20 - Welding Procedure Qualification Overview

Plate	pWPS No	WPQR No	Weld A Original WPS No	Weld B Repair WPS No	Notes	Q-labs Cert.No.
1	S420PL1-M	S420PL1-M	PL1-SW		Welding procedure qualification plate.	8612-1
2					Not used	
3		S420PL1-M	PL1-SW	PL3/4-DW50-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	8612-2
4		S420PL1-M	PL1-SW	PL3/4-DW50-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	
5		S420PL1-M	PL1-SW	PL5/6-DW15-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	8612-3
6		S420PL1-M	PL1-SW	PL5/6-DW15-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	
7		S420PL1-M	PL1-SW	PL7/8-DW5-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	8612-4
8		S420PL1-M	PL1-SW	PL7/8-DW5-Rep	The WPS is based on WPQR and the rep-WPS is based on original WPS.	
9					Used for fatigue testing.	
10					Not used.	

Legend: pWPS=Preliminary Welding Procedure Specification, WPS=Weding Procedure Specification, WPQR=Welding Procedure Qualification Record, PL=Plate, SW=Single Weld, DW=Dual Weld, Rep=Repair

7.5.6 *preliminary Welding Procedure Specification*

Together with the filler material supplier NST and the KIWA TI, pWPS-S420PL1-M was manufactured, see Figure 7-15.

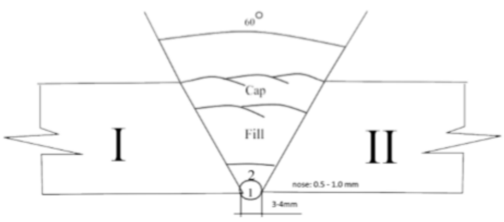
University of Stavanger	**Preliminary WELDING PROCEDURE SPECIFICATION (pWPS)**	pWPS No.: S420PL1-M Ref.: Magnus Larsson Date: 2019.04.05 Rev.4

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc Thesis - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	N/A		

		1		2		3
Welding process		**138**		**136**		
Shielding gas type	1	**Argon /18%CO2 (M21)**	2	**Argon /18%CO2 (M21)**	3	
Weaving (yes/no)		**yes** max: **7** mm		**yes** max: **13** mm		max: mm

Purging gas type	**N/A** l/min
Welding positions	**PF, vertical up**
Joint type	**BW**
Joint preparation	**Waterjet cutting, Grinding**
Cleaning method	**Wire brush**
Backing	**N/A**
Single/Double	**Single**
Back gouging	**N/A**
Flux designation	**N/A**
Flux handling	**N/A**
Tungsten electrode	**N/A** mm
Torch angle	**70-90** °
Stand off distance	**10-25** mm
Nozzle diameter(s)	**10-20** mm
Tack welding proc.	**General** Rev: **0**

WPQR No.: S420PL1-M



Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0.22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	**TM**	**15,00**	-
II	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	**TM**	**15,00**	-

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	**NSSW SM-47A**	**EN ISO 17632-A T46 6 1Ni M M 1 H5**	**FM1**	Suppliers recommendation
2	**NSSW SF-3AM**	**EN ISO 17632-A-T 46 4 Z P M 2 H5** **EN ISO 17632-A-T 46 6 Z P M 2 H5**	**FM1**	Suppliers recommendation

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	1	1,20	138	2,2 - 2.4	100 - 120	14.5 - 15	DC+	60 - 80	N/A	20	1.3 - 1.6
Fill	2	1,20	136	7.0 - 8.0	210 - 230	22 - 23	DC+	140 - 200	N/A	20	1.4 - 2.0
CAP	2	1,20	136	6.5 - 7.5	200 - 210	22 - 23	DC+	160 - 220	N/A	20	1.2 - 1.7

Heat treatment Method: –

Preheat min: 20 °C Interpass temp. max: 250 °C Heat treatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:	Additional info enclosed (Yes/~~No~~):
The pWPS is created with estimated and fixed parameters. Position fixing: 3 strongbacks to be used.	Date/Signature: 2019.04.05 / Magnus Larsson Approved: 2019.04.05 / Mattias Larsson

Page 1 of 1

Figure 7-15 - pWPS

7.5.7 *Welding process*

All welding and logging was done together with the KIWA TI in Stavanger. KIWA supported the project with welders, welding engineers, welding booths, equipment, accessories, material handling and storage.

Before welding, the welding machine was calibrated, parameters such as Volts, Amperes and welding gas flow were set and a test plate was welded. Before welding PL1, it was checked that the bevel and groove angle were in accordance with pWPS. The welding machine used was a Fronius-Trans Steel 2700 and the logging equipment used was FLUKE 376 TRMS clamp meter, folding ruler, stopwatch, lamp, cam type gauge and a welding log diagram.

The welding process started with the installation of strongbacks on the back side according to Figure 7-13. The plate was then mounted and welded in the welding position PF (vertical up position) according to ISO 6947:2011. Prior to welding, fit-up, joint preparation and welding position was approved by examiner at KIWA TI.

Welding was done according to pWPS: S420PL1-M, Figure 7-15 and all welding was logged (all logs can be seen in Appendix C&D). The root string was welded with method 138, MAG welding with metal cored electrode; gas metal arc welding using active gas and metal cored electrode. Fill and cap were welded using method 136, MAG welding with flux cored electrode; Gas metal arc welding using active gas and flux cored electrode. When welding was completed, visual inspection was performed by IWI/IWE Arild Finnesand, KIWA TI. The visual inspection was performed according to ISO 17637:2016 and the acceptance criteria was EN ISO 5817:2014 B/C.

The strongbacks were later removed when the plate had reached room temperature. The plate was transported to non-destructive testing (NDT) 24 hours after the completion of welding.

(a) Calibration of welding machine (b) Gas 20 l/min (c) Test welding

(d) Control of bevel angle

(e) Welding machine

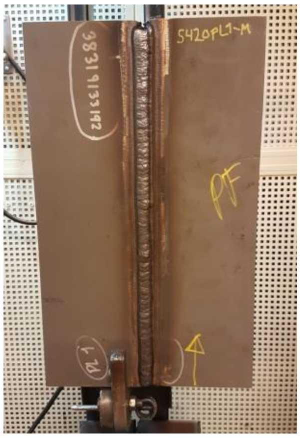
(f) Digital contact thermometer.

(g) Installation of strongbacks

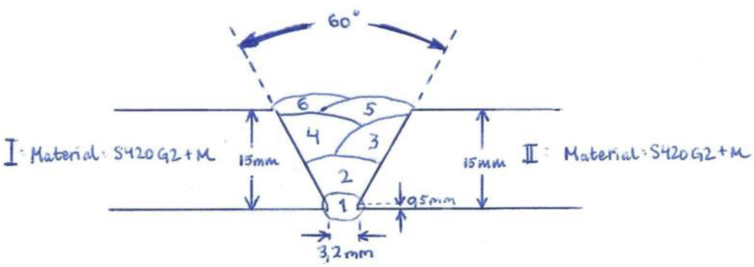
(h) Welding and Logging of qualification plate

(i) Visual inspection

(j) Visual inspection



(k) Plate 1



(l) Placement of welding passes

Figure 7-16 - Welding of qualification plate

7.5.8 *NDT and mechanical testing*

After welding, the plate was transported to IKM Inspection for radiographic testing.

After the approved radiographic test, the plate was transported to Qlab in Forsand where the remaining NDT and mechanical testing were performed. After testing, Qlab produced material report: 8612-1 which is part of the document WPQR: S420PL1-M.

All testing in the project was conducted according to NS-EN ISO 15614: 2017 Level 2. In Figure 7-17 we see the tests that were performed and the location of test specimens for the butt joint plate.

Table 7-21 shows the procedure and acceptance criteria used in qualifying.

Welding procedure testing: PL1-SW

Type piece	Item #	Type of test	Extent of testing	Footnote
Butt joint with full penetration with a single weld (SW). *	1	Discard 25mm	-	a
	2	Hardness test and Maroscopic examination	2 specimens	b
	3	Transverse tensile test	2 specimens	c
	4	Side bend test	4 specimens	d
	5	Impact test	4sets	e
		Visual testing	100%	f
		Radiographic test	100%	g
		Surface crack detection	100%	h

* Tests and acceptance criteria are according to Table 2 - For level 2 NS-EN ISO 15614-1:2017. The test scope has expanded with a macroscopic and a hardness test.

a According to the standard, material should be removed 25 mm at the top and bottom of the plate.
b Two specimens are produced. To see if hardness and microstructure changes occur at high temperature, the test scope was expanded in NS-EN ISO 15614-1 so an extra specimens shall be taken from the top and tested. On each specimen, both a macroscopic and a hardness test is performed.
c
d For thicknesses ≥ 12mm, four side bend specimens may be used instead of root and face bend tests, see 15614-1 section 7.4.2.
e Impact test is according to section 7.4.4 NS-EN ISO 15614:2017. One set in the welding material (W), one set in fusion line (FL), one set 2mm next to the fusion line (FL2) and one set 5mm next to the fusion line. All tests are conducted at the same temperature as the base material tested, -40°C.
f
g
h Magnetic particle testing (MPI) is performed to find surface cracks.

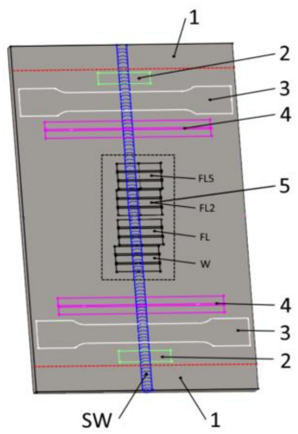


Figure 7-17 - Welding procedure testing

Table 7-21 - Examination and testing of qualification plate

Activity Description	Specification/ Procedure	Acceptance Criteria	Verifying Document	Result
Visual testing	ISO 17637:2016	EN ISO 5817:2014 B/C	Material report: 8612-1	OK
Radiographic	ISO 17636-2:2013	ISO 10675-1:2016	Material report: 8612-1	OK
Surface Crack Detection Test (Magnetic particle inspection)	NS-EN ISO 17638:2016, NS-EN ISO 3452-1:2013	ISO 23278:2015 Level B	Material report: 8612-1	OK
Macro examination	NS-EN 17639:2013	EN ISO 5817:2014 (quality level B)	Material report: 8612-1	OK
Transverse Tensile Test	ISO 4136:2012, ISO 6892-1:2016 Method A1	NS-EN 15614-1: 2017, NS-EN 10225:2009	Material report: 8612-1	OK
Charpy V Impact Test	NS-EN ISO 148-1:2016, ISO 9016:2012	NS-EN 15614-1, NS-EN 10225:2009	Material report: 8612-1	OK
Side bend test	NS-EN ISO 5173:2010	NS-EN 15614-1:2017	Material report: 8612-1	OK
Vickers hardness test	NS-EN ISO 9015:2011	NS-EN 15614-1:2017	Material report: 8612-1	OK

7.5.9 *Welding Procedure Qualification Record*

NS-EN ISO 15607 defines a WPQR as "Record comprising all necessary data needed for qualification of a preliminary welding procedure specification". The document WPQR S420PL1-M contains the following:

- WPQ
- Summary
- pWPS
- Results from NDT and mechanical testing
- Material certificate base material
- Material certificate filler material

7.5.10 *Welding Procedure Specification*

NS-EN ISO 15607 defines a WPS as "A document that has been qualified by one of the methods described in clause 6 and provides the required variables of the welding procedure to ensure repeatability during production welding".

Two different variants of WPSs were produced. The first WPS was for weld A and the second was a repair WPS for approximity welds (weld B). The Repair WPS was based on the same WPQ as the original weld but was converted into a repair WPS according to Norsok M-101: 2011 Rev.5 Section 6.11-Preheat and interpass termperature and Section 10.4-Repair welding procedure.

A total of four WPSs were produced:

- PL1-SW
- PL3-DW50-Rep & PL4-DW50-Rep
- PL5-DW15-Rep & PL6-DW15-Rep
- PL7-DW5-Rep & PL8-DW5-Rep

The WPS documents specified the procedure for performing welding processes for production stage which includes welding method, base material, welding consumable, preparation, preheating, welding method, control of welding, post weld heat treatment and equipment to be used.

7.5.11 *Appendix C*

In Stage-C Welding Procedure Qualification Program the following documents has been created.

- WPQR: S420PL1-M and including documents:
    - WPQ S420PL1-M
    - Summary
    - WPS: PL7/8-DW5-Rep

   - pWPS S420PL1-M
   - Weld log - pWPS:S420PL1-M
   - Report7967-19-DRT-1
   - Mill test report - Materialcertifikat S420G2+M - HT43831-9133182
   - Mill test report - Filler material: NSSW SM-47-A Manuf.No. 7U341AW996 MIT 9118
   - Mill test report - Filler material: NSSW SF-3AM Manuf.No. 7S041MP960 MIT 9188
   - Mill test report - Filler material: NSSW SF-3AM Manuf.No. 8X221MP996 MIT 9588
- All WPS's:
   - WPS PL1-SW
   - WPS: PL3/4-DW50-Rep
   - WPS: PL5/6-DW15-Rep
   - WPS: PL7/8-DW5-Rep

7.5.12 *Summary*

The main objective of this step was to present the procedural steps that was performed in other to develop a WPQ. In order to approve WPQ is has to be approved in accordance with NS-EN 15614:2017, which requires extensive mechanical testing. The following production plates would be welded using the WPS based on this WPQ. The WPQ ensured that all the following welding operations carried out met the requirements.

7.6 Stage D – Production welding of plates

In this sub-chapter, the manufacturing and welding process of the project's production plates will be presented. The first weld joint was cut in Stage B and is ready for welding. Production welding shall be done according to the welding procedures manufactured in Stage C.

7.6.1 Objective

Manufacturing of the production plates intended for Non-Destructive Testing (NDT) and Destructive mechanical Testing (DT).

7.6.2 Introduction

In this sub-chapter, the welding and cutting process for the production plates will be described.

In the previous stage C, only one plate was welded and tested. This was carried out to confirm that the welding process was correct and that the mechanical properties of the welds were in accordance with the requirements of NS-EN ISO 15614:2017.

We started Stage D by welding six production plates according to our Welding Procedure Specification (WPS).

7.6.3 Production flow of test plates for production test

Figure 7-18 shows the different fabrication steps that the production plates went through.

In Step 1 and 2 the plates were cut with a waterjet cutter. In step 3, strongbacks was mounted on the backside of the plate and joint A was welded.

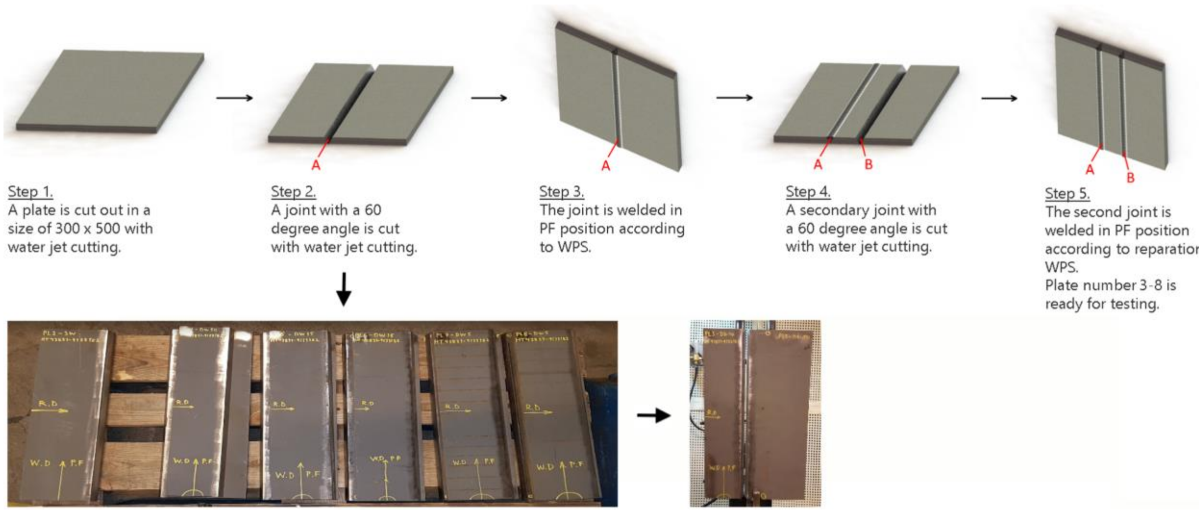


Figure 7-18 - Production flow of test plates for production test.

In step 4 the plates was sent for waterjet cutting of weld joint B. After cutting, the plates were sent back to KIWA TI for welding.

Step 5 is installation of strongbacks and welding of joint B.

Six production plates were prepared with three different spacings between joint edges. The distance between joint edges (D1) was 50, 15 and 5 mm shown in Figure 7-19.

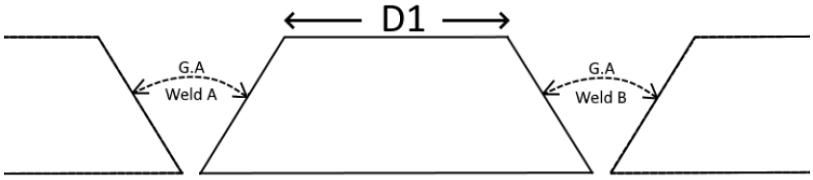
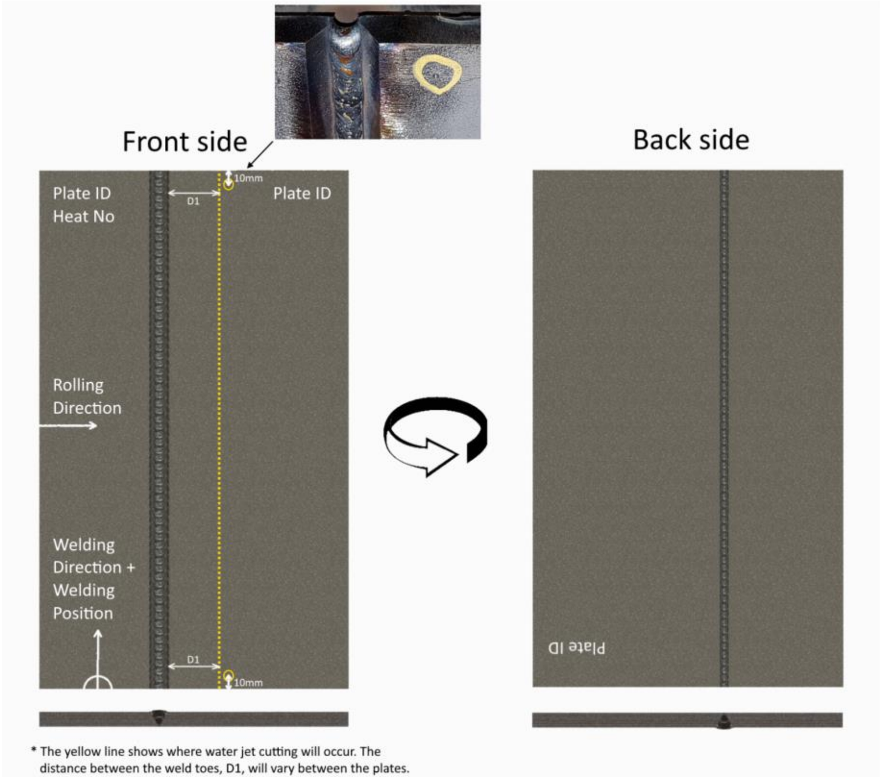


Figure 7-19 – Distance between the weld joints.

To keep track of all parts that were manufactured, a identification and marking system was created, this was important for traceability.

Here is a description how the identification, marking and cutting of plates were carried out. The first qualification plate had only one weld while the production plates had two parallel welds, see Figure 7-20 (c). In the manufacture of weld joint number two (weld B), a parallel cutting was performed alongside the first original weld (weld A), see yellow dotted line in Figure 7-20 (a).



(a) Identification system and yellow cutting line.

(b) Centre punch tools

Figure 7-20 - Identification and marking system

Figure 7-20 - Identification and marking system, shows how the plates were named. The plate ID was written on both of the front side's upper corners, this was important to avoid mixing up the plates after cutting.
Prior to welding, the distance D1 was measured from the joint edge A to the next joint edge B. The three different distances 50, 15 and 5 mm were marked with a center punch. This mark is circled with a yellow circle in Figure 7-20(a) and the tools used are shown in figure b.

After welding, a yellow line was drawn between the two markings, this was the cutting line. The cutting was carried out with a 30 degree bevel angle, see drawing-joint preparation 2.
When the cutting was completed, the plate was flipped so that the back side became the front side which gave a groove angle of 60 degrees. Welding of weld B was done in welding position PF (rising welding position).

The rolling direction of the steel affects the microstructure and mechanical properties of the steel, thus affecting it's anisotropy, which means that the strength can differ between directions. Therefore, the test plates have been produced consistently so that all welding passes have been done across the steels rolling direction.

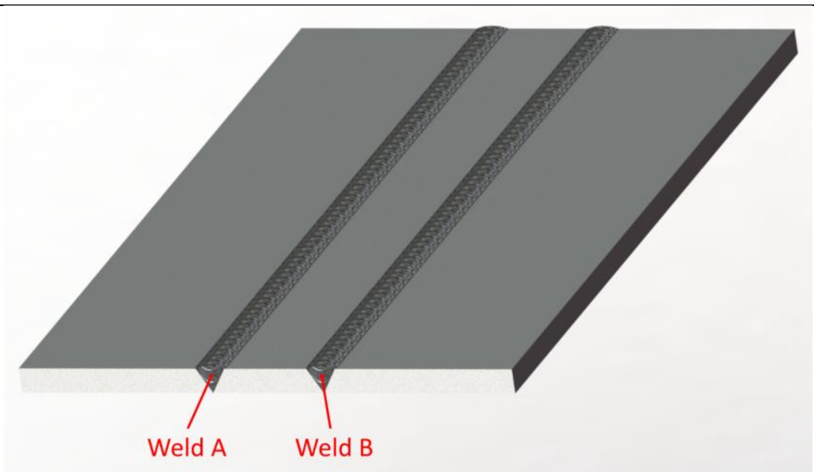
Hard stamping was done on the short sides of the specimen as it is prohibited according to NS 1011-2:2001 to stamp in areas that are highly stressed or where dynamic loads are anticipated.

7.6.4 *Welding and the manufacturing process of the production plates*

Below is a more detailed presentation of the welding process and illustrated with pictures.

7.6.4.1 Weldability

According to the welding and testing procedure defined in NS-EN ISO 15614:2017, the welds were made on plates of 300 mm width, 500 mm height, 15 mm thickness. The root pass was made with MCAW (energy per unit length / heat input around 1.29-1.61) and before welding, fill and cap of the root was grinded and then welded with FCAW (energy per unit length / heat input around 1.21-1.99) in PF position.



(c) Finished welded plate showing welds A and B

7.6.4.2 Welding of weld joint A

Before welding the first weld A, the identification and marking system was checked, see Figure 7-20. Thereafter preparations of the joints, fit-up and alignment of production test plates and installation of strongbacks. On the first plate, PL3, according to procedure, no strongbacks were installed which led to the tack weld for the plate breaking. Upcoming strongbacks were welded according to the "Installation of strongbacks" procedure, see Figure 7-13. In Figure 7-21 (g) we can see the installation of strongbacks with tack welds.

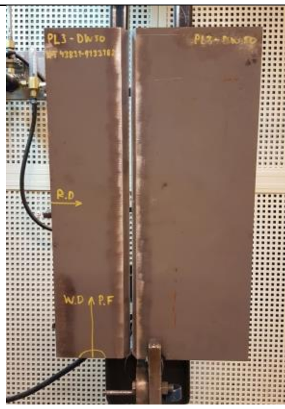
A summary of deformation, crack in welds, etc. is presented as a summary at the end of the chapter.

All primary welds conducted on PL3-PL8 was done according to original WPS: PL1-SW and full logging was performed. To see WPSs and logs, see Appendix D.

When the plates were cooled to about 20 °C, all strongbacks were removed. The deformation that occurred was measured and a visual inspection was carried out according to the acceptance criteria of EN ISO 5817: 2014. After inspection, the plates were transported to Watech AS for waterjet cutting of joint B, weld B.

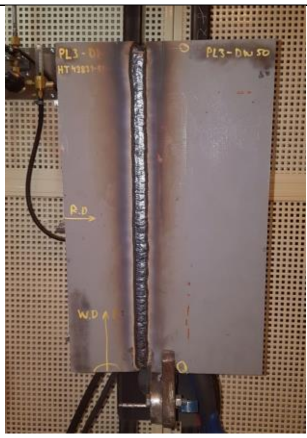
(a) Control of naming and marking system.

(b) Installation of strongbacks PL3.



(c) PL3 fit-up preparation before welding of the first root in weld A.

(d) Root pass of single-V groove weld, frontside PL3.



(e) PL3 WELD A. In the picture we can see the markings circled in yellow.

(f) Root pass of single-V groove weld, backside PL6.

(g) Temperature measuring.

(h) Disassembly of strongbacks after the plates have cooled to 20 °C.

(j) Deformation measuring.

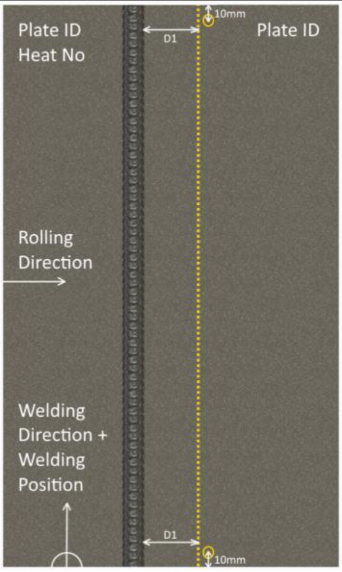
(k) PL3-PL8 ready for transport to Watech for waterjet cutting of weld joint B.

Figure 7-21 - Welding process step 2 and 3.

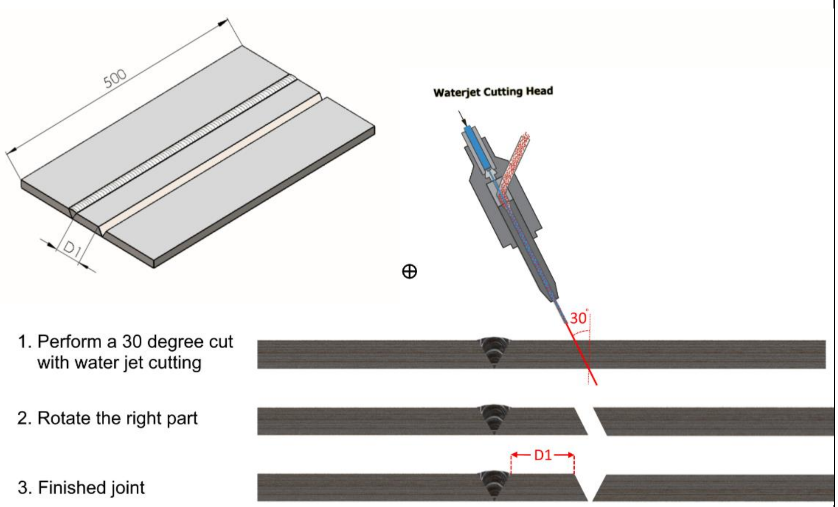
7.6.4.3 Waterjet cutting of weld joint B

Waterjet cutting was carried out at Watech and according to drawing - Joint preparation 2 (Appendix D). Which we can see in Figure 7-21 there were six plates with a yellow cutting line. There were three different distances between the weld joints 50, 15 and 5 mm +/- 2 mm and the distance is called D1. With the waterjet cutting method, a cut with a 30 degree angle was made and after cutting the right plate was flipped, see Figure 7-22. The cut made at Watech varied between 28-30 degrees as the machine had to be adjusted by loosening a screw, see Figure 7-22 (d). The final groove angle ranged between 57-60 degrees.

After cutting, the plates were transported back to KIWA TI. for welding of joint B, weld B.



(a) Yellow cutting line



(b) Cutting operation with waterjet cutting.

(c) Groove angle after waterjet cutting.

(d) Waterjet cutting at Watech AS.

Figure 7-22 – Waterjet cutting of joint 2, weld B.

7.6.4.4 Welding of weld joint B

Before welding the second weld B, the markings on the plates were checked. Thereafter, joint preparation, fit-up and alignment of production test plates and installation of strongbacks. Before installation, the strongbacks had to be reshaped as their support was not sufficient. On the first plate a large notch was made in the strongback, but after welding we noticed that the strongbacks could not withstand the deformation forces that arose during welding. On the other plates, therefore, a smaller notch was made in the strongback and an extra support was welded on the strongbacks Figure 7-23(f). This type of strongback installation caused less deformation of the test plates, but instead some of the strongback holding welds ruptured due to the deformation forces.
Weld B was welded with a repair WPS and all welding was logged. The repair WPS was based on the same WPQ as the original WPS but had an elevated minimum preheat temperature of 50 °C according to Norsok M-101: 2011 Rev.5. Preheating was done with propane.

To see repair WPS’s and logs from welding, see Appendix D.

After the plates had cooled in air down to a temperature about 20 °C, the strongbacks were removed. The deformation that occurred was measured and a final visual inspection was carried out according to acceptance criteria in EN ISO 5817: 2014. After 24 hours after the completion of welding, the plates were sent to IKM Inspection for non-destructive testing (NDT).

A summary of deformations, crack in welds and other results are presented in chapter Results and Discussions.

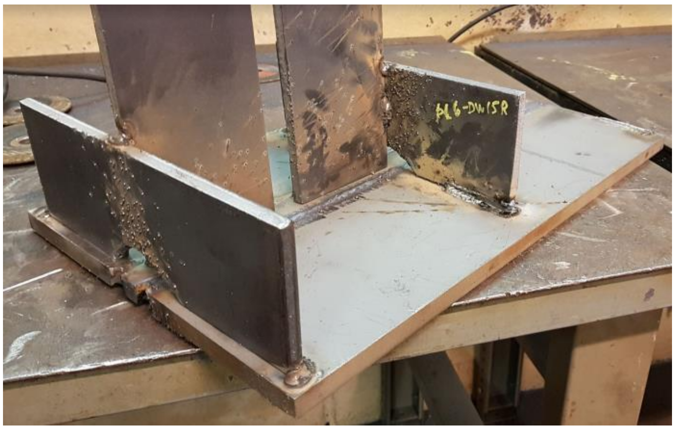
(a) Fit-up of PL3

(b) First strongbacks

(d) Preheating with propane to 50 °C.

(e) Deformation after welding

(f) Second strongbacks with extra middle support.



(g) Cracked tack weld was discovered after finished weld operation.

(h) All production plates ready to be forwarded for NDT and mechanical testing.

Figure 7-23 - Welding process step 4 and 5

7.6.5 *Appendix D*

In step D - Production welding of plates, the following documents have been produced. See Appendix D.

- All Weld log's for Weld A:
    - Weld log: PL3-DW50
    - Weld log: PL4-DW50
    - Weld log: PL5-DW15
    - Weld log: PL6-DW15
    - Weld log: PL7-DW5
    - Weld log: PL8-DW5
- All Weld log's for repair Weld B:
    - Weld log: PL3-DW50-Rep
    - Weld log: PL4-DW50-Rep
    - Weld log: PL5-DW15-Rep
    - Weld log: PL6-DW15-Rep
    - Weld log: PL7-DW5-Rep
    - Weld log: PL8-DW5-Rep

7.6.6 *Summary*

The objective of this stage was to manufacture the production plates that were intended for further mechanical testing at Qlab. The mechanical testing will be described in detail in the next chapter. We had a heavy focus during this operation to log the different procedural steps in the form of drawings, pictures, weld logs and taking notes. To have this information was essential for the future assessment and evaluation of the project.

7.7 Stage E – NDT, Mechanical Testing and Specimen Preparation

In this chapter, the non-destructive and mechanical testing of the production plates will be presented. NDT testing was done at KIWA TI and IKM Inspection AS while the mechanical testing was done at Qlab in Forsand. Testing was carried out according to the same standard as the qualification plate NS-EN ISO 15614: 2017.

7.7.1 Introduction

This section will present and describe how testing of the production plates has been carried out. Results from all plates will be used for a final discussion and conclusion. The aim of the project has been to look at nearby welds and how they affect each other's properties. There was a total of six production test plates, but it was only three of them that were used for mechanical testing. Remaining plates were used for testing residual stresses.

7.7.2 Objective

The objective of this stage was to perform non-destructive and mechanical testing on the production plates that were produced in previous stage.

7.7.3 Non-Destructive Testing (NDT) and Mechanical Testing

The production plates were tested using the same standard as the qualification plate, but the test scope in NS-EN ISO 156214: 2017 Level 2 had expanded with one macroscopic test, one hardness test and two fatigue tests. The fatigue test has replaced previous bending test. We can see the test program for the production plates in Figure 7-24.

Before, during and after welding, a visual inspection was carried out by examiners at the KIWA Institute of Technology, where all welds passed the examination. Non-destructive and destructive tests were conducted at least 24 hours after welding.

After the visual testing at KIWA, the plates were transported to IKM Inspection for radiographic testing.

After radiographic testing, the plates were transported to Qlab where all mechanical testing accept the fatigue test was carried out. Plates PL3, PL5 and PL7 were tested at Qlab while PL4, PL6 and PL8 were to be used for residual stress tests.

Qlab performed the Surface Crack Detection Test (MPI), Macro examination, Transverse Tensile Test, Charpy V Impact Test and Vickers hardness test. After completion of the tests at Qlab the test specimens and production plates were brought to the University of Stavanger for further investigation and preparation. The specimens that were cut for fatigue testing were prepared and tested. The plates that were intended for residual stress testing were cut, prepared and sent to Veqter LTD in England for residual stress testing.

The test results are presented in chapters; F - Microstructural, G - Fatigue Testing and H - Residual Stress Measurements.

Table Table 7-22 shows the activities, procedures, acceptance criteria and verifying documents used during testing of the production plates.

Production sample testing: PL3-DW50, PL5-DW15 and PL7-DW5

Type piece	Item #	Type of test	Extent of testing	Footnote
Butt joint with full penetration with dual welds (DW). *	1	Discard 25mm	-	a
	2	Hardness test and Maroscopic examination	2 specimens	b
	3	Transverse tensile test	2 specimens	c
	4	Fatigue test	2 specimens	d
	5	Impact test	4sets	e
		Visual testing	100%	f
		Radiographic test	100%	g
		Surface crack detection	100%	h

* Tests and acceptance criteria are according to Table 2 - For level 2 NS-EN ISO 15614-1:2017. The test scope has expanded with a macroscopic, a hardness test and with two fatigue test. The side bend test has been removed from "Welding procedure testing: PL1-SW".

a According to the standard, material should be removed 25 mm at the top and bottom of the plate.

b Two specimens are produced. To see if hardness and microstructure changes occur at high temperature, the test scope was expanded in NS-EN ISO 15614-1 so an extra specimens shall be taken from the top and tested. On each specimen, both a macroscopic and a hardness test is performed.

c

d This is a non-standard test piece that is not included in NS-EN ISO 15614-1: 2017. Fatigue specimens should be checked for surface cracks before fatigue testing is performed. This should be done with MPI or liquid penetrate inspection (LPI).

e Impact test is according to section 7.4.4 NS-EN ISO 15614:2017. One set in the welding material (W), one set in fusion line (FL), one set 2mm next to the fusion line (FL2) and one set 5mm next to the fusion line. All tests are conducted at the same temperature as the base material tested, -40°C.

f

g

h Magnetic particle testing (MPI) is performed to find surface cracks.

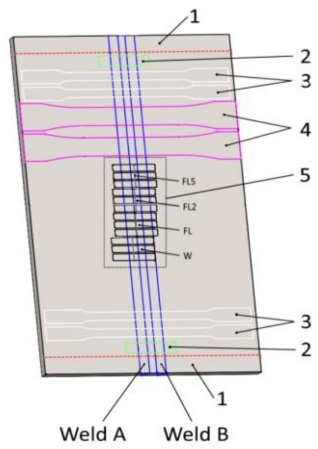


Figure 7-24 - Welding production testing

Table 7-22 - Examination and testing of production plates

Activity Description	Specification/ Procedure	Acceptance Criteria	Verifying Document	Result
Visual testing	ISO 17637:2016	EN ISO 5817:2014 B/C	Material report: 8612-2, 8612-3 & 8612-4	OK
Radiographic	ISO 17636-2:2013	ISO 10675-1:2016	Report serie: 8076	OK
Surface Crack Detection Test (MPI)	NS-EN ISO 17638:2016, NS-EN ISO 3452-1:2013	ISO 23278:2015 Level B	Material report: 8612-2, 8612-3 & 8612-4	OK
Macro examination	NS-EN 17639:2013	EN ISO 5817:2014 (quality level B)	Material report: 8612-2, 8612-3 & 8612-4	OK
Transverse Tensile Test	ISO 4136:2012, ISO 6892-1:2016 Method A1	NS-EN 15614-1: 2017, NS-EN 10225:2009	Material report: 8612-2, 8612-3 & 8612-4	OK
Charpy V Impact Test	NS-EN ISO 148-1:2016, ISO 9016:2012	NS-EN 15614-1:2017, NS-EN 10225:2009	Material report: 8612-2, 8612-3 & 8612-4	OK
Vickers hardness test	NS-EN ISO 9015:2011	NS-EN 15614-1:2017	Material report: 8612-2, 8612-3 & 8612-4	OK

7.7.4 *Appendix E*

In Stage E - NDT, Mechanical Testing and Specimen Preparation. Se Appendix E

- NDT report - Radiograpic Examination
    - Report8076-19-DRT-1
    - Report8076-19-DRT-2-REV1
    - Report8076-19-DRT-3-REV1
    - Report8076-19-DRT-5
    - Report8076-19-DRT-6
    - Report8076-19-DRT-7
- Qlabs Material Report 8612-2 (PL 3)
- Qlabs Material Report 8612-3 (PL 5)
- Qlabs Material Report 8612-4 (PL7)

7.7.5 *Summary*

The objective of this stage was to perform non-destructive and mechanical testing on the production plates that were produced in previous stage. The planning and execution were intensive and required good coordination with our supporting partners. The testing went well and was executed according to plan. The test results are presented in chapter Results and Discussions.

7.8 Results and discussion

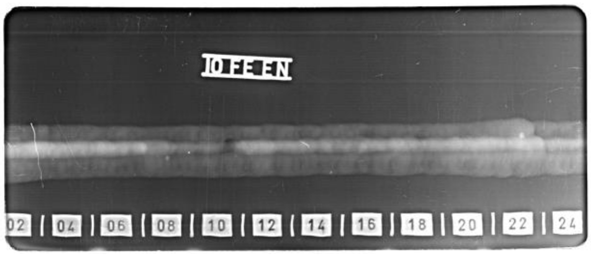
The results presented here are from Stage-C, Stage-D and Stage-E.

7.8.1 *Results from Stage C – Welding Procedure Qualification Program*

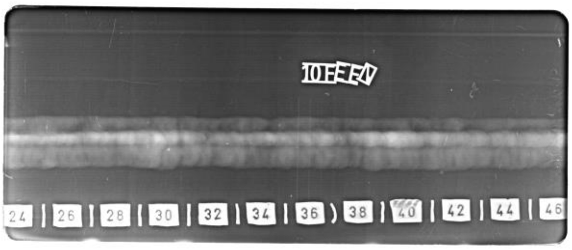
This chapter concerns the testing and approval process of the weld qualifying plate, with one weld joint used for the WPQ. Table 7-21 *summarizes the procedures, acceptance criterias and verifying documents used during the stage. All tests met the requirements, and has been verified by KIWA TI, IKM Testing and Qlab.*

Table 7-23 - Radiographic test of PL1.

Radiographic test					
Plate	Weld No	Film location 20-240	Film location 240-460	Defect location	Remarks
S420PL1-M	Weld A	Accepted	Accepted	106-110	515
515 – Root concavity					



(a) PL 1-SW (0-240) W A



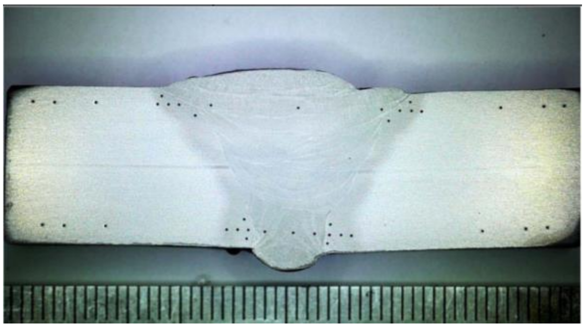
(a) PL 1-SW (240-460) W A

Magnetic particle inspection (MPI)

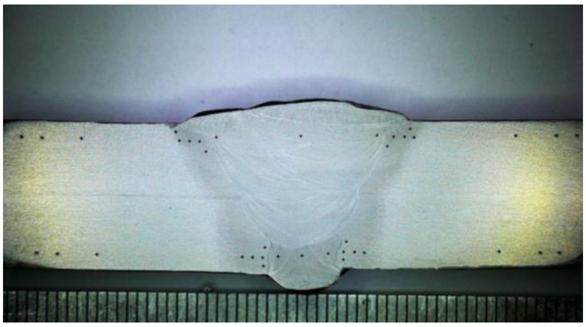
No findings, accepted.

Macro examination

No weld imperfections was visible on the cross section.



(a) PL 1-SW Macro start



(b) PL 1-SW Macro stop

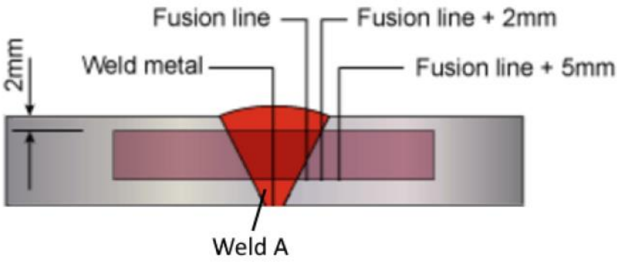
Figure 7-25 - Macro Examination of PL1

Table 7-24 - Tensile test data for PL1

Transverse Tensile test			
Specimen No.	Acceptance criteria [MPa]	R_m [MPa]	Fracture
Cross weld sample 1	500-660	522	Base material
Cross weld sample 2	500-660	528	Base material

Table 7-25 - Charpy test data for PL1.

Charpy V Impact Toughness test, KV_8							
Test ident.	Dimension [mm]	Notch Orientation	Test temp (C °)	Single values [J]			Avarage [J]
				1	2	3	
Acceptance criteria			-40	Min. 42	Min. 42	Min. 42	Min. 60
Weld	10x10x55	T	-40	80	131	106	106
FL	10x10x55	T	-40	113	186	193	164
FL+2	10x10x55	T	-40	253	130	200	194
FL+5	10x10x55	T	-40	234	236	173	214



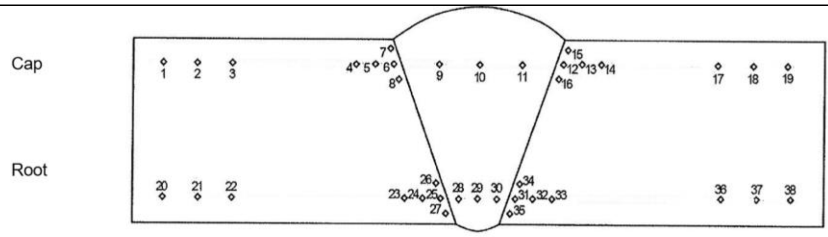
FL=Fusion Line, FL+2=Fusion line+2mm, FL+5=Fusion line+5mm

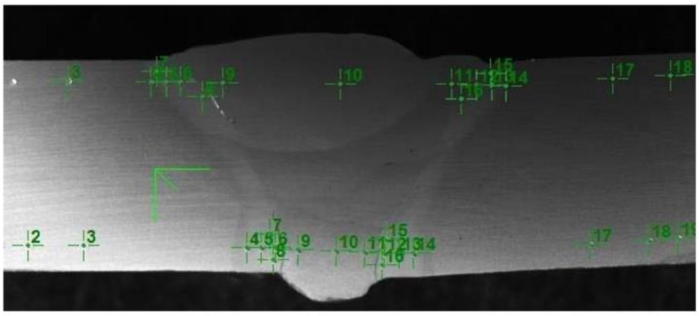
Table 7-26 - Side bend test on PL1.

Side bend test			
Former	Dimension [mm]	Bend angle [°]	Comment
4T	10	180	 Accepted

Table 7-27 - Vickers hardness test data, HV10, for PL1 .

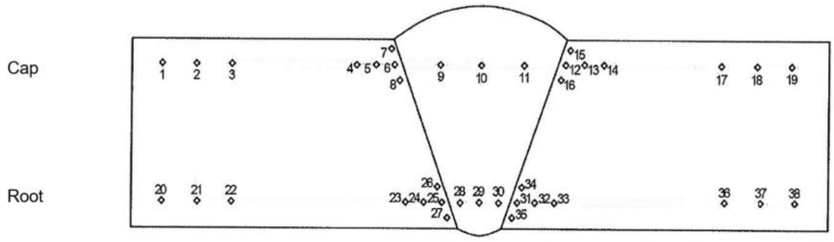
Vickers Hardness Test, HV10	
Position: Start	Surface:Polished and etched

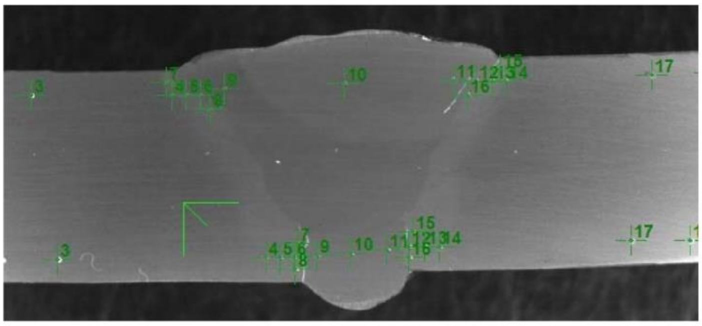




	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	180	184	180	191	200	231	207	223	223	219	227	251	195
	14	15	16	17	18	19							
	192	240	240	179	177	178							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	174	177	180	191	201	207	202	212	210	207	204	209	197
	33	34	35	36	37	38							
	192	211	209	176	178	183							

Position: Stop	Surface:Polished and etched





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	177	177	180	190	198	224	193	207	226	216	215	229	190
	14	15	16	17	18	19							
	183	208	218	174	178	177							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	166	176	176	173	176	197	210	190	198	200	202	195	176
	33	34	35	36	37	38							
	172	199	195	175	177	176							

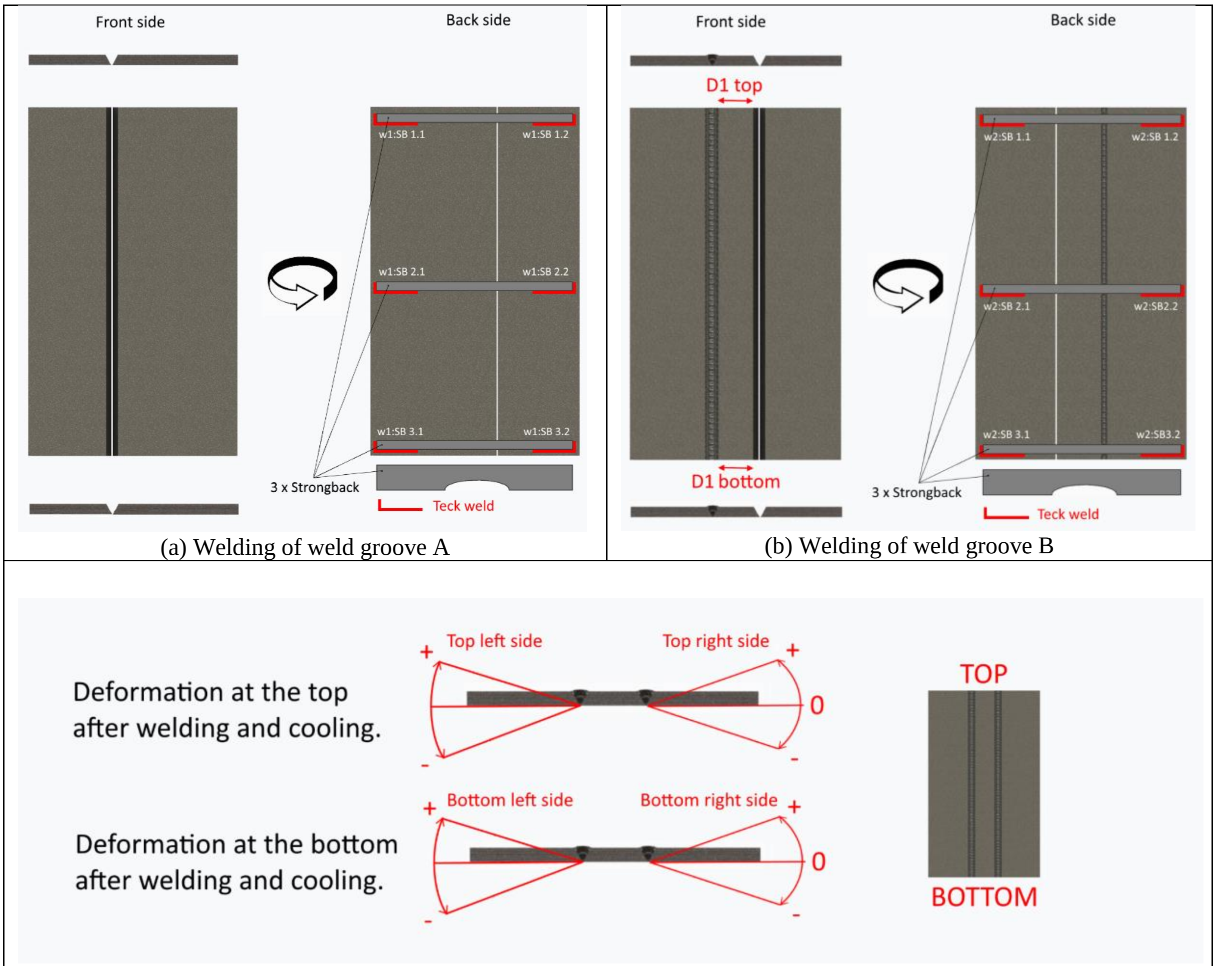
7.8.2 Results from Stage D – Production welding of plates

Below are the remarks from the welding operation of the production plates. During welding the distortional forces from the elastic strain cracked the tack weld of the strongback supports on several welds. It is relevant information when determining the residual stresses, and the source for the stress distribution profiles.

Strongbacks was installed as seen in Figure 7-26. These figures should be read in conjuction with the deformation values in Table 7-20. Every tack weld has a unique ID and belongs to either w1 (weld A) or w2 (weld B).

Ex. ID w1:SB1.1: Strongback (SB) was installed for welding of weld A (w1) and is placed in the far left corner.

All groove angles for weld A was 60 degrees while the groove angle for weld B varied between 57-60 degrees, see table below.



(a) Welding of weld groove A

(b) Welding of weld groove B

(c) Deformation after welding and cooling

Figure 7-26 - Deformation and tack welds for strongbacks

Table 7-28 - Strongback weld rapture PL3-PL8.

History of teck welds for weld 1 and weld 2

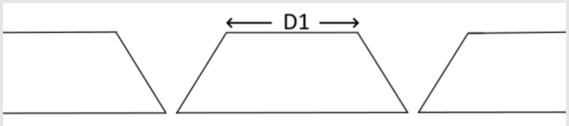
	SB 1.1	SB 1.2	SB 2.1	SB 2.2	SB 3.1	SB 3.2
PL3 Weld 1 (1)(2)	ok	ok	ok	ok	-	ok
PL3 Weld 2 (3)	ok	ok	ok	ok	ok	ok
PL4 Weld 1	ok	ok	ok	ok	ok	ok
PL4 Weld 2	ok	ok	ok	ok	ok	- (4)
PL5 Weld 1	ok	ok	ok	ok	ok	ok
PL5 Weld 2	ok	- (5)	ok	- (6)	- (7)	ok
PL6 Weld 1	ok	ok	ok	ok	ok	ok
PL6 Weld 2	ok	ok	-	ok	ok	ok
PL7 Weld 1	ok	ok	ok	ok	ok	ok
PL7 Weld 2	ok	ok	ok	ok	ok	ok
PL8 Weld 1	ok	ok	ok	ok	ok	ok
PL8 Weld 2	ok	ok	ok	ok	ok	ok

Notes:
Strongback removed when plate had reached room temperatire, if not see extra notes.
OK – Strongback held
- Strongback weld rapture

Extra note:
(1) Strongbacks for weld A was removed before the plate temperature was 20 °C.
(2) One strongback fractured during cooling, no remark was made which one it was.
(3) No strongback fractured but because of the design some bending deformation occured.
(4) Fractured after approx. 1h after welding.
(5) Tack weld fractured during welding of fill. Tack weld was repaired and held.
(6) Tack weld fractured during welding of cap. Tack weld was not repaired.
(7) No tack weld was welded, misstake.

Table 7-29 - Distance between weld joints

Distance between weld joints (D1)

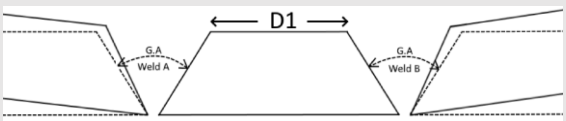


	D1 Should be [mm]	Real distance $D_{1\,Top}$ [mm]	Real distance $D_{1\,Bottom}$ [mm]
PL3	50	49	48
PL4	50	50	50
PL5	15	15	- (1)
PL6	15	- (1)	- (1)
PL7	5	7	- (1)
PL8	5	3	- (1)

(1) Measurement was done after welding. It wasn’t possible to measure D1.

Table 7-30 - Deformation after welding and cooling

Deformation after welding and cooling



	Top, left side [°]	Top, right side [°]	Bottom, left side [°]	Bottom, right side [°]	Groove angle, weld B [°]

PL3	+3	+2	+3	+1	58 (1)
PL4	+3	0	+3	+0.5	57 (1)
PL5	+2	+0.5	+3	+3	57 (1)
PL6	+3	+1	+3	+2	57 (1)
PL7	-1	-3	-1.5	-2	57 (1)
PL8	+1	0	+2	0	57 (1)
(1) Before welding the weld groove B was tiltet 3 degrees to compensate for deformation. Note: Measurements were done with an degree angle ruler.					

7.8.3 *Results from Stage E – NDT, Mechanical Testing and Specimen Preparation*

This chapter concerns the testing and approval process of the production plates with adjacent welds. In Table 7-22 *we see what procedures, accept criterias and verifying documents that were used. All tests met the requirements, and has been verified by KIWA TI, IKM Testing and Qlab..*

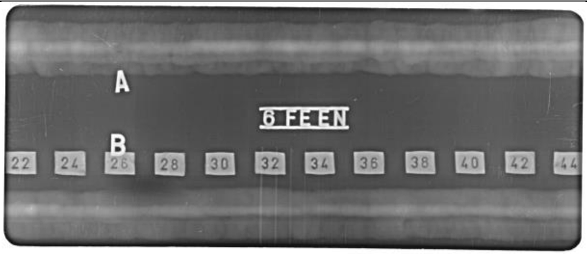
7.8.3.1 Radiographic testing

All welds were tested at radiographically tested at IKM Testing according with ISO 17636-2:2013. The examination was passed for all welds.

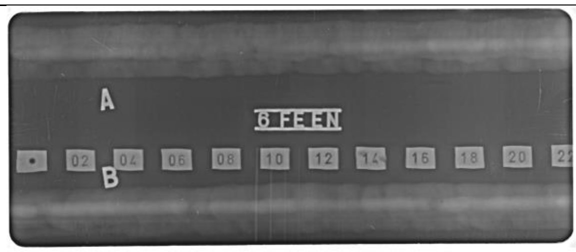
Table 7-31 - Radiographic test of PL3-PL8.

Plate	Weld No	Film location 0-220	Film location 220-440	Defect location	Remarks
PL 3 - DW 50	Weld A	Accepted	Accepted		
	Weld B	Accepted	Accepted		
PL 4 - DW50	Weld A	Accepted	Accepted	270	517
	Weld B	Accepted	Accepted		
PL 5 - DW15	Weld A	Accepted	Accepted	60	2011
	Weld B	Accepted	Accepted		
PL 6 - DW15	Weld A	Accepted	Accepted		
	Weld B	Accepted	Accepted	100, 360	515,515
PL 7 - DW5	Weld A	Accepted	Accepted	395	515
	Weld B	Accepted	Accepted	130, 250	517, 517
PL 8 - DW 5	Weld A	Accepted	Accepted	100, 340	517/2011, 517
	Weld B	Accepted	Accepted		

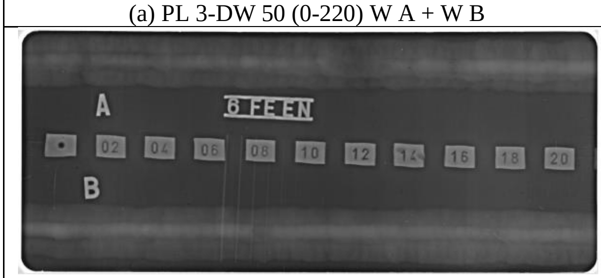
515 – Root concavity
517 – Poor restart
2011 – Gas pore



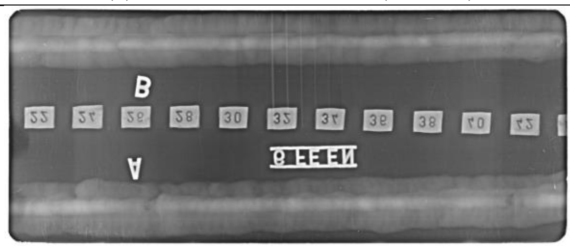
(a) PL 3-DW 50 (0-220) W A + W B



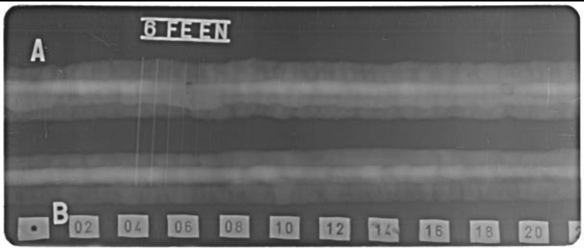
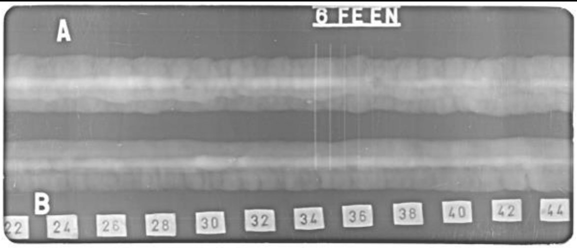
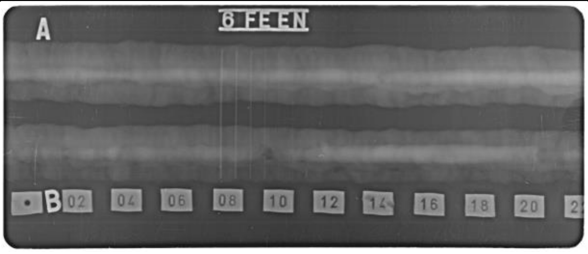
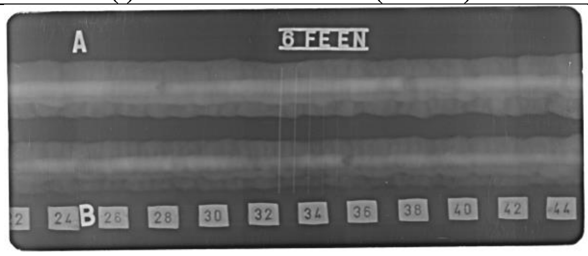
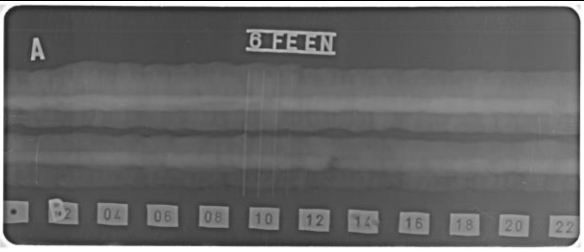
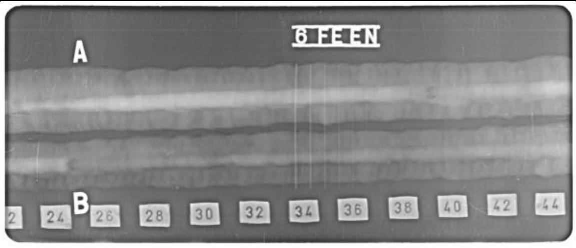
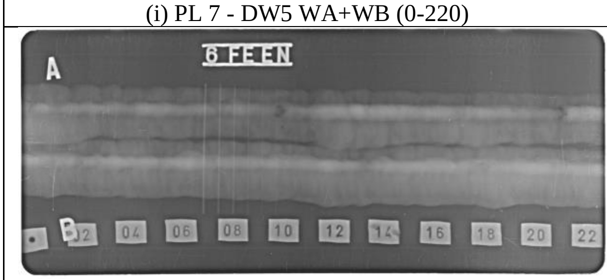
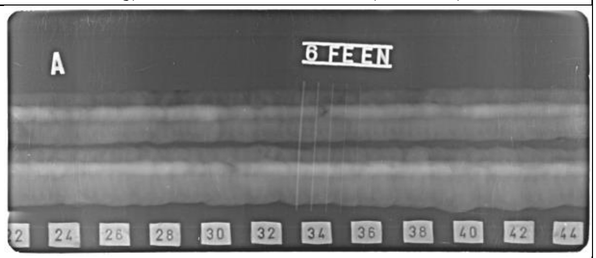
(b) PL 3 - DW 50 WA+WB (220-440)



(c) PL 4 - DW50 WA+WB (0-220)



(d) PL 4 - DW50 WA+WB (220-440)

 (e) PL 5 - DW15 WA+WB (0-220)	 (f) PL 5 - DW15 WA+WB (220-440)
 (g) PL 6 - DW15 WA+WB (0-220)	 (h) PL 6 - DW15 WA+WB (220-440)
 (i) PL 7 - DW5 WA+WB (0-220)	 (j) PL 7 - DW5 WA+WB (220-440)
 (k) PL 8 - DW 5 WA+WB (0-220)	 (l) PL 8 - DW 5 WA+WB (220-440)

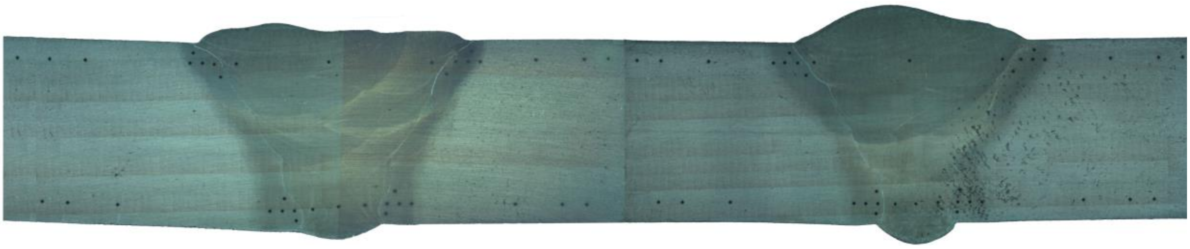
7.8.3.2 MPI examination

MPI was performed on all welds according to NS-EN ISO 17638:2016 and NS-EN ISO 3452-1:2013. The examination was passed for all welds. No findings of defects or impurities, specimens accepted.

7.8.3.3 Macro examination

Macro examination was performed on all plates according with ISO NS-EN 17639:2013. No weld imperfections was visible on the cross sections. Futhermore, an almost straight fusion line can be observed in all cases.

NOTE: The white lines on the macro specimens are purposely introduced on the surface with a a nail in order to being able to determine the fusion line at high magnifications. It was made by Qlab during examination.



(a) Macro start – PL3 Weld A left, Weld B right.

(b) Macro start – PL5 Weld A left, Weld B right.

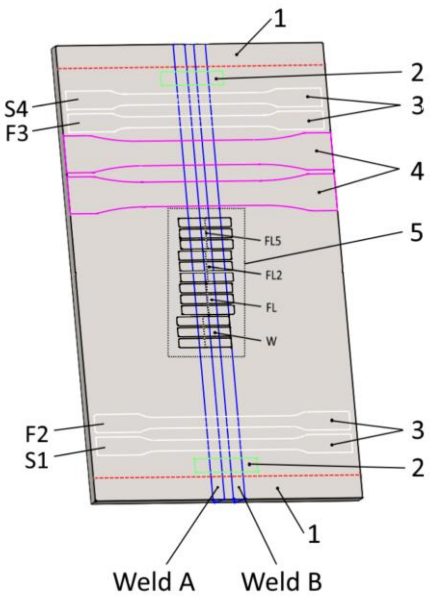
(c) Macro start – PL7 Weld A left, Weld B right.

Figure 7-27 – Macro examination of PL3-PL8. Weld cross section 1.21-1.99 kJ/mm heat input as welded. The macro was polished and etched with Nital and were examined and verified at Qlab, but the pictures were scanned at UIS.

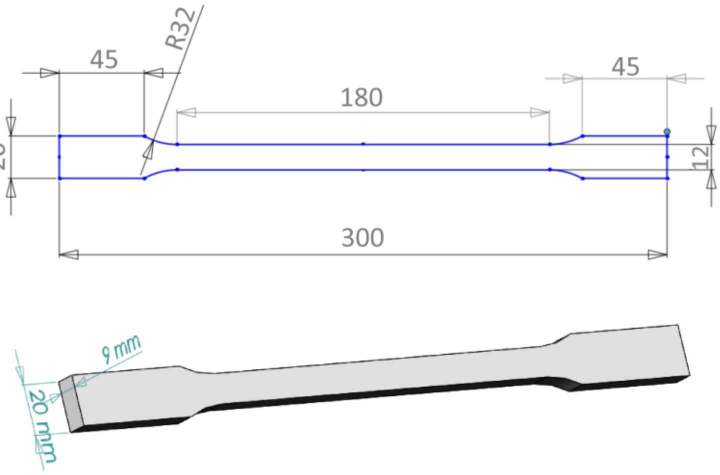
7.8.3.4 Transverse Tensile Test

- Testing according to NS EN ISO 4136-1 / ISO 6892-1:2016 Method A.1
- Name one the tensile specimens are S1, F2, F3 och S4, see Figure 7-28.
- In Figure 7-30 we see the results from the tensile tests.
- Only specimen F was elongation controlled.

All specimens passed the test. Fracture was always in the base material.



(a) Identification system of tensile specimens



(c) Drawing of tensile specimens.

Figure 7-28 – Tensile identification system.

Transverse Tensile test

	Specimen No.	Acceptance criteria [MPa]	R_{eH} [MPa]	R_m [MPa]	R_{eH}/ R_m	A_5 [%]	Fracture
	8612-2 S1	500-660	440.54	528	0.83	-	BM
	8612-2 F2	500-660	458.94	535	0.86	23.03	BM
	8612-2 F3	500-660	-	534		24.45	BM
	8612-2 S4	500-660	444.78	525	0.85	-	BM
	8612-3 S1	500-660	448.19	526	0.85	-	BM
	8612-3 F2	500-660	-	537		28.06	BM
	8612-3 F3	500-660	-	530		28.50	BM
	8612-3 S4	500-660	442.26	517	0.86	-	BM
	8612-4 S1	500-660	461.07	531	0.87	-	BM
	8612-4 F2	500-660	-	534		28.13	BM
	8612-4 F3	500-660	-	533		29.11	BM
	8612-4 S4	500-660	455.23	525	0.87	-	BM

R_{eH} – Yield strength (420-540MPa)
R_m – Tensile strength (500-660MPa)
BM – Base Material
A5 – Elongation, $L_0=5.65\sqrt{S_o}$ (Min. base material 19%.
This requirement is for the base material and not welds, see standard NS-EN 10225:2009
R_{eH}/ R_m – Yield ratio (Max: 0.93).

Table 7-32 – Results of tensile testing and acceptance criteria

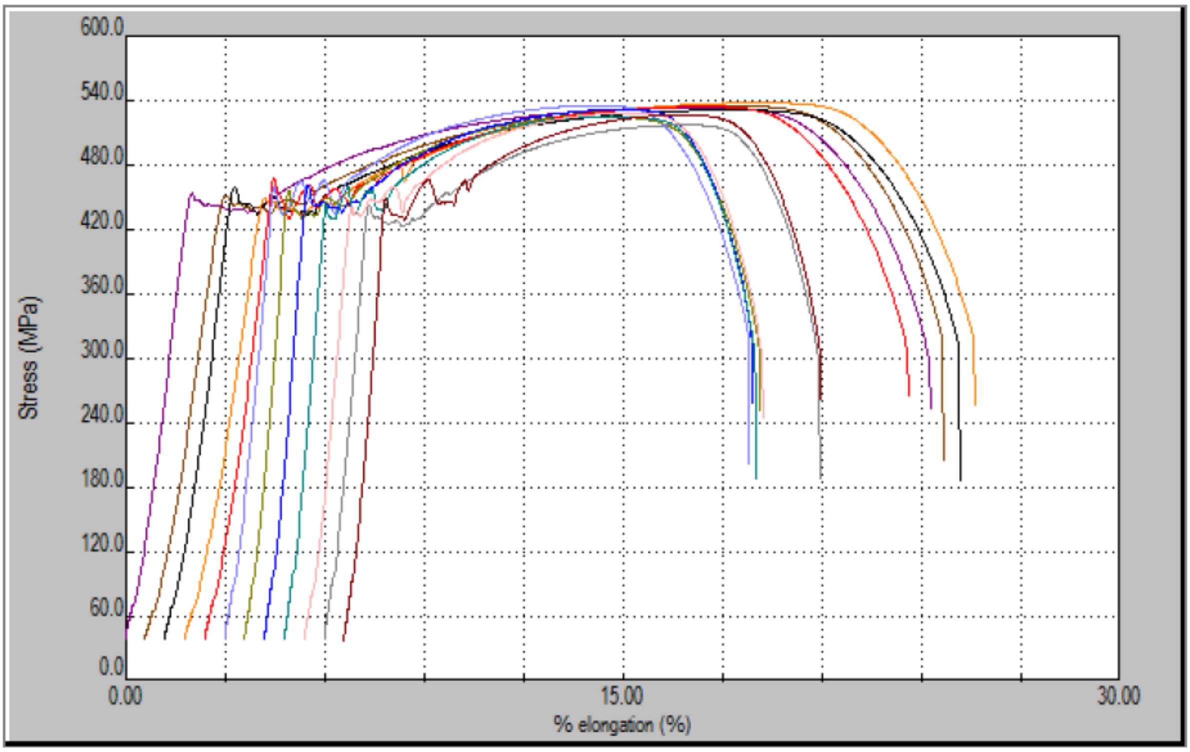
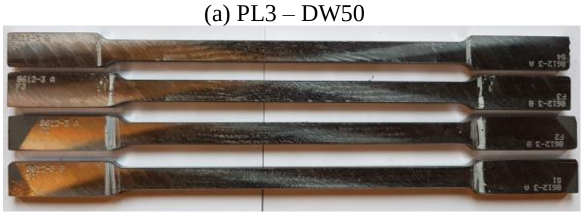


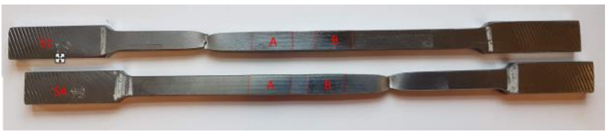
Figure 7-29 - Tensile test graph

(a) PL3 – DW50

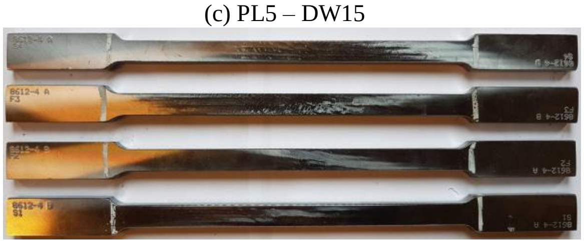
(b) Tensile specimens S1 and S4. Fracture in base material.



(c) PL5 – DW15



(d) Tensile specimens S1 and S4. Fracture in base material.



(e) PL7 – DW5

(f) Tensile specimens S1 and S4. Fracture in base material.

Figure 7-30 - Tensile test. I Figure 2 34 we see the dimensions of the tensile specimens.

7.8.3.5 Charpy V Impact Toughness Test, KV_8

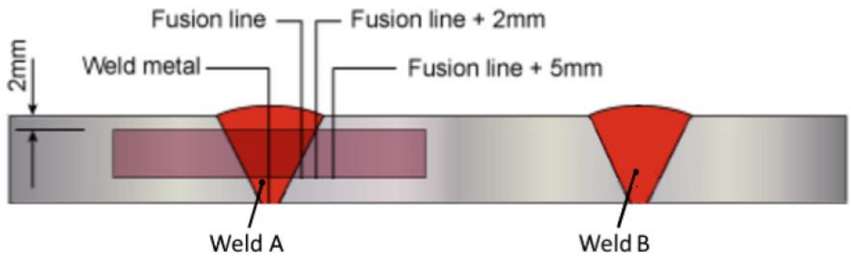
The samples from the Charpy tests are extracted from the initial weld, Weld A, in accordance with NS-EN ISO 148-1:2016, ISO 9016:2012. The locations where the specimen should be extracted is in the Weld, Fusion Line, Fusion Line +2 mm and Fusion Line +5 mm.

- Before testing, all V-notch specimens was controlled with a NO-GO gauge.
- The marking of the test pieces was performed on surfaces that weren't in contact with support, anvils or strikers. Plastic deformation and surface discontinuities caused by marking did not affect the absorbed energy.

Table 7-33 - Charpy V Impact Toughness test KV_8

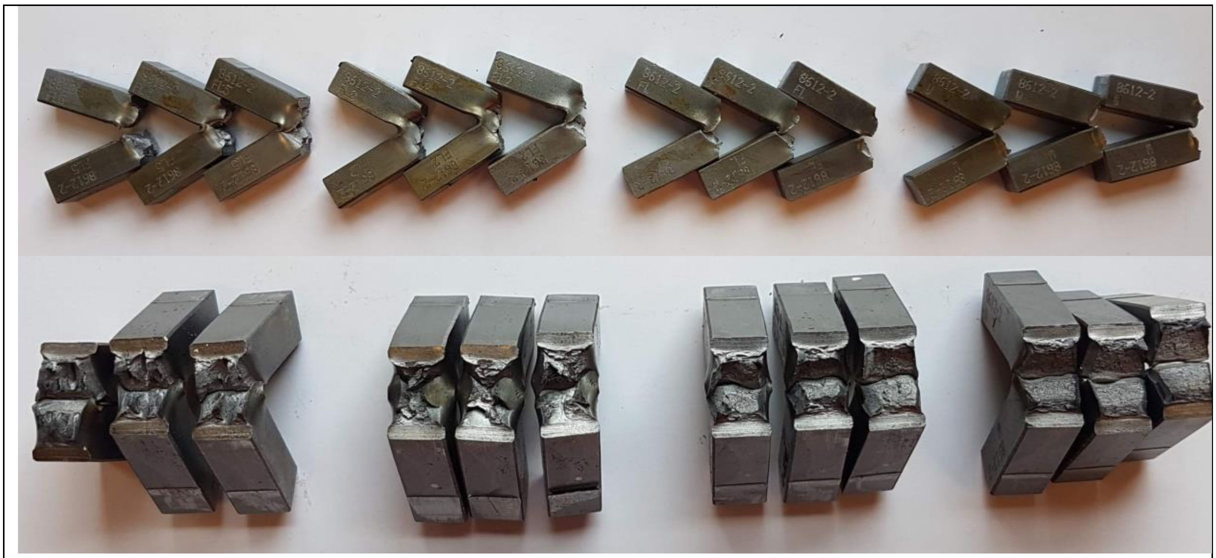
Charpy V Impact Toughness test, KV_8								
Plate	Test ident.	Dimension [mm]	Notch Orientation	Test temp (C °)	Single values [J]			Average [J]
					1	2	3	
Requirements in MDS-S420G2+M					Min. 42	Min. 42	Min. 42	Min. 60
S420PL1-M (1)	Weld	10x10x55	T	-40	80	131	106	106
PL3-DW50 (2)	Weld	10x10x55	T	-40	121.3	120.1	112.2	117.9
PL5-DW15 (2)	Weld	10x10x55	T	-40	100.4	84*	91.4	91.9
PL7-DW5 (2)	Weld	10x10x55	T	-40	107.3	83.7*	81.3*	90.8
S420PL1-M (1)	FL	10x10x55	T	-40	113	186	193	164
PL3-DW50 (2)	FL	10x10x55	T	-40	186.3	123.5	163	157.6
PL5-DW15 (2)	FL	10x10x55	T	-40	168.7	206.2	143.4	172.8
PL7-DW5 (2)	FL	10x10x55	T	-40	202.9	280.8	141*	208.2

S420PL1-M (1)	FL+2	10x10x55	T	-40	253	130	200	194
PL3-DW50 (2)	FL+2	10x10x55	T	-40	394.6	340.5	404.3	379.8
PL5-DW15 (2)	FL+2	10x10x55	T	-40	365.2	365.5	372.4	367.7
PL7-DW5 (2)	FL+2	10x10x55	T	-40	244.7*	354.3*	395.9	331.6
S420PL1-M (1)	FL+5	10x10x55	T	-40	234	236	173	214
PL3-DW50 (2)	FL+5	10x10x55	T	-40	196.2*	214.5	212	207.6
PL5-DW15 (2)	FL+5	10x10x55	T	-40	360.9	319.1	326.9	335.6
PL7-DW5 (2)	FL+5	10x10x55	T	-40	342.6*	305.9*	301.3*	316.6

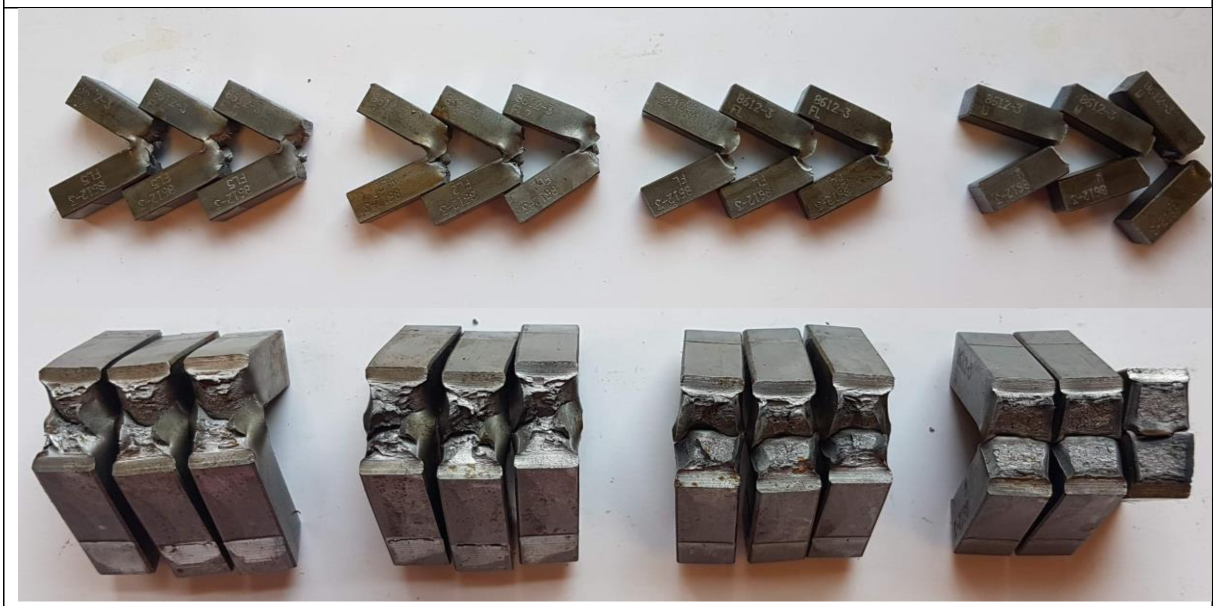


FL=Fusion Line, FL+2=Fusion line+2mm, FL+5=Fusion line+5mm,
KV_8=, T=notch through the thickness
(1) Qualification plate
(2) Production plates

*Broken (complete fracture)



(a) 8612-2. PL3-DW50



(b) 8612-3. PL5-DW15

(b) 8612-4. PL7-DW5

Figure 7-31 - Charpy V Impact test

Fracture appearance

FL+5

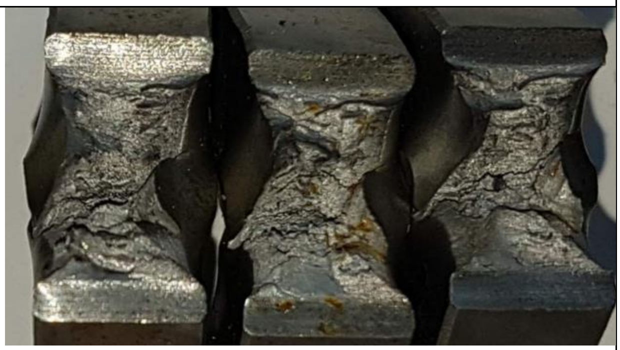
FL+2

FL

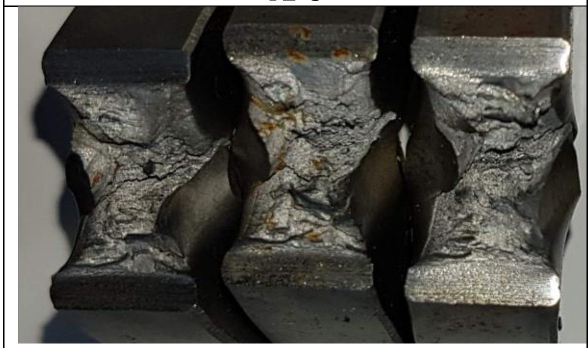
Weld

(a) 8612-2. PL3-DW50

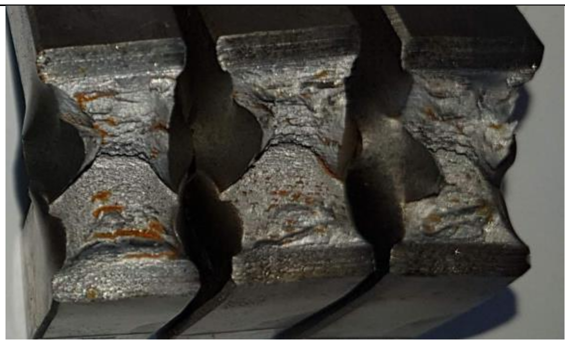
FL+5



FL+2

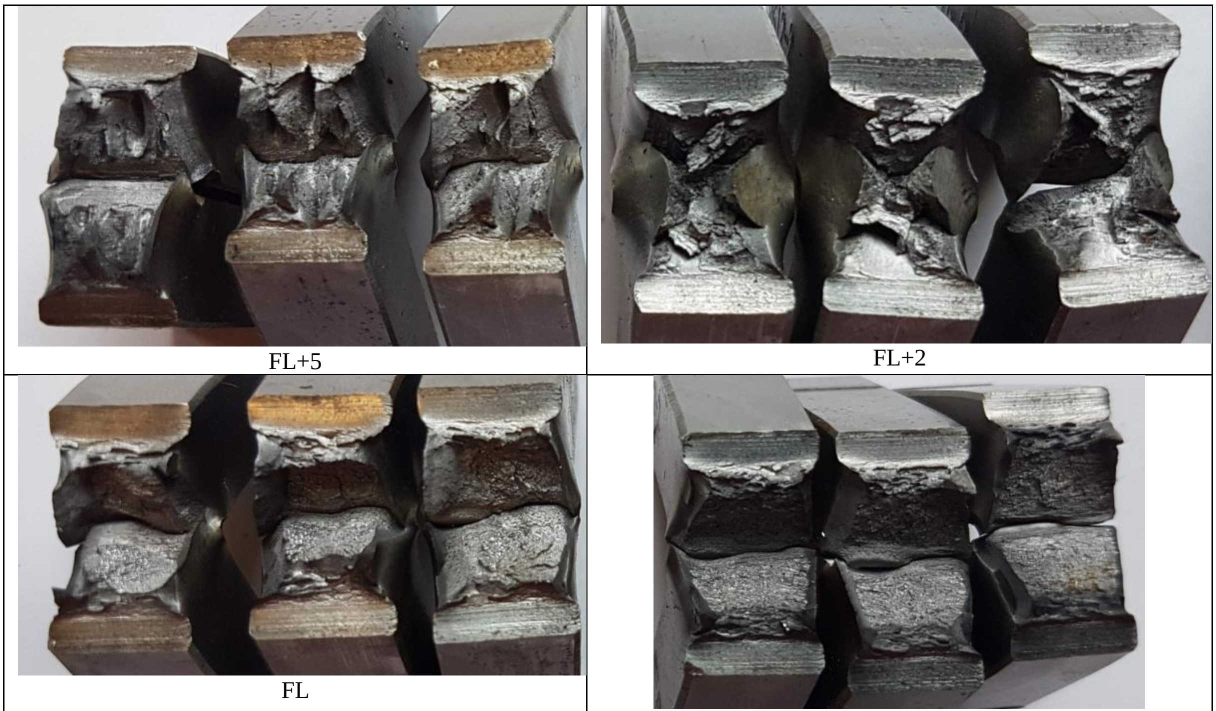


FL



Weld

(b) 8612-3. PL5-DW15



FL+5 | FL+2

FL | Weld

(c) 8612-4. PL7-DW5

Figure 7-32 - Fracture appearance

7.8.3.6 Vickers hardness Test

No indication of hardening in the microstructure.

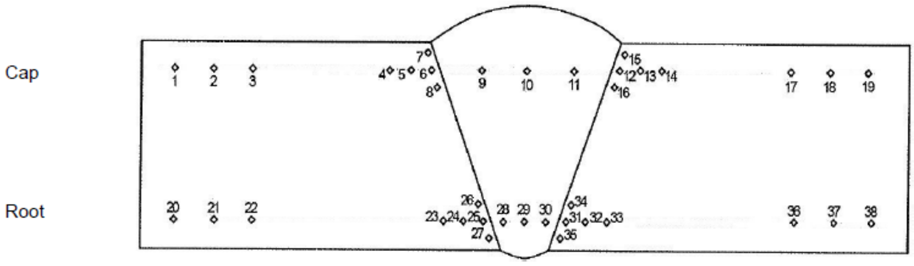


Figure 7-33 - Placement of hardness indents.

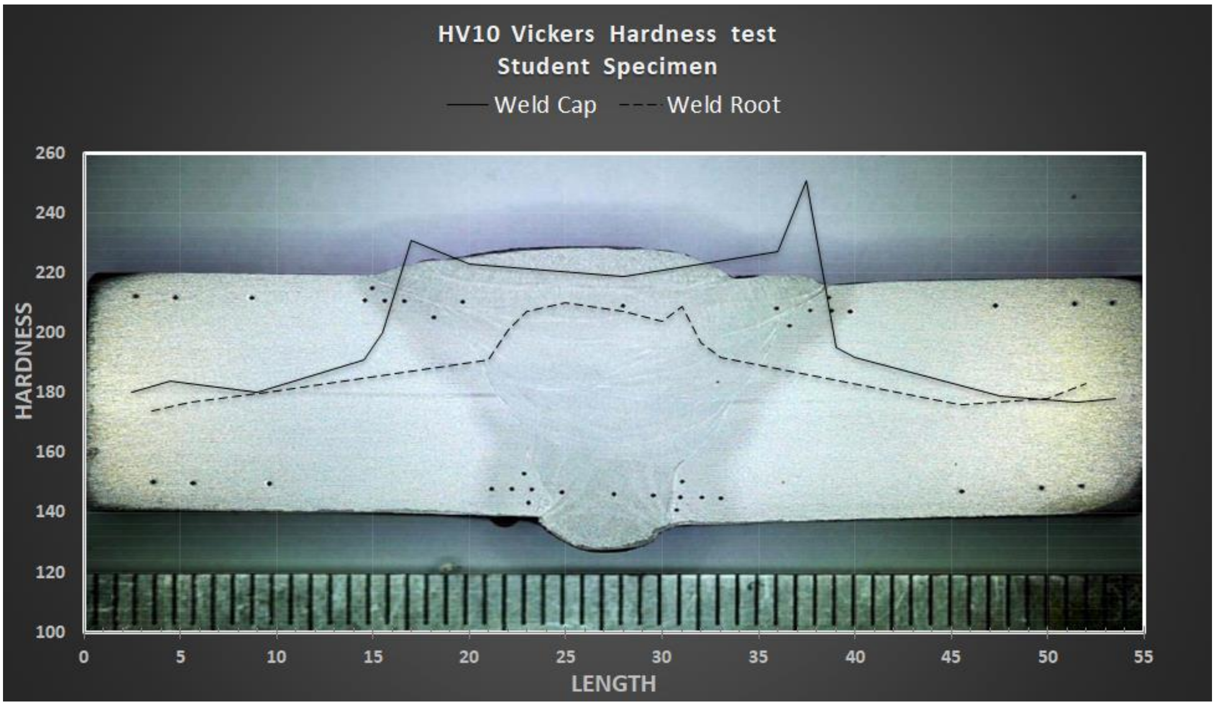


Figure 7-34 - HV Vickers Hardness Test Student Specimen.

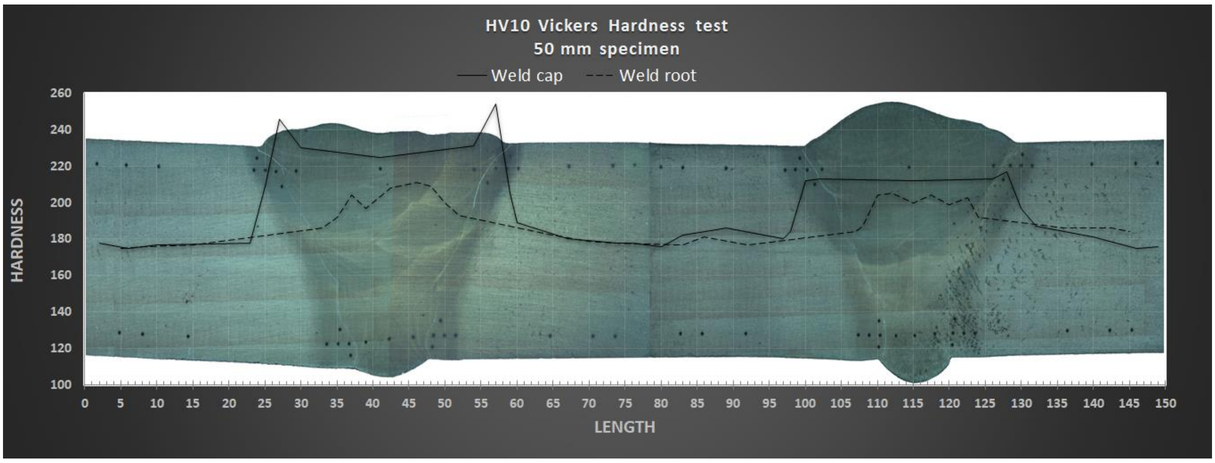


Figure 7-35 HV Vickers Hardness Test 44 mm between the welds.

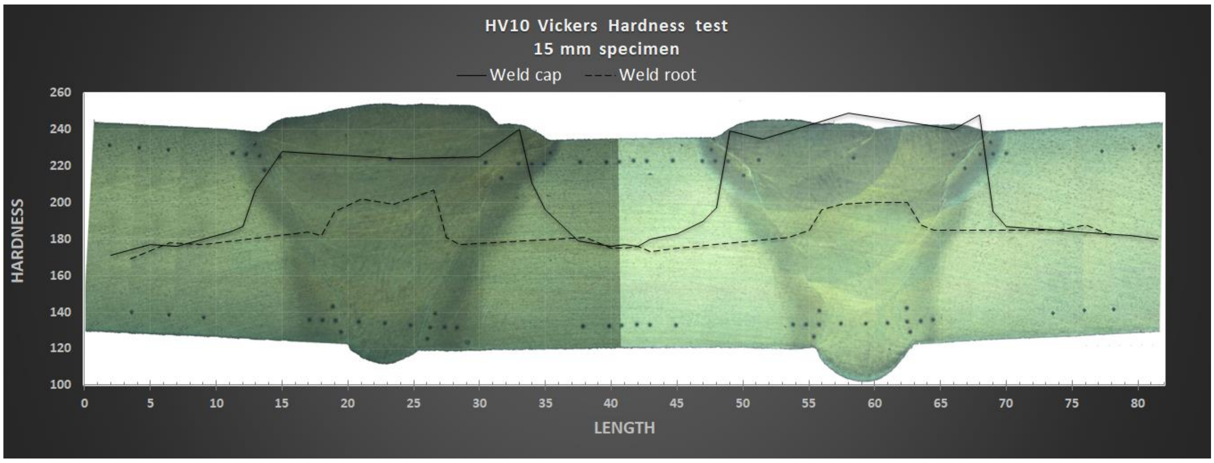


Figure 7-36 - HV Vickers Hardness Test 12 mm between the welds.

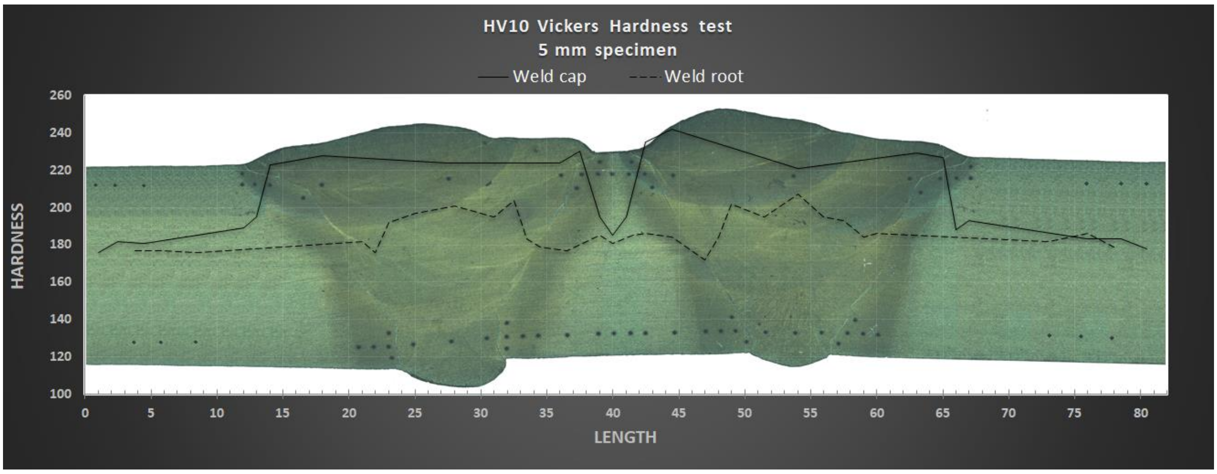


Figure 7-37 - HV Vickers Hardness Test 1.3 mm between the welds.

The results from the hardness tests are shown in Table 7-34 and Table 7-35. The locations for the indents are as shown in Figure 7-33.

Table 7-34 - Vickers hardness test results taken from the upper row in line with the weld cap. The welds are divided into weld A and Weld B. Weld A is the initial weld and Weld B is the secondary parallel weld. Weld DW = Dual Weld, SW = Single Weld, DW50 = Dual Weld 50 mm, DW15 = Dual Weld 15 mm, DW5 = Dual Weld 5 mm. NOTE DW5 Weld Cap A is missing indent 17-19 and Weld Cap B DW5 is missing 1-3 due to lack of base material in the area between the welds.

		CAP WELD A			CAP WELD B			TEST PLATE
#	Description	DW50	DW15	DW5	DW50	DW15	DW5	SW
1	Base material	178	171	176	176	176	-	180
2	Base material	175	177	182	182	180	-	184
3	Base material	177	176	181	186	183	-	180
4	Fusion line + 2	227	184	189	207	190	-	191
5	Fusion line + 1	207	187	195	201	197	195	200
6	Fusion line	178	207	223	180	239	235	231
7	Fusion line Upper	209	209	205	184	219	242	207
8	Fusion line Lower	246	206	244	212	253	216	223
9	Center of Weld	230	228	228	213	235	224	223
10	Center of Weld	225	224	224	212	249	221	219
11	Center of Weld	231	225	224	213	240	229	227
12	Fusion line	246	240	230	213	248	227	251
13	Fusion line + 1	221	211	195	204	195	188	195
14	Fusion line + 2	254	196	185	217	187	193	192
15	Fusion line Upper	205	201	198	197	235	194	240
16	Fusion line Lower	189	229	217	187	251	219	240
17	Base material	180	179	-	181	183	183	179

18	Base material	178	176	-	175	182	183	177
19	Base material	178	177	-	176	180	178	178

Table 7-35 – Vickers hardness test from weld root

		ROOT WELD A			ROOT WELD B			SINGLE WELD
#	Description	DW50	DW15	DW5	DW50	DW15	DW5	TEST PLATE
20	Base material	175	177	169	176	177	185	174
21	Base material	176	181	178	173	177	186	177
22	Base material	177	177	177	175	176	184	180
23	Fusion line + 2	204	205	184	181	182	172	191
24	Fusion line + 1	201	205	182	185	176	184	201
25	Fusion line	186	184	195	196	192	202	207
26	Fusion line Upper	192	187	206	197	200	197	202
27	Fusion line Lower	204	204	214	195	193	198	212
28	Center of Weld	197	205	202	199	197	195	210
29	Center of Weld	208	200	199	200	201	207	207
30	Center of Weld	211	204	203	200	195	195	204
31	Fusion line	207	200	207	200	204	193	209
32	Fusion line + 1	208	197	181	188	183	184	197
33	Fusion line + 2	209	199	177	185	179	186	192
34	Fusion line Upper	200	203	209	202	208	205	211
35	Fusion line Lower	193	192	208	196	203	207	209
36	Base material	182	186	181	185	177	182	176
37	Base material	179	186	175	188	185	186	178
38	Base material	178	184	175	182	181	179	183

7.8.4 *Summary and conclusion*

The mechanical testing results from the NS-EN ISO/IEC 17025 accredited Qlab, indicated no degradation in material properties due to weld proximity. This statement was based on results from tensile tests, Charpy V Impact toughness test and Vickers hardness tests. The distance between the weld toes of the butt welded joints was 44, 12 and 1.3 mm.

All **Tensile Test** specimens failed in the BM outside the HAZ. This was as assumed since the UTS of the WM is higher than the BM. The result seemed to indicate that the influence of the adjacent secondary weld did not have a negative impact on the tensile strength properties of the initial weld. The fracture also initiated a considerable distance away from the weld showing no sign of reduction of tensile strength in the HAZ. The WM were machined flush with the BM.

The results from the **Charpy V Impact Toughness test** showed no reduction in toughness properties from the adjacent secondary weld. Due to inherent spread of the test results it was not possible to determine any distinct variation between the results at the different distances. All tests showed that the weld joint had toughness properties well above the requirements. The fracture appearance and lateral expansion was well within the limits. The test results are shown in Table 7-33.

The results from the **Vickers Hardness test** did not indicate any reduction in material hardness properties due to the adjacent secondary weld. As seen in Figure 7-37 the hardness values between a weld joint with 1.3 mm between the weld toes did not have any significant increase in hardness. Due to the spread in results in the WM and HAZ it was not possible to see if the secondary weld had any softening effect on the initial weld. The welds at 12 mm and 44 mm from weld-toe to weld-toe did not show any adverse effect due to the weld proximity, and showed a similar toughness pattern as the welds at 1.3 mm from eachother. More tests are needed in order determine if there is any difference between the various distances. Important to note also is that only one specimen at 1.3 mm was hardness tested. This is sufficient to approve a WPQ, but due to the nature of this test more tests are needed in order to ascertain the initial test results.

These results indicate that weld proximity as close as 1.3 mm does not have any degrading impact on the weld joint. This is based on level 2 mechanical testing in accordance with 15614-1:2017, used to approve WPQs.

It is important to note that these results are for this set of parameters and materials, but the findings can act as a baseline for further testing at various HI, welding positions, distances, etc.

8 Experimental Investigation: Microstructural examination

8.1 Objective

- Observe the microstructural properties of the weld and corresponding heat-affected zone.
- Determine any adverse microstructure in the area of overlapping.

8.2 Experimental procedure

Standardized transverse macro samples were extracted from the welded plates in order to study the microstructure in an optical microscope. The samples were taken from both the weld start and stop location and were large enough to contain both parallel welds in accordance with NS-EN 15614-1:2017 Specification and qualification of welding procedures for metallic materials [17]. After extraction, the samples were molded in epoxy and subsequently grinded and polished with a 1 µm finish according to the procedure in Table 8-1. When the desired surface finish was reached, the samples were prepared for etching with 2 % nital.

Table 8-1 - Grinding and polishing procedure.

Surface	Suspension	Lubricant	Time
SiC-Pap #80	-	Water	5 min
SiC-Pap #500	-	Water	3 min
SiC-Pap #4000	-	Water	5 min
Mol	DiaPro AllegroLargo 9 µm	-	20 min
Dap	DiaPro Dac 3 µm	-	30 min
Mol	DiaPro Nap-B 1 µm	-	20 min

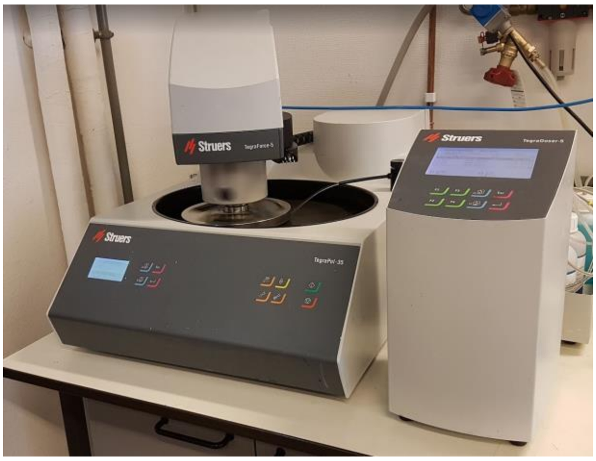


Figure 8-1 - Struers grinding and polishing machine including TegraForce-5, TegraPol-35 and TegraDoser-5.

Figure 8-2 - Olympus GX53 Optical microscope.

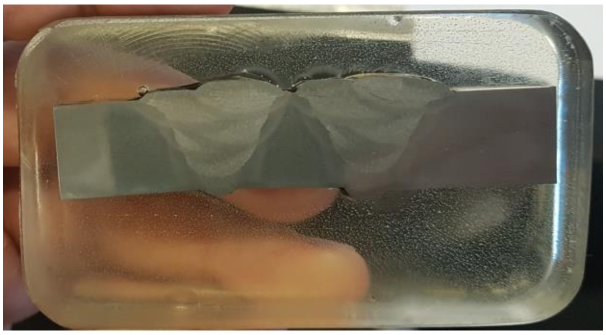


Figure 8-3 – Polished with 1 µm polishing cloth and subsequently etched with 2 % nital.

8.3 Results and discussion

8.3.1 *Microscopic specimen 8612-1-SW-Start*

This section presents the results obtained from the macro specimen 8612-1-SW-Start 25 mm from the weld starting location. The macrograph of the weld section is shown in Figure 8-4 and displays the weld passes and corresponding heat-affected zones. The multipass weld consists of six weld passes in accordance with the schematic diagram in the weld log Figure 8-4. Each multipass weld has used the same weld layer setup and using the flux-cored arc welding method, with exception from the root pass where metal-core arc welding was used instead.

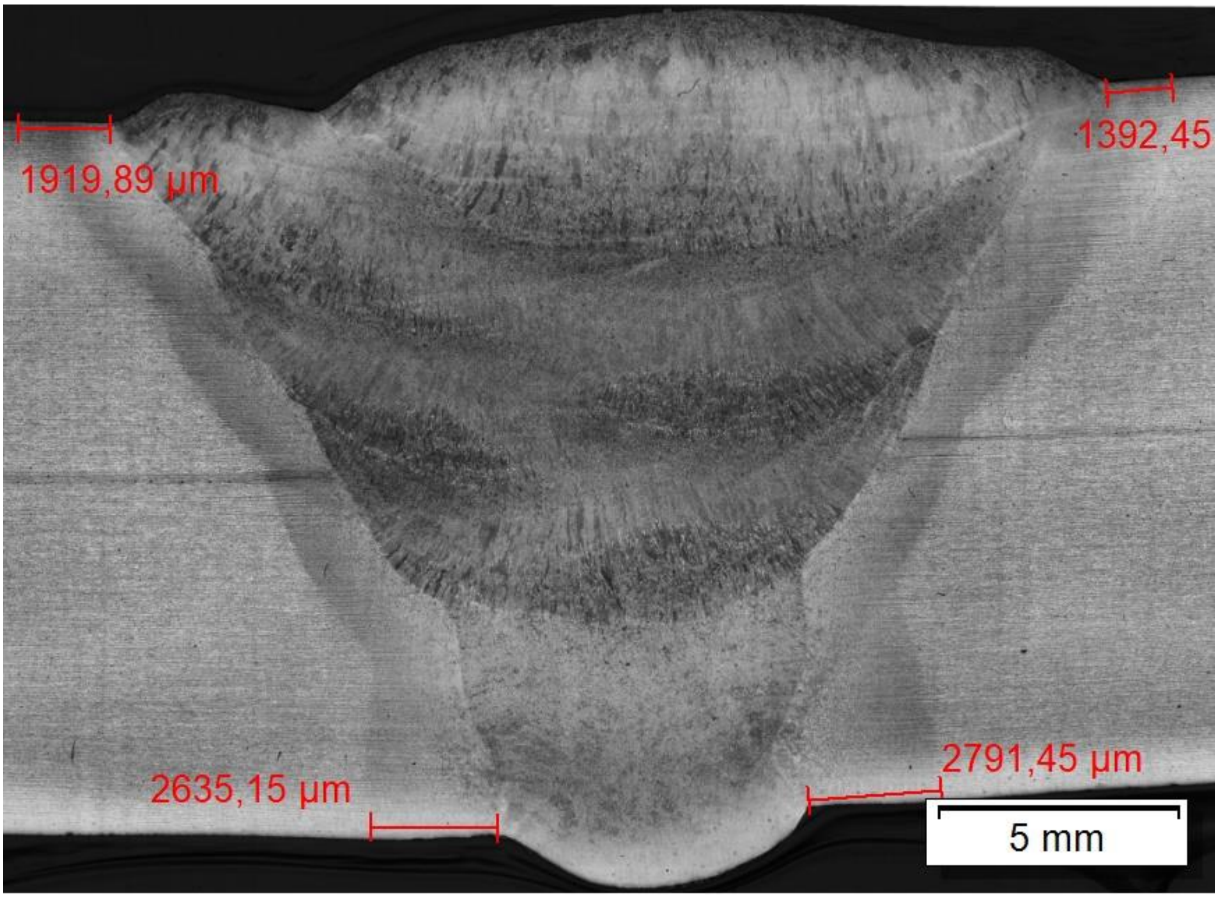


Figure 8-4 – Macrograph of a multipass weld with corresponding heat-affected zones. The specimen extracted from the plate the welding procedure qualification was based on with a single weld. Etching reagent: 2% nital.

The resulting approximate lengths of the heat-affected zones can be seen in Table 8-2 and corresponding weld log in Table 8-3. Each test plate has been welded in accordance with the same WPQR and been logged and documented.

Table 8-2 - Heat input and corresponding lengths of heat-affected zones in weld qualification plate.

Weld string, #	Heat input [kJ/mm]	Approximate length of HAZ [mm]
1 – Root	1.57	2.6-2.8
2 – Hot-Pass	1.21	1.6
3 – Fill	1.44	1.5
4 – Fill	1.97	1.7
5 – Weld Cap	1.68	1.9
6 – Weld Cap	1.61	1.7

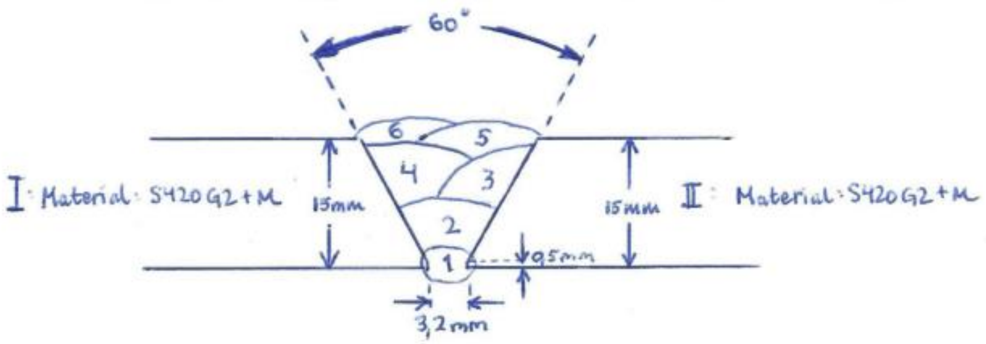
Table 8-3 - Weld log from test plate.

Welding procedure qualification record procedure

Kiwa Teknologisk Institutt

WPQR No.: S420 PL1 - M

Sketch,



Dimensions: (OD, WT, GAP, NOSE, ANGLE)

Welding parameters:

	Pass no.	measure no.	Preheat / interpass °C	Filler OD (mm)	Welding process	Wire feed speed (m/min)	Current Polarity AC/ DC-/DC+	Current (A)	Volt (V)	Welding length (mm)	Welding time (s)	Welding speed (mm/min)	Shielding gas (L/min)	Purging gas (L/min)	Weld Bead width (mm)	Heat input kJ/mm
Root	1	1	30	1.2	138	2.2	DC+	103	14.7	175	186	56	20	0	7	1.61
		2		1.2	138	2.2	DC+	103	14.7	220	187	71	20	0	7	1.29
		3		1.2	138	2.2	DC+	103	14.7	115	103	67	20	0	7	1.36
Hp	2	1	42	1.2	136	7.1	DC+	214	23.6	340	113	181	20	0	13	1.68
		2		1.2	136	7.1	DC+	214	23.6	150	59	153	20	0	13	1.99
Fill	3	1	75	1.2	136	7.1	DC+	214	23.6	490	191	154	20	0	12	1.97
	4	1	100	1.2	136	7.1	DC+	214	23.6	225	64	211	20	0	13	1.44
		2		1.2	136	7.1	DC+	214	23.6	260	75	208	20	0	13	1.46
Cap	5	1	103	1.2	136	7.1	DC+	204	22	275	74	223	20	0	13	1.21
		2		1.2	136	7.1	DC+	204	22	225	66	205	20	0	13	1.32
	6	1	117	1.2	136	7.1	DC+	204	22	200	70	171	20	0	13	1.57
		2		1.2	136	7.1	DC+	204	22	295	89	199	20	0	13	1.35

The Figure 8-5 below shows an extruded view of the weld toe outside the final weld cap. The various sub-regions in the HAZ are visible and has a length of approximately 1.7 mm.

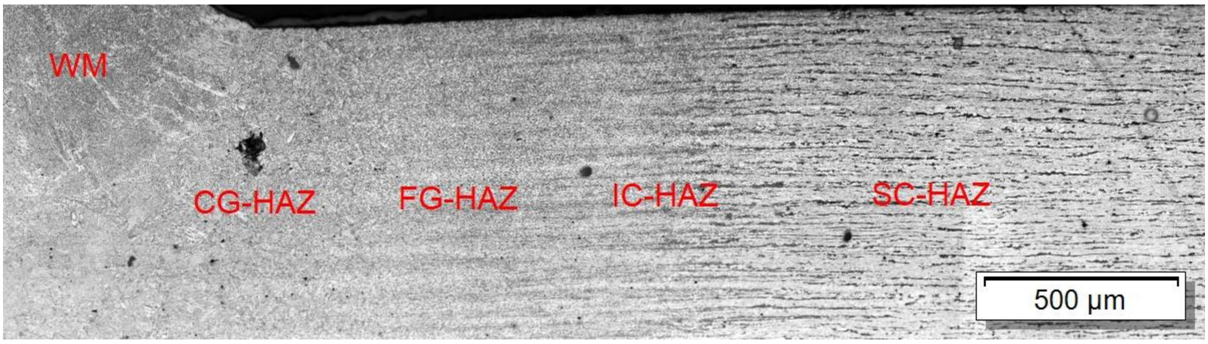


Figure 8-5 - Heat-affected zone outside the weld toe. The weld metal, coarse-grained HAZ, fine-grained HAZ, tempered and partially austenitised HAZ and unaffected base material is visible.

8.3.1.1 Microstructures in the weld metal, HAZ and base material of test plate

The Figure 8-6 shows the microstructure of the weld metal (WM), coarsed-grained heat-affected zone (CG-HAZ), fine-grained heat-affected zone (FG-HAZ), intercritical heat-affected zone (IC-HAZ) and sub-critical heat-affected zone (SC-HAZ).

Classification of microstructures:

- Grain boundary (or allotriomorphic) ferrite (GF)
- Polygonal (or equiaxed) ferrite (PF)
- Widmanstätten ferrite (WF)
- Acicular ferrite (AF)
- Pearlite (PC)

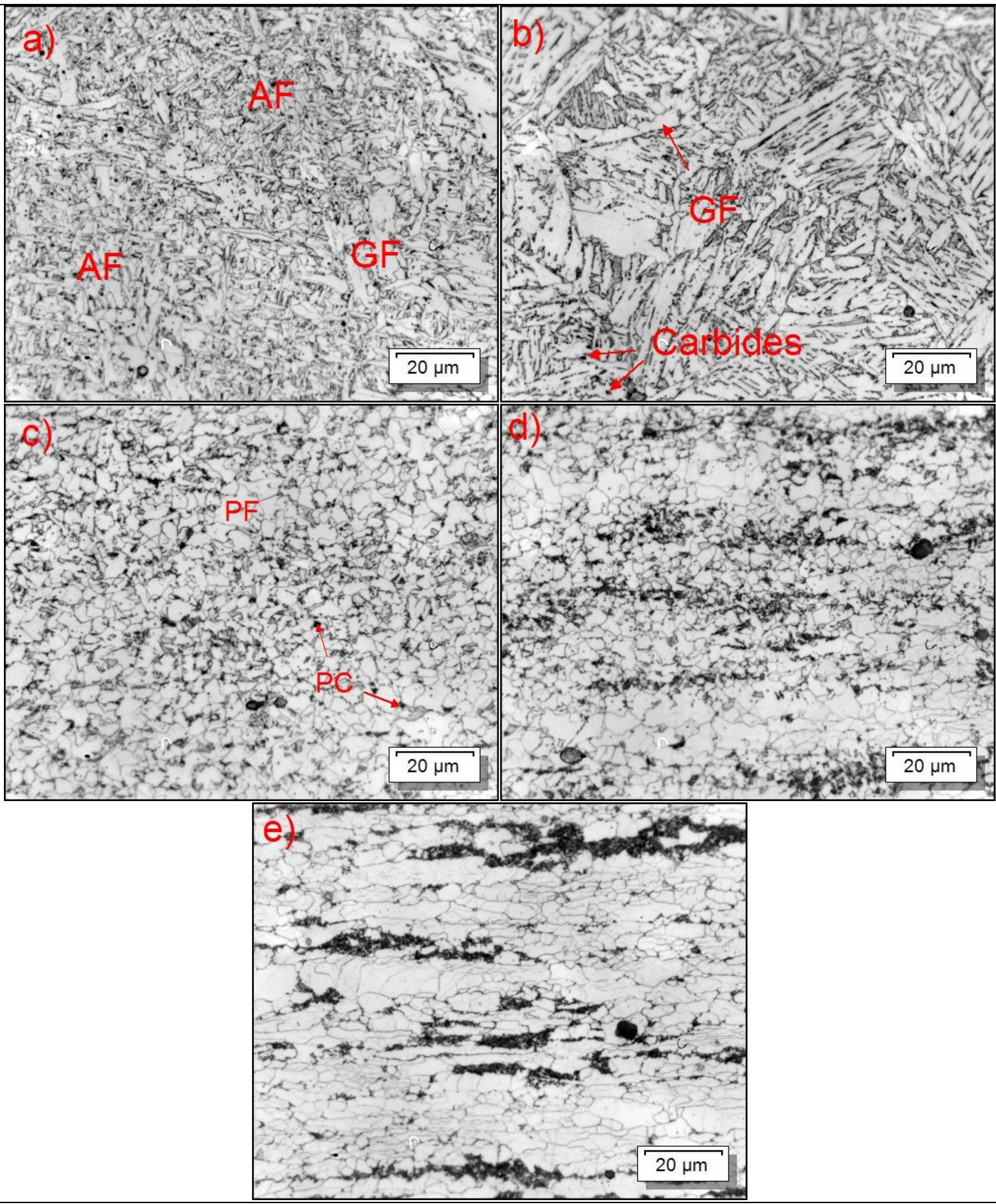


Figure 8-6 – Micrographs from WM, HAZ and BM outside the weld cap showing representative microstructures of the weld. a) WM b) CG-HAZ c) FG-HAZ d) IC-HAZ e) SC-HAZ. Etching: nital 2 %. Magnification: 650x

8.3.1.2 Weld metal

The microconstituents in the weld metal constituted mainly of grain boundary (or allotriomorphic) ferrite (GF), acicular ferrite (AF), polygonal (or equiaxed) ferrite (PF), Widmanstätten ferrite (WF), ferrite plus carbides and as well as pearlite (PC).

Figure 8-7 is showing the distribution between the microconstituents in the weld metal based on carbon content.

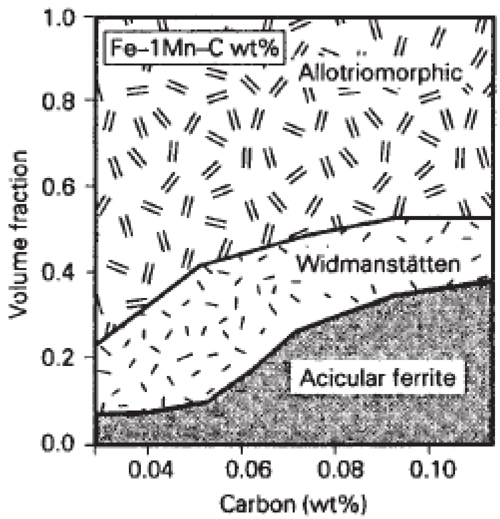


Figure 8-7 - Graph showing the prevalence of the different phases in a primary microstructure as a function of carbon content [7].

Side plate Widmanstätten ferrite and allotriomorphic ferrite reveals the prior austenite grain structure in Figure 8-8. These grains have a columnar grain structure in the direction of the heat gradient.

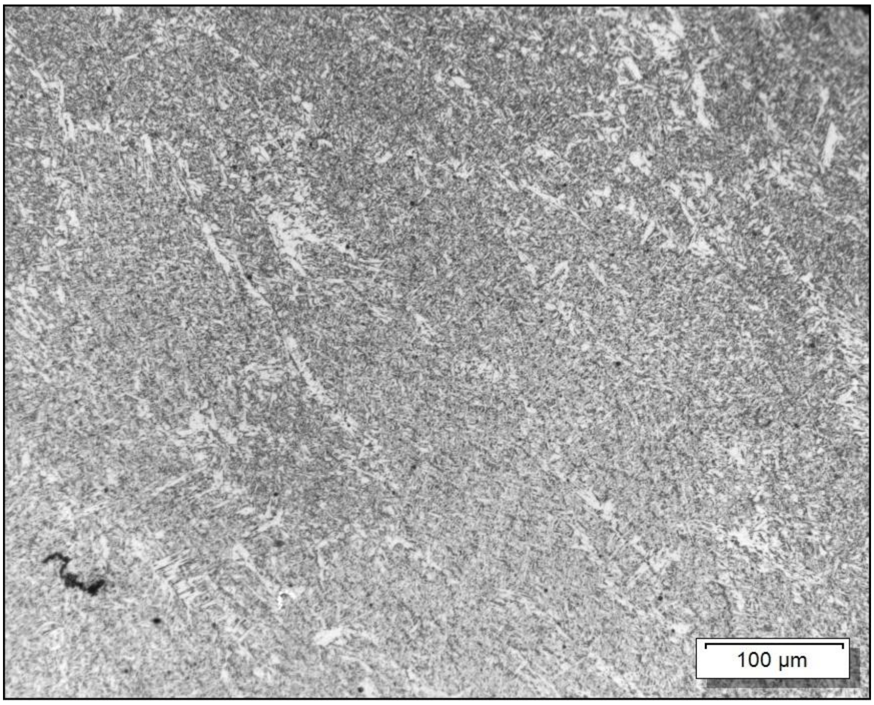


Figure 8-8 - The prior austenite grain profile in the weld metal.

8.3.1.3 Coarse-grained HAZ

As with the case of lower CE-steels the CG-HAZ is predominately proeutectoid ferrite networks (white phases) in the grain boundaries as allotriomorphic ferrite (GF) and polygonal ferrite (PF).

The grain size in this area is due to the high temperatures over 1200 °C, allowing for a complete austenitization of the microstructure despite being subjected to these temperatures only for a short moment [8].

8.3.1.4 Fine-grained HAZ

The FG-HAZ consists of refined ferrite and pearlite in the form of polygonal ferrite (PF) and fine pearlite FC (P). This is the result of a recrystallization during the heat cycle. The region has completely austenitised, but at a lower peak temperature and cooling rate. This inhibited the growth of large grains, but instead resulted in smaller grains that are more refined. The following phase transformation from austenite to proeutectoid ferrite and posterior pearlite is followed by a process of intensive nucleation rate with slow rate of growth, resulting in a microstructure with small grain size, lower than the original base material [44].

8.3.1.5 Intercritical HAZ

The IC-HAZ is formed in the range between the A_{c1} to A_{c3} curves. In comparison to the CG- and FG-HAZ this region only gets partially austenitised. This process results in the pearlite and only some of the ferrite will undergo a transformation to austenite as seen in Figure 8-6. Depending on the cooling rate, this region can form martensite when transforming from austenite. This is due to the austenite that is formed has a higher carbon concentration [44]. During microscopic examination however no martensite was found in this region and the only microconstituents remaining was equiaxed ferrite and pearlite.

8.3.1.6 Sub-critical HAZ

The SC-HAZ is the region affected by temperature below A_{c1} . The area experiences tempering during the heat cycle which results in the forming of spheroidization, also known as degenerated pearlite. No phase transformation occurred in this region. The ferritic and perlitic banded microstructure comes from the hot rolling process of a hypoeutectoid steel.

8.3.1.7 Weld root WM and HAZ

The filler metal used in the weld root was metal-cored instead of flux-cored as seen in Figure 8-9. The distance of the HAZ was further than at the weld cap. This could be due to the localized heating during the heating cycle due to the joint bevel configuration. The grain structure did not have any columnar growth properties.

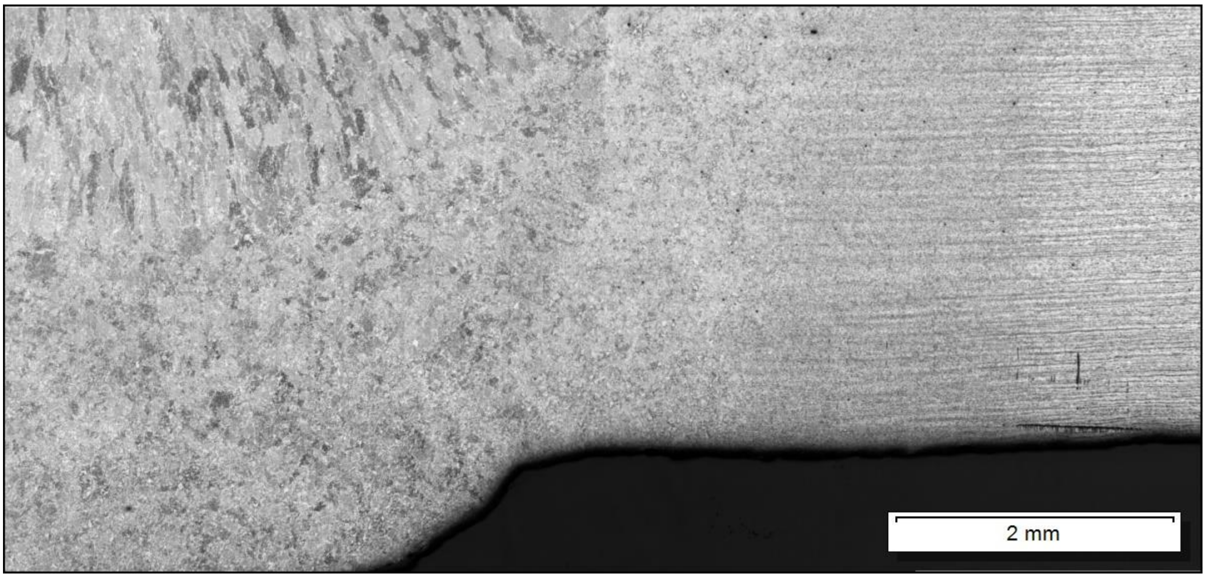


Figure 8-9 - Weld root from test plate specimen.

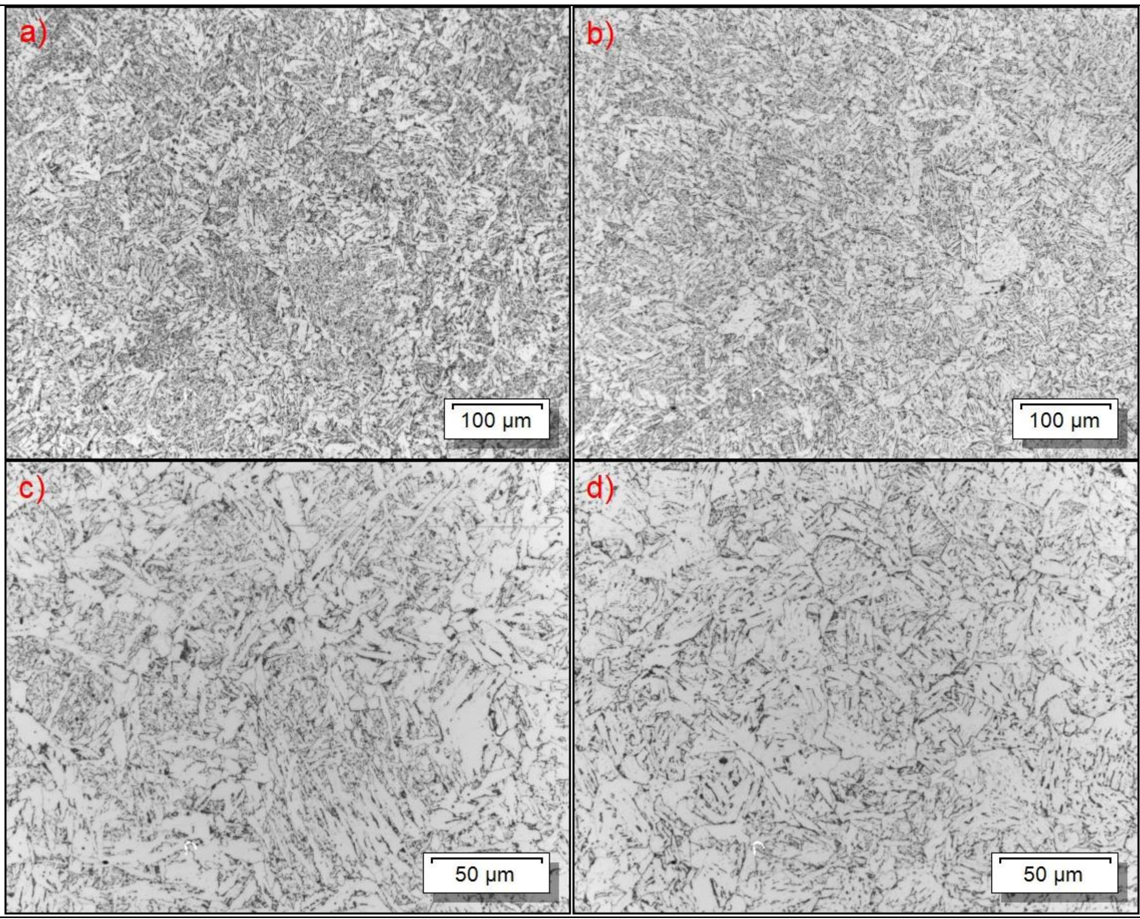


Figure 8-10 – Microstructure in the weld root with metal-core filler material. a) Weld Metal 150X magnification b) Fusion boundary 150X c) Weld Metal 300X and d) CG-HAZ at 300X.

8.3.2 *Results and discussion - Microscopic specimen 8612-4 PL7*

The macrograph of the common HAZ between weld A and weld B is shown in Figure 8-11. The region had experienced a complete overlap of heat-affected zones. The distance between the weld toes were 1.3 mm with a depth from top surface about 1.7 mm. No detrimental microconstituents were observed in the region that would affect the microstructural properties. Microstructural grain structure did not seem to contain any brittle phases. The region appeared to have experienced a tempering and partially austenitizing effect from the welding procedure.

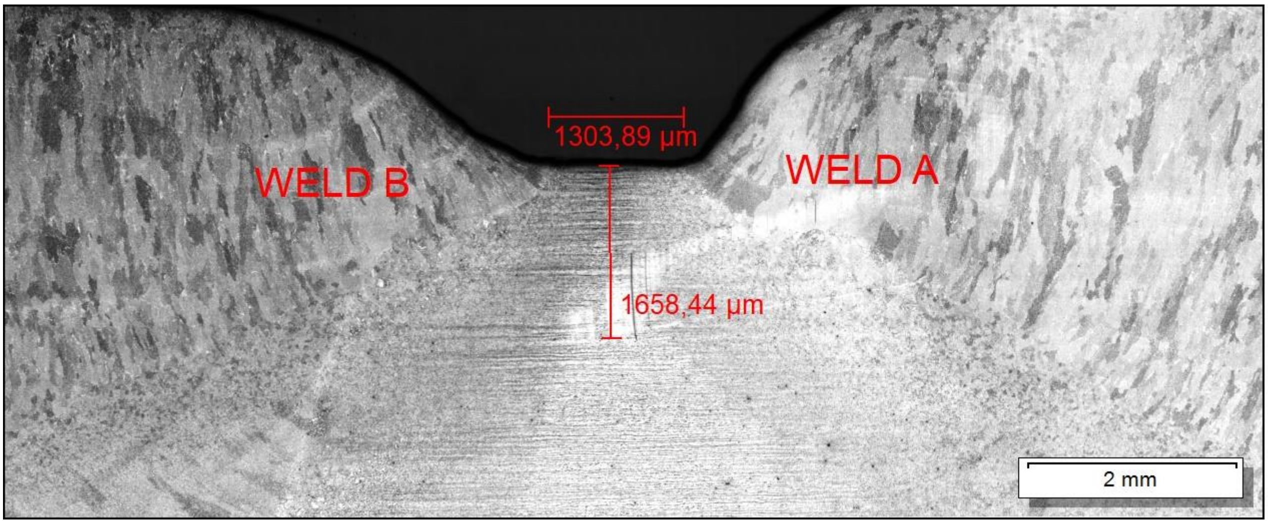


Figure 8-11 - Overlapping HAZ in specimen 8612-4 PL7. Weld A is the initial weld and Weld B is the secondary overlapping weld. Distance between the weld toes are 1.3 mm and HAZ are overlapping 1.7 mm from the top surface.

Figure 8-12 below is showing the fusion boundary of weld A. It did not seem like the coarse-grained region had experienced any brittle transformation due to reheating to the region between A_{c1} and A_{c3}.

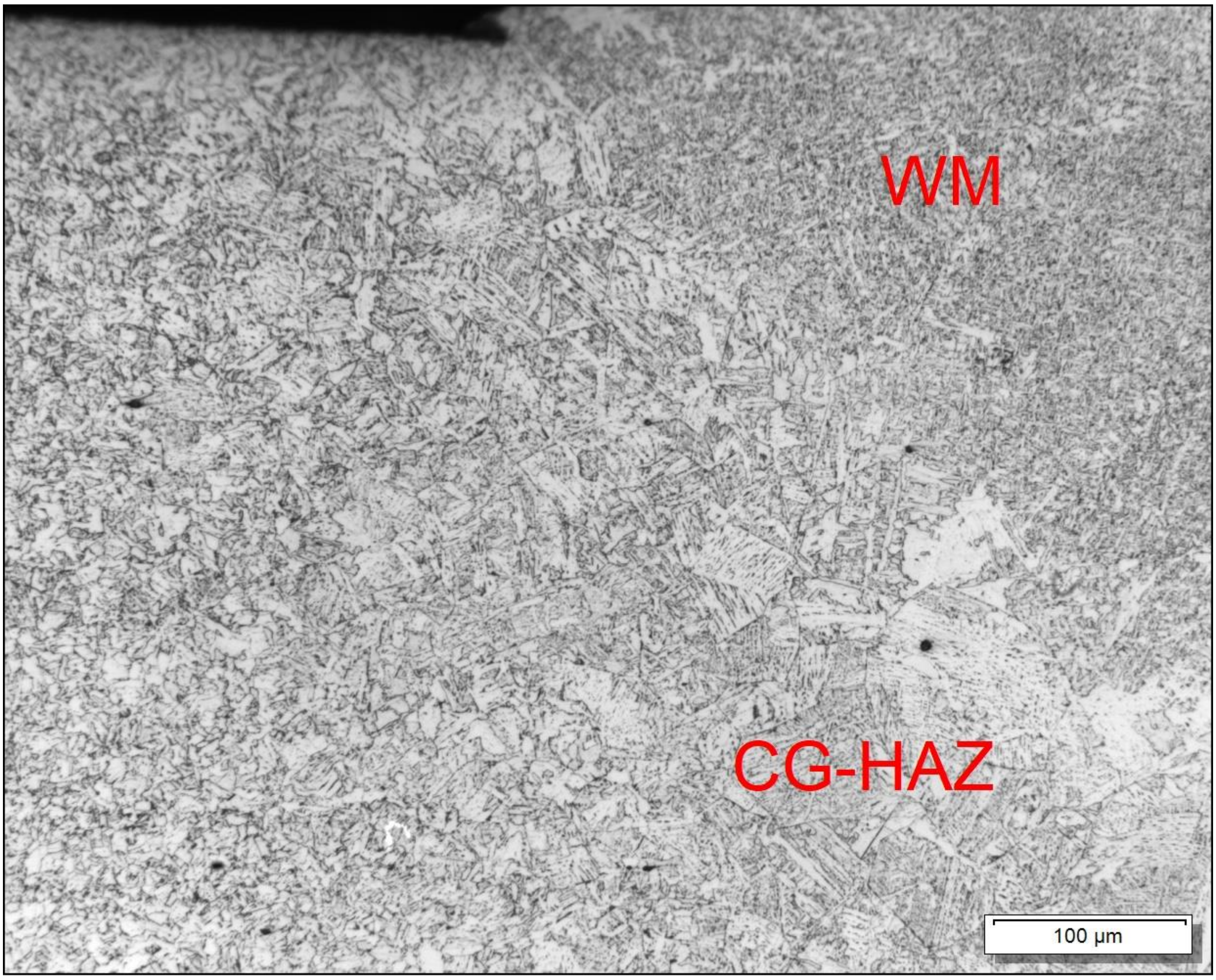


Figure 8-12 - Fusion boundary of weld A.

Figure 8-13 is showing the fine-grained and partially austenitized HAZ. This region still had the banded grain structure from the initial hot rolling after being subjected to two heating cycles.

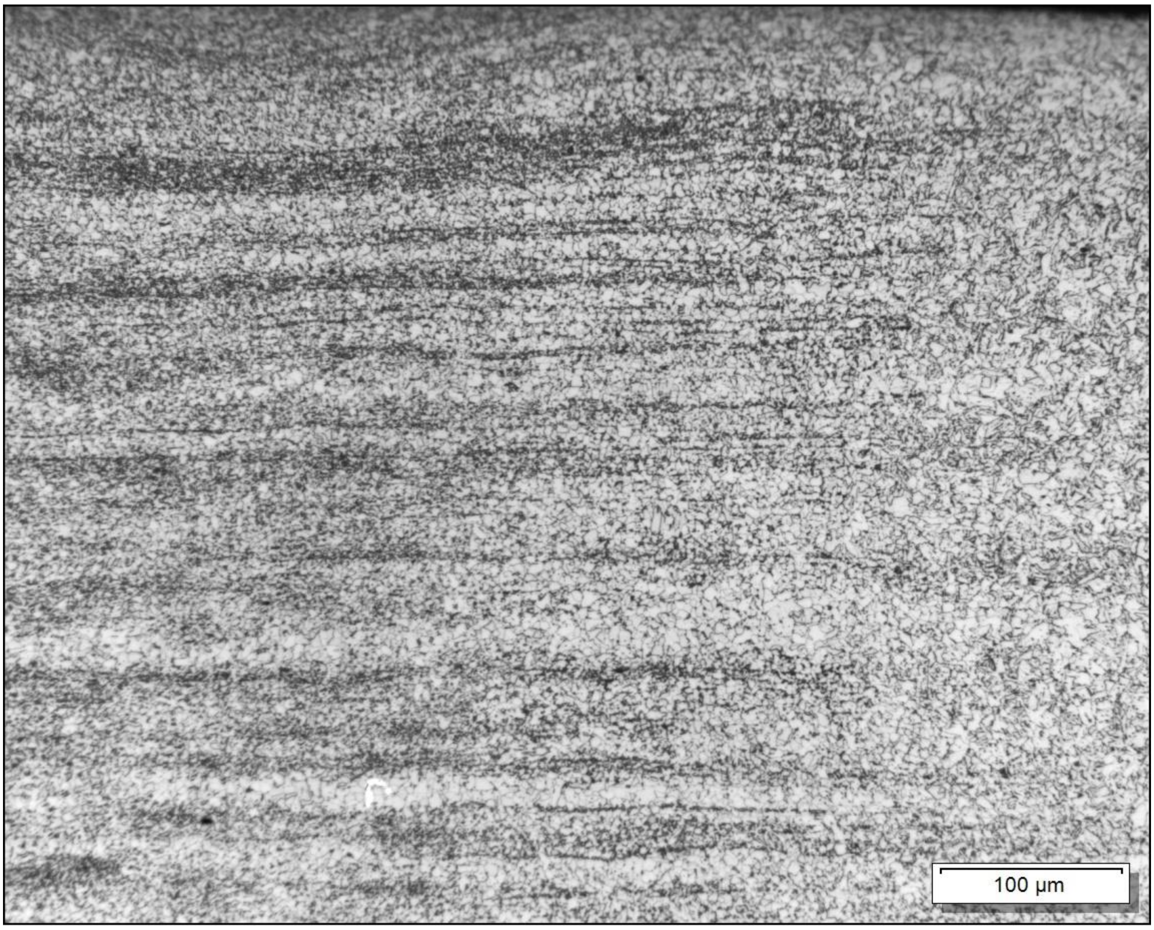


Figure 8-13 - Overlapping heat-affected zones between weld toes. The initial HAZ has experienced a normalizing effect from the overlapping HAZ.

Figure 8-14 shows the root of the weld joint. Due to the distance between the regions, the heat-affected zones had no effect on each other.

Figure 8-14 - Distance between weld toes was approximately 16 mm.

8.3.3 *Results and discussion - Microscopic specimens 8612-3 PL5 and 8612-2 PL3*

Figure 8-15 shows the heat-affected zones from the 8612-3 PL5 sample. There was no sign of interaction between the two heat-affected zones at this distance between the two welds. The microstructure was unchanged in both instances. The same can be stated about 8612-2 PL3 that had approximately 50 mm between the weld toes. At these distances, the heat generated from the heat source will not be sufficient to have any impact on the microstructure.

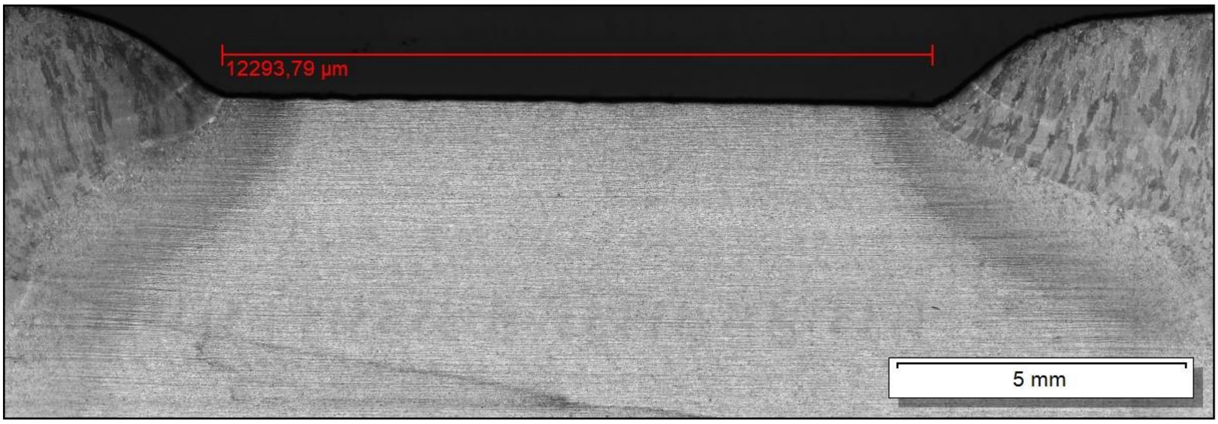


Figure 8-15 - Common HAZ of 8612-3 PL5. There was no interaction between the two heat-affected zones from weld A and weld B when the distance between the weld toes was 12 mm.

8.4 Chapter conclusion

The microconstituents in the weld metal and HAZ are typical, and a common combination in the industry. In only one specimen did the weld HAZ overlap. This was the weld with 1.3 mm between the weld toes. No visible harmful phases were detected with the optical microscope in either the WM or the HAZ. The impact of the overlap only seemed to have a normalizing effect of the previous HAZ of weld A.

Between subsequent weld passes and unaffected region of the coarse-grain HAZ microstructure can be distinguished. The reheated pockets of the CG HAZ regions are small and discontinuous, which make their microstructure difficult to identify and investigate. The reheated IC CG HAZ is very susceptible to failure, due to the fact that the phase transformation into austenite began on the grain boundaries; these small areas are rapidly cooled and have a strong possibility to become hard and brittle. The subcritical regions are mainly tempered bainite and martensite with precipitated carbides and therefore represent no danger to the structural integrity of the weld.

The welds with a distance of 12 mm and 44 mm between the weld toes had no overlap of HAZ. There never was any overlap of visible HAZ of the weld roots, despite the larger area of effect.

Important to note though is that the magnification of the optical microscope is limited and further analysis with a scanning electron microscope (SEM) and a transmission electron microscope (TEM) is necessary in order to assure that this is the case. Investigation in these microscopes are needed in order to confirm the exact nature of all phase transformations occurring in the overlapping HAZ.

9 Experimental Investigation: Fatigue Testing

This chapter will present the experimental procedure and results from the fatigue test conducted at the University of Stavanger. Three different fatigue test series were performed as part of the experiment. In the first test the main objective was to test the viability of the experiment and to gain a basic understanding of the mechanisms involved in fatigue testing. The purpose of the second test was to determine a rough SN-curve for the base material. In the final test the welded production plates were tested and analyzed.

9.1 Specimen appendix

Table 9-1 - Related information in appendix.

Specimen Serie	Fatigue test log	Roughness test	Pre-test visual examination	Appendix
Prior to fabrication:				
F1	Yes	No	No	Appendix G
F2	Yes	No	No	Appendix G
F3	Yes	No	No	Appendix G
F4	Yes	No	No	Appendix G
F5	Yes	No	No	Appendix G
Unwelded base material:	Fatigue test log	Roughness test	Pre-test visual examination	
BM1	Yes	Yes	Yes	Appendix G
BM2	Yes	Yes	Yes	Appendix G
BM3	Yes	Yes	Yes	Appendix G
BM4	Yes	Yes	Yes	Appendix G
BM5	Yes	Yes	Yes	Appendix G
Production:	Fatigue test log	Roughness test	Pre-test visual examination	
8612-2 PL3 2A(B)	Yes	Yes	Yes	Appendix G
8612-2 PL3 2A(BB)	Yes	No	Yes	Appendix G
8612-3 PL5 A3	Yes	Yes	Yes	Appendix G
8612-3 PL5 3A	Yes	Yes	Yes	Appendix G
8612-4	Yes	Yes	Yes	Appendix G

9.2 Equipment specifications

The fatigue testing machine was installed in the workshop of the Department of Mechanical and Structural Engineering and Materials Science at the University of Stavanger. The machine specifications are shown in table 9-2.

Table 9-2.

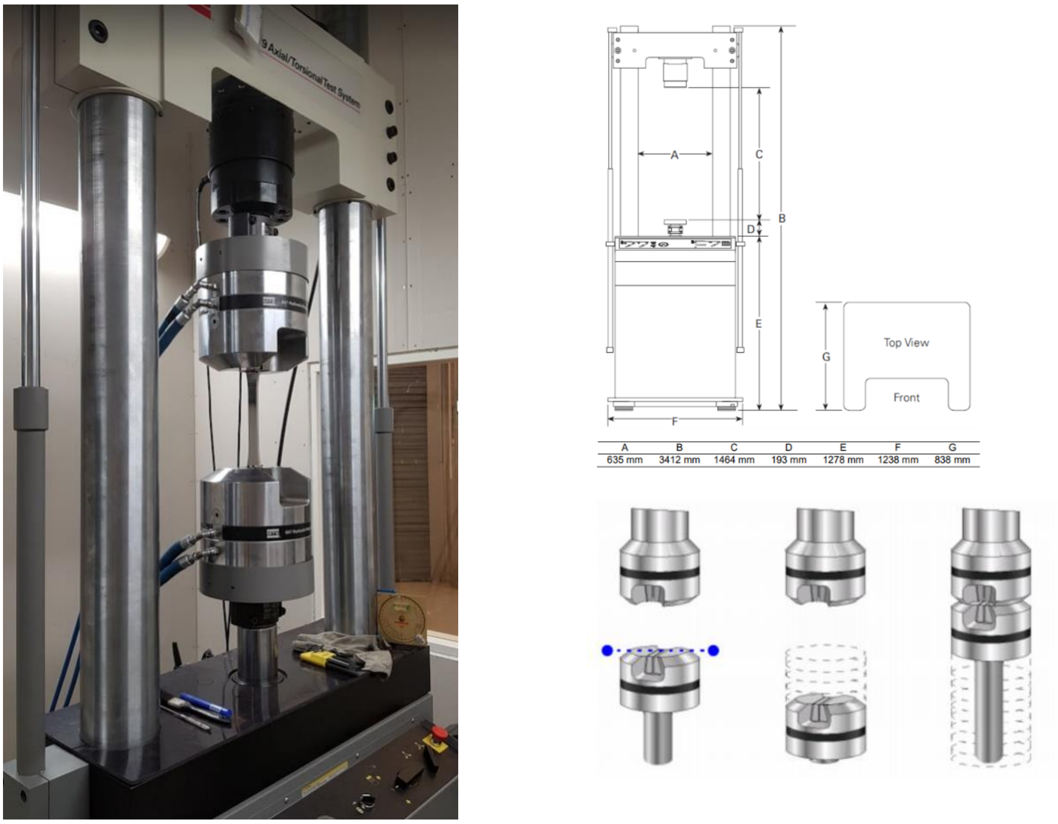


Figure 9-1 – MTS 809 Axial/Torsional Test System and dimensions. The lower grip is the actuator and the upper grip is static while testing, but can be manually moved by adjusting the overhead crossbeam.

Table 9-2 - Specifications fatigue testing machine MTS 809 Axial-Torsional Test System

MTS 809 Axial-Torsional Test System Model 319.25 Axial-Torsional Load Frame	
Dynamic force rating	±250 kN
Dynamic torque rating	±220 Nm
Axial displacement	±75 mm
Rotation	±45° (Theoretical – In practice, the hydraulic hoses are too short to allow a dynamic rotation larger than 15 °.)
Controller hardware	FlexTest 40
Wedge Grip Model	647.25 Axial-Torsional
Grips for plate specimen	Thickness of plate 1-11.9 mm and Grip depth: 89 mm
Grips for Compact Tension specimen	Part number D071727-45, model number 640.20B-21. Designed for specimens with B = 12.7 mm, W = 50.8 mm and hole diameter D = 12.7 mm according to ASTM E1820.

9.3 Fatigue test – Prior to fabrication test specimens

9.3.1 *Objective*

- Test the viability of the experiment
- Gain an understanding of the different factors influencing the fatigue life.

9.3.2 *Experimental procedure*

In the initial stages of the project, a 10 mm S355 test plate was prepared in order to determine the viability of the test. This operation was performed at Vest Norge Doors AS in Sandnes. The plate was initially cut into three parts using a metal cutting band saw and subsequently grinded until the weld groove was 60° with 2.5 mm root spacing with an angle grinder. The width of the middle section was estimated in order to obtain a weld toe distance of approximately 50 mm. The plates were subsequently welded by shielded metal arc welding. No weld logging was performed at this stage due to a lack of necessary equipment.

Figure 9-2 - Initial test plate welded at Vest Norge Doors AS, Sandnes.

The finalized plates where then transported to the University of Stavanger for machining and subsequent tensile and fatigue testing.

Figure 9-3 – Finished prior to fabrication test specimens.

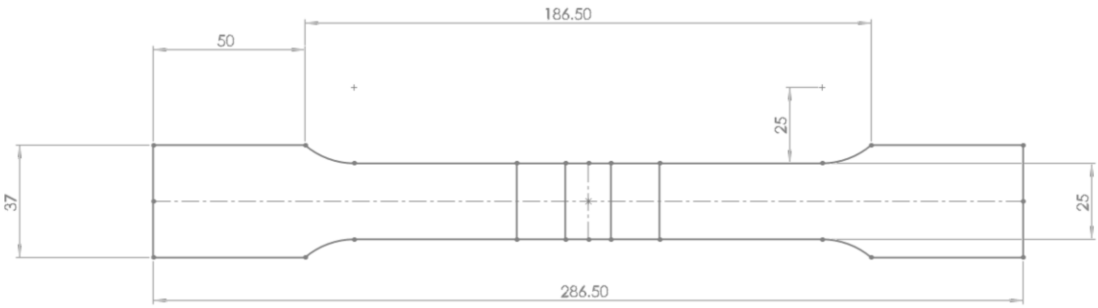


Figure 9-4 – Dimensions of prior to fabrication specimens.

9.3.3 *Results and discussion*

The results obtained from the fatigue tests are presented in

Table 9-3.

Table 9-3 – Prior to fabrication test plate fatigue test specimens

Fatigue Test R=0.1 Prior to fabrication test plate fatigue specimens							
Specimen ID	F1	F2	F2	F2	F3	F4	F5
Test Number	1	3,6	11	11	5	4	2
Run sequence	1^{st} run	1^{st} run	2^{nd} run	3^{rd} run	1^{st} run	1^{st} run	1^{st} run
Stress range [MPa]	481	200	300	350	300	300	481
Area [mm^2]	205.0	201.3	193.44	193.44	220	212.5	205.0
Max load [MPa]	534.4	222.2	333.3	388.9	333.3	333.3	534.4
Min Load [MPa]	53.4	22.2	33.3	38.9	33.3	33.3	53.4
Mean load [MPa]	293.9	122.2	183.3	213.9	183.3	183.3	293.9
Machine Load [MPa]	293.9±240.5	122.2±100	183.3±150	213.9±175	183.3±150	183.3±150	293.9±240.5
Cycles	12 195	9 659 157	2 300 000	747 488	924 104	312 278	38 570
Displacement range	-	0.3	0.40	0.47	0.48	0.46	-
Run out/Fracture	Fracture	Run out	Run out	Fracture	Fracture	Fracture	Fracture

Specimen ID	**Description**	**References**
F1	Fracture at 481 MPa after 12 195 cycles. Premature fracture due to miscalculation of the specimen area. This resulted in an extreme overload with plastic fracture as a result. The specimen failed in the weld toe.	Figure 9-5
F2	Run out at 200 MPa after 9 659 157 cycles. Run out at 300 MPa after 2 300 000 cycles. Fracture at 350 MPa after 747 488 cycles (re-grinded before testing) Improved surface finish by manual grinding. Surface was uneven, but it had no critical geometric stress concentration features. Crack initiated in the weld root.	Figure 9-5
F3	Fractured at 300 MPa after 924 104 cycles. Crack initiated in the base material. Likely cause for the crack to initiate there was because of an angular misalignment that produced a hinge effect, which amplified the stress. In addition, due to the grinding of the weld cap, the cross-sectional area had been reduced and resulted in some undercut.	Figure 9-5
F4	Fracture at 300 MPa after 312 278 cycles. Fractured in the weld toe. Probable cause of crack initiation is due to stress concentration in the weld toe.	Figure 9-5
F5	Fracture at 481 MPa after 38 570 cycles. Premature fracture due to miscalculation of the specimen area. Fracture occurred in the root of the weld joint.	Figure 9-5
F6	Fracture due to tensile test. The yield and tensile strength in the steel was 410 MPa and 540 MPa respectively.	Figure 9-5

In Figure 9-5 the fractured specimens with corresponding stress range and number of cycles at fracture. Five fatigue tests and one tensile test were conducted. In the tensile test the specimen failed in the base material, which is supported by Maddox for one buttweld in [11]. A transverse buttweld subjected to transverse loading during static loading conditions will under normal conditions fail in the weld metal and will experience no reduction in strength due to the weld. However, if the weld is subjected to fatigue stress the result will be different. Fatigue failure consists of crack initiation at one or more weld toes, with following crack propagation normal to the direction of loading due to stress concentrations, including the effect of weld toe intrusions. Complete removal of the weld cap and weld toe intrusions can restore the weldment to a state where fatigue failure instead occurs in the base material itself. The presence of weld flaws in this region may be significant.

Figure 9-5 - Fractured specimens from the prior to fabrication test plate and tensile tested specimen. Specimen F1-F5 fractured in the weld metal or HAZ during fatigue testing. Specimen T6 fractured in the base material after being subjected to a tensile test.

9.3.4 *Appendix G*

- Doc-G701Fatigue test - Prior to fabrication specimens
- Doc-G702Fatigue test - Unwelded base material specimens
- Doc-G703Fatigue test - Production test plate specimens
- Doc-H800The chapter "Residual Stress Measurements" has no attachments.

9.3.5 *Summary*

The implications of stress concentrations and misalignments in the specimens was the dominating features that resulted in fracture of the specimens. All but one fatigue specimen failed in the weld in either the weld cap or the weld root. The fatigue life improved substantially by improving the surface finish and removing all major stress concentrations.

9.4 Fatigue test – Unwelded base material plate specimens

9.4.1 *Objective*

- To gain an understanding of the fatigue properties of a pure base material sample from S420G2+M steel.
- To approximate a SN-curve based on the results.

9.4.2 *Experimental procedure*

In order to determine the appropriate stress range for the main welded specimens, some fatigue tests were conducted on pure base material. The preparation was performed accordance to the requirements in ASTM E466-15 [45]. The standard covers the procedural steps in order to design a specimen in the fatigue stress range where the strains are predominately elastic. It is limited to axially loaded specimens subjected to constant amplitude loading at ambient temperature. The specimen can be either notched or unnotched. It is designed for measuring the effects of variations of material, geometry, surface condition and residual stress of metallic specimens at a rather large amount of cycles.

Careful considerations of the procedural steps are vital in order to verify that the results are viable and reproducible. To achieve this, a tight control of variables is necessary; such as hardness, cleanliness, grain size, composition, directionality, surface residual stress, surface finish, etc. All obtained data should be logged and stored for future evaluation [45].

The design of the specimen dimensions should be such that the eventual failure occurs in the reduced area in the test section. It is therefore vital when reducing the area of the test section, that the radius introduced from the machining doesn’t cause any detrimental stress concentrations. In addition, using a square or rectangular cross section might reduce the fatigue life of the specimen, due to reduced resistance to plane slippage at the edges. In a circular cross section, the surrounding grains confines the material and inhibits the process and might increase fatigue life [45].

The specimen dimensions were designed as a rectangular cross section with tangentially blended fillets between uniform test section at the ends. The radius of the specimen is supposed to be eight times the specimen test section width to minimize the stress concentration. The specimen test section width should be 2-6 times the thickness, whereas the resulting area should lie in between 19.4-645 mm^2. The test section length should be 2-3 times the test section width. The width of the grip should be 1.5 times the test section width. The length of the whole specimen was 300 mm, resulting in a grip length of 40 mm on each side.

This test dimension is designed for pure base material specimens, but due to the following tests had to fit two welds, some adjustments had to be made of the original design. In order to fit both welds in the test specimen section the length had to be increased. The finished design of the specimen was as shown in Figure 9-6.

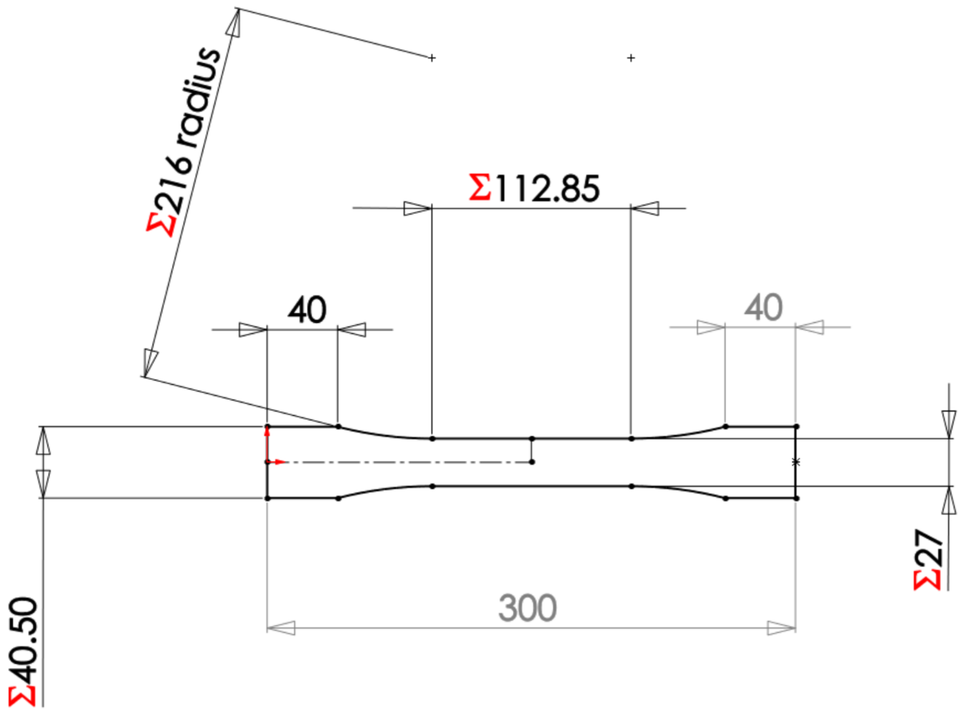


Figure 9-6 - Specimen dimensions according to ASTM E466.

The following procedural steps was taken to machine and prepare the said specimen. according to ASTM E466-15 Appendix X1. Example of the machining procedure:

1. X1.2.1 – Machining was done gradually where the second-last step was 0.4 mm and last 0.2 mm.
2. X1.2.2 - Removed the next 0.1-0.2 mm on the front and backside of the specimens with cylindrical grinding (plane Surfaces Grinding Machine). It was not possible to use the plane surface grinding machine on the sides of the samples, so this was done later with abrasive paper.
3. X1.2.2 - The final grinding was done manually with abrasive paper. Sanding was done with Hermes WS Flex Waterproof P180, Struers FEPA P # 500, Hermes WS Flex Waterproof P1000, Struers FEPA P # 1200 and Silicon Carbide 1200/4000
4. X1.2.4 - Requirements after grinding were that all slip marks would be along the test direction of the test specimens. Finally, a visual check was made with a magnifying glass, where no transverse grinding marks were accepted. A visual log was made where all errors were written down.
5. A roughness check was carried out. Requirements for Maximum surface roughness were 0.2um in the longitudinal direction
6. After surface treatment and control, specimens were lubricated into grease while waiting for testing. Specimens were stored in towels.

Figure 9-7 - Finished test specimen sample.

9.4.3 *Results and discussion*

The results from the tests on the pure base material fatigue specimens are as shown in Table 9-4.

Table 9-4 - Results from fatigue test of unwelded base material plate specimens.

Fatigue test R=0.1 Unwelded base material plate specimens					
Specimen ID	BM1	BM2	BM3	BM4	BM5
Test Number	8	7	16	10	9
Run sequence	1st run	1st run	1st run	1st run	1st run
Stress range [MPa]	430	350	400	375	400
Area [mm^2]	237.5	234.8	240.14	233.9	228.2
Max load [MPa]	477.8	388.9	444.4	416.7	444.4
Min Load [MPa]	47.8	38.9	44.4	41.7	44.4
Mean load [MPa]	262.8	213.9	244.4	229.2	244.4
Machine Load [MPa]	262.8 ± 215	213.9 ± 175	244.4 ± 200	229.2 ± 187.5	244.4 ± 200
Cycles	15 643	2 760 746	394 701	6 770 000	426 615
Displacement range	0.93	0.63	0.82	0.70	0.77
Run out/Fracture	Fracture	Run out	Fracture	Run out	Fracture

Specimen ID	Description	References
BM1	Fracture at 430 after 15 643 cycles Plastic fracture. Low-cycle fatigue range.	
BM2	Run out at 350 MPa after 2 760 746 cycles.	
BM3	Fracture at 400 MPa after 394 701 cycles. Crack initiated in the side face.	
BM4	Run out at 375 MPa after 6 770 000 cycles.	
BM5	Fracture at 400 MPa after 426 615 cycles. Crack initiation at surface face.	

For a crack to initiate, the stress range had to be above yield point level. At a stress range of 375 MPa, which equals to 417 MPa in maximum load due to stress ratio R=0.1, the test ran out at 6 770 000 cycles. The yield point of the metal was approximately 430 MPa which means that the specimen was subjected to dynamic loads equaling 97 % without fracturing.

Three tests were loaded until fracture; one at 430 MPa and two at 400 MPa. With stress ratio R=0.1 the resulting maximum load was 478 MPa and 444 MPa. The specimen at stress range 430 MPa failed prematurely in the low-cycle fatigue stress range.

The final crack initiation in the high-cycle fatigue specimens may have nucleated in intrusions due to plane dislocation slippage. The fatigue life of the high-cycle fatigue specimens consisted mainly in the crack initiation stage. When a crack finally was initiated the subsequent crack propagation growth rate was extremely fast. It wasn't possible to detect any visible crack before fracture, despite regular check-up during testing.

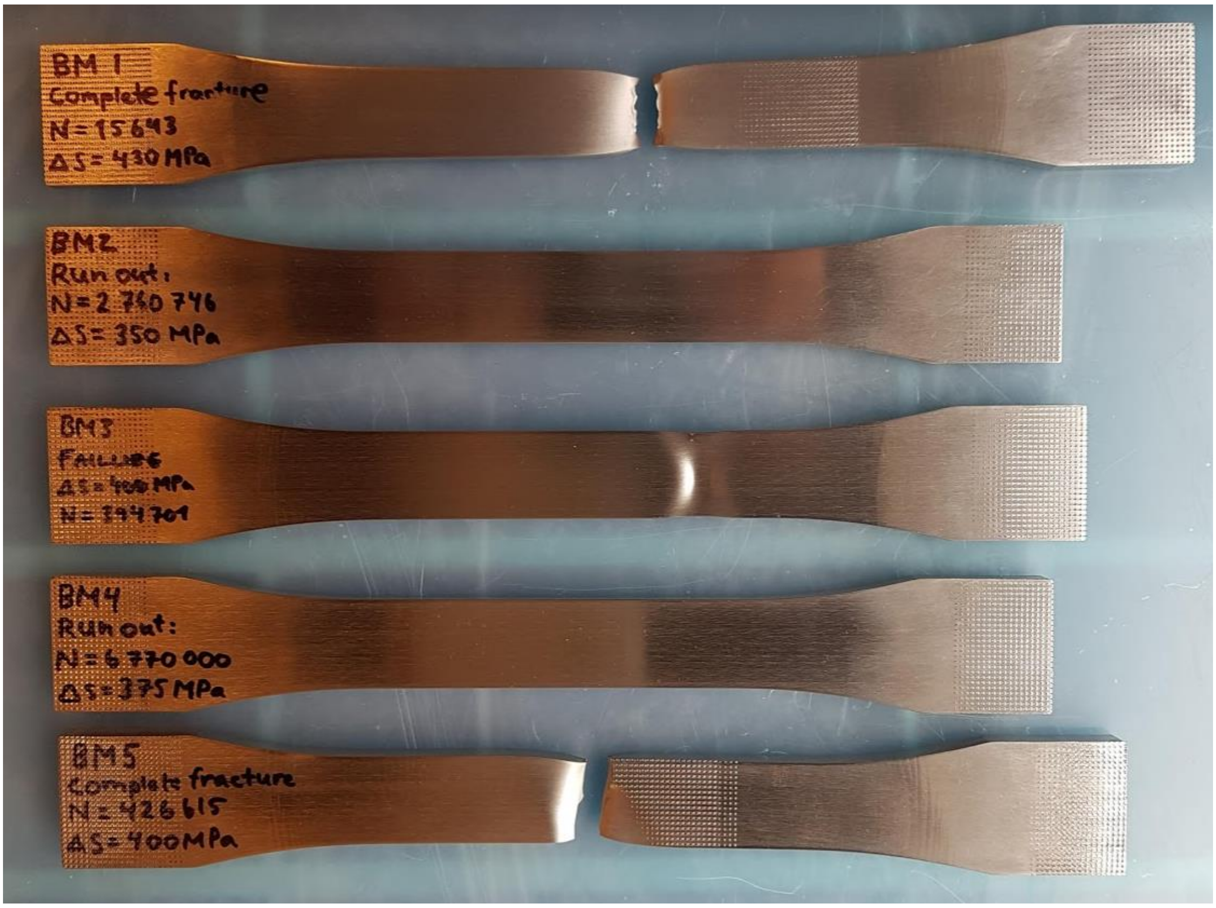


Figure 9-8 - Unwelded base material fatigue specimens after testing.

9.4.4 *Summary*

The main fatigue life of the unwelded base material test specimens consisted of the crack initiation stage. This was increased even further by following the procedural steps in ASTM E466-15. The surface finish greatly improved the fatigue life.

These tests stands in direct contrast to the previous fatigue tests on the welded "prior to fabrication specimens" having reduced fatigue strength due to discontinuities and defects in the weld.

To create an approximated SN-curve based on the testing results was not possible due to the limited sample size. It was also not advisable to conduct further fatigue tests on the used specimens at an increased stress range due to uncertainties from the influence of strain hardening.

9.5 Fatigue test - Production plate specimens

9.5.1 *Objective*

- Determine if the fatigue strength of the microstructure is reduced by overlapping the heat-affected zones of two parallel welds.
- In order to focus on the microstructure, it is necessary to design the fatigue test specimen such that the test excludes the influence of geometrical stress concentrations, weld discontinuities as well as linear and angular misalignments.
- Determine the location of crack initiaion.

9.5.2 *Experimental procedure*

The fatigue specimens were extracted from the welded production plates in chapter 7. The objective of the test was to see if overlapping heat-affected zones influences the fatigue behavior in the absence of stress concentrations due to geometry, weld discontinuities, angular and linear misalignments. In order to achieve this, it was decided to remove any influence from stress concentrations. It was decided to machine the top and bottom surface of the specimens before fatigue testing, mainly from the bottom face. The fatigue machine grip limit was 11 mm and the thickness of the plate was 15 mm so 4 mm had to be removed from the bottom face. This also removed the weld cap and introduced compressive stresses in the weld surface.

Some angular misalignment due to distortion was observed after welding as documented in Table 9-5 and in figures below.

Table 9-5 - Welding distortion in production plates

Welding Distortion in [°]						
Plate ID	8612-2 PL3	PL4	8612-3 PL5	PL6	8612-4 PL7	PL8
Bottom Weld A	3	3	3	3	-1.5	2
Bottom Weld B	1	0.5	3	2	-2	0
Top Weld A	3	3	2	3	-1	1
Top Weld B	2	0	0.5	1	-3	0

Figure 9-9 – Weld distortion after second weld PL3.

Figure 9-10 - Weld distortion after second weld PL5.

Figure 9-11 - Weld distortion after second weld PL7.

The specimen was machined in sequence as shown in Figure 9-12. Initially the top face was machined down until parallel and subsequently the bottom face was machined until the surface was parallel to the top. In order to minimize the effect on the microstructure the machining was performed at lower speeds and with an increase amount of coolant.

Figure 9-12 – Machining of fatigue specimens from welded S420G2+M plates in order to remove stress concentrations and misalignments the top face was initially machined until parallel followed by the machining of the bottom face.

The specimen dimensions were the same as for the unwelded pure base material specimens as seen in Figure 9-6 and method of preparation was also the same.

9.5.3 *Results and discussion*

The sample size from the fatigue testing of the welded production plates are presented in Table 9-6. Due to the distortion of the plate 8612-4 PL7 DW5 the machining of the top face resulted in the removal of the critical area of the conjoining HAZ. Due to time constraints it was not possible to machine more specimens that had this critical distance between the welds.

Table 9-6 – Fatigue test sample size production plate.

Fatigue test samples		
Specimen ID	Sample size	Distance between welds
8612-2 PL3 DW50	2	44 mm
8612-3 PL5 DW15	2	12 mm
8612-4 PL7 DW5	1	1.2 mm

The results from the fatigue tests are shown in Table 9-7 and

Table 9-8.

Table 9-7 - Results from fatigue test of the production plate specimens.

Fatigue test R=0.1 Production plate specimens					
Specimen ID	8612-2 2A (B)	8612-2 2A (B)	8612-2 2A (BB)	8612-3 A3	8612-3 A3
Weld distance	44 mm	44 mm	44 mm	12 mm	12 mm
Test number	12	13	17	14	14
Run sequence	1st run	2nd run	1st run	1st run	2nd run
Stress range [MPa]	375	400	400	375	400
Area [mm^2]	232.0	232.0	243.1	235.25	235.25
Max load [MPa]	416.7	444.4	444.4	416.7	444.4
Min Load [MPa]	41.7	44.4	44.4	41.7	44.4
Mean load [MPa]	229.1	244.42	244.42	229.1	244.42
Machine Load [MPa]	229.1 ± 187.5	244.42 ± 200.0	244.42 ± 200.0	229.1 ± 187.5	244.42 ± 200.0
Cycles	5 000 000	439 404	322 187	4 953 349	483 574
Displacement range	0.69	-	0.80	0.70	0.76
Run out/Fracture	Run out	Fracture	Fracture	Run out	Fracture

Specimen ID	Description	References
8612-2 2A (B)	Run out at 375 MPa after 5 000 000 cycles. Continued second run at 400 MPa and fractured after 439 404 cycles. Fracture occurred in the base material at a previously detected surface defect.	
8612-2 2A (BB)	Fractured at 400 MPa after 322 187 cycles. Fracture occurred in the base material on the side face.	
8612-3 A3	Run out at stress range 375 MPa after 4 953 349 cycles. Continued second run at 400 MPa and fractured after 483 574 cycles. Fracture at surface defect in base material. An additional crack initiated in the base material at another surface defect.	Figure 9-13, Figure 9-14, Figure 9-15

Table 9-8 - Results from fatigue test of the production plates.

Fatigue test R=0.1 **Production plate specimens**			
Specimen ID	8612-3 3A	8612-4	8612-4
Weld distance	12 mm	Initial distance was 1.2 mm.	Initial distance was 1.2 mm.
Test number	18	15	15
Run sequence	1st run	1st run	2nd run
Stress range [MPa]	400	375	400
Area [mm^2]	244.07	205.85	205.85
Max load [MPa]	444.4	416.7	444.4
Min Load [MPa]	44.4	41.7	44.4
Mean load [MPa]	244.42	229.1	244.42
Machine Load [MPa]	244.42 ± 200.0	229.1 ± 187.5	244.42 ± 200.0
Cycles	306 418	4 938 994	2 084 237
Displacement range	0.80	0.66	0.73
Run out/Fracture	Fracture	Run out	Fracture

Specimen ID	Description	References
8612-3 3A	Fractured at 400 MPa after 306 418 cycles. Fracture initiated in the base material.	
8612-4	Initial run out at 375 MPa after 4 938 994 cycles. Fracture at 2 084 237 cycles at 400 MPa. The fracture initiated between the welds inside the specimen in what seemed to be a weld defect in weld B. This sample was also subjected to a lower load level due to miscalculation of the cross-sectional area.	

The results from the fatigue testing indicates that the welded joints had a higher fatigue strength than the base material. This agrees with Maddox, that writes [11] that if a weld joint would be machined and grinded flush, the most normal crack initiation location would be the base material. This statement is based on one single weld. The results from the fatigue test showed that this was the case for 12 mm and 44 mm between two parallel butt-welds.

The preparation procedure might have adversely affected the results due to introducing compressive residual stresses that inhibited crack initiation.

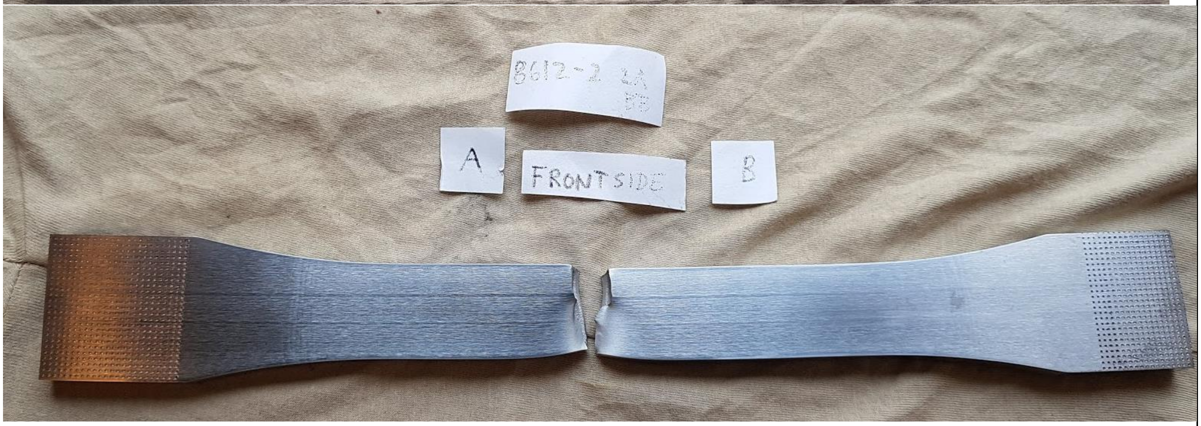
The fatigue test of the sample with 1.2+ mm between the welds failed in what seemed was a weld defect on the side face of the specimen, so the result from this was inconclusive.

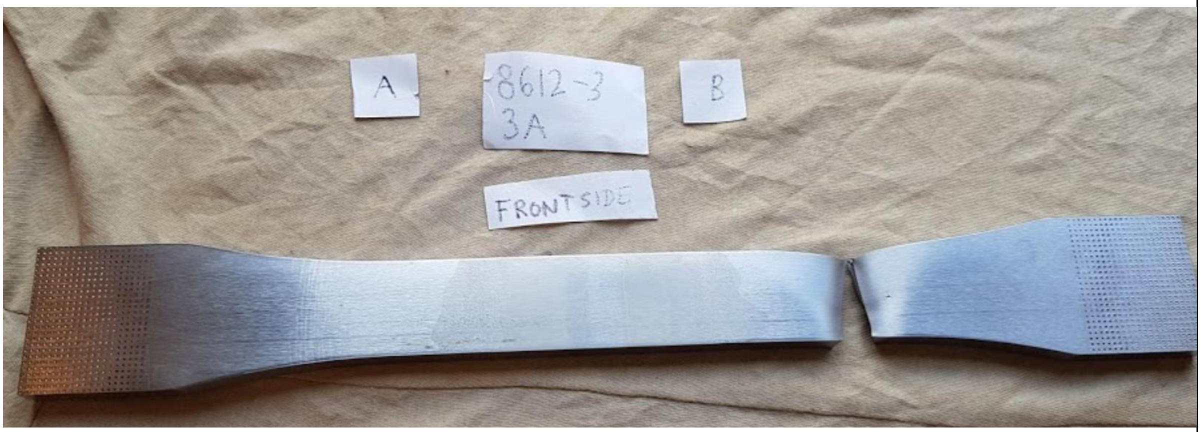
The effect of residual stresses did not result in a fracture in the weld joint.

The number of cycles needed to fracture the specimen was very similar to that of pure base material. This may be due to the careful preparation process that all specimens underwent and since the base material was the weakest part of the specimen.

A visual inspection of each specimen was performed before every test, and some (Figure 9-13,Figure 9-14 and Figure 9-15) visible surface defects was detected and recorded. After fracturing, these specimens where examined and in several cases these locations were the source of crack initiation.


8612-2
2A
A
B
8612-2 2A
Run out:
ΔS=375MPa N=5000000
complete fracture
ΔS=400MPa N: 439404


A
FRONTSIDE
B


A
8612-3
3A
B
FRONTSIDE


8612-4
RUN OUT
COMPLETE FRACTURE

Figure 9-13 – Final fracture and location of crack initiation of 8612-3 A3 specimen.

Figure 9-14 – Location of a small defect in the base material surface where fracture occurred.

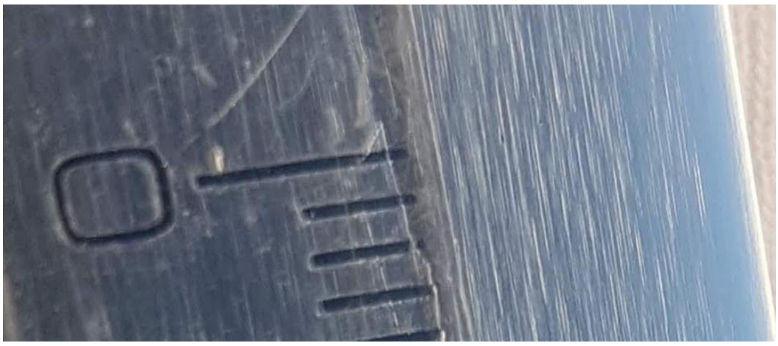


Figure 9-15 - Location where the crack initiated was at the location of the defects in the base material.

9.5.4 *Summary*

The results from the fatigue test indicates that having two parallel buttwelds, in the absence of stress concentrations and welds discontinuities, does not negatively impact the fatigue performance of the weld joint at the distances of 12 mm and 44 mm.

The specimen with an initial distance between the welds of 1.2 mm failed due to a weld defect, and therefore was inconclusive.

The preparation method might have adversely affected the results due to introducing compressive residual stresses that inhibited crack initiation.

The main fatigue life of the “production plate specimens” composed of the crack initiation stage.

9.6 Stress range vs total cycles of S420G2+M base material

The crack initiation occurred in the base material during the fatigue testing of the unwelded base material and production plate fatigue specimens. The total cycles required for fracture to occur was also very similar. In addition, all preparation and prior documentation of the state of the metal was also the same and in accordance with ASTM E466-15 [45]. This made it plausible to combine the two results in a single graph, to estimate the fatigue life of the S420G2+M metal.

Figure 9-16 shows the combined results in a Stress Range vs total Cycles graph from the main welded and base material fatigue specimens. Both the results from the fractured and run out specimens are shown in the diagram.

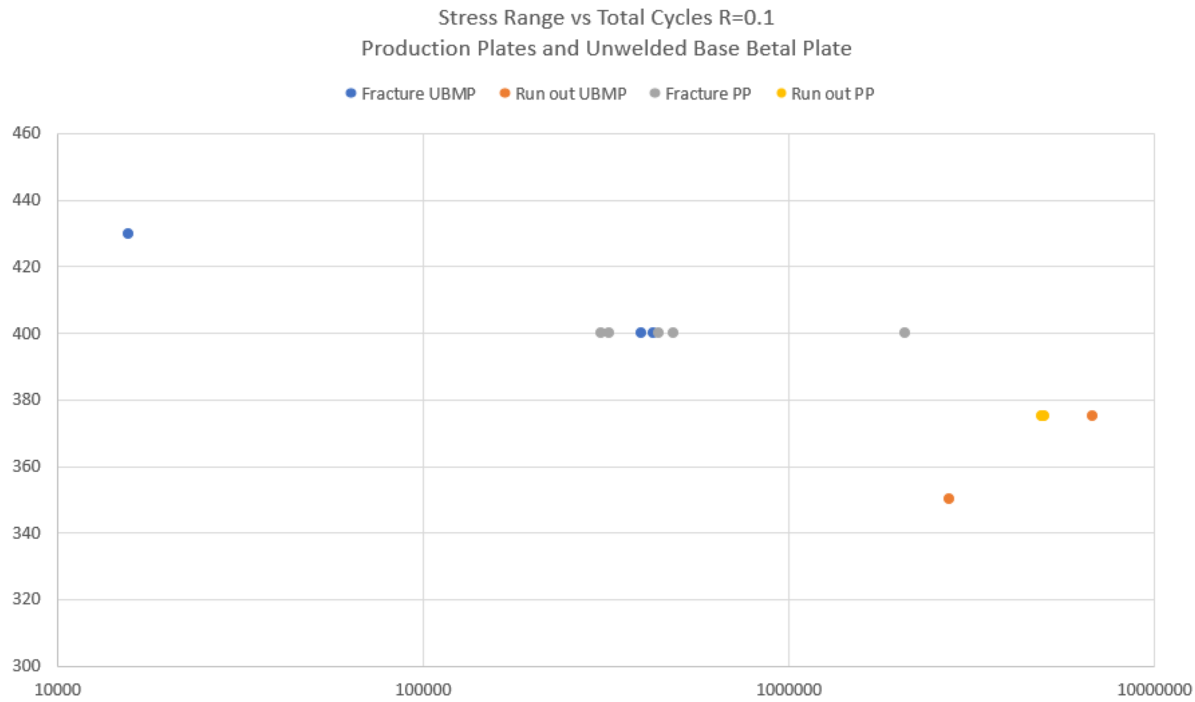


Figure 9-16 –Stress range vs total cycles graph of production plate specimens and unwelded base material specimens. R=0.1.

When adjusting the stress ranges based on the averaged registered displacements it was possible to derive a trend line using linear regression. By adjusting the stress ranges based on this, we get the approximated stress range vs total cycles curve as seen in Figure 9-17. The lowest value at fracture was 380 MPa and the highest value at run out was 370 MPa. Endurance limit was determined to be at 5 million cycles.

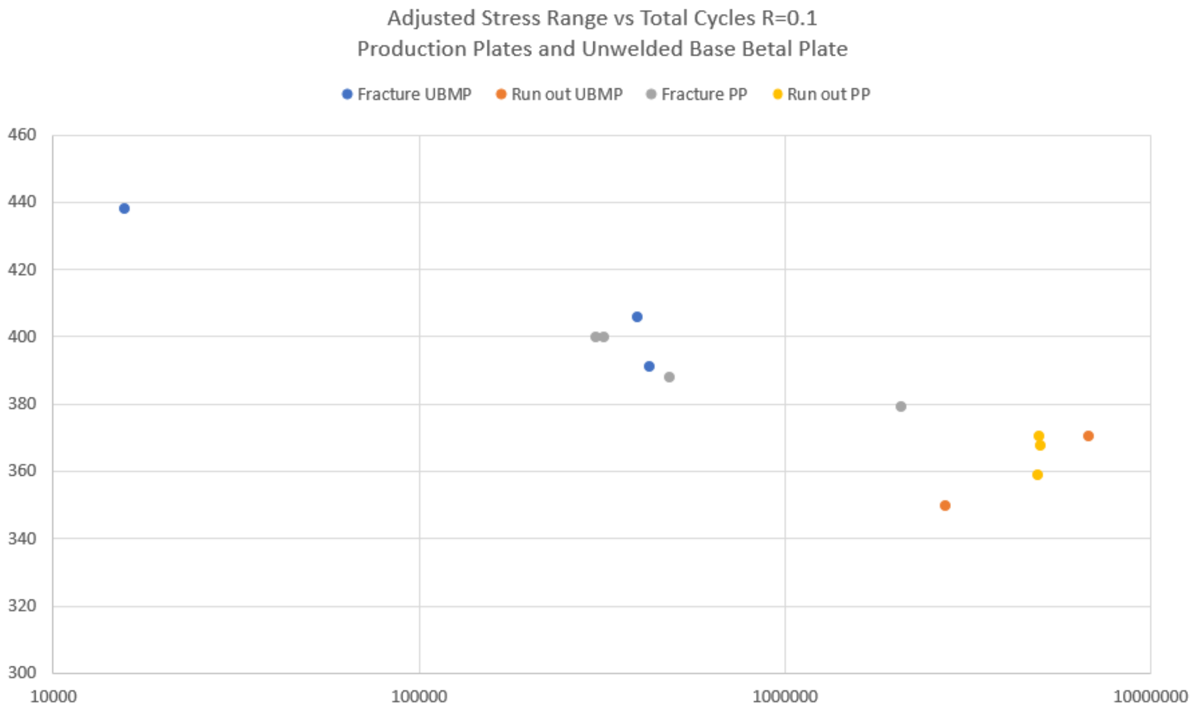


Figure 9-17 - Adjusted stress range vs total cycles. R=0.1.

10 Experimental Investigation: Residual Stress Measurements

Six specimens as seen in Table 10-1 were sent to Veqter in Bristol, England for residual stress testing. The ASTM E466-15 specimens had an identical preparation as the fatigue specimens in previous chapter. The as-welded samples just had the weld cap grinded of in order to be able to perform ultrasonic residual stress testing.

Table 10-1 - Test Samples sent to Veqter for residual stress analysis

Weld Proximities	ASTM E466-15	As-welded
50 mm	1	1
15 mm	1	1
5 mm	1	1

10.1 Performed Tests

- CNC-machined, machine precision grinded and manually grinded test specimen (ASTM E466-15)
    - Ultrasonic testing (US)
        - Average Longitudinal residual stress from 0 to 2 mm on the top and bottom face
        - Average Transverse residual stress from 0 to 2 mm on the top and bottom face
    - X-ray diffraction testing (XRD)
        - 50 µm from top face
- As-welded specimen weld cap removed by flap disk grinding
    - Incremental Centre-Hole Drilling testing (ICHD)
        - Bi-axial residual stress profile 1 mm from the top face on the weld centerline side B of the 5mm apart seams weld specimen
    - X-ray diffraction testing (XRD)
        - Bi-axial residual stress at 50 µm from top and bottom face
        - Bi-axial residual stress at 150 µm from top and bottom face

10.2 Ultrasound measurement technique

10.2.1 Ultrasound procedure

The Ultrasound (US) residual stress measurement technique exploits the acousto-elastic property of common materials, in which the speed of sound through a material changes with stress. It was determined [46, 47] that the speed of a longitudinal ultrasound wave through a material was the most sensitive to stress changes in the direction of propagation of the wave. In essence, the speed of the longitudinal wave would decrease through tensile stress regions and increase through compressive stress regions [48]. By using Snell's law it is possible to generate a critically refracted longitudinal (L_{cr}) wave travelling parallel to the surface of a specimen reaching depths below the surface roughly equal to its wavelength [49, 50].

The US probe head used during this project is shown schematically in Figure 10-1 which comprises of 2 MHz ultrasound probes attached to a single acrylic wedge at specific angles according to Snell's law. The transmitting probe (T) emits the longitudinal wave, which is then critically refracted at the specimen surface, travelling parallel to and just beneath the surface of the specimen before being detected by receivers 1 and 2 (R1 and R2). The time needed for the L_{cr} wave to travel between the transmitter and receivers is the Time-of-Flight (ToF) and is used to calculate the change in average stress experienced in the specimen material between the ultrasound probes when referenced against a known stress field, i.e. ideally a stress-free region.

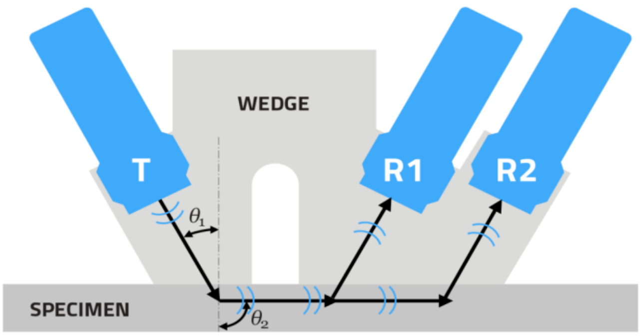


Figure 10-1 - A diagram showing the US residual stress measurement probe head.

When measuring the ToF at different locations within a specimen using the same gauge volume, it is possible to determine the relative change in stress experienced using the following formula:

$$\Delta\sigma = \frac{E(T - T_0)}{L_{11}.T_0} \tag{10-1}$$

Where $\Delta\sigma$ is the change in stress between the two stress states, T is the Time of Flight in the unknown stress state, T_0 is the Time of Flight in the known stress state (usually the stress free state, but can be another known stress state) and L_{11} is the acousto-elastic coefficient. L_{11} is a constant property specific to the specimen material and is calibrated experimentally or using a different residual stress measurement technique [51].

For this project, the equipment was arranged to provide results from a gauge area of 5 mm long, 4 mm wide and 2.8 mm deep below the material surface. Only the Longitudinal ToF was measured using the US system due to the gauge size. Ultrasonic couplant was applied over the measurement location to facilitate the transmission of the ultrasound. The transmitted and received signals were recorded by a fast sampling oscilloscope and processed off-line using in-house software. To convert the Time of Flight to residual stress to known stress value need to be obtain. This can be done using another residual stress measurement technique. The results presented in this report where calibrated using an Incremental Centre Hole-Drilling (ICHD) measurement carried out on as welded specimen. As measurement was taken only 15 mm from an edge only the Transverse stress was taken into consideration as the Longitudinal stress would have been reduced to the proximity of a free surface.

A Contour measurement planned in the future will provide the longitudinal residual stress and will be used as an additional source for calibration.

10.2.2 *Technique Accuracy*

The uncertainty of the UT residual stress measurement technique is determined by several parameters, with only some being accounted for in this analysis. The uncertainty is dependent upon the thickness of the ultrasound couplant, the gradients of residual stresses within the gauge volume, the material texture, the temperature and the resolution/accuracy of the oscilloscope recording equipment. It was assumed that the microstructure was the same throughout the material and therefore the L_{11} coefficient and $T0$ were assumed to be constant. The UT equipment was designed to apply a constant contact force each time to the acrylic wedge so controlling the thickness of couplant and was monitored and recorded during the tests. The oscilloscope recording equipment provides a state-of-the-art resolution of measurement of 0.4 ns, which is highly accurate.

10.3 Results: Residual Stress Measurements

10.3.1 *CNC-machined, precision grinded and manually grinded specimens*

The time of flight (ToF) measured on the three CNC-Machined specimens on the top and bottom surface across the welds are shown in Figure 10-2. The measured ToF was then shifted to show about 0 ns in the base material. The increases in ToF relates to increases in stresses and decreases in ToF relates to decreases in stresses. As it can been seen, clear changes occur at the weld location. In the longitudinal direction the ToF increases by about 10 to 15 nanoseconds in a M shape form center at the weld centerline. Some drop in ToF was generally found on either side of the weld. Each on the max peaks where found to be center to the weld centerline at the bottom and top side of the specimen. In the transverse direction the ToF looks like a near mirror to the longitudinal direction at the exception that, each negative drop where balanced with a sharp increase in ToF.

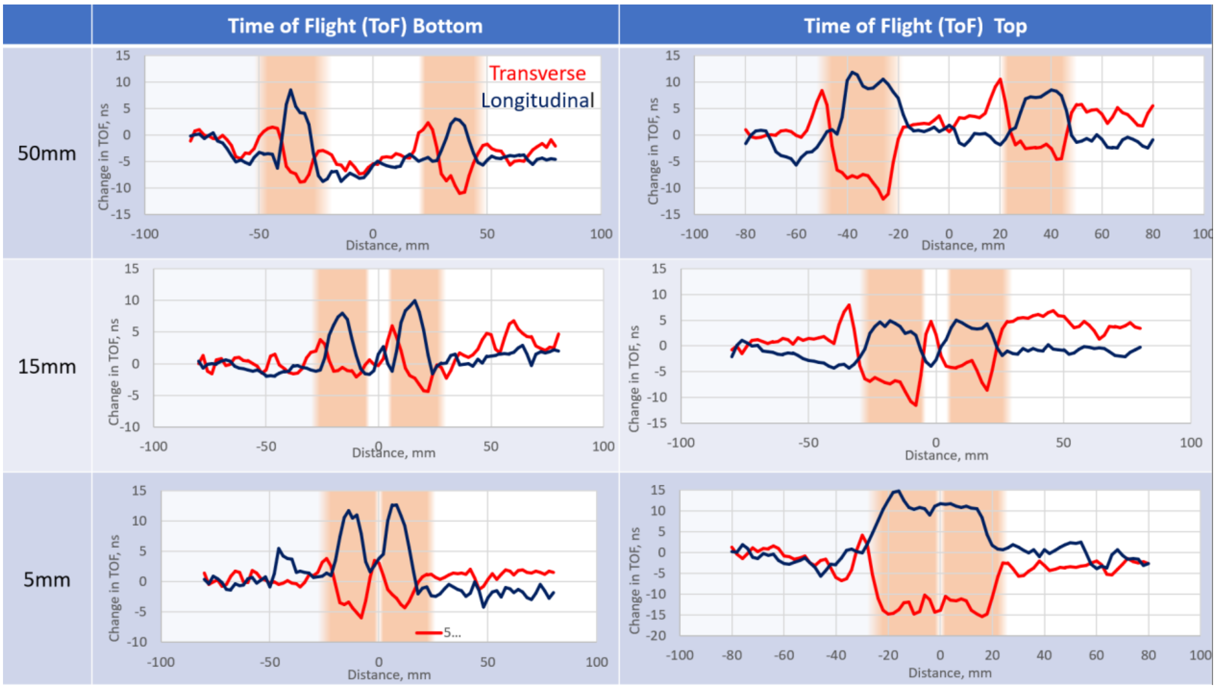


Figure 10-2 - Time of Flight results from US testing. Weld A is the leftmost weld.

The ToF shown about where then converted to residual stress using two values. Zero in the base material and -100 MPa for the max compressive peak found over the three specimens. The Ultrasonic measurement can be severely affected by changes in texture which occurs naturally in welds. Often several additional calibration values need to be used. A Contour measurement will be performed in the near future to provide further confidence in the results. One of the clear results provided by the ICHD measurement was that the longitudinal residual stress was in tension while the transverse direction was in compression, which is also shown in the Ultrasonic measurement. It should be noted that the near surface of the specimen within 150 μm was in high compression near yield. This compressive level was introduced by the grinding process. The XRD carried out on the surface of the CNC-machined specimen measuring up to 15 μm show that all surfaces were between -320 MPa and -450 MPa. As the Ultrasonic technique is a relative technique, which measure the changes in residual stress, the addition of a constant layer of compressive stress will not influence the results.

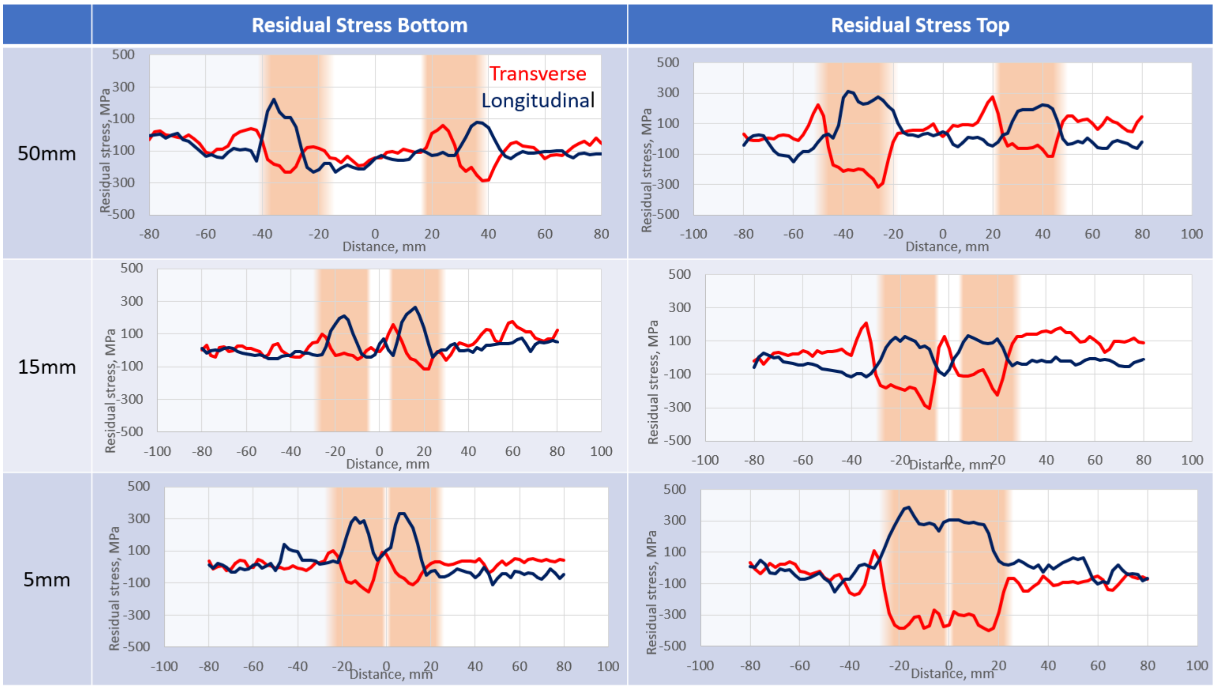


Figure 10-3 - Residual stress test results from US testing. Weld A is the leftmost weld.

Table 10-2 - Results X-ray diffraction machined and grinded specimen.

	XRD 5 mm Top transverse	XRD 5 mm Top longitudinal
Weld Center Line	-336 MPa	-440 MPa
-5 mm from WCL	-400 MPa	-392 MPa
-60 mm from WCL	-300 MPa	-346 MPa

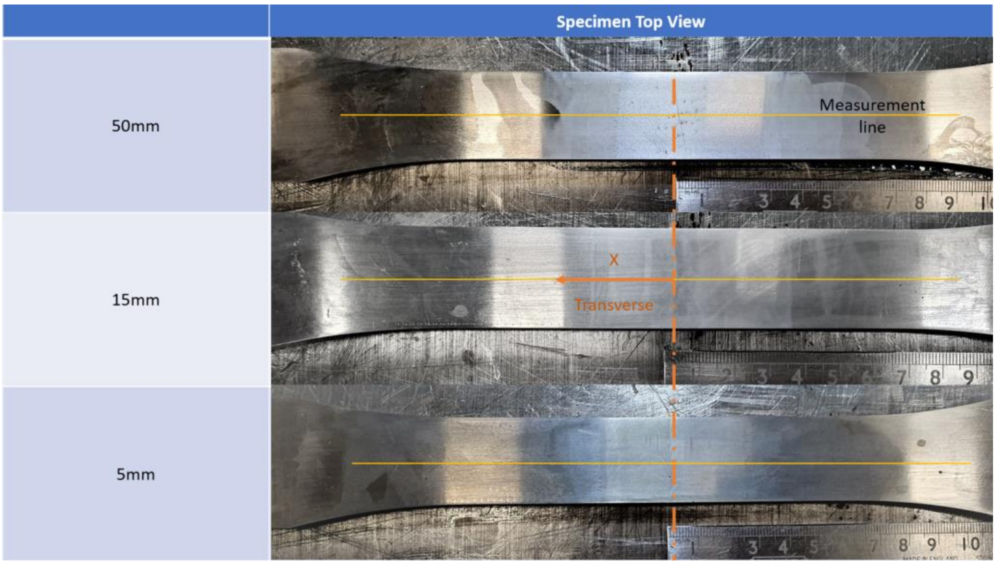


Figure 10-4 - ASTM E466-15 Test Sample measuring direction.

Figure 10-5 - Ultrasonic Residual Stress Measurement.

10.3.2 *As-welded specimen*

XRD and ICHD measurement were carried out on the 5 mm weld apart specimen at 15 mm from the edge at the weld centerline. The XRD measurements were carried out at 15 µm and 150 µm and the ICHD measurement was performed to provide 1 mm of residual stress measurement as shown in Figure 10-6.

Figure 10-7 shows a comparison of both the XRD and ICHD results. As it can be seen both transverse and longitudinal residual stress are in high compression at the surface which was caused by the grinding of the weld cap. The effect of the grinding was found up to about 150 µm the residual stress from the weld was measured thereafter. The longitudinal stress was found negligible which was expected due to the proximity of the weld. The transverse stress was found to be about -100 MPa.

Figure 10-6 - Specimen test locations in the as-welded specimen.

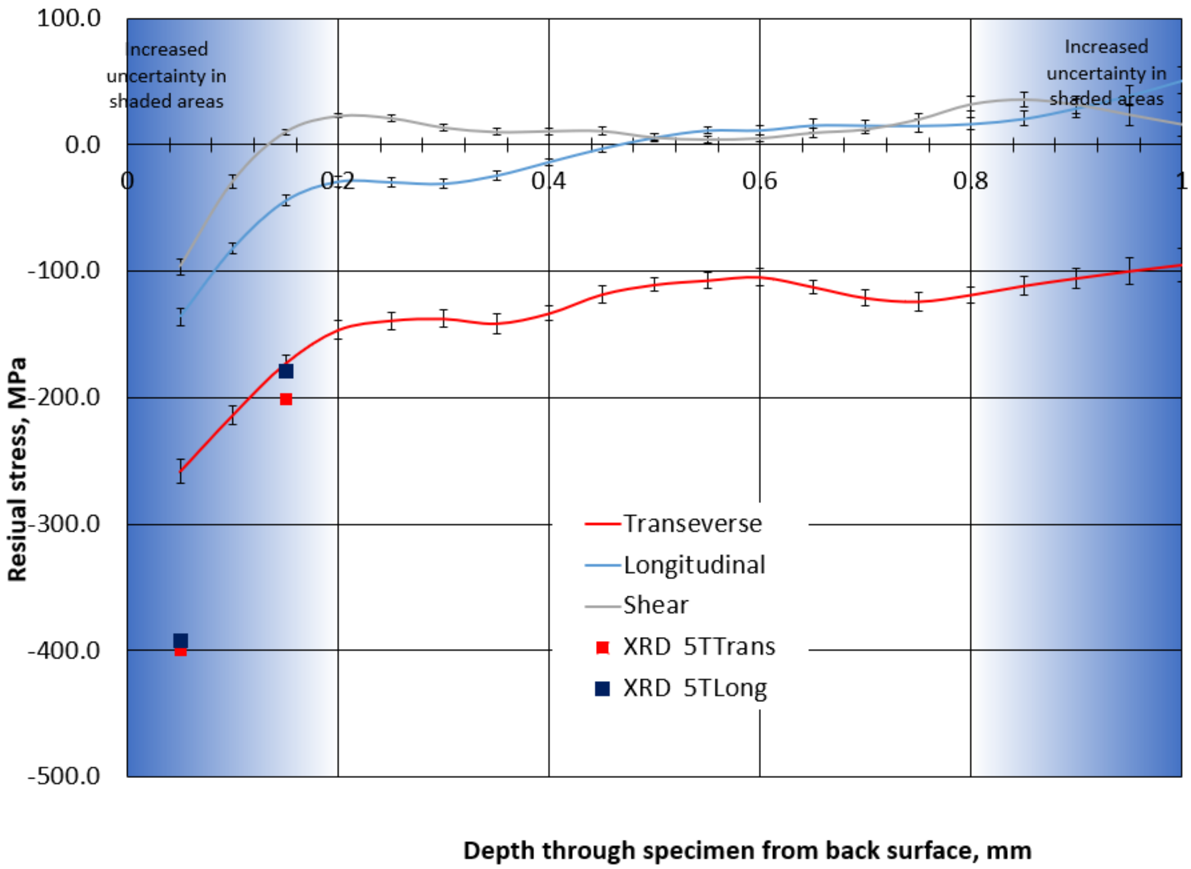


Figure 10-7 - XRD and ICHD Measurements on 5 mm section Top as-welded specimen.

10.4 Summary: Residual Stress Measurement

10.4.1 *CNC-Machined, precision grinded and manually grinded specimen ASTM E466-15*

US testing was performed on all the specimens on both root and weld cap. XRD was performed on the 5 mm specimen in weld cap B.

The preparation of the specimens was in accordance with E466-15 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials. Similar to the fatigue test specimens. It was CNC-milled, precision grinded and subsequently manually grinded until a surface roughness of 0.2 µm was achieved. The influence of the preparation operation on the residual stresses was assumed to be 150 µm into the specimen surface.

In the majority of US tests performed the longitudinal residual stress was in tensile and the transverse residual stress was in compression. The ICHD measurement seemed to confirm this finding.

The effect weld proximity had on the residual stress profile was not noticeable in the 50 mm and 15 mm specimens. But, in the specimen with 1.2 mm between the weld toes there was a clear increase in both tensile and compressive residual stress distribution.

The ultrasonic test showed a clear transition from parent to unwelded metal.

The US test only provide relative changes which needs to be calibrated with a minimum of 2 know stress values. The US will also be affected by changes in texture in material which occurs in the weld.

The XRD shows that we have yield level compressive and tensile residual stresses 50 µm from the top face. This is the result from the grinding and milling operations.

10.4.2 *As-welded specimen*

XRD and ICHD was performed on the top surface of the 5 mm as-welded specimen.

The weld cap of the specimen was removed with a flap disk.

XRD and ICHD was performed on weld A and weld B, respectively at the locations shown in Figure 10-1. ICHD was performed down to 1000 µm and XRD was performed at 50 µm and 150 µm.

The results differed slightly, but both showed that there were high compressive residual stresses in the top surface from the grinding operation at an approximated depth of 0-150 µm.

The ICHD showed the residual stress profile 1000 µm into the specimen surface in the weld B center line. From 500 µm the longitudinal and shear residual stresses was in tension, while the compressive still was in compression. This was not as expected. The location the test was performed might have reduced the longitudinal residual stress result.

10.5 Further work

- Perform a contour test to determine the residual stress distribution.
- Conduct further US testing on as-welded plates.

11 Summary and main Conclusion

The experimental chapters consists of a methodology, result and conclusion of the findings from each experiment. This chapter serves the purpose of summarising the key findings.

Predetermined distances for weld proximity have been set in most standards, codes and specifications in the industry today. There is still a lack of information regarding the implications when divergences from the requirements are necessary or have been detected in the service-life of a structure. It is vital to understand the implications it has on mechanical and material properties of the weld joint when exceeding these set requirements.

The objective of this thesis was aimed at obtaining quantifiable data regarding the implications of having two adjacent weld joints in close proximity.

11.1 Test Setup

An experimental analysis was designed where the resulting material behavior was analyzed and documented. The test consisted of six welded 500x300x15 mm S420G2+M steel plates, each having two adjacent parallel butt welds along its full length. The distances between two adjacent welds were 50, 15 and 5 mm in order to analyze the effect a variation in distance have on the properties of the initial weld pass.

11.2 Welding Procedure Qualification

In order to maintain conformity of all welded plates a welding procedure qualification record (WPQR) were initially established. This was achieved by welding an initial qualifying plate that was tested and qualified in accordance with the requirements in NS-EN ISO 15614-1:2017 [17]. Following welding procedures were then subsequently based of the approved welding procedure qualification (WPQ).

11.3 Range of Testing

All plates were welded at KIWA in Stavanger, and subsequently mechanically tested at Quality Lab in Forsand in accordance with NS-EN ISO 15614-1:2017.:

- Visual testing
- Surface crack detection
- Vickers Hardness Test
- Charpy V Impact Test
- Transverse Tensile test
- Bending test
- Macroscopic examination
- Radiographic or ultrasonic testing was performed at IKM Testing

Fatigue test and microstructural analysis (optical microscope) was conducted at the Department of Mechanical and Structural Engineering and Materials Science at the University of Stavanger. Residual stress analysis was conducted at Veqter in Bristol using ultrasound (US), Incremental Centre-Hole Drilling (ICHD) and X-ray Diffraction (XRD) technique.

11.4 Mechanical Testing

The mechanical testing results from the NS-EN ISO/IEC 17025 accredited Qlab, indicated no degradation in material properties due to weld proximity. This statement was based on results from tensile tests, Charpy V Impact toughness test and Vickers hardness tests. The distance between the weld toes of the butt welded joints was 44, 12 and 1.3 mm.

All Tensile Test specimens failed in the BM outside the HAZ. This was as assumed since the UTS of the WM is higher than the BM. The result seemed to indicate that the influence of the adjacent secondary weld did not have a negative impact on the tensile strength properties of the initial weld. The fracture also initiated a considerable distance away from the weld showing no sign of reduction of tensile strength in the HAZ. The WM were machined flush with the BM.

The results from the Charpy V Impact Toughness test showed no reduction in toughness properties from the adjacent secondary weld. Due to inherent spread of the test results it was not possible to determine any distinct variation between the results at the different distances. All tests showed that the weld joint had toughness properties well above the requirements. The fracture appearance and lateral expansion was well within the limits. The test results are shown in Table 7-33.

The results from the Vickers Hardness test did not indicate any reduction in material hardness properties due to the adjacent secondary weld. As seen in Figure 7-37 the hardness values between a weld joint with 1.3 mm between the weld toes did not have any significant increase in hardness. Due to the spread in results in the WM and HAZ it was not possible to see if the secondary weld had any softening effect on the initial weld. The welds at 12 mm and 44 mm from weld-toe to weld-toe did not show any adverse effect due to the weld proximity, and showed a similar toughness pattern as the welds at 1.3 mm from eachother. More tests are needed in order determine if there is any difference between the various distances. Important to note also is that only one specimen at 1.3 mm was hardness tested. This is sufficient to approve a WPQ, but due to the nature of this test more tests are needed in order to ascertain the initial test results.

These results indicate that weld proximity as close as 1.3 mm does not have any degrading impact on the weld joint. This is based on level 2 mechanical testing in accordance with 15614-1:2017, used to approve WPQs.

It is important to note that these results are for this set of parameters and materials, but the findings can act as a baseline for further testing at various HI, welding positions, distances, etc.

11.5 Weld Microstructure

The microconstituents in the weld metal and HAZ are typical, and a common combination in the industry. In only one specimen did the weld HAZ overlap. This was the weld with 1.3 mm between the weld toes. No visible harmful phases were detected with the optical microscope in either the WM or the HAZ. The impact of the overlap only seemed to have a normalizing effect of the previous HAZ of weld A.

Between subsequent weld passes and unaffected region of the coarse-grain HAZ microstructure can be distinguished. The reheated pockets of the CG HAZ regions are small and discontinuous, which make their microstructure difficult to identify and investigate. The reheated IC CG HAZ is very susceptible to failure, due to the fact that the phase transformation into austenite began on the grain boundaries; these small areas is rapidly cooled and have a strong possibility to become hard and brittle. The subcritical regions are mainly tempered bainite and martensite with precipitated carbides and therefore represent no danger to the structural integrity of the weld.

The welds with a distance of 12 mm and 44 mm between the weld toes had no overlap of HAZ. The was never any overlap of visible HAZ of the weld roots, despite the larger area of effect.

Important to note though is that the magnification of the optical microscope is limited and further analysis with a scanning electron microscope (SEM) and a transmission electron microscope (TEM) is necessary in order to assure that this is the case. Investigation in these microscopes are needed in order to confirm the exact nature of all phase transformations occurring in the overlapping HAZ.

11.6 Fatigue test

The objective of the fatigue test was to assess if any reduction in fatigue strength had occurred due to the weld proximity situation. The fatigue test specimens were prepared with the intention to isolate and study the microstructure. The preparation of the sample were conducted in accordance with ASTM E466-15 for a homogenous material subjected to high-cycle fatigue. Weld discontinuities was avoided in order to isolate and focus on the HAZ microstructure, and any geometrical and angular weld stress concentrations was removed. The result from the test was that the specimen at 5 mm distance with overlapping welds seemed to have failed in the secondary weld. The reason for the crack initiation was not possible to determine. Important to note though, was that the failure did not occur in the first weld, which was the focus of the study, but the secondary overlapping weld. In the absence of stress concentrations, the remaining fatigue specimens failed in the parent metal. The sample size was limited, but the results indicated that at 12 mm between two weld toes, the weld has the higher fatigue strength.

11.7 Residual Stress Measurements

Six specimens as seen in Table 10-1 were sent to Veqter in Bristol, England for residual stress testing. The ASTM E466-15 specimens had an identical preparation as the fatigue specimens in previous chapter. The as-welded samples just had the weld cap grinded of in order to be able to perform ultrasonic residual stress testing.

11.7.1 CNC-Machined, precision grinded and manually grinded specimen

US testing was performed on all the specimens on both root and weld cap. XRD was performed on the 5 mm specimen in weld cap B.

The preparation of the specimens was in accordance with E466-15 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials. Similar to the fatigue test specimens. It was CNC-milled, precision grinded and subsequently manually grinded until a surface roughness of 0.2 µm was achieved. The influence of the preparation operation on the residual stresses was assumed to be 150 µm into the specimen surface.

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The ultrasonic test showed a clear transition from parent to unwelded metal.

The US test only provide relative changes which needs to be calibrated with a minimum of 2 know stress values. The US will also be affected by changes in texture in material which occurs in the weld.

The XRD shows that we have yield level compressive and tensile residual stresses 50 µm from the top face. This is the result from the grinding and milling operations.

11.7.2 As-welded specimen

XRD and ICHD was performed on the top surface of the 5 mm as-welded specimen.

The weld cap of the specimen was removed with a flap disk.

XRD and ICHD was performed on weld A and weld B, respectively at the locations shown in Figure 10-1. ICHD was performed down to 1000 µm and XRD was performed at 50 µm and 150 µm.

The results differed slightly, but both showed that there were high compressive residual stresses in the top surface from the grinding operation at an approximated depth of 0-150 µm.

The ICHD showed the residual stress profile 1000 µm into the specimen surface in the weld B center line. From 500 µm the longitudinal and shear residual stresses was in tension, while the compressive still was in compression. This was not as expected. The location the test was performed might have reduced the longitudinal residual stress result.

12 Future research

This project served the purpose of being a baseline in the matter of weld proximity research. The findings can assist in the assessment of a weld proximity or weld-on-weld scenario.

The welding operation did not seem to introduced any degradation of the material properties in the WM and HAZ. The mechanical properties of similar weld joints in the field could be assumed to be unaffected due to the welding of an adjacent weld.

Important to note is that this is for this type of method and materials. More testing has to be performed in other to ascertain the findings. The results can be used as a baseline for further research.

Future research regarding this topic is listed below:

Mechanical testing

Further mechanical testing is needed in order to confirm results obtained in the project. Especially at a distance where we have HAZ overlap. The sample size of hardness tests conducted in this area with overlapping HAZ consisted solely of one macro specimen. This is sufficient when approving a WPQ, but lacking when performing an experiment of this nature. Hardness tests would have to be performed at distances that increases the risk of forming brittle reheated grain structures.

Further study and experimentation can be performed on welded joints of plates with various HI, welding positions, environmental conditions, pre-heat, welding method, filler material, plate thickness, use of a pipe instead of plate, fixations, etc.

Instead of using a 15 mm thick plate, it would have been interesting to test a 10 mm plate. This would have reduced the deformation due to the welding process. However, the side effect this could have been that the residual stresses would be reduced, which was a part of the study. Thicker goods may be more representative of thick-walled pipe sections. The welding time had been reduced because not as many passes had been needed. This would have been more economical and you might have time to produce more plates. In addition, the plates would not have been machined to accommodate the fatigue machine due to a maximum grip distance of 11 mm.

These results could be used as a guideline for other normalized steels. Further research could be conducted on QT steel which has a higher hardenability.

Microstructural examination

Due to the limitations of the optical microscope more thorough analysis is needed in the SEM and TEM to confirm the results. The results would have to be verified and compared with the results from the mechanical testing.

Fatigue test

The welded joint subjected to fatigue testing was prepared in accordance with ASTM E466-15. This introduced high compressive residual stresses based on the results from the XRD and ICHD. For future research the analysis of a welded specimen in its original state would be more representative for a structure. Fatigue test on plates with remaining weld cap.

In this test the stress range R=0.1. For future research other stress ratios could be tested.

Residual stress measurement

Use the findings from the residual stress test to model and calibrate a FEA. The welding operation, including the location of all fixations, was documented on all test results. This also offers a possibility to determine the reason why we had tensile transverse compressive stresses in the weld joints. The residual stresses obtained could be difficult model due to the additional introduction of grinding which introduced compresssive residual stresses in the surface of the specimen. A residual stress test would have to be performed on an un-grinded specimen in order to map the original residual stress distribution.

More residual stress measurements was still being performed after the delivery of this thesis. This included contour plotting, which is a destructive test method that measures the residual stress on the surface of a specimen after it has been cut. This method provides information of the residual stresses on the whole surface.

In addition, further ultrasonic testing was being performed on the as-welded specimens. These results could be used to calibrate the method.

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Appendices

*A. **Manufacturing and welding process, characterization of the Steel S420G2+M - Prior to fabrication***

*B. **Manufacturing and welding process, characterization of the Steel S420G2+M - Material Selection and Cutting Process***

*C. **Manufacturing and welding process, characterization of the Steel S420G2+M - Welding Procedure Qualification Program***

*D. **Manufacturing and welding process, characterization of the Steel S420G2+M - Production Welding of Plates***

*E. **Manufacturing and welding process, characterization of the Steel S420G2+M - NDT, Mechanical Testing and Specimen Preparation***

*F. **Microstructural Examination***

*G. **Fatigue Testing***

*H. **Residual Stress Measurement***

Instruction

The project Weld proximity INVES. has undergone different stages, which in this document are shown in one hundred series. The different steps are represented by letters and can be seen in the Inspection and Test Plan. The documents are grouped under the stage in which they were produced.

Stage (Appx.)	Series	
A	100-199:	Experimental investigation: Manufacturing and welding processes - Prior to fabrication
B	200-299:	Experimental investigation: Manufacturing and welding processes - Material Selection and Cutting Process
C	300-399:	Experimental investigation: Manufacturing and welding processes - Welding Procedure Qualification Program
D	400-499:	Experimental investigation: Manufacturing and welding processes - Production Welding of Plates
E	500-599:	Experimental investigation: Manufacturing and welding processes - NDT, Mechanical Testing and Specimen Preparation
F	600-699:	Experimental investigation: Microstructural Examination
G	700-799:	Experimental investigation: Fatigue Testing
H	800-899:	Experimental investigation: Residual Stress Measurements

Document No.	Title
Doc-A101	Inspection and Test Plan for Master Thesis-Weld Proximity Investigation
Doc-A102	MDS Base material - S355J2+M
Doc-A103	MDS Filler metal - OERLIKON SPEZIAL
Doc-B201	Mill test report - Base Material S420G2+m - HT43831-9133182
Doc-B202	Certified Material Test Report - Filler material NSSW SM-47-A Manuf.No. 7U341AW996 MIT 9118
Doc-B203	Certified Material Test Report - Filler material NSSW SF-3AM Manuf.No. 7S041MP960 MIT 9188
Doc-B204	Certified Material Test Report - Filler material NSSW SF-3AM Manuf.No. 8X221MP996 MIT 9588
Doc-C301	WPQR: S420PL1-M and including documents:
	- WPQ S420PL1-M
	- Summary
	- pWPS S420PL1-M
	- Weld log - pWPS:S420PL1-M
	- Report7967-19-DRT-1
	- Mill test report - Materialcertifikat S420G2+M - HT43831-9133182
	- Mill test report - Filler material: NSSW SM-47-A Manuf.No. 7U341AW996 MIT 9118
	- Mill test report - Filler material: NSSW SF-3AM Manuf.No. 7S041MP960 MIT 9188
	- Mill test report - Filler material: NSSW SF-3AM Manuf.No. 8X221MP996 MIT 9588
Doc-C302	All WPS's:
	- WPS PL1-SW
	- WPS: PL3/4-DW50-Rep
	- WPS: PL5/6-DW15-Rep
	- WPS: PL7/8-DW5-Rep
Doc-D401	All Weld log's for Weld A:
	- Weld log: PL3-DW50
	- Weld log: PL4-DW50
	- Weld log: PL5-DW15
	- Weld log: PL6-DW15
	- Weld log: PL7-DW5
	- Weld log: PL3-DW5
Doc-D402	All Weld log's for repair Weld B:
	- Weld log: PL3-DW50-Rep
	- Weld log: PL4-DW50-Rep
	- Weld log: PL5-DW15-Rep
	- Weld log: PL6-DW15-Rep
	- Weld log: PL7-DW5-Rep
	- Weld log: PL3-DW5-Rep
Doc-E501	NDT report - Radiograpic Examination
	- Report8076-19-DRT-1
	- Report8076-19-DRT-2-REV1
	- Report8076-19-DRT-3-REV1
	- Report8076-19-DRT-5
	- Report8076-19-DRT-6
	- Report8076-19-DRT-7
Doc-E502	Qlabs Material Report 8612-2 (PL 3)
Doc-E503	Qlabs Material Report 8612-3 (PL 5)
Doc-E504	Qlabs Material Report 8612-4 (PL7)
Doc-F600	The chapter "Microstructural Examination" has no attachments.
Doc-G701	Fatigue test - Prior to fabrication specimens
Doc-G702	Fatigue test - Unwelded base metal specimens
Doc-G703	Fatigue test - Production test plate specimens
Doc-H800	The chapter "Residual Stress Measurements" has no attachments.

Appendix A

Manufacturing and welding process, characterization of the Steel S420G2+M

- Prior to fabrication

- Doc A101 - Inspection and Test Plan for Master Thesis - Weld Proximity Investigation
- Doc A102 - MDS Base material - S355J2+M
- Doc A103 - MDS Filler metal - OERLIKON SPEZIAL

- Doc A101 - Inspection and Test Plan for Master Thesis - Weld Proximity Investigation

Inspection and Test Plan for Master Thesis - Weld Proximity Investigation

Doc No: A101
ITP No: ITP-W&W-002
Issue Date: 01.02.2019
Revision no: Rev 4
Rev date: 09.05.2019

Legend: D=Docment Review, M=Monitor, W=Witness Point, H=Hold Point, Dwg=Drawing, pWPS=preliminary Welding Procedure Specification, WPS=Welding Procedure Specification, BOM=Bill of Material, M&M=Magnus&Mattias, DT=Destructive Testing, NDT=Non Destructive Testing, MPI=Magnetic Particle Testing,
WPQR=Welding Procedure Qualification Records, SJA=Sikker jobb analyse, UIS=Univeristy of Stavanger, IWE=International welding engineer, UIS= University Of Stavanger, AFC=Approved for construction
People and purpose involved in the project: Mattias Larsson (Master Student UIS), Magnus Larsson (Master Student UIS), Dr Ratnayake, R.M. Chandima (Prof. UIS), Arild Finnesand (IWE KIWA), Petter Lunde (Daily leader Q-lab, metalurg), Emil Surnevik (Senior Engineer), Jørgen Grønsund (Senior Engineer), Dr Xavier Ficquet (CEng MIMechE)

STAGE	Ref.	Activity Description	Specification / Procedure / Drawing	Acceptance Criteria	Verifying Document	Responsible	M&M Sign.	Comments / Notes	Involvement							
									Prof. C.R		M&M		KIWA		Qlab	
									A	Sign	A	Sign	A	Sign	A	Sign
A. Prior to fabrication	1.1	Pre Inspection meeting for weld on weld project	Meeting agenda	Schedule	Minutes of meeting	Magnus		Carried out before the project begins. The scope of the project is defined.	H		H					
	1.2	Perform a test welding on proximity welds. Welding of two adjacent welds will be performed at Vest Norway Doors AS.			Pictures			The goal of this activity is to gain some understanding of the task and its limitations before making the I&TP and contact partners. After welding carried out the plate is transported to UIS.	D		H					
	1.3	Transport plate to UIS				Magnus					H					
	1.4	Try to machine specimens to see if it is possible to implement this on UIS.			Pictures	Magnus and Emil		Different methods for obtaining a good surface finish should be tested. After machining and surface preparation, some specimens are prepared which can be tested later in the project.	D		H					
	1.5	Find partners for the project.				M&M		Collaboration partners and expertise: KIWA - Welding, interpretation of standards and production of WPQ. Q-lab - Mechanical testing, interpretation of microstructures and qualification of WPQ. VEQTER-Interpretation of residual stresses and fatigue testing.	D		H		H		H	
	1.6	Make an Inspection and Test Plan.		M&M:s approval	Test and Inspection Plan for project Weld Proximity Investigation	Magnus		The document should describe the project's progress and act as a quality-assuring document.	D		H		D		D	
	1.7	Verify and approve documents to be used in the project.		M&M:s approval	Document list	Mattias		Document list gives an overview of all the documents produced relating to the project			H		D		D	
	1.8	Produce SJA och meldeskjema			SJA / Meldeskjema.	Magnus		The SJA document should be used for tasks that are considered critical. The meldeskjema should be used for unwanted events in the UIS workshop.			H					
	1.9	Produce a method for carrying out welding procedure test and production test.			Figures: Production flow of test plate for welding procedure test / Production flow of test plates for production test	M&M, KIWA and Q-lab.		These two figures show roughly the various steps for producing the WPQ and the production plates.			H		H		D	
	1.10	Prepare drawings and illustrations for how the steel plates should be cut, fixed, prepared and named before welding.			Naming and marking system / Installation of strongbacks / Drawings - Joint Preparation 1 / Drawings - Joint preparation 2	M&M, KIWA and Q-lab		Design documentation must have AFC status before the project begins.			H		D		D	
	1.11	Produce test plans for WPQ qualification plate and production plates.	NS-EN ISO 15614-1:2017 Level 2 / ASTM E466-15 / ASTM E468-11	NS-EN ISO 15614-1:2017 Level 2 / ASTM E466-15	Welding procedure and production sample testing	M&M and KIWA		Three versions of test plans will be produced. The first must comply with NS-EN ISO 15614: 2017 to qualify as a WPQ. The other two will be based on this standard but adapted for fatigue and ultrasonic testing.			H		H		D	
B. Material Selection and Cutting Process	2.1	Approval and ordering of materials.	Supplier procedure	NS-EN 10225:2009	Receipt / BOM	Magnus		Steel is delivered to Smedtkristansen and welding filler metal to KIWA.	D		H		D			
	2.2	Plan for how materials should be handled and stored.		Mill test reports	Material handling	Magnus and IWE Arild		Steel must be stored indoors by KIWA and filler material must be stored according to the material handling document.			H		H			
	2.3	Check incoming material. Material identification includes visual inspection, type of material & traceability dimensional check.	Supplier procedure	NS-EN 10225:2009	BOM / Mill test reports / Drawing / Pictures	Manus & IWE Arild		Both the parent and filler material must be checked. Parent metal: S420G2+M; Filler metal: NSSW SM-47A and NSSW SF-3AM. Verify that materials comply to PO / BOM upon receipt. Filler material must be handled according to doc-material handling.			H		H			
	2.4	Cut out plates and prepare joints with Water-jet cutting.	Drawing - Joint preparation 1	Drawing - Joint preparation 1	Pictures	Magnus		Conducted at SmedtKristiansen. Method to check the result is through visual check and control measurement.			W					
	2.5	Transport plates to KIWA.				Magnus		Plates should be stored indoors.			H					
C. Welding Procedure Qualification Program	3.1	Create pWPS	pWPS NST		pWPS: S420PL1-M	M&M		pWPS was produced together with KIWA and NST.	D		H		H			
	3.2	Create and prepare the weld log sheet.			Weld log - pWPS:S420PL1-M	IWE Arild & Magnus		The same log template to be used for all welding.			H		H			
	3.3	Check and calibrate equipment to be used for welding and logging.	pWPS: S420PL1-M	pWPS: S420PL1-M	Pictures	IWE Arild Finnesand		Equipment used for logging and welding is arranged by KIWA. The welding machine is a Fronius-TransSteel 2700.			W		H			
	3.4	Perform joint preparation, fit-up & alignment of qualification test plate.	Drawing - Joint preparation 1 / Installation of strongbacks / pWPS: S420PL1-M	Drawing - Joint preparation 1 / pWPS: S420PL1-M	Pictures	Welder and Magnus		Fit-up of plates must be approved by Mattias before welding can start.			W		H			
	3.5	Welding & Logging of WPS qualifying plate	pWPS: S420PL1-M	pWPS: S420PL1-M	Weld log - pWPS:S420PL1-M / Pictures	Welder and Mattias		All deviations must be reported. Deviations can be cracks in the strongback welds, unexpected deformation, all weld parameters that deviate from pWPS, etc.	D		H		H			
	3.6	Name and mark the plate according to instructions.	Naming and marking system		Pictures	Magnus		If marking disappears during welding, marking should be done again.			H		W			
	3.7	Perform visual testing	ISO 17637:2016	EN ISO 5817:2014 B/C	WPQR: S420PL1-M	IWE Arild Finnesand		Visual check is made by IWE Arild Finnesand at KIWA. If the plate is approved visually, it is transported to IKM Inspection for X-Ray testing.	D		W		H			
	3.8	Plates are transported to IKM inspection for X-ray inspection.				Magnus					H					
	3.9	Perform X-ray testing	ISO 17636-2:2013	ISO 10675-1:2016	WPQR: S420PL1-M	IKM Inspections AS		After an approved test, IKM Inspection will deliver an inspection report that will be a basis for the WPQR. If the test is approved, the qualification plate is transported to Q-Lab.			D					
	3.10	The plates are transported to Q-lab for mechanical testing.				Magnus					H					
	3.11	Perform the Surface Crack Detection Test (Magnetic particle inspection)	NS-EN ISO 17638:2016, NS-EN ISO 3452-1:2013	ISO 23278:2015 Level B	WPQR: S420PL1-M	Q-Lab					W				H	
	3.12	Specimens preperation				Q-lab		Complete the test samples for all mechanical tests .			W				H	
	3.13	Perform Vickers Hardness test	NS-EN ISO 9015:2011	15614-1:2017	WPQR: S420PL1-M	Q-lab					W				H	
	3.14	Perform Transverse Tensile Test	ISO 4136:2012, ISO 6892-1:2016 Method A1	15614-1, Mill test report	WPQR: S420PL1-M	Q-lab					W				H	
	3.15	Macroscopic testing	ISO 17639:2013	EN ISO 5817:2014	WPQR: S420PL1-M	Q-lab					W				H	
	3.16	Perform Charpy V Impact test, KV8	NS-EN ISO 148-1:2016, ISO 9016:2012	15614-1, Mill test report	WPQR: S420PL1-M	Q-lab					W				H	
	3.17	If all tests are approved, Qlab writes a material report that verifies that all mechanical tests have been approved.	NS-EN ISO 15614-1.2017 Level 2	NS-EN ISO 15614-1.2017 Level 2	Material report: 8612-1			This report will be the basis of the WPQR-S420PL1-M.	D		D		D		H	
	3.18	Compile all documentation that has been produced in the Welding Procedure Qualification Program and material data and manufacture a WPQ and WPQR.	NS-EN ISO 15614-1.2017 Level 2	NS-EN ISO 15614-1.2017 Level 2	WPQR: S420PL1-M	Magnus och Arild			D		H		H		D	
	3.19	Produce welding procedures for production welding stage	NS-EN ISO 15614-1.2017 Level 2	NS-EN ISO 15614-1.2017 Level 2	WPS / WPS-Rep			Produces 12 WPS for plate 3-8. Six WPSs for the first weld, weld A, and six Repair-WPSs for the second weld, weld B.	H		H		H		H	
D. Production welding of plates	4.1	Check and calibrate equipment to be used for welding and logging.	WPS	WPS	Pictures	IWE Arild Finnesand		Equipment used for logging and welding is arranged by KIWA. The welding machine is a Fronius-TransSteel 2700.			W		H			
	4.2	Perform joint preparation, fit-up & alignment of production test plates for the first weld, weld A.	Drawing - Joint preparation 1 / Installation of strongbacks / WPS /	Drawing - Joint preparation 1 / WPS	Pictures	Welder and Magnus		The plates were pre-cut in Stage B and transported to KIWA. Fit-up of plates must be approved by master student Mattias before welding can start.			W		H			
	4.3	Perform production welding and logging on the first weld, weld A.	WPS	WPS	Weld logg / Pictures	Welder and Mattias		All deviations must be reported. Deviations can be if welds for strongback cracks, unexpected deformation, all welds that deviate from wps, etc.			H		H			
	4.4	Name and mark the plate according to instructions.	Naming and marking system		Pictures	Magnus		If marking disappears during welding, marking should be done again.			H					
	4.5	Perform visual inspection.	ISO 17637:2016	EN ISO 5817:2014 B/C	Test report	IWE Arild Finnesand		If visual inspection is approved, the plates are forwarded for cutting.			W		H			
	4.6	Transport plates to Watech for water jet cutting of joint 2, weld B.				Mattias					H					
	4.7	Water jet cut weld joint B at Watech.	Drawing - Joint preparation 2	WPS-Rep	Pictures	Watech		Cut a new parallel joint next to the first weld, weld A. Method to check the result is through visual check and control measurement.			W					
	4.8	Transport back plates to KIWA for welding welding joint 2, weld B.				Mattias					H					
	4.9	Check and calibrate equipment to be used for welding and logging.	WPS-Rep	WPS-Rep	Pictures	IWE Arild Finnesand		Equipment used for logging and welding is arranged by KIWA. The welding machine is a Fronius-TransSteel 2700.			W		H			
	4.10	Perform joint preparation, fit-up & alignment of production test plates for the second weld, weld B.	Drawing - Joint preparation 2 / Installation of strongbacks / WPS-Rep	Drawing - Joint preparation 2 / WPS-Rep	Pictures	Welder and Magnus		Fit-up of plates must be approved by Mattias before welding can start.			W		H			
	4.11	Perform production welding and logging on the second weld, weld B.	WPS-Rep	WPS-Rep	Weld logg	Welder and Mattias		All deviations must be reported. Deviations can be cracks in the strongback welds, unexpected deformation, all weld parameters that deviate from pWPS, etc.			H		H			
	4.12	Final visual inspection of welds, marking, compilation of data and preparation of plates before being sent off for testing.	ISO 17637:2016	WPS / WPS-Rep / EN ISO 5817:2014 B/C	Test report			Conducted on KIWA . Interest is, among other things, to see how the plates have deformed because of the heat, polish the welds, mark the plates.	D		H		H			
	5.1	Plates are transported to "IKM Inspection" for Non Destructive Testing.				IKM Inspections AS		IKM Inspection AS picks up the plates at KIWA.			W					

E. NDT, Mechanical Testing and Specimen Preparation	5.2	Perform X-ray testing	ISO 17636-2:2013	ISO 10675-1:2016	NDT report, pictures			Conducted on IKM Testing	D		D		D		D	
	5.3	Plates are transported to Q-lab for mechanical testing.				Magnus and Mattias					H					
	5.4	Perform the Surface Crack Detection Test (Magnetic particle inspection)	NS-EN ISO 17638:2016 / NS-EN ISO 3452-1:2013	ISO 23278:2015 Level B	WPQR: S420PL1-M	Q-lab		Conducted on Q-lab			W		D		H	
	5.5	Specimens preperation for mechanical testing.	NS-EN ISO 15614-1.2017 Level 2	NS-EN ISO 15614-1.2017 Level 2		Q-lab		Completes the test samples for all mechanical tests.			W		D		H	
	5.6	Perform Vickers Hardness test	NS-EN ISO 9015:2011	NS-EN ISO 15614-1.2017 Level 2	Qlab Material report	Q-lab					W		D		H	
	5.7	Perform Transverse Tensile Test	Specimens preparation - Tensile test / ISO 4136:2012 /	15614-1 / Mill test report	Qlab Material report						W		D		H	
	5.8	Macroscopic testing	ISO 17639:2013	EN ISO 5817:2014	Qlab Material report	Q-lab		The hardness samples from Qlab are analyzed.			W		D		H	
	5.9	Perform Charpy V Impact test, KV8	NS-EN ISO 148-1:2016 / ISO 9016:2012	NS-EN ISO 15614-1:2017 / Mill test report	Qlab Material report	Q-lab					W		D		H	
	5.10	Qlab produces material report for sheet PL3, PL5 and PL7.	Welding procedure and production sample testing	NS-EN ISO 15614-1.2017 Level 2	Material report: 8612-2, 8612-3 and 8612-4.	Q-lab			D		H		D		H	
	5.11	Specimens preperation for fatigue testing.	Specimens preparation - Fatigue testing / ASTM E466-15	ASTM E466-15	Pictures	Q-lab					H				H	
	5.12	Transport the proximity weld fatigue specimens from Q-lab to UIS. All tested and untested material shall also be sent to UIS.				Magnus		A total of 5 specimens. 2pcs of 50mm between the welds, 2pcs of 15mm between the welds and 1st of 5mm between the welds.			H					
	5.13	Transport all material stored at KIWA to UIS.				Magnus		All material stored at KIWA is transporteted to UIS, this includes unwelded plate PL2, PL9 and PL10 and welded plates PL4, PL6 and PL8.			H					
F. Microscopic Investigation	6.1	Preparation and interpretation of microstructure. The macros we received from Q-lab are embedded in Epoxy in a silicone form.				M&M		It is one macros from the start and one from the stop of each plate. Q-lab had 4 plates which gives 8 pieces of macros.			H					
	6.2	Analysis of microstructure	ISO 17639:2003		Report - Macroscopic and microscopic examinations of welds	Mattias		The equipment used for this study is an Inverted Metallurgical Microscope GX53			H				D	
F. Fatigue Test Investigation	7.1	Machine the sides of the weld poximity fatigue specimens. Machine five fatigue specimens from plates without welding.	Doc - Fatigue test 2 / Doc - Fatigue test 3 / ASTM E466-15 / ASTM E468-11	ASTM E466-15	Pictures	Emil (UIS) and Magnus		The maching should be done according to ASTM E466-15 Appendix X1, step X1.2.1.			H					
	7.2	Transports all fatigue specimens to CASTOLIN TRIO AS for precision grinding.				Magnus		Five weld proximity fatigue specimens and five base material fatigue specimens.			H					
	7.3	CASTOLIN TRIO AS performs precision grinding with a Surface grinding machine.	Doc - Fatigue test 2 / Doc - Fatigue test 3 / ASTM E466-15 / ASTM E468-11	ASME E466-15	Pictures	CASTOLIN TRIO		The maching should be done according to ASTM E466-15 Appendix X1. This step goes under X1.2.2. Ten specimens receive precision grinding. Five welded specimens and five from base material.			W					
	7.4	Transports fatigue specimens from CASTOLIN TRIO AS to UIS for final surface treatment.				Magnus					H					
	7.5	Last surface treatment of fatigue specimens is carried out at the lab at UIS.	Doc - Fatigue test 2 / Doc - Fatigue test 3 / ASTM E466-15 / ASTM E468-11	ASME E466-15	Visual inspection log / Picture / Roughness check	Magnus		Last surface treatment is carried out at the lab at UIS. This includes step X1.2.2-X.1.2.4 in ASTM 466-15, roughness check were maximum surface roughness is .2um in the longitudinal direction and a final visual check with magnifying glass. Test is lubricated in rust protection while waiting for test.			H					
	7.6	Perform fatigue testing	Doc -Fatigue test 1 / Doc-Fatigue test 2 / Doc- Fatigue test 3	DNVGL-RP-C203 / ASME E466-15 / ASTM E468-11	Fatigue test log	Magnus och Jörgen		Conducted at the University of Stavanger. There are three different tests to be carried out. These are: Doc-Fatigue test 1 (the specimens we produced in Stage 1-Prior to fabrication), Doc-Fatigue test 2 (base material) and Doc-Fatigue test 3 (weld proximity investigation test).			H					
F. Residual stress test investigation	8.1	From plate PL4, PL6 and PL8 two pieces were cut out per plate. These should be prepared and sent to the VEQTER - Residual Stress Specialist.	Doc - Ultrasonic measurement test		Picture	Magnus and Xavier (VEQTER)		Two different types of samples are produced for each plate. The first is cut-out part where only the weld is sanded down with flap disc, the other is a fatigue specimen. The goal of the test is to see how much residual stress we have between the welds and how much residual stress is lost when we perform machining of fatigue specimens.			H					
	8.2	Preparation of Specimen 1 - Fatigue specimen for Ultrasonic measurement test.	Doc-Ultrasonic Measurement Test / ASTM E466-15 / ASTM E468-11	ASME E466-15	Picture	Magnus		This is prepared according to ASTM E466-15. Unlike previous fatigue specimens, precision grinding will be performed on the UIS. Step 2-X1.2.2 will be performed with cylindrical grinding (Surfaces Grinding Machine).			H					
	8.3	Preparation of Specimen 2 - Residual stress specimens for Ultrasonic measurement test.	Doc-Ultrasonic Measurement Test		Picture	Magnus		Weld end machined flush with the plate edges (flap disc).			H					
	8.4	Six specimens are sent with DHL to VEQTER in UK for analysis of residual stresses between welds.			Pictues	Magnus		The plates from which the samples are taken are PL4, PL6 and PL8. There are two samples per plate.			H					
	8.5	VEQTER conducts Residual Stress Analysis.			Residual Stress Report	VEQTER		The method used to measure residual stress is the Ultrasonic Measurement Test.			D					
	8.6	Specimens are sent back to UIS (Stavanger) from the UK with DHL.				VEQTER		Specimens should be handled with care when surface preparation can be								
	8.7	Fatigue tests are performed on the 3 specimens that have been tested for residual stresses.	Doc-Ultrasonic Measurement Test	DNVGL-RP-C203 / ASME E466-15 / ASTM E468-11		Magnus		Before testing is carried out, the specimens must be inspected visually and in case of defects, surface preperation is done before testing.			H					

- Doc A102 - MDS Base material - S355J2+M

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A02
INSPECTION CERTIFICATE "3.1" EN 10204:2004

Z02
Ostrava,24.04.2017

A03 Document No.
1000635839

ArcelorMittal

A07	Purchaser's Order No. and/or Item No.
	46113771-3040

A08	Manufacturer's Job No.	A10 Delivery Advise No. 8100867220/ 000030 14/17/015536	A06 Customer/consignee **TIBNOR AS PROF. BIRKELANDS VEI 21 1081 OSLO Norway**
	1421 65638 0 7		
A09	Supplier's Order No.		
	3100299188/30		

Product, Dimensions, Steel designation, Condition, Terms of Delivery, Any supplementary requirements:

B01,B02,B03,B04,B05,B09
FLAT BARS P-150X10 acc.to EN 10058:2003 Length 6100 mm + 100 /- 0 S355J2+M ACCORDING TO EN 10025-2/2004 WITH INDICATION14TH ANALYSIS

B13	Actual weight	4.620,000 KG

C71 Chemical Analysis of Liquid Alloy (%)

B07 Heat No.	Test type	C70	C [%]	MN [%]	SI [%]	P [%]	S [%]	N [%]	CU [%]	NI [%]	CR [%]	MO [%]	V [%]	AL [%]	B [%]	TI [%]	NB [%]	B08	
			>0 <0.2	>0 <1.6	>0,14 <0,25		>0 <0.025		>0 <0.55									Pieces	Bunches
86336Y	H	0	0.15	1.29	0.190	0.026	0.012	0.005	0.04	0.02	0.07	0.01	0.05	0.003	0.0004	< 0.001	< 0.001	64	2

B07 Heat No.	Test type	C70	AS [%]	SN [%]	CA [%]	CEV [%]
86336Y	H	0	0.002	0.002	0.0010	0.39

1 Continuation see Attachment

5 Test results			2 Tensile test acc.to EN ISO 6892-1:2009			4 Charpy impact test acc.to EN ISO 148-1:2010				
Heat No.	C00 Specimen No.	C02	C11 Yield or proof limit	C12 Tensile strength	C13 Elongation on A5	C03 Test temperature (°C)	C40 KV2 C41 7.50			
					A5	°C	C04 min	C04 max	J (J/cm2)	
	C04 Regulation		>355	>470 <630	22.0	-20.00	21.00			
							C43	C42		
86336Y	20423404	0	414	541	30.8					
86336Y	20423407	0				-20.00	118	132	104	118

1 Continuation see Attachment

6 Bend test according to EN ISO 7438:2005

C52	Bend Test
C53	Rebend test

Environmental product declaration: EPD-BFS-20130094-IBG1-EN

Designed for the following application
Civil and machine engineering
Intended to be used in welded, bolted and riveted structures
Weldability:
Guaranteed through karbon equivalent(Cev)
Performance expressed as indicated in the Declaration of Performance
Dangerous substance: No performance determined

1020
06
DoP No. AMOS-2/09-CPR-13-1

EN 10025-1

C93 The mass activity ionizing radiation value in liquid alloy analysis does not exceed 100 Bq/kg. B06, Z04

Z01 The Manufacturer confirms that such Product is in duly compliance with Order's requirements, the Purchase Contract's requirements and that it has been tested in duly compliance with technical requirements

D01 The inspection and the test were caried out on the delivered product or on a product test unit.

Z02, Z03,A05

ArcelorMittal
ArcelorMittal Ostrava a.s.
Vratimovská 689, 707 02 Ostrava-Kunčice
IČ: 45193258
Issuer of inspection document
/ 017

WORKS INSPEKTOR
IDENTIFICATION No. 14
Zdeněk Podešva
PHONE: +420 595682303

replaces seal and signature
Issued by: Sylvie Tkáčová

- Doc A103 - MDS Filler metal - OERLIKON SPEZIAL

OERLIKON

MMA Electrodes
C-Mn and low-alloy steels

SPEZIAL

SPEZIAL is a basic, double-coated multi-purpose MMA electrode. The composition of the double coating confers exceptionally good welding characteristics and a highly stable and directional arc. Very good gap bridging and ideally suited for root passes and positional welding. The glassy slag is easily removed from the finely-rippled weld seams, the excellent welding characteristics and ISO-V toughness to -30°C.
Structural steelwork, production and assembly jobs in industry and for pipeline construction for decades. Very good gap bridging and ideally suited for root passes. Material to be welded S(P)235; S(P)355; GP 240; GP 280; L 245; L260.
ISO-V toughness at -30°C. Deposit free from porosity and good of X-ray quality. Optimum AC weldability requires an OCV > 65V. Very good gap bridging and ideally suited for root passes and positional welding.The glassy slag is easily removed from the finely-rippled.

Classification	
EN ISO	2560-A: E 38 3 B 12 H10
AWS	A5.1: E 7016-H8

Approvals	Grade
ABS	3YH10
BV	3YH10
DB	●
DNV	3Y40H10

Approvals	Grade
GL	3YH10
LRS	3YmH15
RMRS	3YHH
TÜV	●

CE

Chemical analysis (Typical values in %)

C	Mn	Si	P	S
0.06	0.9	0.7	≤ 0.020	≤ 0.015

All-weld metal Mechanical Properties

Heat Treatment	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation A5 (%)	Impact Energy ISO - V (J)	
				+20 °C	-30 °C
As Welded	≥ 380	470-600	≥ 25	≥ 150	≥ 60

Materials

S(P)235-S(P)355; GP240-GP280; L245-L360

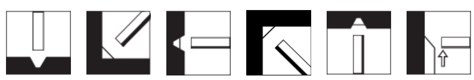
Storage

Keep dry and avoid condensation.

HD ≤ 10: Re-dry at 300-350°C for 2 hours, 5 times max.

Current condition and welding position

AC; DC+



PA PB PC PD PE PF

Packaging data

Diam. (mm)	Length (mm)	Current (A)	Approx. weightn(kg/1000)	CBOX		VPMD	
				PC	Code	PC	Code
2.0	350	55-65	12.73	330	W000287401	160	W000287407
2.5	350	55-95	19.50	200	W000287402	100	W000287408
3.2	350	80-150	32.73	125	W000287403	55	W000287409
3.2	450	95-150	41.82	125	W000287404	55	W000287410
4.0	450	120-190	65.00	80	W000287405	40	W000287411
5.0	450	190-250	100.45	50	W000287406		

Appendix B

Manufacturing and welding process, characterization of the Steel S420G2+M

- Material Selection and Cutting Process

- Doc B201 - Mill test report - Base Material S420G2+m - HT43831-9133182
- Doc B202 - Certified Material Test Report - Filler material NSSW SM-47-A
- Doc B203 - Certified Material Test Report - Filler material NSSW SF-3AM
- Doc B204 - Certified Material Test Report - Filler material NSSW SF-3AM

- Doc B201 - Mill test report - Base Material S420G2+m - HT43831-9133182

CO #	Item #	Del #	Heat	Lot	Your art #	Qty	Description
201904011/SWK	100	RP5367 20	43831-9133182			1	HR PL S420G2+M/Q-Y30 15X2500X12000 MM

NORSK STÅL

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 1/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02-B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Marking of the product (B06)
Trademark/Steelgrade/Heat-No/Product-No/
inspector's stamp

Material data (B01-B99)

Item	Quantity (B08)	Product No. (B07)	Heat No. (B07)	Cond. of delivery (B04)	Thickness x Width x Length (B09-B11) mm x mm x mm
02	1	913317 1	43831	TM	15,00 x 2500,0 x 12000
02	1	913317 2	43831	TM	15,00 x 2500,0 x 12000
02	1	913318 1	43831	TM	15,00 x 2500,0 x 12000
02	1	913318 2	43831	TM	15,00 x 2500,0 x 12000
Σ	4	Weight (B12) 14.132 kgs		TM : thermomechanically rolled	

100

Dimensional check and visual examination of the surface condition:
without objection

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT - 1864 DNV·GL

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 2/5
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NORWEGEN

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NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Ladle analysis (C70–C99)

Manufacturer standard

Heat No. (B07)	C % ≤ 0,14	Si % 0,15 – 0,55	Mn % ≤ 1,65	P % ≤ 0,020	S % ≤ 0,005	N % ≤ 0,010	Al % 0,015–0,055	Cu % ≤ 0,30	Cr % ≤ 0,25	Ni % ≤ 0,70
43831	0,10	0,28	1,49	0,011	0,002	0,005	0,041	0,02	0,05	0,04
Heat No. (B07)	V % ≤ 0,080	Ti % ≤ 0,025	Nb % ≤ 0,040	B % ≤ 0,0005	Mo % ≤ 0,25	As % ≤ 0,030	Sn % ≤ 0,020	Pb % ≤ 0,010	Ca % ≤ 0,005	EV1 1) % ≤ 0,22
43831	0,003	0,002	0,026	0,0001	0,002	0,002	0,005	0,001	0,002	0,19
Heat No. (B07)	Sb % ≤ 0,010	EV2 2) % ≤ 0,42	Bi % ≤ 0,010	EV3 3) % ≤ 0,11	EV4 4) % ≤ 0,90	Nb+V % ≤ 0,09				
43831	0,000	0,36	0,001	0,03	0,11	0,03				

1) EV1 : PCM=C+Mn/20+Mo/15+Ni/60+Cr/20+V/10+Cu/20+Si/30+5xB
2) EV2 : CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15
3) EV3 : V+Nb+Ti
4) EV4 : Cr+Cu+Mo+Ni

Steel making: Basic oxygen process
(C70)

vacuum degassed

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT 1864 DNV·GL

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 3/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Check analysis (C70–C99)

Specimen No. (C00)	Heat No. (B07)	C % ≤ 0,14	Si % 0,15 – 0,55	Mn % ≤ 1,65	P % ≤ 0,020	S % ≤ 0,005	N % ≤ 0,010	Al % 0,015–0,055	Cu % ≤ 0,30
913146 *)	43831	0,11	0,28	1,46	0,007	0,003	0,004	0,042	0,02
913146 *)	43831	0,10	0,27	1,49	0,014	0,000	0,006	0,050	0,02
Specimen No. (C00)	**Heat No. (B07)**	**Cr % ≤ 0,25**	**Ni % ≤ 0,70**	**V % ≤ 0,080**	**Ti % ≤ 0,025**	**Nb % ≤ 0,040**	**Mo % ≤ 0,25**	**B % ≤ 0,0005**	**EV1 1) % ≤ 0,22**
913146 *)	43831	0,05	0,05	0,002	0,001	0,029	0,002	0,0000	0,20
913146 *)	43831	0,05	0,03	0,005	0,002	0,025	0,00	0,0005	0,19
Specimen No. (C00)	**Heat No. (B07)**	**EV2 2) % ≤ 0,42**	**EV3 3) % ≤ 0,90**	**EV4 4) % ≤ 0,11**	**Nb+V % ≤ 0,09**				
913146 *)	43831	0,37	0,12	0,03	0,03				
913146 *)	43831	0,36	0,10	0,03	0,03				

1) EV1 : PCM=C+Mn/20+Mo/15+Ni/60+Cr/20+V/10+Cu/20+Si/30+5xB
2) EV2 : CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15
3) EV3 : Cr+Cu+Mo+Ni
4) EV4 : V+Nb+Ti
*) The sample product is not part of the delivery

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

18 64 DNV·GL SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 4/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Tensile test (C10–C29)

Specimen No. (C00)	Heat No. (B07)	Location (C01) 1) 2) 3)	Direct. (C02) 4)	Cond. (B05) 5)	Type (C10) 6)	Yield point (C11) ReH N/mm2 420 – 540	Tensile strength (C12) Rm N/mm2 500 – 660	ReH/Rm ≤ 0,93	Elongation (C13) A5 7) % ≥ 19	
913318	43831	K4G	Q	TM	P	489	557	0,88	31	

1) K : Top
2) 4 : 1/4 Width
3) G : Thickness of product
4) Q : transversal
5) TM : thermomechanically rolled
6) P : prismatic
7) A5 : Lo=5,65 √So

Impact test (C40–C49)

Specimen No. (C00)	Heat No. (B07)	Location (C01) 1) 2) 3)	Direct. (C02) 4)	Cond. (B05) 5)	Type of specimen (C40–C41)	Temperature (C03) °C	Impact energy (C42–C43) 1 J ≥ 42	2	3	MW 6) J ≥ 60
913318	43831	K4O	Q	TM	KV450	-040	118	111	114	114

1) K : Top
2) 4 : 1/4 Width
3) O : near surface
4) Q : transversal
5) TM : thermomechanically rolled
6) MW : Average

All plates have been ultrasonically tested according to EN 10160 07/99
in area and edges
Class of areatesting: S1
Class of edgestesting: E2
Results: No faults were found.

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT · 18 64 · DNV·GL

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 5/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Our products are free of radioactive substances and do not exceed the clearing limit value of 100 Bq/kg, which guarantees the compliance with limit values given in the Radiation Protection Ordinance(StrlSchV) for the unrestricted clearance of solid material (StrlSchV Annex III, Section 5) for ferrous nuclides.

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

- Doc B202 - Certified Material Test Report - Filler material NSSW SM-47-A

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N06547	Purchaser's Spec. No. : NSTN-13 Rev.0
Date of issue : June 29, 2017	Material Classification
Purchaser : Norsk Sveiseteknikk AS	EN ISO 17632-A-T 46 6 1Ni M M 1 H5
Trade Designation : NSSW SM-47A	AWS A5.36 E80T15-M21A8-Ni1-H4

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SM-47A	1.2 mm	7U341AW996	7V311	June 12, 2017

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	30	30	25	140	135 ～ 163
Spec.	270 ± 10	30 ± 2	30 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	527	617	28
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-60	93, 104, 115	104
Spec.			32 Min.	47 Min.
Spec.				

Chemical composition (%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	
	0.07	0.59	1.26	0.009	0.008	0.25	1.02	0.02	0.01	0.01	0.01	
Spec.	0.04/ 0.10	0.40/ 0.80	1.1/ 1.4/	0.020 Max.	0.020 Max.	0.3 Max.	0.80/ 1.10	0.15 Max.	0.15 Max.	0.05 Max.	0.05 Max.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.0, 1.7, 1.0	1.2	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-13 Rev.0

No. 170639HFH (MIT 9118)

Net Weight
7U341AW996 : 17,880.0 kg

Certified by ISAO KANAUCHI
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

- Doc B203 - Certified Material Test Report - Filler material NSSW SF-3AM

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N06726	Purchaser's Spec. No. : NSTN-03 Rev.3
Date of issue : September 6, 2017	Material Classification
Purchaser : Norsk Sveiseteknikk AS	EN ISO 17632-A-T 46 4 Z P M 2 H5
Trade Designation : NSSW SF-3AM	EN ISO 17632-A-T 46 6 Z P M 2 H5 AWS A5.36 E81T9-M21A8-Ni1-H4

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SF-3AM	1.2 mm	7S041MP960	7T051	August 02, 2017
NSSW SF-3AM	1.2 mm	7S071MP960	7T051	August 03, 2017
NSSW SF-3AM	1.2 mm	7S101MP960	7T051	August 04, 2017

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	27	25	25	140	135 ～ 163
Spec.	270 ± 10	27 ± 2	25 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	556	614	26
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-40	112, 126, 142	127
Spec.			32 Min.	47 Min.
	AW	-60	82, 80, 87	83
Spec.			32 Min.	47 Min.

Chemical composition (%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	
	0.06	0.31	1.22	0.010	0.005	0.26	1.02	0.02	0.01	0.01	0.01	
Spec.	0.03/ 0.07	0.25/ 0.60	1.00/ 1.50	0.020 Max.	0.020 Max.	0.40 Max.	0.80/ 1.10	0.15 Max.	0.35 Max.	0.05 Max.	Ref.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.4, 1.2, 1.3	1.3	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-03 Rev.3

No. 170830HFH (MIT 9188)

Net Weight

7S041MP960	:	2,575.0 kg
7S071MP960	:	4,275.0 kg
7S101MP960	:	1,375.0 kg

Certified by ISAO KANAUCHI
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

- Doc B204 - Certified Material Test Report - Filler material NSSW SF-3AM

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N07653	Purchaser's Spec. No. : NSTN-03 Rev.4
Date of issue : April 23, 2018	Material Classification
Purchaser : Norsk Sveiseteknikk AS	EN ISO 17632-A-T 46 4 Z P M 2 H5
Trade Designation : NSSW SF-3AM	EN ISO 17632-A-T 46 6 Z P M 2 H5 AWS A5.36 E81T9-M21A8-Ni1-H4

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SF-3AM	1.2 mm	8X221MP996	8Y261	March 08, 2018

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	27	25	25	140	135 ～ 163
Spec.	270 ± 10	27 ± 2	25 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	535	606	27
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-40	137, 151, 162	150
Spec.			32 Min.	47 Min.
	AW	-60	115, 95, 74	95
Spec.			32 Min.	47 Min.

Chemical composition (%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	B	
	0.05	0.27	1.15	0.010	0.004	0.30	1.03	0.03	0.01	0.01	0.02	0.003	
Spec.	0.03/ 0.07	0.20/ 0.55	1.00/ 1.50	0.020 Max.	0.020 Max.	0.40 Max.	0.80/ 1.10	0.15 Max.	0.35 Max.	0.05 Max.	Ref.	Ref.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.8, 1.2, 1.0	1.3	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-03 Rev.4

No. 180424HFH (MIT 9588)

Net Weight
8X221MP996 : 16,000.0 kg

Certified by SHUSHIRO NAGASHIMA
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

Appendix C

Manufacturing and welding process, characterization of the Steel S420G2+M

- Welding Procedure Qualification Program

- Doc C301 - WPQR: S420PL1-M
- Doc C302 - All WPS's
  - WPS PL1-SW
  - WPS: PL3/4-DW50-Rep
  - WPS: PL5/6-DW15-Rep
  - WPS: PL7/8-DW5-Rep

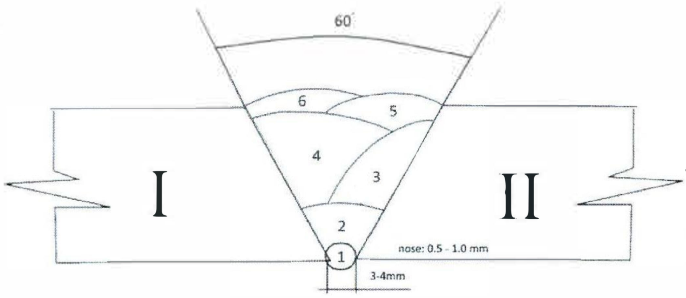
- Doc C301 - WPQR: S420PL1-M

University of Stavanger	WELDING PROCEDURE QUALIFICATION RECORD (WPQR)	WPQR No.: S420PL1-M Ref.: Magnus Larsson Date: 2019.06.06 Rev.4

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc Thesis - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. pWPS:	S420PL1-M		

	1	2	3
Welding process	138	136	
Shielding gas type	Argon /18%CO2 (M21)	Argon /18%CO2 (M21)	
Weaving (yes/no)	yes max: 7 mm	yes max: 13 mm	max: mm

Purging gas type	N/A l/min
Welding positions	PF, vertical up
Joint type	BW
Joint preparation	Waterjet cutting, Grinding
Cleaning method	Wire brush
Backing	N/A
Single/Double	Single
Back gouging	N/A
Flux designation	N/A
Flux handling	N/A
Tungsten electrode	N/A mm
Torch angle	70-90 °
Stand off distance	10-25 mm
Nozzle diameter(s)	10-20 mm
Tack welding proc.	General Rev: 0



Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0,22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	-
II	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	-

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	NSSW SM-47A	EN ISO 17632-A T 46 6 1Ni M M 1 H5	-	Suppliers recommendation
2	NSSW SF-3AM	EN ISO 17632-A-T 46 4 Z P M 2 H5 EN ISO 17632-A-T 46 6 Z P M 2 H5	-	Suppliers recommendation

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	1	1.20	138	2,2	103	14.7	DC+	56 - 71	N/A	20	1.29 - 1.61
2 (HP)	2	1.20	136	7,1	214	23.6	DC+	153 - 181	N/A	20	1.68 - 1.99
3 (FILL)	2	1.20	136	7,1	214	23.6	DC+	154 - 154	N/A	20	1.97 - 1.97
4 (FILL)	2	1.20	136	7,1	214	23.6	DC+	208 - 211	N/A	20	1.44 - 1.46
5 (CAP)	2	1.20	136	7,1	204	22.0	DC+	205 - 223	N/A	20	1.21 - 1.32
6 (CAP)	2	1.20	136	7,1	204	22.0	DC+	171 - 199	N/A	20	1.35 - 1.57

Heat treatment Method: -

Preheat min: 20 °C Interpass temp. max: 117 °c Heattreatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:
For additional documents, see SUMMARY.
Material heat No.: 43831-9133182
Consumable manuf. No.: 7U341AW996, 7S041MP960, 7SO71MP960, 7S101MP960, 8X221MP996.

VT performed and accepted by Arild Finnesand, KIWA.
Only valid for Master Thesis - Weld Proximity INVES.

Additional info enclosed (Yes/~~No~~):

Date/Signature:
2019.06.06 / Magnus Larsson

Approved:
2019.06.06 / Arild Finnesand

Kiwa Teknologisk Institutt

Summary

pWPS-S420PL1-M_Rev4

Weldlogg_Rev4

DigitalRT - Report 7967-19-DRT-1

Material Report 8612-1_Rev B

Material certificate S420G2+m - 43831-9133182

Consumable certificate - NSSW SM-47A - 7U341AW996 MIT 9118

Consumable certificate - NSSW SF-3AM - 7S041MP960 MIT 9188

Consumable certificate - NSSW SF-3AM - 8X221MP996 MIT 9588

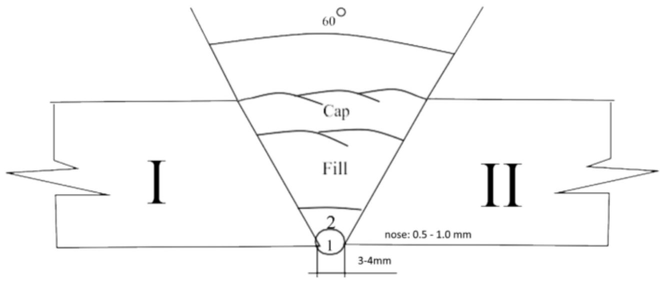
University of Stavanger	**Preliminary WELDING PROCEDURE SPECIFICATION (pWPS)**	pWPS No.: S420PL1-M Ref.: Magnus Larsson Date: 2019.04.05 Rev.4

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc Thesis - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	N/A		

Welding process	1	**138**	2	**136**	3	
Shielding gas type		**Argon /18%CO2 (M21)**		**Argon /18%CO2 (M21)**		
Weaving (yes/no)		**yes** max: **7** mm		**yes** max: **13** mm		max: mm

Purging gas type	**N/A** l/min
Welding positions	**PF, vertical up**
Joint type	**BW**
Joint preparation	**Waterjet cutting, Grinding**
Cleaning method	**Wire brush**
Backing	**N/A**
Single/Double	**Single**
Back gouging	**N/A**
Flux designation	**N/A**
Flux handling	**N/A**
Tungsten electrode	**N/A** mm
Torch angle	**70-90** o
Stand off distance	**10-25** mm
Nozzle diameter(s)	**10-20** mm
Tack welding proc.	**General** Rev: 0

WPQR No.: S420PL1-M



Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0.22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	**TM**	**15,00**	-
II	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	**TM**	**15,00**	-

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	**NSSW SM-47A**	**EN ISO 17632-A T46 6 1Ni M M 1 H5**	**FM1**	**Suppliers recommendation**
2	**NSSW SF-3AM**	**EN ISO 17632-A-T 46 4 Z P M 2 H5** **EN ISO 17632-A-T 46 6 Z P M 2 H5**	**FM1**	**Suppliers recommendation**

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	**1**	**1,20**	**138**	**2,2 - 2.4**	**100 - 120**	**14.5 - 15**	**DC+**	**60 - 80**	**N/A**	**20**	**1.3 - 1.6**
Fill	**2**	**1,20**	**136**	**7.0 - 8.0**	**210 - 230**	**22 - 23**	**DC+**	**140 - 200**	**N/A**	**20**	**1.4 - 2.0**
CAP	**2**	**1,20**	**136**	**6.5 - 7.5**	**200 - 210**	**22 - 23**	**DC+**	**160 - 220**	**N/A**	**20**	**1.2 - 1.7**

Heat treatment Method: -

Preheat min: 20 °C Interpass temp. max: 250 °c Heattreatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:	Additional info enclosed (Yes/~~No~~):
The pWPS is created with estimated and fixed parameters. **Position fixing: 3 strongbacks to be used.**	Date/Signature: 2019.04.05 / Magnus Larsson Approved: 2019.04.05 / Mattias Larsson

Welding procedure qualification record procedure

WPQR No.: S420 PL1 - M

Kiwa Teknologisk Institutt

Weldeye index: 630……………………..

Place, date	Stavanger, 08.04.2019
Manufacturer	Magnus Larsson and Mattias Larsson
Project	Master Thesis - Weld on weld
Ref.stand	NS-EN 15614:2017
Ref. Spec.	NORSOK M-101:2011 Rev.5
Welders name / ID	Bjørn Ivar Kaarvaag
pWPS Nr.	S420 PL1 - M

Identification of parent metal I	S420 G2+M			
Delivery cond./Heat no.	TMCP / 43831 - 9133182			
Pipe (T) eller Plate (P):	OD (mm):	N/A	WT (mm):	15mm
Identification of parent metal II	S420 G2+M			
Delivery cond./Heat no.	TMCP / 43831 - 9133182			
Pipe (T) eller Plate (P):	OD (mm):	N/A	WT (mm):	15mm

Identification of filler metal	NSSW SM-47A	NSSW SF-3AM	NSSW SF-3AM
Classification, batch/lot/heat	EN ISO 17632 AT 466 1Ni MM1 H5	EN ISO 17632-A-T 464 ZPM2 H5	EN ISO 17632 AT 46 6 ZPM2 H5
Filler handling			

Welding equipment, name/brand	Fronius - Trans Steel 2700
Welding process/processes	138, 136
Shield gas type	Argon / 18% CO_2 (M21)
Purging gas type	N/A
Weaving, weld bead width	13mm
Welding position	PF
Joint type	BW
Joint preparation	Water Jet cutting, grinding
Cleaning method	Wire brush
Backing	N/A
Single/double	Single
Back gauging	N/A
Flux designation, flux handling	N/A
Tungsten electrode	N/A
Torch angle	70-90
Stand of distance	10-25mm
Nozzle diameter(s)	10-25 mm
Tack welding proc.	111 - Manual metal arc welding
Heat treament, preheat, interpass	See Welding procedure qualification record procedure
Heat treament method, temp.control	N/A
PWHT	N/A
Additional information:	3 strongbacks to be used

K-factor:	**1,0**	(12)	**0,8**	(111, 131, 135, 114, 136, 137)	**0,6**	(141, 15)

Welding coordinator, signature	[signature]
Witnessed by, signature	[signature]

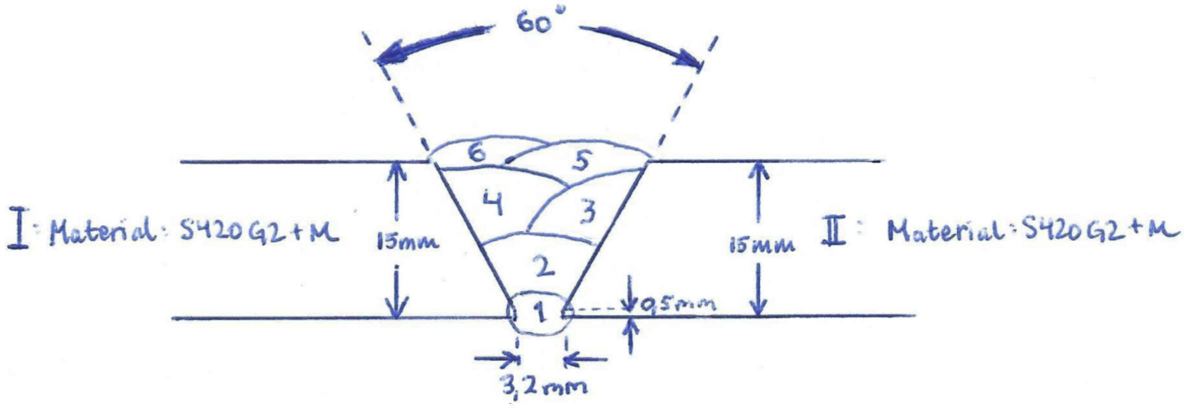
kiwa

Welding procedure qualification record procedure

Kiwa Teknologisk Institutt

WPQR No.: S420 PL1 - M

Sketch,



Dimensions: (OD, WT, GAP, NOSE, ANGLE)

Welding parameters:

	Pass no.	measure no.	Preheat / interpass °C	Filler OD (mm)	Welding process	Wire feed speed (m/min)	Current Polarity AC/ DC-/DC+	Current (A)	Volt (V)	Welding length (mm)	Welding time (s)	Welding speed (mm/min)	Shielding gas (L/min)	Purging gas (L/min)	Weld Bead width (mm)	Heat input kJ/mm
Root	1	1	30	1.2	138	2.2	DC+	103	14.7	175	186	56	20	0	7	1.61
		2		1.2	138	2.2	DC+	103	14.7	220	187	71	20	0	7	1.29
		3		1.2	138	2.2	DC+	103	14.7	115	103	67	20	0	7	1.36
Hp	2	1	42	1.2	136	7.1	DC+	214	23.6	340	113	181	20	0	13	1.68
		2		1.2	136	7.1	DC+	214	23.6	150	59	153	20	0	13	1.99
Fill	3	1	75	1.2	136	7.1	DC+	214	23.6	490	191	154	20	0	12	1.97
	4	1	100	1.2	136	7.1	DC+	214	23.6	225	64	211	20	0	13	1.44
		2		1.2	136	7.1	DC+	214	23.6	260	75	208	20	0	13	1.46
Cap	5	1	103	1.2	136	7.1	DC+	204	22	275	74	223	20	0	13	1.21
		2		1.2	136	7.1	DC+	204	22	225	66	205	20	0	13	1.32
	6	1	117	1.2	136	7.1	DC+	204	22	200	70	171	20	0	13	1.57
		2		1.2	136	7.1	DC+	204	22	295	89	199	20	0	13	1.35

Digital RT
Digital RT

IKM Inspection AS

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
KIWA Teknologisk Institutt AS	**35170742**	**2019-04-09**	**180-7967-19-DRT-1**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
WPQR
S420PL1-M
Plate 15 mm
138/136 C/S

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
Carbon steel	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 300 Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3 mm

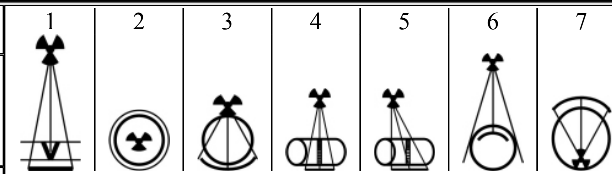
EXP. DATA

	A	B	C	D
TUBE VOLT kV	**220**			
FILMFOCUS DISTANCE mm	**700**			
EXP.TIME mAmin. Cimin.	**6**			

I.Q.I. SOURCE SIDE
☑ KILDESIDE
☐ FILMSIDE

TYPE OF I.Q.I. / I.Q.I. TYPE
W 10 FE

1 2 3 4 5 6 7



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**N/A**	**0,063**	**25 micron**	**150**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
TEST	**09-04-2019**	**Plate**	**20 - 240**	**W 13**	**	**15**	**Accepted**	**106-110**	**515 (4mm)**	**A**	**1**
TEST	**09-04-2019**	**Plate**	**240 - 460**	**W 13**	**	**15**	**Accepted**	**--**	**--**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

**** See weld log.**

Result: Accepted.

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-04-09	OPERATOR / OPERATØR DATO:
	Approved /Godkjent IKM Inspection AS	IKM Inspection AS

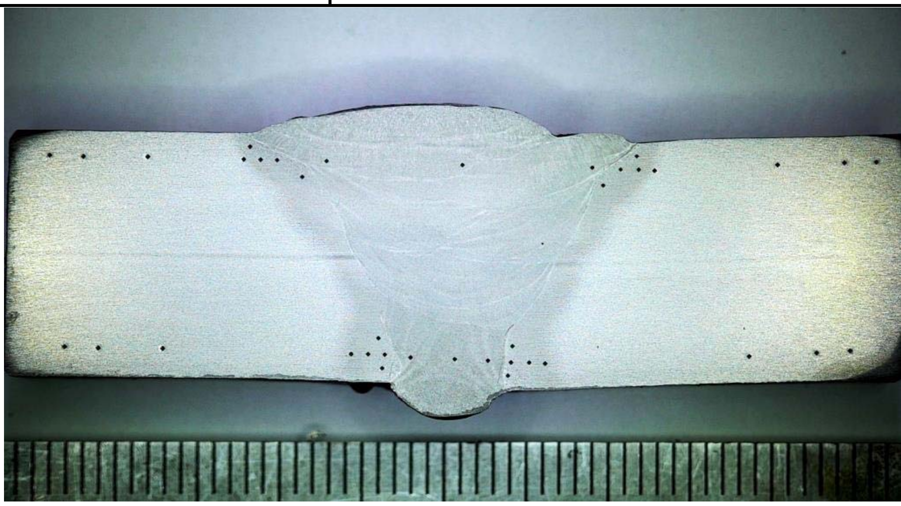
MATERIAL REPORT

Certificate no:	Rev	Order no:	
8612-1	B	8612	Quality Lab AS Industrivegen 54 4110 Forsand Norge

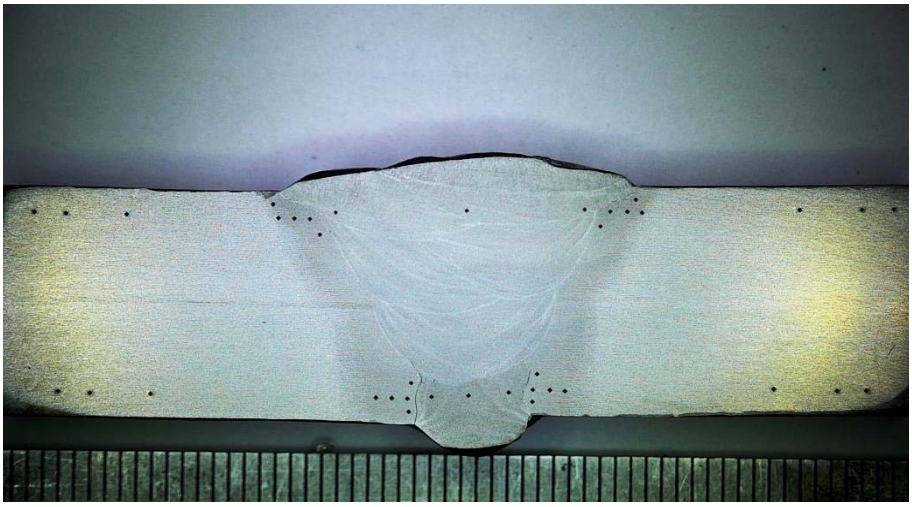
Client:	Test date/Report date	
Master Thesis UIS	07.06.2019	
	Client contact Mattias Larsson	Equipment identification: Mechanical testing of WPQ S420PL1-M
Pages 4	Surveyor Mattias & Magnus Larsson	Standard

Additional information: Quality Lab Confirms that the results are connected to the object tested.
Rev B replaces Rev A. Comment to MPI added

Macro examination according to NS-EN 17639:2013			
Etchant:	Nital	Visual examination:	X5



Macro Start



Macro Stop

Comment: The Macro are inside the acceptance criteria of NS-EN ISO 5817:2014
Imperfections are inside quality level B.

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-1	B	8612
Client:		Test date/Report date
Master Thesis UIS		07.06.2019

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

quality lab

NORSK AKKREDITERING TEST 248

Tensile test, NS EN ISO 4136-1:2012 / ISO 6892-1:2016 Method A.1			
Test ident:	Area [mm^2]	R_m [Mpa]	Fracture
Cross weld sample 1	260,10	522	Base material
Cross weld sample 2	255,75	528	Base material

Charpy V impact test, KV8, NS-EN ISO 148-1:2016; ISO 9016:2012							
Test ident	Dimension [mm]	Notch Orientation	Test temp [^{0}C]	Single values [J]			Average [J]
				1	2	3	
Weld	10x10x55	T	-40	80	131	106	106
FL	10x10x55	T	-40	113	186	193	164
FL+2	10x10x55	T	-40	253	130	200	194
FL+5	10x10x55	T	-40	234	236	173	214

Bend test, NS-EN ISO 5173:2010		
Type:	Side Bend	
Former: 4T	Dimension: 10mm	
Bend angle:	180°	
Comments:	Accepted	

MPI examination according to ISO 23278:2015 level B (non accreditated test)
MPI performed, No findings, Accepted

MATERIAL REPORT

Certificate no:	Rev	Order no:	
8612-1	B	8612	
Client:		Test date/Report date	
Master Thesis UIS		07.06.2019	

quality lab
Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

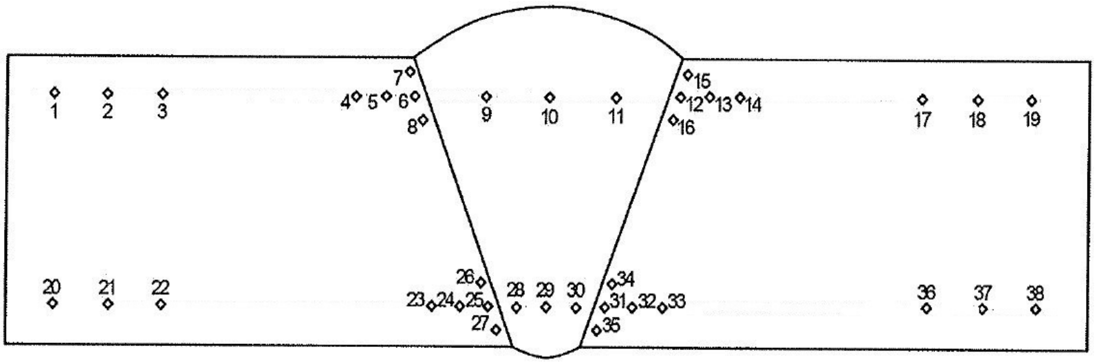
NORSK AKKREDITERING TEST 248

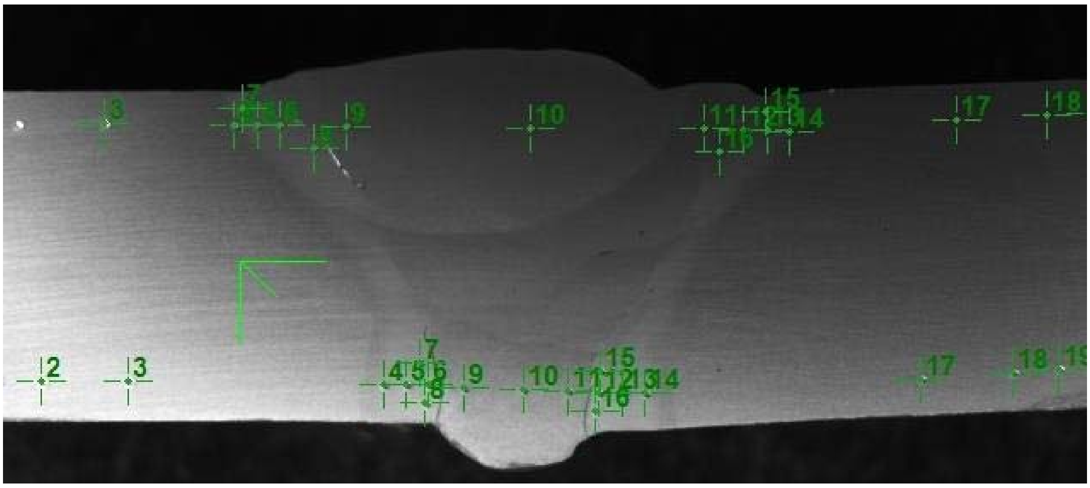
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Start	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	180	184	180	191	200	231	207	223	223	219	227	251	195
	14	15	16	17	18	19							
	192	240	240	179	177	178							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	174	177	180	191	201	207	202	212	210	207	204	209	197
	33	34	35	36	37	38							
	192	211	209	176	178	183							

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-1	B	8612

Client:	Test date/Report date
Master Thesis UIS	07.06.2019

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

quality lab

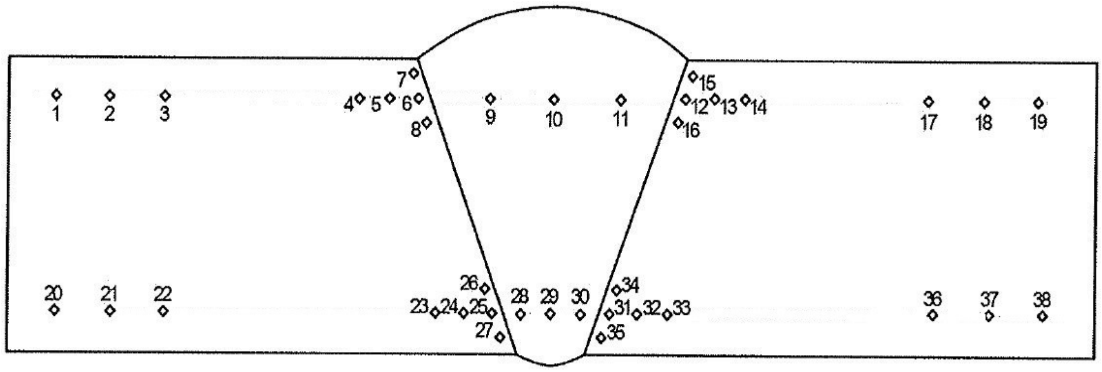
NORSK AKKREDITERING TEST 248

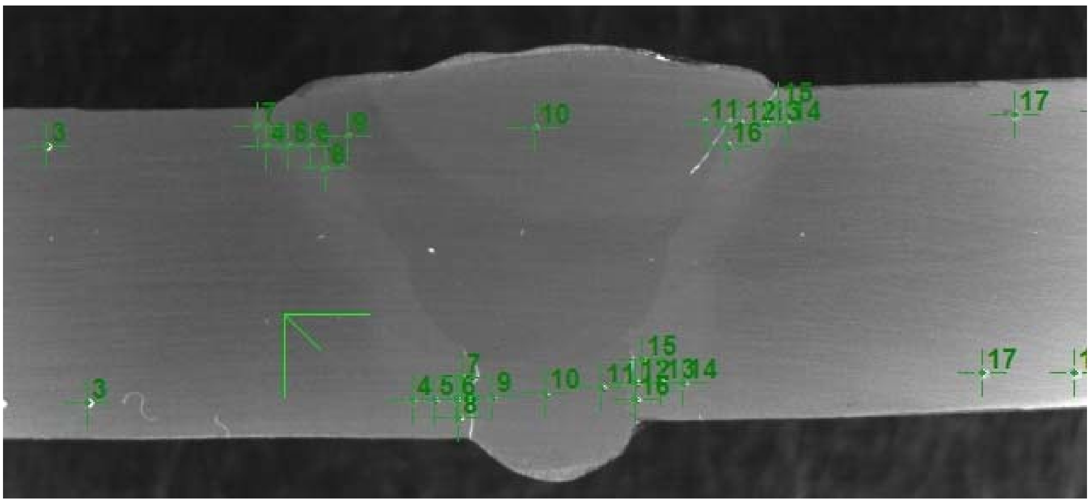
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Stop	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	177	177	180	190	198	224	193	207	226	216	215	229	190
	14	15	16	17	18	19							
	183	208	218	174	178	177							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	166	176	176	173	176	197	210	190	198	200	202	195	176
	33	34	35	36	37	38							
	172	199	195	175	177	176							

Date and signature Quality Lab AS	
07.06.2019	*Petter Lunde Metallurgist*

CO #	Item #	Del #	Heat	Lot	Your art #	Qty	Description
201904011/SWK	100	RP5367 20	43831-9133182			1	HR PL S420G2+M/Q-Y30 15X2500X12000 MM

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NORSK STÅL

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 1/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Marking of the product (B06)
Trademark/Steelgrade/Heat-No/Product-No/
inspector's stamp

Material data (B01–B99)

Item	Quantity (B08)	Product No. (B07)	Heat No. (B07)	Cond. of delivery (B04)	Thickness x Width x Length mm x mm x mm (B09–B11)
02	1	913317 1	43831	TM	15,00 x 2500,0 x 12000
02	1	913317 2	43831	TM	15,00 x 2500,0 x 12000
02	1	913318 1	43831	TM	15,00 x 2500,0 x 12000
02	1	913318 2	43831	TM	15,00 x 2500,0 x 12000
Σ	4	Weight (B12) 14.132 kgs		TM : thermomechanically rolled	

100

Dimensional check and visual examination of the surface condition:
without objection

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT - 1864 DNV·GL

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 2/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
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4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS−Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163−2 Kl. A UG3 03/05
312604
Application onboard DNV − classed objects is subject to special consideration.

Ladle analysis (C70–C99)
Manufacturer standard

Heat No. (B07)	C % ≤ 0,14	Si % 0,15 – 0,55	Mn % ≤ 1,65	P % ≤ 0,020	S % ≤ 0,005	N % ≤ 0,010	Al % 0,015–0,055	Cu % ≤ 0,30	Cr % ≤ 0,25	Ni % ≤ 0,70
43831	0,10	0,28	1,49	0,011	0,002	0,005	0,041	0,02	0,05	0,04
Heat No. (B07)	**V % ≤ 0,080**	**Ti % ≤ 0,025**	**Nb % ≤ 0,040**	**B % ≤ 0,0005**	**Mo % ≤ 0,25**	**As % ≤ 0,030**	**Sn % ≤ 0,020**	**Pb % ≤ 0,010**	**Ca % ≤ 0,005**	**EV1 1) % ≤ 0,22**
43831	0,003	0,002	0,026	0,0001	0,002	0,002	0,005	0,001	0,002	0,19
Heat No. (B07)	**Sb % ≤ 0,010**	**EV2 2) % ≤ 0,42**	**Bi % ≤ 0,010**	**EV3 3) % ≤ 0,11**	**EV4 4) % ≤ 0,90**	**Nb+V % ≤ 0,09**				
43831	0,000	0,36	0,001	0,03	0,11	0,03				

1) EV1 : PCM=C+Mn/20+Mo/15+Ni/60+Cr/20+V/10+Cu/20+Si/30+5xB
2) EV2 : CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15
3) EV3 : V+Nb+Ti
4) EV4 : Cr+Cu+Mo+Ni

Steel making: Basic oxygen process
(C70)

vacuum degassed

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM–System: Certification as per ISO 9001 since 28 February 1990

Kesten

1864 DNV·GL SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D–38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 3/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS−Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163−2 Kl. A UG3 03/05
312604
Application onboard DNV − classed objects is subject to special consideration.

Check analysis (C70–C99)

Specimen No. (C00)	Heat No. (B07)	C % ≤ 0,14	Si % 0,15 – 0,55	Mn % ≤ 1,65	P % ≤ 0,020	S % ≤ 0,005	N % ≤ 0,010	Al % 0,015–0,055	Cu % ≤ 0,30
913146 *)	43831	0,11	0,28	1,46	0,007	0,003	0,004	0,042	0,02
913146 *)	43831	0,10	0,27	1,49	0,014	0,000	0,006	0,050	0,02

Specimen No. (C00)	Heat No. (B07)	Cr % ≤ 0,25	Ni % ≤ 0,70	V % ≤ 0,080	Ti % ≤ 0,025	Nb % ≤ 0,040	Mo % ≤ 0,25	B % ≤ 0,0005	EV1 1) % ≤ 0,22
913146 *)	43831	0,05	0,05	0,002	0,001	0,029	0,002	0,0000	0,20
913146 *)	43831	0,05	0,03	0,005	0,002	0,025	0,00	0,0005	0,19

Specimen No. (C00)	Heat No. (B07)	EV2 2) % ≤ 0,42	EV3 3) % ≤ 0,90	EV4 4) % ≤ 0,11	Nb+V % ≤ 0,09
913146 *)	43831	0,37	0,12	0,03	0,03
913146 *)	43831	0,36	0,10	0,03	0,03

1) EV1 : PCM=C+Mn/20+Mo/15+Ni/60+Cr/20+V/10+Cu/20+Si/30+5xB
2) EV2 : CEV=C+Mn/6+Mo/5+Ni/15+Cr/5+V/5+Cu/15
3) EV3 : Cr+Cu+Mo+Ni
4) EV4 : V+Nb+Ti
*) The sample product is not part of the delivery

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM–System: Certification as per ISO 9001 since 28 February 1990

Kesten

SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT 18 64 DNV·GL

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D–38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 4/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191
12.11.2018
Inspection (A05) DNVGL
N141JYW8

Steel grade and terms of delivery (B02–B03) S420G2+M
EN 10225 08/01
MDS–Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163–2 Kl. A UG3 03/05
312604
Application onboard DNV – classed objects is subject to special consideration.

Tensile test (C10–C29)

Specimen No. (C00)	Heat No. (B07)	Location (C01) 1) 2) 3)	Direct. (C02) 4)	Cond. (B05) 5)	Type (C10) 6)	Yield point (C11) ReH N/mm2 420 – 540	Tensile strength (C12) Rm N/mm2 500 – 660	ReH/Rm ≤ 0,93	Elongation (C13) A5 7) % ≥ 19	
913318	43831	K4G	Q	TM	P	489	557	0,88	31	

1) K : Top
2) 4 : 1/4 Width
3) G : Thickness of product
4) Q : transversal
5) TM : thermomechanically rolled
6) P : prismatic
7) A5 : Lo=5,65 √So

Impact test (C40–C49)

Specimen No. (C00)	Heat No. (B07)	Location (C01) 1) 2) 3)	Direct. (C02) 4)	Cond. (B05) 5)	Type of specimen (C40–C41)	Temperature (C03) °C	Impact energy (C42–C43) 1 J ≥ 42	2	3	MW 6) J ≥ 60
913318	43831	K4O	Q	TM	KV450	–040	118	111	114	114

1) K : Top
2) 4 : 1/4 Width
3) O : near surface
4) Q : transversal
5) TM : thermomechanically rolled
6) MW : Average

All plates have been ultrasonically tested according to EN 10160 07/99 in area and edges
Class of areatesting: S1
Class of edgestesting: E2
Results: No faults were found.

Kesten

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM–System: Certification as per ISO 9001 since 28 February 1990

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D–38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

ILSENBURGER GROBBLECH
Ein Unternehmen der Salzgitter Gruppe

Inspection certificate 3.2
DIN EN 10204
(A02)

No. (A03) **1145686**
Page 5/5
Date 13.11.2018

No. (A07) P12001207 28.08.2018
Purchaser (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

No. (A07)
Customer (A06) Norsk Stal AS
4683 SOEGNE
NORWEGEN

Product (B01) Heavy plate

Works order No. (A08) 0000096751
Dispatch note No. 0087902191 12.11.2018
Inspection (A05) DNVGL **N141JYW8**

Steel grade and terms of delivery (B02–B03)
S420G2+M
EN 10225 08/01
MDS-Y30 Rev.5
DIN EN 10029 A 02/11
DIN EN 10163-2 Kl. A UG3 03/05
312604
Application onboard DNV - classed objects is subject to special consideration.

Our products are free of radioactive substances and do not exceed the clearing limit value of 100 Bq/kg, which guarantees the compliance with limit values given in the Radiation Protection Ordinance(StrlSchV) for the unrestricted clearance of solid material (StrlSchV Annex III, Section 5) for ferrous nuclides.

We hereby certify that the delivered material complies with the terms of the order.
(Z01)
QM-System: Certification as per ISO 9001 since 28 February 1990

Kesten

Trademark (A04)

Ilsenburger Grobblech GmbH
Veckenstedter Weg 10
D-38871 Ilsenburg
(A01)

Inspection Stamp (Z03)

Inspection Representative (Z02)
Langemann

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N06547 Date of issue : June 29, 2017 Purchaser : Norsk Sveiseteknikk AS Trade Designation : NSSW SM-47A	Purchaser's Spec. No. : NSTN-13 Rev.0 Material Classification EN ISO 17632-A-T 46 6 1Ni M M 1 H5 AWS A5.36 E80T15-M21A8-Ni1-H4

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SM-47A	1.2 mm	7U341AW996	7V311	June 12, 2017

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	30	30	25	140	135 ～ 163
Spec.	270 ± 10	30 ± 2	30 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	527	617	28
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-60	93, 104, 115	104
Spec.			32 Min.	47 Min.
Spec.				

Chemical composition (%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	
	0.07	0.59	1.26	0.009	0.008	0.25	1.02	0.02	0.01	0.01	0.01	
Spec.	0.04/ 0.10	0.40/ 0.80	1.1/ 1.4/	0.020 Max.	0.020 Max.	0.3 Max.	0.80/ 1.10	0.15 Max.	0.15 Max.	0.05 Max.	0.05 Max.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.0, 1.7, 1.0	1.2	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-13 Rev.0

No. 170639HFH (MIT 9118)

Net Weight
7U341AW996 : 17,880.0 kg

Certified by ISAO KANAUCHI
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N06726	Purchaser's Spec. No. : NSTN-03 Rev.3
Date of issue : September 6, 2017	Material Classification
Purchaser : Norsk Sveiseteknikk AS	EN ISO 17632-A-T 46 4 Z P M 2 H5
Trade Designation : NSSW SF-3AM	EN ISO 17632-A-T 46 6 Z P M 2 H5 AWS A5.36 E81T9-M21A8-Ni1-H4

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SF-3AM	1.2 mm	7S041MP960	7T051	August 02, 2017
NSSW SF-3AM	1.2 mm	7S071MP960	7T051	August 03, 2017
NSSW SF-3AM	1.2 mm	7S101MP960	7T051	August 04, 2017

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	27	25	25	140	135 ～ 163
Spec.	270 ± 10	27 ± 2	25 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	556	614	26
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-40	112, 126, 142	127
Spec.			32 Min.	47 Min.
	AW	-60	82, 80, 87	83
Spec.			32 Min.	47 Min.

Chemical composition (%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	
	0.06	0.31	1.22	0.010	0.005	0.26	1.02	0.02	0.01	0.01	0.01	
Spec.	0.03/ 0.07	0.25/ 0.60	1.00/ 1.50	0.020 Max.	0.020 Max.	0.40 Max.	0.80/ 1.10	0.15 Max.	0.35 Max.	0.05 Max.	Ref.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.4, 1.2, 1.3	1.3	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-03 Rev.3

No. 170830HFH (MIT 9188)

Net Weight

7S041MP960	:	2,575.0 kg
7S071MP960	:	4,275.0 kg
7S101MP960	:	1,375.0 kg

Certified by ISAO KANAUCHI
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

Certified Material Test Report According to EN 10204, type 3.1	Chiba Plant Nippon Steel & Sumikin Welding Co., Ltd.
Test Report No. : N07653	Purchaser's Spec. No. : NSTN-03 Rev.4
Date of issue : April 23, 2018	Material Classification
Purchaser : Norsk Sveiseteknikk AS	EN ISO 17632-A-T 46 4 Z P M 2 H5 EN ISO 17632-A-T 46 6 Z P M 2 H5 AWS A5.36 E81T9-M21A8-Ni1-H4
Trade Designation : NSSW SF-3AM	

1. Materials

Trade Designation	Size	Manuf. No.	Flux lot No.	Manuf. Date
NSSW SF-3AM	1.2 mm	8X221MP996	8Y261	March 08, 2018

Test type	Test Unit
EN ISO	14344 Lot class : T1 (each flux lot), Testing Schedule : 4 (exclude soundness test)

2. Welding Condition (Test type : ISO)

Base Metal (mm)	KL33 20tx250wx300L	Welding Position	Flat	Kind of Gas	80% Ar + 20% CO_2	CTWD (mm)	20

	Current DC(+) (A)	Voltage (V)	Travel Speed (cm/min)	Flow Rate of Gas (l/min)	Preheat Temp. (℃)	Inter-pass Temp. (℃)
	270	27	25	25	140	135 ～ 163
Spec.	270 ± 10	27 ± 2	25 ± 5	20 ～ 25	135 ～ 163	135 ～ 163

3. Test results of All-Weld-Metal (Test type : ISO)

Tension Test	Conditions	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
	AW	535	606	27
Spec.		460 Min.	530 ～ 680	20 Min. A5

Impact Test	Conditions	Temp. (℃)	Ind. Value (J)	Ave. (J)
	AW	-40	137, 151, 162	150
Spec.			32 Min.	47 Min.
	AW	-60	115, 95, 74	95
Spec.			32 Min.	47 Min.

Chemical composition (%)													
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	B	
	0.05	0.27	1.15	0.010	0.004	0.30	1.03	0.03	0.01	0.01	0.02	0.003	
Spec.	0.03/ 0.07	0.20/ 0.55	1.00/ 1.50	0.020 Max.	0.020 Max.	0.40 Max.	0.80/ 1.10	0.15 Max.	0.35 Max.	0.05 Max.	Ref.	Ref.	

S, P and N of the strip : Below specified maximum

4. Hydrogen Content of Deposited Metal (Acc. to ISO 3690)

HDM (ml/100g)	Ave.	Spec.
1.8, 1.2, 1.0	1.3	5 Max.

Statement :
We hereby certify that the contents of this report are correct and accurate, and all operations performed by us or our subcontractors are in compliance with the requirements of the DATA SHEET No. : NSTN-03 Rev.4

No. 180424HFH (MIT 9588)

Net Weight
8X221MP996 : 16,000.0 kg

Certified by SHUSHIRO NAGASHIMA
Group Manager, Quality Control Dept.

This is electronically made and is not signed.

- Doc C302 - All WPS's
    - WPS PL1-SW
    - WPS: PL3/4-DW50-Rep
    - WPS: PL5/6-DW15-Rep
    - WPS: PL7/8-DW5-Rep

University of Stavanger

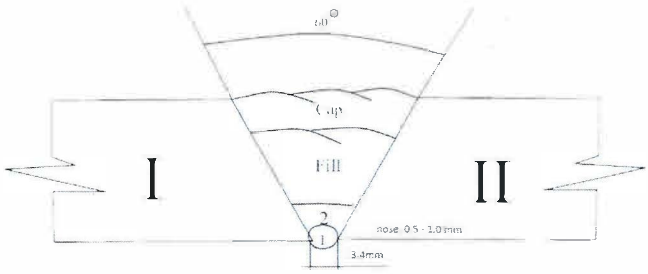
WELDING PROCEDURE SPECIFICATION (WPS)

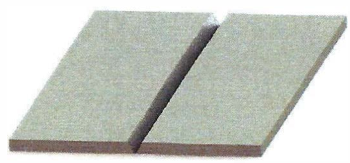
WPS No.:	PL1-SW
Ref.:	Magnus Larsson
Date:	2019.05.09 Rev.2

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	S420PL1-M		

		1		2		3
Welding process		138		136		
Shielding gas type	1	Argon /18%CO2 (M21)	2	Argon /18%CO2 (M21)	3	
Weaving (yes/no)		yes max: 7 mm		yes max: 13 mm		max: mm

Purging gas type	N/A l/min
Welding positions	PF, vertical up
Joint type	BW
Joint preparation	Waterjet cutting, Grinding
Cleaning method	Wire brush
Backing	N/A
Single/Double	Single
Back gouging	N/A
Flux designation	N/A
Flux handling	N/A
Tungsten electrode	N/A mm
Torch angle	70-90 °
Stand off distance	10-25 mm
Nozzle diameter(s)	10-20 mm
Tack welding proc.	General Rev: 0





Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0,22 II: CE max: 0 42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	500-<
II	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	500-<

->Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	NSSW SM - 47A	EN ISO 17632-A-T 46 6 1Ni M M 1 H5	FM1	Suppliers recommendation
2	NSSW SF - 3AM	EN ISO 17632-A-T 46 4 Z P M 2 H5 EN ISO 17632-A-T 46 6 Z P M 2 H5	FM1	Suppliers recommendation

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed [m/min]	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	1	1,20	138	2.2	93 - 113	13.2 - 16.2	DC+	42 - 88	N/A	20	1.0 - 2.0
2	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	114 - 226	N/A	20	1.3 - 2.5
Fill	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	115 - 264	N/A	20	1.1 - 2.5
CAP	2	1,20	136	7.1	184 - 224	19.8 - 24.2	DC+	129 - 279	N/A	20	0.9 - 2.0

Heat treatment Method: -

Preheat min: 20 °C Interpass temp. max: 150 °C Heat treatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:
The interval used for Welding speed and Heat input is calculated according to 15614-1:2017.

All welds on this WPS are to be used for master thesis. Subsequent welds should be performed as close to the original weld (WPQR) as possible. Following welds should be performed on plates with similar thickness.

Additional info enclosed (Yes/No):

Date/Signature:
2019.05.09 / Magnus Larsson

Approved:
2019.05.09 / Prof. Chandima Ratnayake

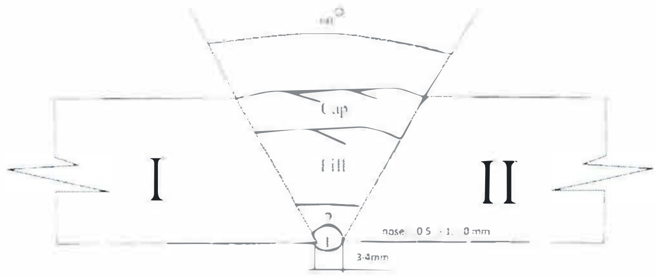
University of Stavanger 4036 Stavanger NORWAY

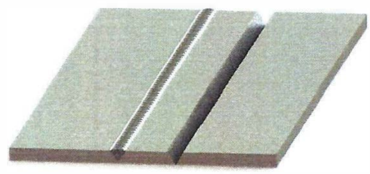
University of Stavanger	**WELDING PROCEDURE SPECIFICATION (WPS)**	WPS No.: PL3/4-DW50-Rep Ref.: Magnus Larsson Date: 2019.05.09 Rev.2

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	S420PL1-M		

Welding process	1	**138**	2	**136**	3
Shielding gas type		**Argon /18%CO2 (M21)**		**Argon /18%CO2 (M21)**	
Weaving (yes/no)		**yes** max: **7** mm		**yes** max: **13** mm	max: mm

Purging gas type	**N/A** l/min
Welding positions	**PF, vertical up**
Joint type	**BW**
Joint preparation	**Waterjet cutting, Grinding**
Cleaning method	**Wire brush**
Backing	**N/A**
Single/Double	**Single**
Back gouging	**N/A**
Flux designation	**N/A**
Flux handling	**N/A**
Tungsten electrode	**N/A** mm
Torch angle	**70-90** °
Stand off distance	**10-25** mm
Nozzle diameter(s)	**10-20** mm
Tack welding proc.	General Rev: 0





50mm between the weld toes

Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0,22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	TM	**15,00**	**500-<**
II	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	TM	**15,00**	**500-<**

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	**NSSW SM - 47A**	**EN ISO 17632-A-T 46 6 1Ni M M 1 H5**	FM1	Suppliers recommendation
2	**NSSW SF- 3AM**	**EN ISO 17632-A-T 46 4 Z P M 2 H5** **EN ISO 17632-A-T 46 6 Z P M 2 H5**	FM1	Suppliers recommendation

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	**1**	**1,20**	**138**	**2.2**	**93 - 113**	**13.2 - 16.2**	**DC+**	**42 - 88**	**N/A**	**20**	**1.0 - 2.0**
2	**2**	**1,20**	**136**	**7.1**	**192 - 235**	**21.2 - 26.0**	**DC+**	**114 - 226**	**N/A**	**20**	**1.3 - 2.5**
Fill	**2**	**1,20**	**136**	**7.1**	**192 - 235**	**21.2 - 26.0**	**DC+**	**115 - 264**	**N/A**	**20**	**1.1 - 2.5**
CAP	**2**	**1,20**	**136**	**7.1**	**184 - 224**	**19.8 - 24.2**	**DC+**	**129 - 279**	**N/A**	**20**	**0.9 - 2.0**

Heat treatment Method: -

Preheat min: 70 °C Interpass temp. max: 150 °C Heattreatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:
Repair WPS is based on the same WPQ as the original weld. All welds on this WPS are to be used for master thesis.
Repair and preheat as in Norsok M-101:2011 Rev.5 section:
- 6.11 Preheat and interpass temperature
- 10.4 Repair welding procedure

Additional info enclosed (Yes/No):

Date/Signature:
2019.05.09 / Magnus Larsson

Approved:
2019.05.09 / Prof. Chandima Ratnayake

University of Stavanger 4036 Stavanger NORWAY

University of Stavanger

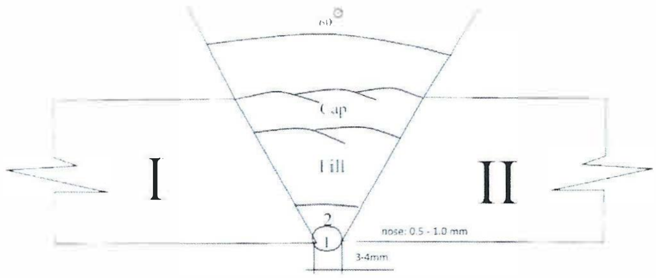
WELDING PROCEDURE SPECIFICATION (WPS)

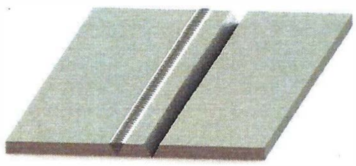
WPS No.:	PL5/6-DW15-Rep
Ref.:	Magnus Larsson
Date:	2019 05.09 Rev.2

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc Thesis - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	S420PL1-M		

	1		2		3	
Welding process		138		136		
Shielding gas type	1	Argon /18%CO2 (M21)	2	Argon /18%CO2 (M21)	3	
Weaving (yes/no)		yes max: 7 mm		yes max: 13 mm		max: mm

Purging gas type	N/A l/min
Welding positions	PF, vertical up
Joint type	BW
Joint preparation	Waterjet cutting, Grinding
Cleaning method	Wire brush
Backing	N/A
Single/Double	Single
Back gouging	N/A
Flux designation	N/A
Flux handling	N/A
Tungsten electrode	N/A mm
Torch angle	70-90 °
Stand off distance	10-25 mm
Nozzle diameter(s)	10-20 mm
Tack welding proc.	General Rev: 0





15mm between the weld toes

Identification of parent metal

I: CE max: 0,42 C max: 0,14 PCM max: 0,22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	500-<
II	S420G2+M, MDS-Y30 Rev.5	EN 10225:2009	2.1	TM	15,00	500-<

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	NSSW SM - 47A	EN ISO 17632-A-T 46 6 1Ni M M 1 H5	FM1	Suppliers recommendation
2	NSSW SF- 3AM	EN ISO 17632-A-T 46 4 Z P M 2 H5 EN ISO 17632-A-T 46 6 Z P M 2 H5	FM1	Suppliers recommendation

Welding Parameters

Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	1	1,20	138	2.2	93 - 113	13.2 - 16.2	DC+	42 - 88	N/A	20	1.0 - 2.0
2	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	114 - 226	N/A	20	1.3 - 2.5
Fill	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	115 - 264	N/A	20	1.1 - 2.5
CAP	2	1,20	136	7.1	184 - 224	19.8 - 24.2	DC+	129 - 279	N/A	20	0.9 - 2.0

Heat treatment

Method: -

Preheat min: 70 °C Interpass temp. max: 150 °C Heattreatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:

Repair WPS is based on the same WPQ as the original weld. All welds on this WPS are to be used for master thesis.

Repair and preheat as in Norsok M-101:2011 Rev.5 section:
- 6.11 Preheat and interpass temperature
- 10.4 Repair welding procedure

Additional info enclosed (Yes/No):

Date/Signature:
2019.05.09 / Magnus Larsson

Approved:
2019.05.09 / Prof. Chandima Ratnayake

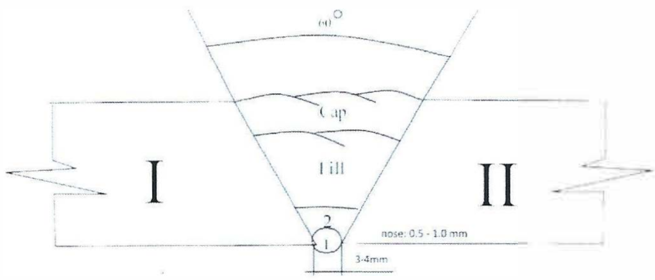
University of Stavanger 4036 Stavanger NORWAY

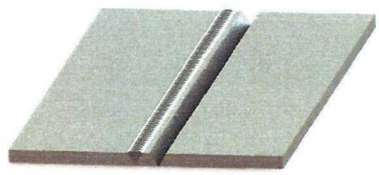
University of Stavanger	**WELDING PROCEDURE SPECIFICATION (WPS)**	WPS No.: PL7 /8-D W5-Rep Ref.: Magnus Larsson Date: 2019.05.09 Rev.2

Prod. by:	KIWA TI.	Client:	University of Stavanger	Ref. stand:	NS-EN ISO 15614-1:2017
Project:	MSc Thesis - Weld Proximity INVES.	Ref. spec.:	NORSOK M-101:2011 Rev.5	Exam. body:	Teknologisk Institutt (KIWA)
Location:	General	Ref. WPQR:	S420PL1-M		

		1		2		3
Welding process		**138**		**136**		
Shielding gas type	1	**Argon /18%CO2 (M21)**	2	**Argon /18%CO2 (M21)**	3	
Weaving (yes/no)		**yes** max: **7** mm		**yes** max: **13** mm		max: mm

Purging gas type	**N/A** l/min
Welding positions	**PF, vertical up**
Joint type	**BW**
Joint preparation	**Waterjet cutting, Grinding**
Cleaning method	**Wire brush**
Backing	**N/A**
Single/Double	**Single**
Back gouging	**N/A**
Flux designation	**N/A**
Flux handling	**N/A**
Tungsten electrode	**N/A** mm
Torch angle	**70-90** °
Stand off distance	**10-25** mm
Nozzle diameter(s)	**10-20** mm
Tack welding proc.	General Rev: 0





5mm between the weld toes

Identification of parent metal I: CE max: 0,42 C max: 0,14 PCM max: 0,22 II: CE max: 0,42 C max: 0,14 PCM max: 0,22

Part	Name/Grade	Standard	Group	Delivery cond.	Thickness range [mm]	Diameter range [mm]
I	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	TM	**15,00**	**500-<**
II	**S420G2+M, MDS-Y30 Rev.5**	**EN 10225:2009**	**2.1**	TM	**15,00**	**500-<**

Identification of filler metal

Index	Brand name	Classification	Group	Filler handling
1	**NSSW SM - 47A**	**EN ISO 17632-A-T 46 6 1Ni M M 1 H5**	FM1	Suppliers recommendation
2	**NSSW SF- 3AM**	**EN ISO 17632-A-T 46 4 Z P M 2 H5** **EN ISO 17632-A-T 46 6 Z P M 2 H5**	FM1	Suppliers recommendation

Welding Parameters Equipment:

Pass no.	Index	Dia. [mm]	Welding method	Wire feed speed	Current [A]	Voltage [V]	Current / Polarity	Welding speed [mm/min]	Run Out Length [mm]	Gas [l/min]	Heat input [kJ/mm]
BW:				-	-	-		-			-
1(Root)	1	1,20	138	2.2	93 - 113	13.2 - 16.2	DC+	42 - 88	N/A	20	1.0 - 2.0
2	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	114 - 226	N/A	20	1.3 - 2.5
Fill	2	1,20	136	7.1	192 - 235	21.2 - 26.0	DC+	115 - 264	N/A	20	1.1 - 2.5
CAP	2	1,20	136	7.1	184 - 224	19.8 - 24.2	DC+	129 - 279	N/A	20	0.9 - 2.0

Heat treatment Method: -

Preheat min: 70 °C Interpass temp. max: 150 °C Heattreatment proc.: Temp. control: Digital contact thermometer

PWHT min: °C max: °C Soaking: min/mm min Heating rate: °C/h Cooling rate: °C/h

Remarks:
Repair WPS is based on the same WPQ as the original weld. All welds on this WPS are to be used for master thesis.
Repair and preheat as in Norsok M-101:2011 Rev.5 section:
- 6.11 Preheat and interpass temperature
- 10.4 Repair welding procedure

Additional info enclosed (Yes/No):

Date/Signature:
2019.05.09 / Magnus Larsson

Approved:
2019.05.09 / Prof. Chandima Ratnayake

University of Stavanger 4036 Stavanger NORWAY

Appendix D

Manufacturing and welding process, characterization of the Steel S420G2+M

- Production Welding of Plates

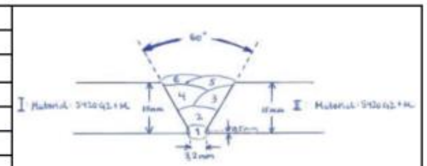
- Doc D401 - All Weld log's for Weld A
- Doc D402 - All Weld log's for repair Weld B

- Doc D401 - All Weld log's for Weld A

All Weld log's for Weld A:

PL3-DW 50 (Weld A)

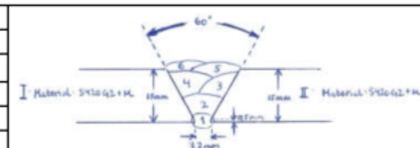
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	25 April 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 3 - DW50	Welding position	PF
Procedure standard	PL1-SW	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	23.8	1.2	2.2	DC+	103	14.7	107	159	40.4	20	0	9	2.25
	2	Björn-Ivar	138		1.2	2.2	DC+	103	14.7	175	228	46.1	20	0	9	1.97
	3	Björn-Ivar	138		1.2	2.2	DC+	103	14.7	215	162	79.6	20	0	7	1.14
2	1	Björn-Ivar	136	45.0	1.2	8.2	DC+	211	23.8	235	77	183.1	20	0	12	1.65
	2	Björn-Ivar	136		1.2	8.2	DC+	211	23.8	250	95	157.9	20	0	12	1.91
3	1	Björn-Ivar	136	85.0	1.2	8.2	DC+	211	23.8	380	94	242.6	20	0	12	1.24
	2	Björn-Ivar	136		1.2	8.2	DC+	211	23.8	110	32	206.3	20	0	12	1.46
4	1	Björn-Ivar	136	100.0	1.2	8.2	DC+	211	23.8	485	146	199.3	20	0	13	1.51
5	1	Björn-Ivar	136	60.0	1.2	7.2	DC+	201	22.0	485	148	196.6	20	0	14	1.35
6	1	Björn-Ivar	136	117.0	1.2	7.2	DC+	201	22.0	485	151	192.7	20	0	17	1.38

PL4-DW 50 (Weld A)

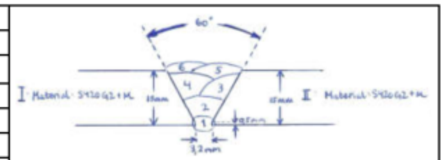
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	29 April 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 4 - DW50	Welding position	PF
Procedure standard	PL1-SW	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	51.9	1.2	2.2	DC+	105	14.7	145	131	66.4	20	0	8	1.39
	2	Björn-Ivar	138		1.2	2.2	DC+	105	14.7	145	122	71.3	20	0	8	1.30
	3	Björn-Ivar	138		1.2	2.2	DC+	105	14.7	160	125	76.8	20	0	8	1.21
	4	Björn-Ivar	138		1.2	2.2	DC+	105	14.7	50	46	65.2	20	0	8	1.42
2	1	Björn-Ivar	136		1.2	8.3	DC+	209	23.0	265	74	214.9	20	0	12	1.34
	2	Björn-Ivar	136		1.2	8.3	DC+	209	23.0	230	71	194.4	20	0	12	1.48
3	1	Björn-Ivar	136	83.8	1.2	8.3	DC+	209	23.0	160	56	171.4	20	0	12	1.68
	2	Björn-Ivar	136		1.2	8.3	DC+	209	23.0	175	42	250.0	20	0	12	1.15
	3	Björn-Ivar	136		1.2	8.3	DC+	209	23.0	75	22	204.5	20	0	13	1.41
4	1	Björn-Ivar	136	77.6	1.2	8.3	DC+	209	23.0	390	121	193.4	20	0	16	1.49
	2	Björn-Ivar	136		1.2	8.3	DC+	209	23.0	105	33	190.9	20	0	16	1.51
5	1	Björn-Ivar	136	70.0	1.2	8.3	DC+	202	22.0	280	71	236.6	20	0	14	1.13
	2	Björn-Ivar	136		1.2	8.3	DC+	202	22.0	220	62	212.9	20	0	14	1.25
6	1	Björn-Ivar	136	40.3	1.2	8.3	DC+	202	22.0	305	94	194.7	20	0	17	1.37
	2	Björn-Ivar	136		1.2	8.3	DC+	202	22.0	195	63	185.7	20	0	17	1.44

PL5-DW 15 (Weld A)

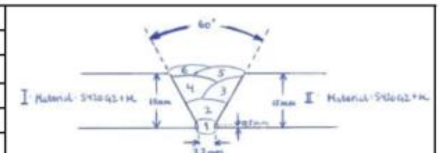
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	29 April 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 5 - DW15	Welding position	PF
Procedure standard	PL1-SW	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138		1.2	2.1	DC+	98	14.7	95	79	72.2	20	0	7	1.20
	2	Björn-Ivar	138		1.2	2.1	DC+	98	14.7	130	108	72.2	20	0	7	1.20
	3	Björn-Ivar	138		1.2	2.1	DC+	98	14.7	105	78	80.8	20	0	7	1.07
	4	Björn-Ivar	138		1.2	2.2	DC+	107	14.7	85	59	86.4	20	0	7	1.09
	5	Björn-Ivar	138		1.2	2.2	DC+	107	14.7	105	65	96.9	20	0	7	0.97
2	1	Björn-Ivar	136		1.2	8.3	DC+	224	23.0	495	90	330.0	20	0	12	0.94
3	1	Björn-Ivar	136	101.8	1.2	8.3	DC+	230	23.0	310	122	152.5	20	0	16	2.08
	2	Björn-Ivar	136		1.2	8.3	DC+	229	23.0	185	53	209.4	20	0	16	1.51
4	1	Björn-Ivar	136	125.2	1.2	8.3	DC+	217	23.0	495	137	216.8	20	0	-	1.38
5	1	Björn-Ivar	136	62.0	1.2	8.3	DC+	204	22.0	450	124	217.7	20	0	15	1.24
	2	Björn-Ivar	136		1.2	8.3	DC+	204	22.0	45	18	154.3	20	0	15	1.75
6	1	Björn-Ivar	136	114.0	1.2	8.3	DC+	204	22.0	495	161	184.5	20	0	18	1.46

PL6-DW 15 (Weld A)

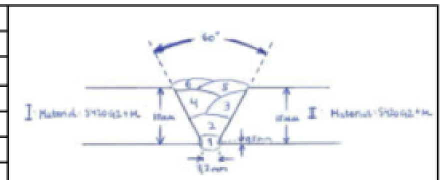
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	30 April 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 6 - DW15	Welding position	PF
Procedure standard	PL1-SW	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	18.6	1.2	2.2	DC+	100	14.7	170	153	66.7	20	0	8	1.32
	2	Björn-Ivar	138		1.2	2.2	DC+	99	14.7	140	121	69.4	20	0	8	1.25
	3	Björn-Ivar	138		1.2	2.2	DC+	99	14.7	110	95	69.5	20	0	8	1.25
	4	Björn-Ivar	138		1.2	2.2	DC+	97	14.7	90	89	60.7	20	0	8	1.40
2	1	Björn-Ivar	136	46.0	1.2	8.3	DC+	238	23.0	495	172	172.7	20	0	12	1.90
3	1	Björn-Ivar	136	107.8	1.2	8.3	DC+	227	23.0	410	120	205.0	20	0	-	1.53
	2	Björn-Ivar	136		1.2	8.3	DC+	227	23.0	85	26	196.2	20	0	-	1.60
4	1	Björn-Ivar	136	136.0	1.2	8.3	DC+	214	23.0	495	156	190.4	20	0	15	1.55
5	1	Björn-Ivar	136	70.0	1.2	7.0	DC+	196	22.0	495	173	171.7	20	0	16	1.51
6	1	Björn-Ivar	136	89.0	1.2	7.0	DC+	202	22.0	495	163	182.2	20	0	17	1.46

PL7-DW 5 (Weld A)

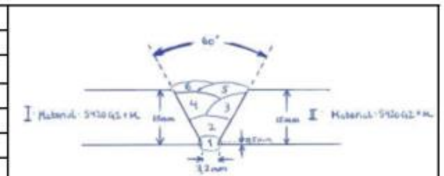
WPQR nr.:	**S420PL1-M**	**Welding method**	**138 / 136**
Date & Place	**30 April 2019 KIWA**	**Gas/Purge gas**	**Argon/18% CO2 (M21)**
Plate ID:	**Plate 7 - DW5**	**Welding position**	**PF**
Procedure standard	**PL1-SW**	**Groove type**	**BW**
Welder.: ID	**BI**	**Stand off distance**	**10-25 mm**
Material / heat nr.:	**43831-9133182**	**Torch angle**	**70-90**
Filler mat. / batch / Lot	**NSSW SM-47A, NSSW SF-3AM**	**Nozzle diam**	**10-20 mm**



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	59.0	1.2	2.2	DC+	97.0	14.7	250	242	62.0	20	0	8	1.38
	2	Björn-Ivar	138		1.2	2.2	DC+	92.0	14.7	180	168	64.3	20	0	-	1.26
	3	Björn-Ivar	138		1.2	2.2	DC+	98.8	14.7	65	66	59.1	20	0	-	1.47
2	1	Björn-Ivar	136	64.0	1.2	8.3	DC+	227.1	23.0	495	170	174.7	20	0	-	1.79
3	1	Björn-Ivar	136	97.0	1.2	8.3	DC+	227.2	23.0	495	145	204.8	20	0	15	1.53
4	1	Björn-Ivar	136	124.0	1.2	8.3	DC+	224.0	23.0	495	160	185.6	20	0	16	1.67
5	1	Björn-Ivar	136	67.0	1.2	7.0	DC+	202.0	22.0	495	173	171.7	20	0	17	1.55
6	1	Björn-Ivar	136	99.0	1.2	7.0	DC+	202.9	22.0	495	157	189.2	20	0	18	1.42

PL8-DW 5 (Weld A)

WPQR nr.:	**S420PL1-M**	**Welding method**	**138 / 136**
Date & Place	**30 April 2019 KIWA**	**Gas/Purge gas**	**Argon/18% CO2 (M21)**
Plate ID:	**Plate 8 - DW5**	**Welding position**	**PF**
Procedure standard	**PL1-SW**	**Groove type**	**BW**
Welder.: ID	**BI**	**Stand off distance**	**10-25 mm**
Material / heat nr.:	**43831-9133182**	**Torch angle**	**70-90**
Filler mat. / batch / Lot	**NSSW SM-47A, NSSW SF-3AM**	**Nozzle diam**	**10-20 mm**



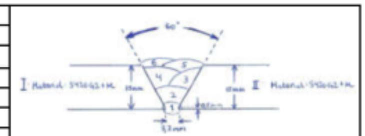
String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138		1.2	2.2	DC+	100	14.7	175	146	71.9	20	0	7	1.23
	2	Björn-Ivar	138		1.2	2.2	DC+	96	14.7	130	100	78.0	20	0	7	1.09
	3	Björn-Ivar	138		1.2	2.2	DC+	93	14.7	110	72	91.7	20	0	7	0.90
	4	Björn-Ivar	138		1.2	2.2	DC+	87	14.7	95	68	83.8	20	0	7	0.91
2	1	Björn-Ivar	136		1.2	8.3	DC+	223	23.0	495	174	170.7	20	0	13	1.80
3	1	Björn-Ivar	136	131.4	1.2	8.3	DC+	220	23.0	495	138	215.2	20	0	15	1.41
4	1	Björn-Ivar	136	134.2	1.2	8.3	DC+	225	23.0	290	90	193.3	20	0	15	1.61
	2	Björn-Ivar	136		1.2	8.3	DC+	225	23.0	205	64	192.2	20	0	15	1.62
5	1	Björn-Ivar	136	53.8	1.2	7.0	DC+	202	22.0	495	166	178.9	20	0	17	1.49
6	1	Björn-Ivar	136	116.5	1.2	7.0	DC+	189	22.0	495	167	177.8	20	0	18	1.40

- Doc D402 - All Weld log's for repair Weld B

All Weld log's for repair Weld B:

PL3-DW 50-Rep (Weld B)

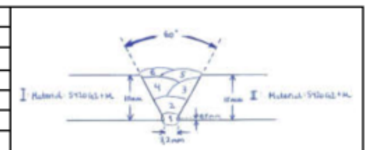
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	7 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 3 - DW50 - weld 2	Welding position	PF
Procedure standard	PL3/4-DW50-Rep	Groove type	BW
Welder.: ID	AF	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Arild	138	82.0	1.2	2.2	DC+	95	14.7	90	77	70.1	20	0	-	1.19
	2	Arild	138		1.2	2.2	DC+	95	14.7	70	58	72.4	20	0	-	1.16
	3	Arild	138		1.2	2.2	DC+	97	14.7	75	61	73.8	20	0	-	1.16
	4	Arild	138		1.2	2.2	DC+	98	14.7	85	66	77.3	20	0	-	1.12
	5	Arild	138		1.2	2.2	DC+	96	14.7	125	73	102.7	20	0	-	0.82
	6	Arild	138		1.2	2.2	DC+	96	14.7	160	99	97.0	20	0	6	0.87
2	1	Arild	136	74.0	1.2	8.3	DC+	229	23.0	185	43	258.1	20	0	11	1.22
	2	Arild	136		1.2	8.3	DC+	217	23.0	155	51	182.4	20	0	11	1.64
	3	Arild	136		1.2	8.3	DC+	213	23.0	170	62	164.5	20	0	11	1.79
3	1	Arild	136	75.0	1.2	8.3	DC+	218	23.0	205	40	307.5	20	0	13	0.98
	2	Arild	136		1.2	8.3	DC+	231	23.0	220	53	249.1	20	0	13	1.28
	3	Arild	136		1.2	8.3	DC+	231	23.0	75	21	214.3	20	0	13	1.49
4	1	Arild	136	101.0	1.2	8.3	DC+	220	23.0	270	68	238.2	20	0	-	1.27
	2	Arild	136		1.2	8.3	DC+	226	23.0	230	65	212.3	20	0	-	1.47
5	1	Arild	136	117.0	1.2	7.0	DC+	199	22.0	205	72	170.8	20	0	15	1.54
	2	Arild	136		1.2	7.0	DC+	204	22.0	200	69	173.9	20	0	15	1.55
	3	Arild	136		1.2	7.0	DC+	208	22.0	95	28	203.6	20	0	16	1.35
6	1	Arild	136	124.0	1.2	7.0	DC+	200	22.0	105	47	134.0	20	0	12	1.97
	2	Arild	136		1.2	7.0	DC+	203	22.0	195	59	198.3	20	0	12	1.35
	3	Arild	136		1.2	7.0	DC+	206	22.0	200	48	250.0	20	0	12	1.09

PL4-DW 50-Rep (Weld B)

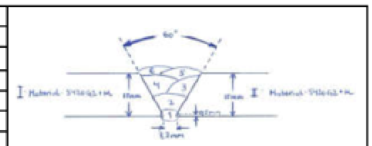
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	9 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 4 - DW50 - weld 2	Welding position	PF
Procedure standard	PL3/4-DW50-Rep	Groove type	BW
Welder.: ID	AF	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Arild	138	85.0	1.2	2.2	DC+	96	14.7	100	91	65.9	20	0	-	1.28
	2	Arild	138		1.2	2.2	DC+	98	14.7	110	89	74.2	20	0	-	1.17
	3	Arild	138		1.2	2.2	DC+	97	14.7	100	90	66.7	20	0	-	1.28
	4	Arild	138		1.2	2.2	DC+	98	14.7	105	75	84.0	20	0	-	1.03
	5	Arild	138		1.2	2.2	DC+	97	14.7	140	103	81.6	20	0	-	1.05
2	1	Arild	136	72.0	1.2	8.3	DC+	227	23.0	340	90	226.7	20	0	11	1.38
	2	Arild	136		1.2	8.3	DC+	227	23.0	160	50	192.0	20	0	11	1.63
3	1	Arild	136	74.0	1.2	8.3	DC+	225	23.0	250	66	227.3	20	0	-	1.37
	2	Arild	136		1.2	8.3	DC+	225	23.0	230	64	215.6	20	0	-	1.44
4	1	Arild	136	85.0	1.2	8.3	DC+	235	23.0	210	68	185.3	20	0	-	1.75
	2	Arild	136		1.2	8.3	DC+	235	23.0	270	77	210.4	20	0	-	1.54
5	1	Arild	136	76.0	1.2	7.0	DC+	202	22.0	285	98	174.5	20	0	18	1.53
	2	Arild	136		1.2	7.0	DC+	204	22.0	195	66	177.3	20	0	18	1.52
6	1	Arild	136	146.0	1.2	7.0	DC+	204	22.0	435	114	228.9	20	0	11	1.18

PL5-DW 15-Rep (Weld B)

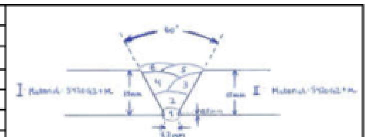
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	9 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 5 - DW15 - weld 2	Welding position	PF
Procedure standard	PL5/6-DW50-Rep	Groove type	BW
Welder.: ID	AF	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Arild	138	76.0	1.2	2.2	DC+	95	14.7	150	166	54.2	20	0	8	1.55
	2	Arild	138		1.2	2.2	DC+	99	14.7	125	125	60.0	20	0	8	1.46
	3	Arild	138		1.2	2.2	DC+	97	14.7	250	205	73.2	20	0	8	1.17
2	1	Arild	136	76.0	1.2	8.3	DC+	226	23.0	275	73	226.0	20	0	11	1.38
	2	Arild	136		1.2	8.3	DC+	226	23.0	200	63	190.5	20	0	11	1.64
3	1	Arild	136	80.0	1.2	8.3	DC+	231	23.0	215	55	234.5	20	0	12	1.36
	2	Arild	136		1.2	8.3	DC+	231	23.0	105	25	252.0	20	0	12	1.27
	3	Arild	136		1.2	8.3	DC+	222	23.0	135	37	218.9	20	0	12	1.40
4	1	Arild	136	74.0	1.2	8.3	DC+	229	23.0	130	44	177.3	20	0	13	1.78
	2	Arild	136		1.2	8.3	DC+	220	23.0	360	111	194.6	20	0	13	1.56
5	1	Arild	136	70.0	1.2	7.0	DC+	207	22.0	460	138	200.0	20	0	15	1.37
6	1	Arild	136	88.0	1.2	7.0	DC+	208	22.0	235	54	261.1	20	0	12	1.05
	2	Arild	136	110.0	1.2	7.0	DC+	201	22.0	255	58	263.8	20	0	-	1.01

PL6-DW 15-Rep (Weld B)

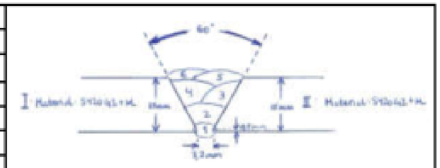
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	10 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 6 - DW15 - weld 2	Welding position	PF
Procedure standard	PL5/6-DW50-Rep	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	62.0	1.2	2.2	DC+	101	14.7	120	112	64.3	20	0	-	1.39
	2	Björn-Ivar	138		1.2	2.2	DC+	98	14.7	115	136	50.7	20	0	-	1.70
	3	Björn-Ivar	138		1.2	2.2	DC+	99	14.7	155	150	62.0	20	0	-	1.40
	4	Björn-Ivar	138		1.2	2.2	DC+	97	14.7	115	77	89.6	20	0	-	0.95
2	1	Björn-Ivar	136	100.0	1.2	8.3	DC+	239	23.0	495	154	192.9	20	0	-	1.71
3	1	Björn-Ivar	136	110.0	1.2	8.3	DC+	229	23.0	495	123	241.5	20	0	-	1.31
4	1	Björn-Ivar	136	148.0	1.2	8.3	DC+	233	23.0	495	140	212.1	20	0	13	1.52
5	1	Björn-Ivar	136	80.0	1.2	7.0	DC+	204	22.0	495	152	195.4	20	0	16	1.38
6	1	Björn-Ivar	136	101.0	1.2	7.0	DC+	198	22.0	495	161	184.5	20	0	14	1.42

PL7-DW 5-Rep (Weld B)

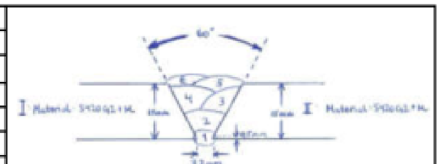
WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	10 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 7 - DW5 - weld 2	Welding position	PF
Procedure standard	PL7/8-DW50-Rep	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	64.0	1.2	2.2	DC+	100	14.7	150	130	69.2	20	0	-	1.27
	2	Björn-Ivar	138		1.2	2.2	DC+	99	14.7	115	120	57.5	20	0	-	1.52
	3	Björn-Ivar	138		1.2	2.2	DC+	100	14.7	235	168	83.9	20	0	-	1.05
2	1	Björn-Ivar	136	81.0	1.2	8.3	DC+	227	23.0	495	155	191.6	20	0	-	1.64
3	1	Björn-Ivar	136	70.0	1.2	8.3	DC+	224	23.0	495	134	221.6	20	0	14	1.39
4	1	Björn-Ivar	136	100.0	1.2	8.3	DC+	233	23.0	495	149	199.3	20	0	-	1.62
5	1	Björn-Ivar	136	87.0	1.2	7.0	DC+	206	22.0	495	148	200.7	20	0	-	1.36
6	1	Björn-Ivar	136	92.0	1.2	7.0	DC+	204	22.0	495	130	228.5	20	0	13	1.18

PL8-DW 5-Rep (Weld B)

WPQR nr.:	S420PL1-M	Welding method	138 / 136
Date & Place	10 May 2019 KIWA	Gas/Purge gas	Argon/18% CO2 (M21)
Plate ID:	Plate 8 - DW5 - weld 2	Welding position	PF
Procedure standard	PL7/8-DW50-Rep	Groove type	BW
Welder.: ID	BI	Stand off distance	10-25 mm
Material / heat nr.:	43831-9133182	Torch angle	70-90
Filler mat. / batch / Lot	NSSW SM-47A, NSSW SF-3AM	Nozzle diam	10-20 mm



String	Seq.	Welder	Method	Temp °C	Wire Ø (mm)	Wirefeed m/min	AC/DC+/DC-	Current (A)	Voltage (V)	Length (mm)	Time (s)	Speed mm/min	Gass (L/min)	Purge gas (L/min)	weld width (mm)	Heat input kJ/mm
1	1	Björn-Ivar	138	50.0	1.2	2.2	DC+	95	14.7	135	117	69.2	20	0	8	1.22
	2	Björn-Ivar	138		1.2	2.2	DC+	97	14.7	135	144	56.3	20	0	8	1.53
	3	Björn-Ivar	138		1.2	2.2	DC+	98	14.7	115	113	61.1	20	0	8	1.42
	4	Björn-Ivar	138		1.2	2.2	DC+	98	14.7	120	85	84.7	20	0	8	1.02
2	1	Björn-Ivar	136	80.0	1.2	8.3	DC+	224	23.0	495	150	198.0	20	0	12	1.56
3	1	Björn-Ivar	136	130.0	1.2	8.3	DC+	223	23.0	495	128	232.0	20	0	13	1.33
4	1	Björn-Ivar	136	74.0	1.2	8.3	DC+	223	23.0	495	144	206.3	20	0	14	1.49
5	1	Björn-Ivar	136	124.0	1.2	7.0	DC+	208	22.0	495	156	190.4	20	0	16	1.44
6	1	Björn-Ivar	136	70.0	1.2	7.0	DC+	208	22.0	495	141	210.6	20	0	-	1.30

Appendix E

Manufacturing and welding process, characterization of the Steel S420G2+M

- NDT, Mechanical Testing and Specimen Preparation

- Doc E501 - NDT report - Radiograpic Examination
- Doc E502 - Qlabs Material Report 8612-2 (PL 3)
- Doc E503 - Qlabs Material Report 8612-3 (PL 5)
- Doc E504 - Qlabs Material Report 8612-4 (PL7)

- Doc E501 - NDT report - Radiograpic Examination

Doc E5XX - Report8076-19-DRT-1

Doc E5XX - Report8076-19-DRT-2-REV1

Doc E5XX - Report8076-19-DRT-3-REV1

Doc E5XX - Report8076-19-DRT-5

Doc E5XX - Report8076-19-DRT-6

Doc E5XX - Report8076-19-DRT-7

IKM Inspection AS

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Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-1**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 3 - DW 50.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

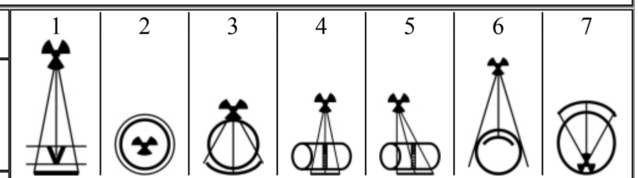
MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3

EXP. DATA		A	B	C	D
	TUBE VOLT kV	**220**			
	FILMFOCUS DISTANCE mm	**700**			
	EXP.TIME mAmin. Cimin.	**4,5**			

I.Q.I. SOURCE SIDE
☑ KILDESIDE
☐ FILMSIDE
TYPE OF I.Q.I. / I.Q.I. TYPE
W 6 FE<



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15 **Approved /Godkjent** IKM Inspection AS	OPERATOR / OPERATØR DATO:2019-05-15 IKM Inspection AS

IKM Inspection AS

Digital RT
Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-2-REV1**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 4 - DW 50.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

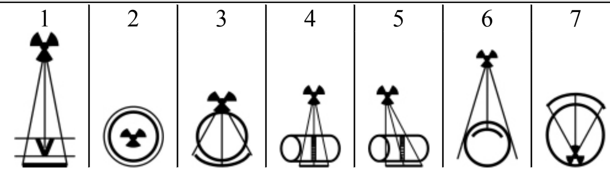
EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3

EXP. DATA		A	B	C	D
	TUBE VOLT kV	**220**			
	FILMFOCUS DISTANCE mm	**700**			
	EXP.TIME mAmin. Cimin.	**4,5**			

I.Q.I. SOURCE SIDE
☑ KILDESIDE
☐ FILMSIDE
TYPE OF I.Q.I. / I.Q.I. TYPE
W 6 FE<

1 2 3 4 5 6 7



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**270**	**517**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15	OPERATOR / OPERATØR DATO:2019-05-15
	Approved /Godkjent IKM Inspection AS	IKM Inspection AS

IKM Inspection AS

Digital RT
Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-3-REV1**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 5 - DW 15.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

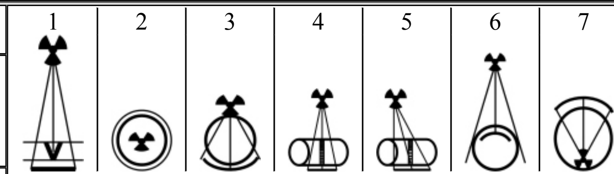
MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3

EXP. DATA		A	B	C	D	
	TUBE VOLT kV	**220**				I.Q.I. SOURCE SIDE: ☑ KILDESIDE ☐ FILMSIDE
	FILMFOCUS DISTANCE mm	**700**				
	EXP.TIME mAmin. Cimin.	**4,5**				TYPE OF I.Q.I. / I.Q.I. TYPE **W 6 FE<**

1 2 3 4 5 6 7



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**60**	**2011**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15 **Approved /Godkjent**	OPERATOR / OPERATØR DATO:2019-05-15

IKM Inspection AS

Digital RT
Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-5**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 6 - DW 15.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

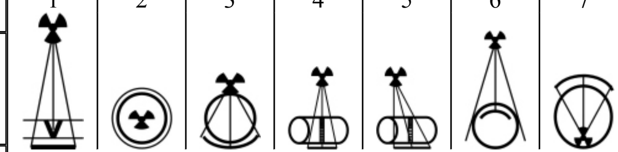
PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3

1 2 3 4 5 6 7



EXP. DATA		A	B	C	D
	TUBE VOLT kV	**220**			
	FILMFOCUS DISTANCE mm	**700**			
	EXP.TIME mAmin. Cimin.	**4,5**			

I.Q.I. SOURCE SIDE
☑ KILDESIDE
☐ FILMSIDE

TYPE OF I.Q.I. / I.Q.I. TYPE
W 6 FE<

DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**100**	**515**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**360**	**515**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15	OPERATOR / OPERATØR DATO:2019-05-15
	Approved /Godkjent IKM Inspection AS [signature]	IKM Inspection AS [signature]

IKM Inspection AS

Digital RT
Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-6**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 7 - DW 5.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

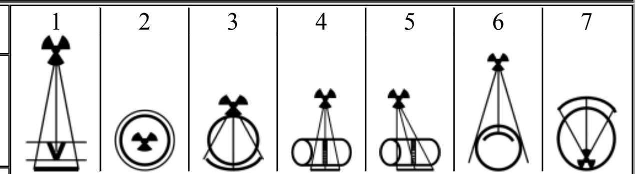
FOCAL SPOT SIZE / BRENNFLEKK
3

EXP. DATA

	A	B	C	D
TUBE VOLT kV	**220**			
FILMFOCUS DISTANCE mm	**700**			
EXP.TIME mAmin. Cimin.	**4,5**			

I.Q.I. SOURCE SIDE
☑ KILDESIDE
☐ FILMSIDE
TYPE OF I.Q.I. / I.Q.I. TYPE
W 6 FE<

1 2 3 4 5 6 7



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**395**	**515**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**130**	**517**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**250**	**517**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15	OPERATOR / OPERATØR DATO:2019-05-15
	Approved /Godkjent IKM Inspection AS	IKM Inspection AS

IKM Inspection AS

Digital RT
Digital RT

CLIENT / KUNDE	CLIENT O.NO / KUNDE O.NR	DATE OF TESTING / KONTROLLDATO	REPORT NO. / RAPPORT NR.	PAGE / SIDE
UIS Stavanger	**X-ray on welds**	**2019-05-15**	**180-8076-19-DRT-7**	**1 of/av 1**

DRAWING NO. / TEGNING NO.	PLACE OF WORK / KONTROLLSTED	OPERATOR / OPERATØR	ATTACHMENT / VEDLEGG
N/A	**IKM Inspection, Bærheim**	**Sorin Erdei**	**0**

OBJECT / KONTROLL AV
PL 8 - DW 5.
Welding Position: PF
Welder ID: AF / BIK
Material: S420

PROCEDURE / PROSEDYRE	REV	EXTENT OF TESTING / KONTROLLOMFANG	ACCEPTANCE STANDARD / AKSEPTSTANDARD
BPI-01.Radiographic Examination ISO 17636-2	**0**	**100 %**	**ISO 10675-1:2016**

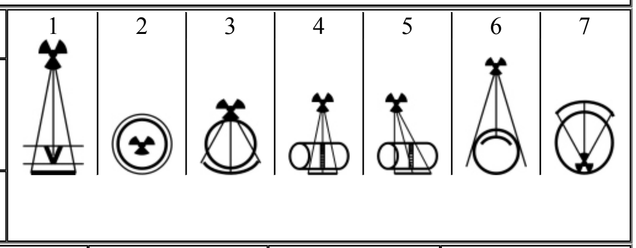
MATERIAL TYPE / MATERIALTYPE	SURFACE / OVERFLATE	GROOVE / FUGEGEOMETRI	WELDING PROCESS / SVEISEPROSESS
S420	**As Welded**	**BW**	**138/136**

EQUIPMENT / UTSTYR X-RAY TUBE / RØNTGENRØR	RADIATION SOURCE POSITION / KILDEPOSISJON TECHNIQUE / TEKNIKK
Smart 225Kv	

FOCAL SPOT SIZE / BRENNFLEKK
3

EXP. DATA		A	B	C	D
	TUBE VOLT kV	**220**			
	FILMFOCUS DISTANCE mm	**700**			
	EXP.TIME mAmin. Cimin.	**4,5**			

I.Q.I. SOURCE SIDE
✔ KILDESIDE
☐ FILMSIDE
TYPE OF I.Q.I. / I.Q.I. TYPE
W 6 FE<



DETECTOR / DETEKTOR	SCREENS AND FILTERS / SKJERMING OG FILTRE	DETECTOR BASIC / SPATIAL RESOLUTION	PIXEL SIZE / PIXELSTØRRELSE	MIN. SNR	TOTAL UNSHARPNESS	MAGNIFICATION / FORSTØRRELSE
HD-IP Plus	**Cu 0,3 mm**	**0,063**	**25 micron**	**168**	**0.1**	**1**

WELD NO SVEIS NR	DATE AND TIME DATO KL.	DIA. PIPE DIA RØR	FILM LOCATION FILM PLASSERING	SENSITIVITY FØLSOMHET % WIRE NR	WELDER SVEISER	MATERIAL THICKNESS TYKKELSE mm	EVALUATION BEDØMMELSE	DEFECT LOCATION FEILENS PLASSERING	REMARKS BEMERKNINGER	EXP. DATA A-D	TECH. TEGN. 1-7
Weld A	**14-05-2019**	**Plate**	**0 - 220**	**W 11**	**AF/BIK**	**15**	**Accepted**	**100**	**517/2011**	**A**	**1**
Weld A	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**340**	**517**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**0 - 220**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**
Weld B	**14-05-2019**	**Plate**	**220 - 440**	**W11**	**AF/BIK**	**15**	**Accepted**	**--**	**--**	**A**	**1**

100 = Sprekk **200** = Hulrom, porer **300** = Fast inneslutting, Slagg **400** = Bindefeil og manglende gjennomsveising **401** = Bindefeil
402 = Rotfeil **500** = Uregelmessig form **501** = Sårkant **600** = Andre uregelmessigheter (spesifiser)

COMMENTS / KOMMENTARER

Result: Accepted

REPAIRS MARKED ON / REPARASJONER AVMERKET PÅ
☐ OBJECT / OBJEKT ☐ SKETCH / SKISSE

N3 NAME CERT. NO. / N3 NAVN SERT. NR.	N2 NAME CERT. NO. / N2 NAVN SERT. NR.	OPERATOR NAME CERT. NO. / OPERATØR NAVN SERT. NR.
()	Sorin Erdei (0816)	Sorin Erdei (0816)
APPROVED / GODKJENT DATO:	APPROVED / GODKJENT DATO:2019-05-15 **Approved /Godkjent** IKM Inspection AS	OPERATOR / OPERATØR DATO:2019-05-15 IKM Inspection AS

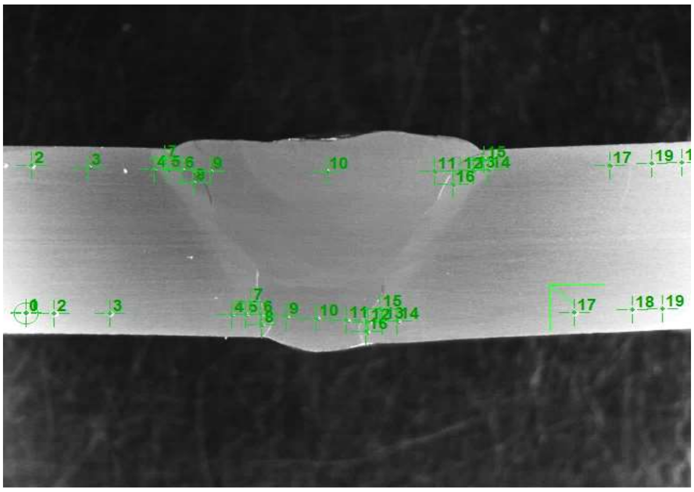
- Doc E502 - Qlabs Material Report 8612-2 (PL 3)

MATERIAL REPORT

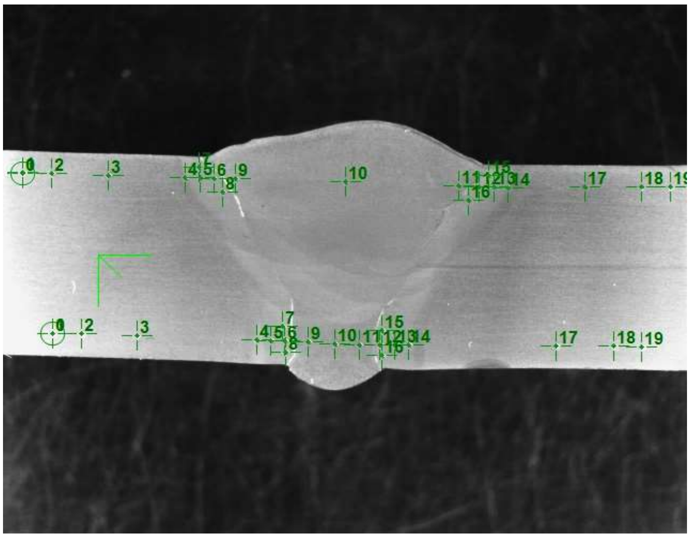
Certificate no:	Rev	Order no:	
8612-2	A	8612	quality lab — *Quality Lab AS, Industrivegen 54, 4110 Forsand, Norge* — NORSK AKKREDITERING TEST 248
Client: Master Thesis UIS		Test date/Report date 22.05.2019 - 27.06.2019	
		Client contact Mattias Larsson	Equipment identification: Mechanical testing of WPQ PL3-DW50
Pages 4		Surveyor Mattias & Magnus Larsson	Standard ISO 15614-1:2017

Additional information: Quality Lab Confirms that the results are connected to the object tested.

Macro examination according to NS-EN 17639:2013			
Etchant:	Nital	Visual examination:	X5



Weld A. A left side



Weld B. B left side

Comment: The Macro are inside the acceptance criteria of NS-EN ISO 5817:2014

Imperfections are inside quality level B.

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-2	A	8612
Client:		Test date/Report date
Master Thesis UIS		22.05.2019 - 27.06.2019

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

NORSK AKKREDITERING TEST 248

Tensile test, NS EN ISO 4136-1:2012 / ISO 6892-1:2016 Method A.1			
Test ident:	Area [mm^2]	R_m [Mpa]	Fracture
Cross weld sample 1	104,66	528	Base material
Cross weld sample 2	102,96	525	Base material

Charpy V impact test, KV8, NS-EN ISO 148-1:2016; ISO 9016:2012							
Test ident	Dimension [mm]	Notch Orientation	Test temp [^{0}C]	Single values [J]			Average [J]
				1	2	3	
Weld	10x10x55	T	-40	121	120	112	118
FL	10x10x55	T	-40	186	124	163	158
FL+2	10x10x55	T	-40	395	341	404	380
FL+5	10x10x55	T	-40	196	215	212	208

MPI examination according to ISO 23278:2015 level B (non accreditated test)

MPI performed, No findings
Accepted

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-2	A	8612
Client:		Test date/Report date
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

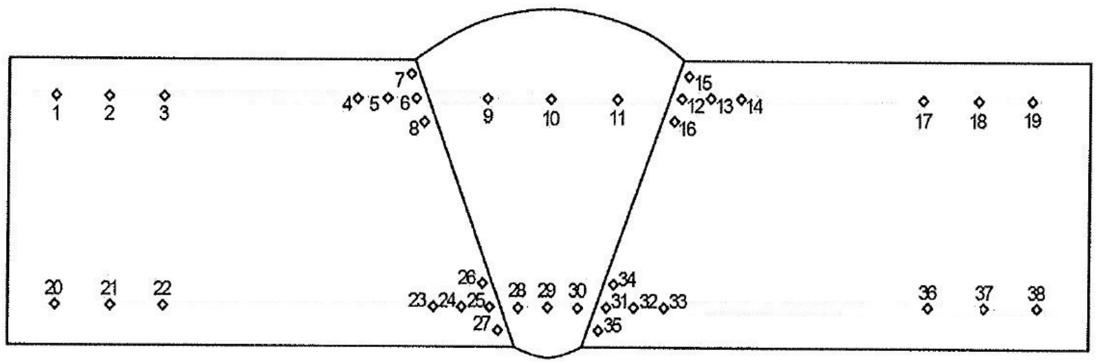
NORSK AKKREDITERING
TEST 248

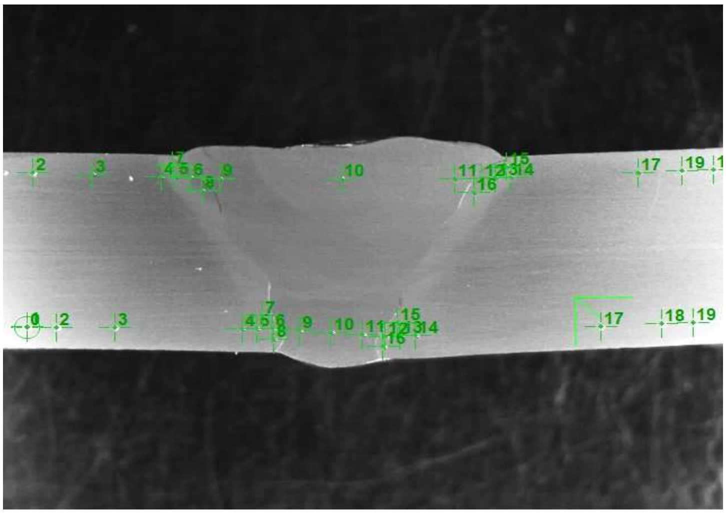
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld A	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	178	178	180	189	205	254	221	246	231	225	230	246	209
	14	15	16	17	18	19							
	179	207	227	177	175	178							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	178	179	182	193	200	209	208	207	211	208	197	204	192
	33	34	35	36	37	38							
	186	201	204	177	176	175							

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-2	A	8612
Client:		Test date/Report date
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

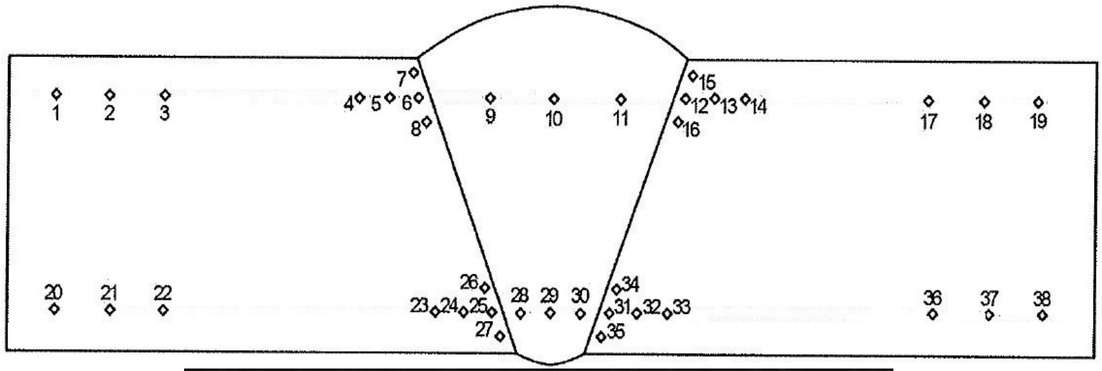
NORSK AKKREDITERING TEST 248

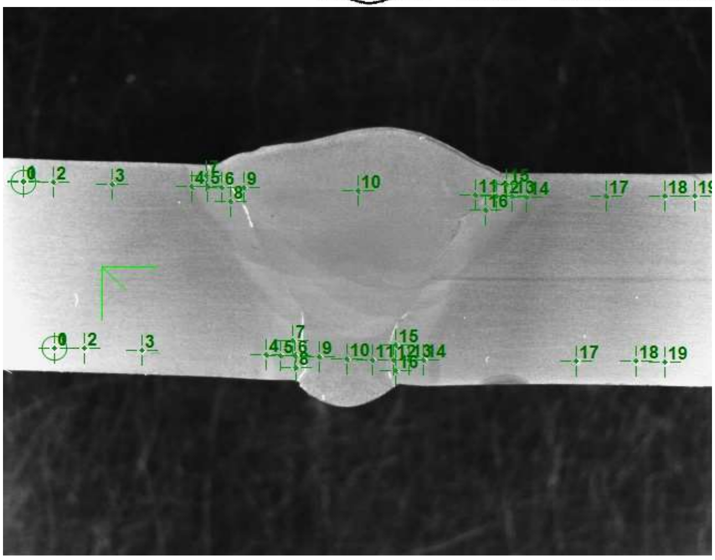
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld B	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	176	175	181	187	197	217	204	213	213	212	213	212	184
	14	15	16	17	18	19							
	180	201	207	186	182	176							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	184	186	186	192	203	199	197	200	204	200	205	204	187
	33	34	35	36	37	38							
	184	205	205	177	181	177							

Date and signature Quality Lab AS	
22.05.2019 - 27.06.2019	*Michael Saavedra, Lab technician*

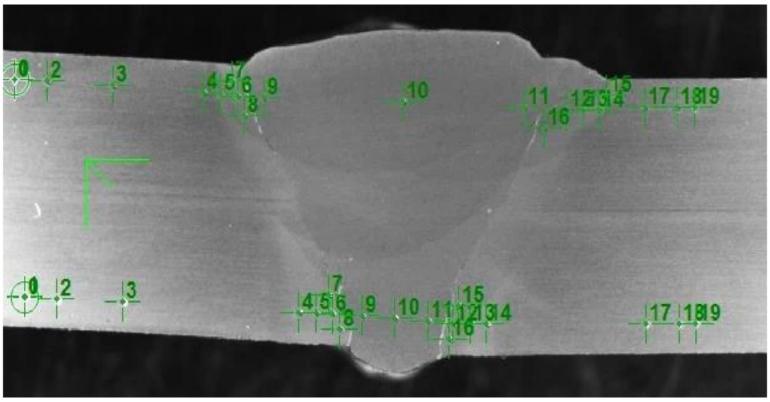
- Doc E503 - Qlabs Material Report 8612-3 (PL 5)

MATERIAL REPORT

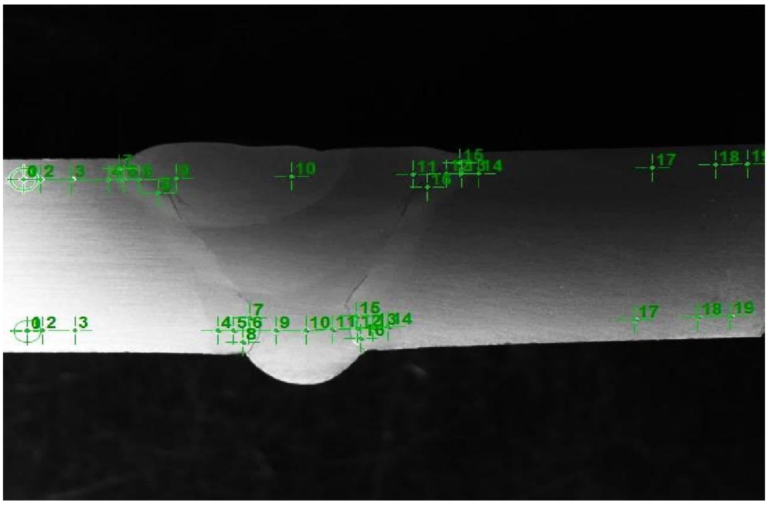
Certificate no:	Rev	Order no:	
8612-3	A	8612	quality lab — Quality Lab AS, Industrivegen 54, 4110 Forsand, Norge — NORSK AKKREDITERING TEST 248
Client: Master Thesis UIS		Test date/Report date: 22.05.2019 - 27.06.2019	
		Client contact: Mattias Larsson	Equipment identification: Mechanical testing of PL5-DW15
Pages: 4		Surveyor: Mattias & Magnus Larsson	Standard: ISO 15614-1:2017

Additional information: Quality Lab Confirms that the results are connected to the object tested.

Macro examination according to NS-EN 17639:2013			
Etchant:	Nital	Visual examination:	X5



Weld A



Weld B

Comment: The Macro are inside the acceptance criteria of NS-EN ISO 5817:2014
Imperfections are inside quality level B.

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-3	A	8612
Client:		Test date/Report date
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

NORSK AKKREDITERING TEST 248

Tensile test, NS EN ISO 4136-1:2012 / ISO 6892-1:2016 Method A.1			
Test ident:	Area [mm^2]	R_m [Mpa]	Fracture
Cross weld sample 1	102,58	537	Base material
Cross weld sample 2	104,11	530	Base material

Charpy V impact test, KV8, NS-EN ISO 148-1:2016; ISO 9016:2012							
Test ident	Dimension [mm]	Notch Orientation	Test temp [^{0}C]	Single values [J]			Average [J]
				1	2	3	
Weld	10x10x55	T	-40	100	84	91	92
FL	10x10x55	T	-40	169	206	143	173
FL+2	10x10x55	T	-40	365	366	372	368
FL+5	10x10x55	T	-40	361	319	327	336

MPI examination according to ISO 23278:2015 Level B (non accreditated test)
MPI performed, No findings Accepted

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-3	A	8612

Client:	Test date/Report date
Master Thesis UIS	22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

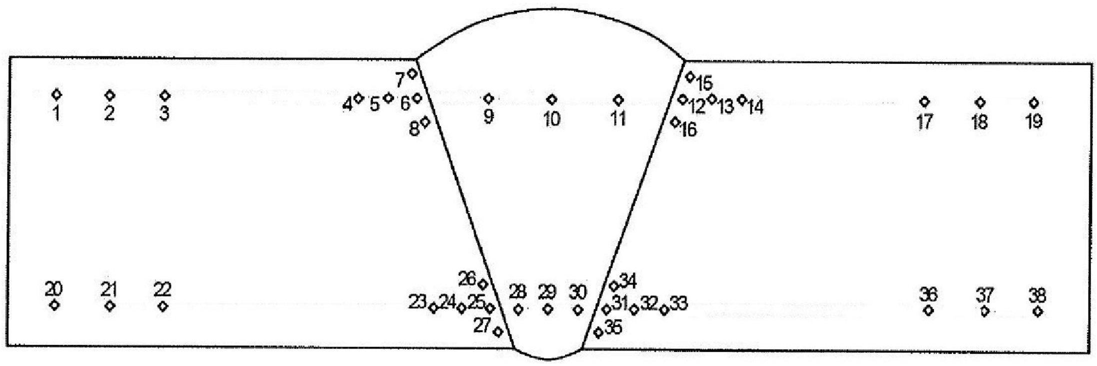
NORSK AKKREDITERING TEST 248

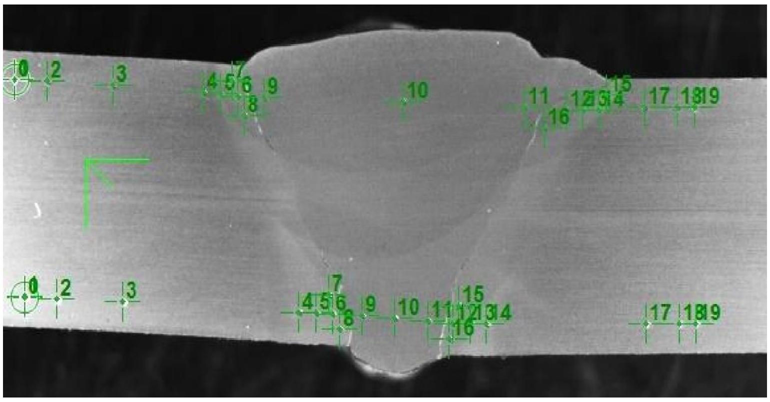
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld A	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	171	177	176	184	187	207	209	206	228	224	225	240	211
	14	15	16	17	18	19							
	196	201	229	179	176	177							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	169	178	177	184	182	195	206	214	202	199	203	207	181
	33	34	35	36	37	38							
	177	209	208	181	175	175							

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-3	A	8612
Client:		**Test date/Report date**
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

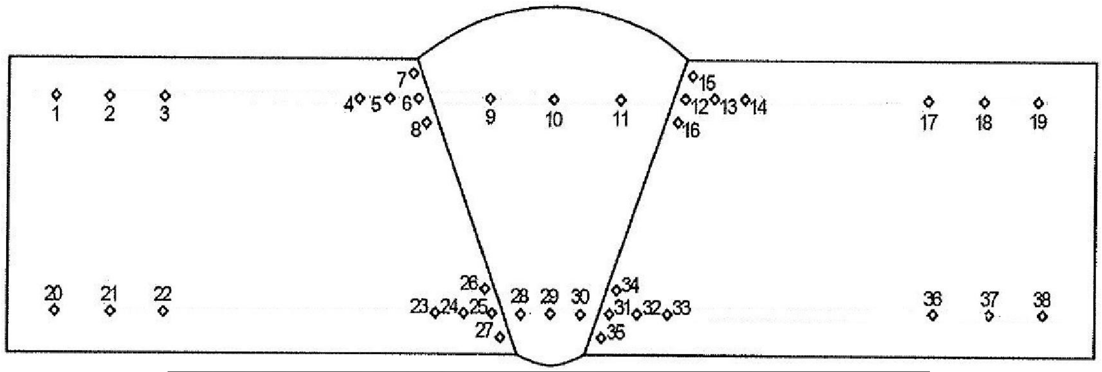
NORSK AKKREDITERING TEST 248

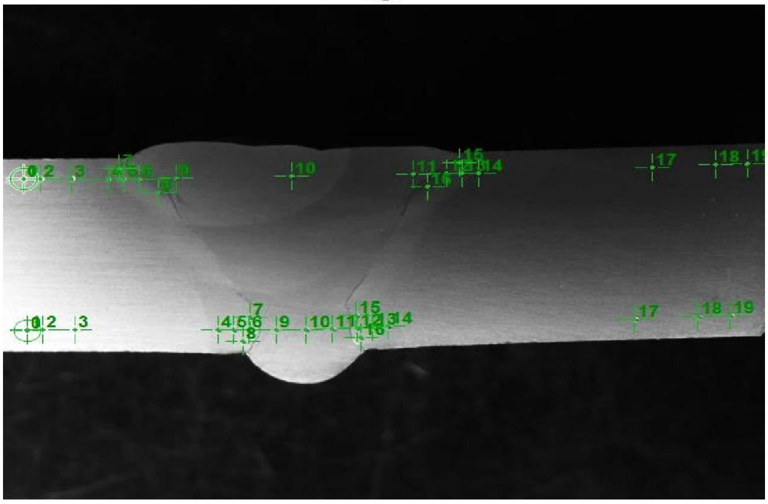
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld B	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	176	180	183	190	197	239	219	253	235	249	240	248	195
	14	15	16	17	18	19							
	187	235	251	183	182	180							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	176	173	175	181	185	196	197	195	199	200	200	200	188
	33	34	35	36	37	38							
	185	202	196	185	188	182							

Date and signature Quality Lab AS	
22.05.2019 - 27.06.2019	*Michael Saavedra, Lab technician*

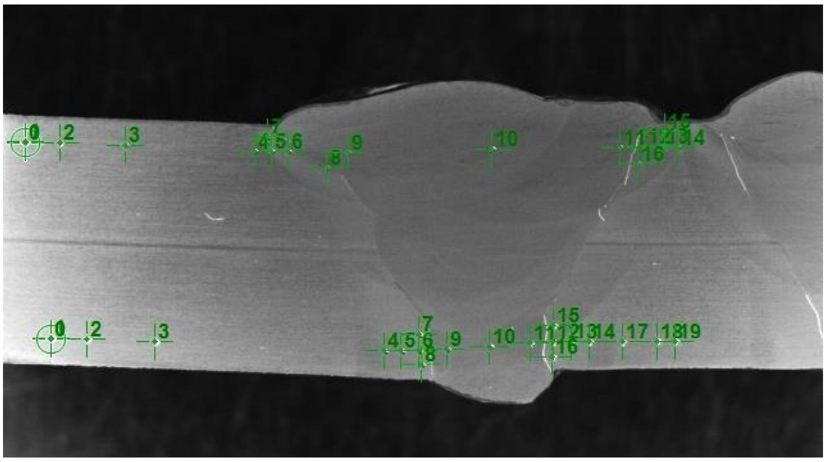
The test report shall not be reproduced except in full, without written approval by the laboratory

- Doc E504 - Qlabs Material Report 8612-4 (PL7)

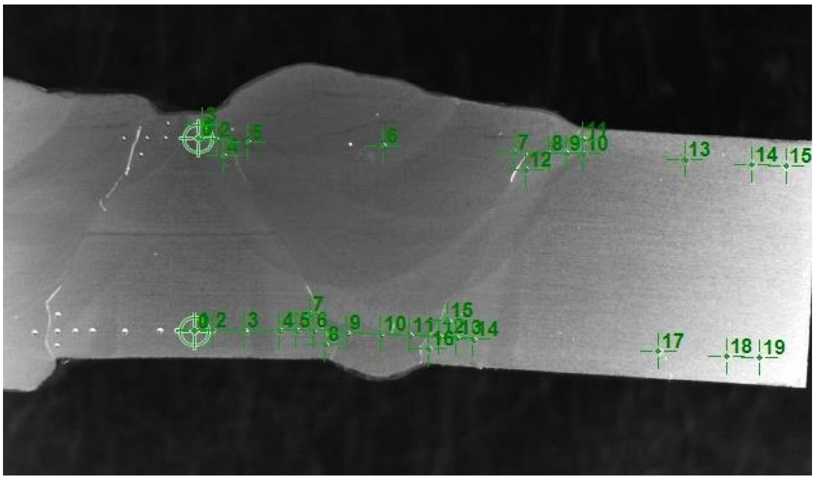
MATERIAL REPORT

Certificate no:	Rev	Order no:		
8612-4	A	8612	quality lab	Quality Lab AS Industrivegen 54 4110 Forsand Norge NORSK AKKREDITERING TEST 248
Client: Master Thesis UIS		Test date/Report date 22.05.2019 - 27.06.2019		
		Client contact Mattias Larsson	Equipment identification: Mechanical testing of PL7-DW5	
Pages 4		Surveyor Mattias & Magnus Larsson	Standard ISO 15614-1:2017	
Additional information:		Quality Lab Confirms that the results are connected to the object tested.		

Macro examination according to NS-EN 17639:2013			
Etchant:	Nital	Visual examination:	X5



Weld A



Weld B

Comment: The Macro are inside the acceptance criteria of NS-EN ISO 5817:2014
Imperfections are inside quality level B.

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-4	A	8612
Client:		**Test date/Report date**
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

NORSK AKKREDITERING TEST 248

Tensile test, NS EN ISO 4136-1:2012 / ISO 6892-1:2016 Method A.1			
Test ident:	Area [mm^2]	R_m [Mpa]	Fracture
Cross weld sample 1	101,63	534	Base material
Cross weld sample 2	105,61	533	Base material

Charpy V impact test, KV8, NS-EN ISO 148-1:2016; ISO 9016:2012							
Test ident	Dimension [mm]	Notch Orientation	Test temp [^{0}C]	Single values [J]			Average [J]
				1	2	3	
Weld	10x10x55	T	-40	107	84	81	91
FL	10x10x55	T	-40	203	281	141	208
FL+2	10x10x55	T	-40	245	354	396	332
FL+5	10x10x55	T	-40	343	306	301	317

MPI examination according to ISO 23278:2015 level B (non accreditated test)

MPI performed, No findings
Accepted

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-4	A	8612
Client:		**Test date/Report date**
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

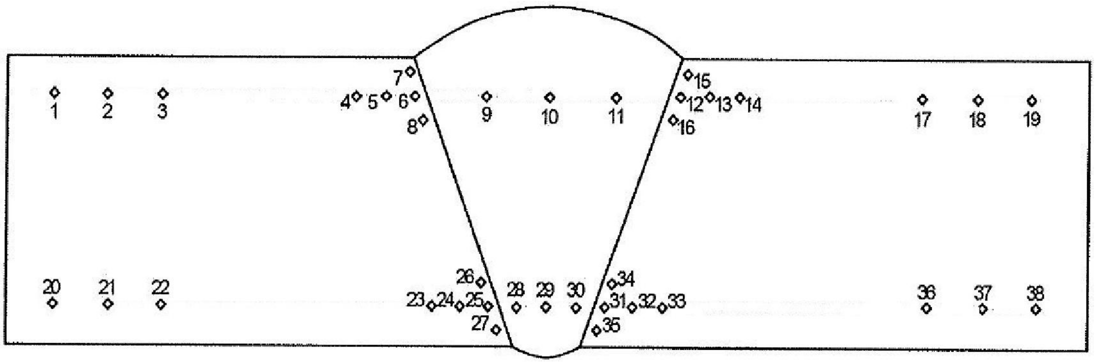
NORSK AKKREDITERING TEST 248

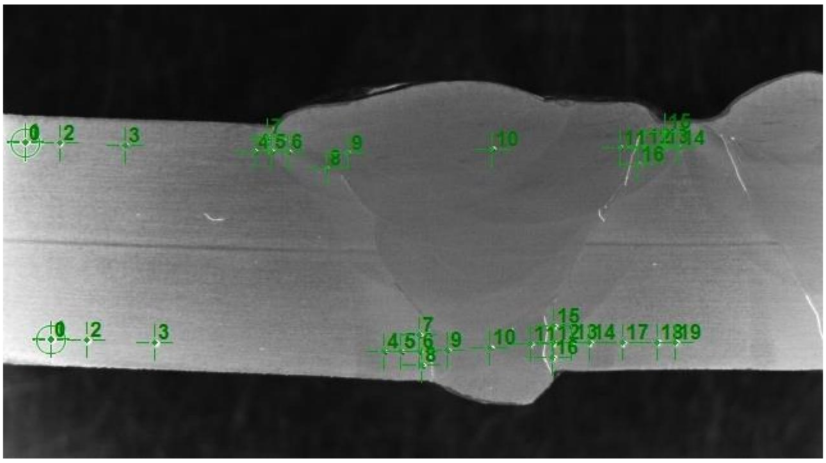
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld A	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	176	182	181	189	195	223	205	244	228	224	224	230	195
	14	15	16	17	18	19							
	185	198	217	NA	NA	NA							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	177	177	176	182	176	192	200	193	197	201	195	204	183
	33	34	35	36	37	38							
	179	208	203	177	185	181							

MATERIAL REPORT

Certificate no:	Rev	Order no:
8612-4	A	8612
Client:		**Test date/Report date**
Master Thesis UIS		22.05.2019 - 27.06.2019

quality lab

Quality Lab AS
Industrivegen 54
4110 Forsand
Norge

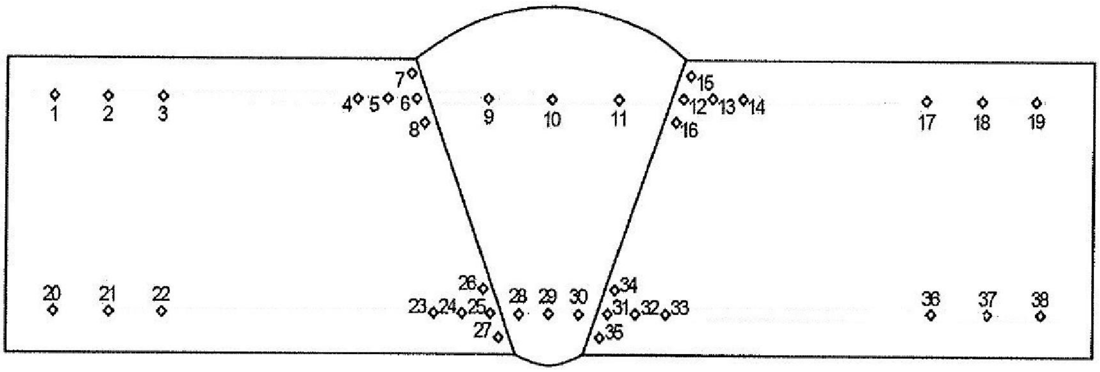
NORSK AKKREDITERING TEST 248

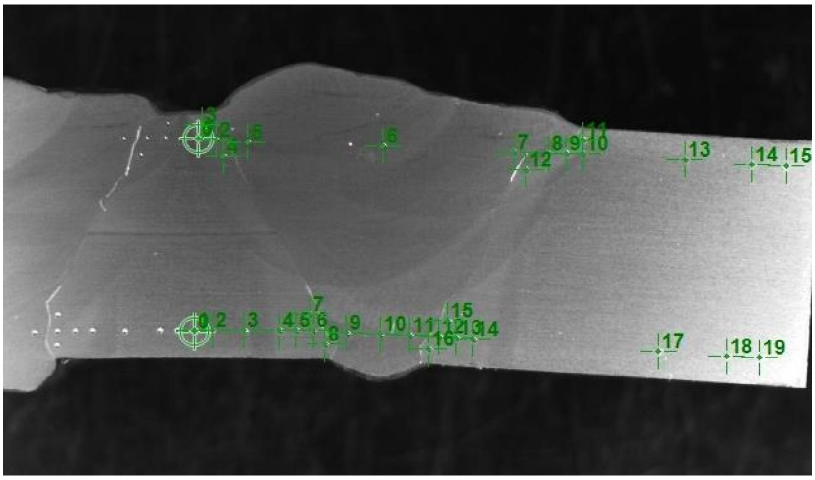
Hardness test, NS-EN ISO 9015-1:2011

Test method: Hardness vickers HV10	Position: Weld B	Surface: Polished and etched

Cap

Root





	1	2	3	4	5	6	7	8	9	10	11	12	13
Cap	NA	NA	NA	NA	195	235	216	224	242	221	229	227	188
	14	15	16	17	18	19							
	193	194	219	183	183	178							
	20	21	22	23	24	25	26	27	28	29	30	31	32
Root	185	186	184	172	184	202	197	198	195	207	195	193	184
	33	34	35	36	37	38							
	186	205	207	182	186	179							

Date and signature Quality Lab AS	
22.05.2019 - 27.06.2019	*Michael Saavedra, Lab technician*

Appendix F

Microstructural Examination

- The chapter "Microstructural Examination" has no attachments.

Appendix G

Fatigue Testing

- Doc G701 - Fatigue test - Prior to fabrication specimens
- Doc G702 - Fatigue test - Unwelded base metal specimens
- Doc G703 - Fatigue test - Production test plate specimens

- Doc G701 - Fatigue test - Prior to fabrication specimens

①

Fatigue test log - rev 0

OBS! Area should be 205 mm2!

$\sigma = \frac{F}{A} = \frac{98.6}{205} = 481.2$ MPa

R= 0,1

Project name: Larsson Master thesis pilot
Specimen ID: F1
Date: 11/6-19

Stress range (ΔS)	~~300~~ 481.2	Mpa	Load range ΔF	98.6	kN
Target life	250 000	Cycles	Max load	109.6	kN
Area	328.8	mm²	Min load	11.0	kN
Cyclic rate		Hz	Mean load	60.3	kN
Test rig	MTS 809	Machine load	60.3	49.3	± kN

ΔF=ΔS*Area/1000

Fmax=ΔF/(1-R)

Fmin=Fmax-ΔF

Fmean=(Fmax+Fmin)/2

F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign
11/6-19	9:30	0		
〃	~~8626~~ 9.45	8626	~~Lite~~ Liten sprela aks.	ZG
		12195	Brudd	
			~~[illegible]~~	
			Failure Criterion:	
			Complete fracture	
			Initiated at weld cap	
			N = 12 195	
			ΔS = 481.2 MPa	

②

Fatigue test log - rev 0

OBS! Area should be 205 mm²

$\sigma = \frac{F}{A} = \frac{98640}{205} = 481.2\ MPa$

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	F5
Date	7/6/19

481.2

Stress range (ΔS)	~~180~~ 300	Mpa	Load range ΔF	~~59,18~~ 98.64	kN
Target life	~~100000~~ 250	Cycles	Max load	~~65,75~~ 109.6	kN
Area	328,8	mm²	Min load	6,58 11.0	kN
Cyclic rate	10	Hz	Mean load	~~36,16~~ 60,28	kN
Test rig	MTS 809	Machine load	~~36,16~~ 60,28	~~29,59~~ 49.32	± kN

ΔF=ΔS*Area/1000

Fmax=ΔF/(1-R)

Fmin=Fmax-ΔF

Fmean=(Fmax+Fmin)/2

F=Fmean±ΔF/2

$\frac{59180}{205} = 288.7\ MPa$

Date	Time	Cycles	Observation, comments	Sign
7/6/19	9.40	0	Start 10Hz ok. PVP comp	Z.L.
"	13.10	26895	New load: 300 MPa. Pause	Z.L.
11/6	7:50	"	Restarted - new load [illegible] 3,77	Z.L.
"	8.20	38570	Broke	Z.L.
			Failure Criterion:	
			Complete fracture	
			Initiated at weld root	
			N= 38570	
			ΔS = 481.2 MPa	

(3) → (6) continue after pause

Fatigue test log - rev 0

R= 0,1

Project name: Larsson Master thesis pilot
Specimen ID: F2
Date: 11/6-2019

R=0,1 Stress range (ΔS)	200	Mpa	Load range ΔF	40.3	kN
Target life		Cycles	Max load	44.7	kN
A: t×w Area	8.2×24.7 = 201.3	mm²	Min load	4.4	kN
Cyclic rate	~~6~~ ~~30~~ 15	Hz	Mean load	24.6	kN
Test rig	MTS 809	Machine load	24.6	20.2	± kN

$\Delta F = \Delta S * Area/1000 = \frac{200 \cdot 201.3}{1000}$

$F_{max} = \Delta F/(1-R) = 40.3/(1-0.1)$

$F_{min} = F_{max} - \Delta F$

$F_{mean} = (F_{max} + F_{min})/2$

$F = F_{mean} \pm \Delta F/2$

Date	Time	Cycles	Observation, comments	Sign
(3) 11/6-2019	13.30	0	Start 0,35mm	Z.G
"	13.55	10000	0,38 mm/0.1mm	Z.G
12/6-2019	0800	670 000	No cracks	Z.G
"	9:35	712000	Kjører 15Hz - var hun 10Hz	Z.G
"	10:05	745000	0,42 / 0,13	
"	12:25	870000	Ingen sprekk obs. –"– 0,12	ZG
–"–	14.27	979900	0,42 / 0,12	
–"–	16:22	1 082 965	——— " ———	Mattias
13/6	7:55	1 920000	" 0,43 / 0,13	Z.G
–"–	10:00	2033347	–"– 0.425/0.12	Mattias
–"–	10:19	2050 000	–"– 0.44/0.13	"
–"–	11.33	2118780	0,44/0,13	
–"–	11:42	2124441	Stopped test → continue with specimen ML.	
(6) 15/6-2019	15:30	+ 0	Same load 0.39/0.10	Mattias
16/6-2019	11:13	+1 066 318	0.40/0.10	"
18/6-2019	09:24	+ 3 559 350	0.40/0.10	"
18/6-2019	17:33	4000000	0,39/0,09	Magnus
19/6-2019	09:47	4876000	0,40/0,09	Magnus
–"–	17:13	5 277 795	0.39/0.09	Mattias
20/6-2019	09:33	6 157 710	0.40/0.10	–"–
21/6-2019	11:02	7534 716	STOP –"–	Mattias
	TOT	= 9 659 157		
			Run out	
			N = 9 654 157	
			ΔS = 200 MPa	

(4)

Fatigue test log - rev 0

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	F4
Date	13/6

Stress range (ΔS)	300	Mpa	Load range ΔF	63.75	kN
Target life	1 000 000	Cycles	Max load	70.83	kN
Area	8.5×25 = 212.5	mm²	Min load	7.08	kN
Cyclic rate	10	Hz	Mean load	38.96	kN
Test rig	MTS 809	Machine load	38.96	31.88	± kN

A ΔF=ΔS*Area/1000 = 300·212.5 / 1000

B Fmax=ΔF/(1-R) = 63.75 / 1 − 0.1

C Fmin=Fmax-ΔF = 70.83 − 63.75

D Fmean=(Fmax+Fmin)/2 = 70.83 − 7.08 / 2

F=Fmean±ΔF/2 63.75 / 2 =

Date	Time	Cycles	Observation, comments	Sign
13/6-19	11:46	0		Mattias
"	12:26	24 851	−2.32/−2.78	"
−"−	12:58	43 782	−2.31/−2.77	Magnus
14/6	7:40	312278	Brudd	[illegible]
			Failure criterion:	
			Complete fracture at weld toe cap	
			N = 312 278	
			ΔS = 300 MPa	

Δd = 0,46 mm

(5)

Fatigue test log - rev 0

UiS

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	F3
Date	14/6

Stress range (ΔS)	300	Mpa	Load range ΔF	66	kN
Target life	320 000	Cycles	Max load	73,33	kN
Area	25x8.8 =220	mm²	Min load	7.33	kN
Cyclic rate	10	Hz	Mean load	40,33	kN
Test rig	MTS 809	Machine load	40.33	33	± kN

$\Delta F=\Delta S*Area/1000$

$F_{max}=\Delta F/(1-R)$

$F_{min}=F_{max}-\Delta F$

$F_{mean}=(F_{max}+F_{min})/2$

$F=F_{mean}\pm\Delta F/2$

Date	Time	Cycles	Observation, comments	Sign
14.06.2014	10:36	0	Misaligned specimen start at -3kN 0.71 / 0.23	Mattias
— " —	11.19	26 800	0.76/0,28	Magnus
— " —	12:11	57 967	0,77/0,29	Mattias
— " —	13:38	110 095	0,78/ 0,29	— " —
— " —	13:50	117 500	0.77/ 0.29	Magnus
— " —	15:28	170 400	0.77	Magnus
15/06-2014	12:16	924104	Fracture	Mattias
			Failure criterion:	
			Complete fracture in base material	
			N = 924 104	
			ΔS = 300 MPa	

0,48

Test (11) (From test (6)) Fatigue test log - rev 0

R= 0,1

Project name	Master thesis Larsson	
Specimen ID	F2	
Date		350

Stress range (ΔS)	300	Mpa	Load range ΔF	58.03	kN	ΔF=ΔS*Area/1000	67.704
Target life	500 000	Cycles	Max load	64.48	kN	Fmax=ΔF/(1-R)	75.23
Area 24.8 × 7.8	= 193.44	mm²	Min load	6.45	kN	Fmin=Fmax-ΔF	7.52
Cyclic rate	13,15	Hz	Mean load	35.47	kN	Fmean=(Fmax+Fmin)/2	41.38
Test rig	MTS 809	Machine load	35.47	29.02	± kN	F=Fmean±ΔF/2	41.38 ± 33.85

	Date	Time	Cycles	Observation, comments	Sign	displ.
ΔS=300	1/7-2019		0	Re-grinded. cont. from (6)	Mattias	
	"	1839	200 000	0.54/0.14	"	0.40 mm
	2/7-2019	07:11	878 000	0.55/0.15	Magnus	
	"	0911	987 000	"	Mattias	
	11-	13 31	1220000	0.54/0.14	Magnus	
	"	1905	1520 000	"	MGHE	
	"	2033	1600 000	"	"	
	3/7-2019	07.27	2189 000	0.55/0.15	"	
	"	09:27	2300 000	STOP "	Mattias	
ΔS=350	"	0933	0	350 MPa 0.66/0.19	"	0.47 mm
	"	13:06	190 800	0.68/0.20	Magnus	
	"	15:02	295 000	0.68/0.21	[illegible]	
	"	17 39	437 000	"	Mattias	
	4/7-2019	07:32	747488			

Fatigue Specimen F2 Tested at 3 different ΔS

Test (3) & (6): Run out:
ΔS = 200 MPa
N = 9 654 157

Test (11) • Run out:
We stoped at 2300 000 cycles at ΔS=300 MPa. We continued to test at ΔS= 350
ΔS = 300 MPa
N = 2300 000 (Stoped)

• Failure criterion:
Complete fracture at weld root
ΔS = 350 MPa
N = 747 488

- Doc G702 - Fatigue test - Unwelded base metal specimens

Test 7

Fatigue test log - rev 0

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	BM2
Date	21/6-2019

Stress range (ΔS)	350	Mpa	Load range ΔF	82.2	kN
Target life		Cycles	Max load	91.3	kN
Area	23.2 x 8.6 = 234.8	mm²	Min load	9.13	kN
Cyclic rate	10	Hz	Mean load	50.2	kN
Test rig	MTS 809	Machine load	50.2	41.1	± kN

Verifierat av Magnus.

(A) ΔF=ΔS*Area/1000 (350 · 234.8)

(B) Fmax=ΔF/(1-R) ((A), 0,1)

(C) Fmin=Fmax-ΔF ((B), (A))

(D) Fmean=(Fmax+Fmin)/2 (B, C)

F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign
21/6-2019	11:23	0	0.83/0.20	Mattias
(as above)	12:41	47200	0,83/0,2	Magnus
(as above)	13:12	62700	0,83/0,2	Magnus
(as above)	15:21	142957	0.83/0.2	Magnus
(as above)	17:10	208000	0.83/0.2	Magnus
(as above)	18:33	258389	0.83/0.19	Mattias
(as above)	19.52	305000	0,83/0.19	Magnus
22/6-2019	08:35	763000	0,83/0,20	Magnus
(as above)	09:38	806000	0,84/0,21	Magnus
(as above)	10:26	830000	0.84/0.20	Magnus
(as above)	11:08	855000	0.83/0.20	Magnus
(as above)	11:18	865000	0.84/0.20	Mattias
(as above)	11:55	885000	0.83/0.20	Magnus
(as above)	12:36	907000	0.83/0.20	Magnus
(as above)	14:24	972933	NO CRACK 0.83/0.20	Mattias
23/6-2019	10:15	1680000	0.84/0.20	Magnus
(as above)	12:32	1736000	0.85/0.21	Magnus
(as above)	13:13	1767000	0.85/0.22	Magnus
(as above)	14:21	1828000	0.85/0.22	Magnus
(as above)	15:24	1886000	0.84/0.20	Magnus
(as above)	16:36	1950000	0.84/0.20	Magnus
(as above)	18:00	2025000	0.84/0.20	Magnus
(as above)	19:13	2084000	0.83/0.19	Magnus
24/6-2019	08:35	2760000	0.83/0.19	Magnus
(as above)	09.41	2760746	0.83/0.20 0.63	Magnus
			Run out:	
			N = 2760746	
			ΔS = 350 MPa	

Pause test. Test will be performed at 400 MPa.

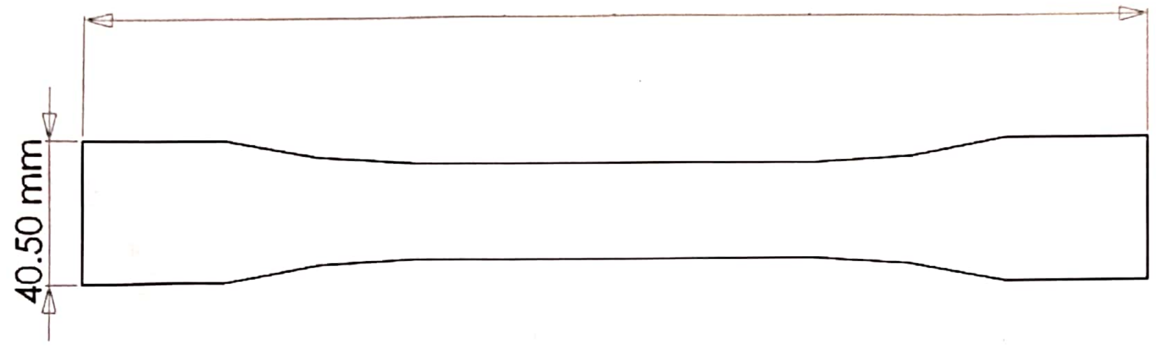
Visual Test Log

Run out
$\Delta S = 350$ MPa
N = 2760 746

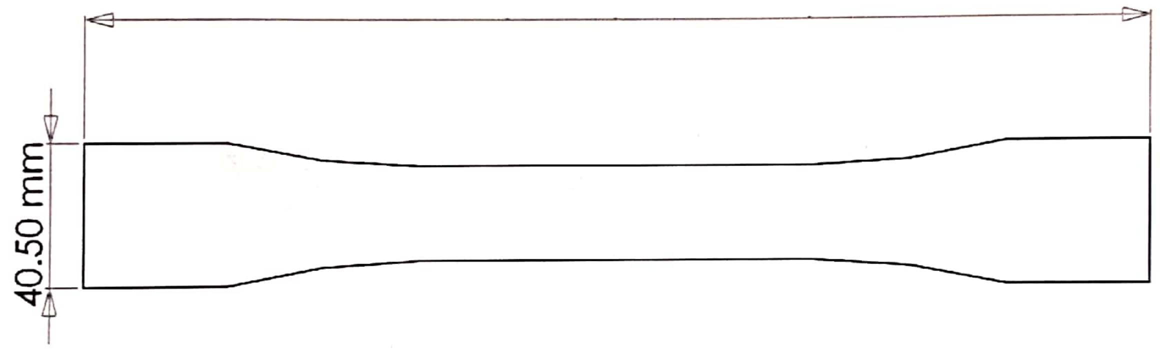
Test : 7

Name: BM2
Magnus Larsson.

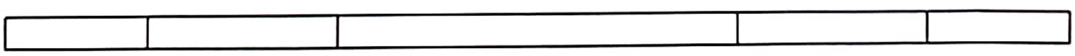
Front side



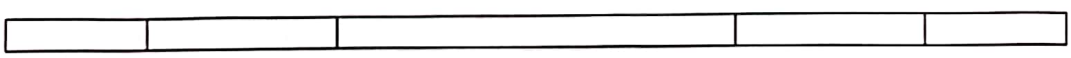
Back side



Right side



Left side

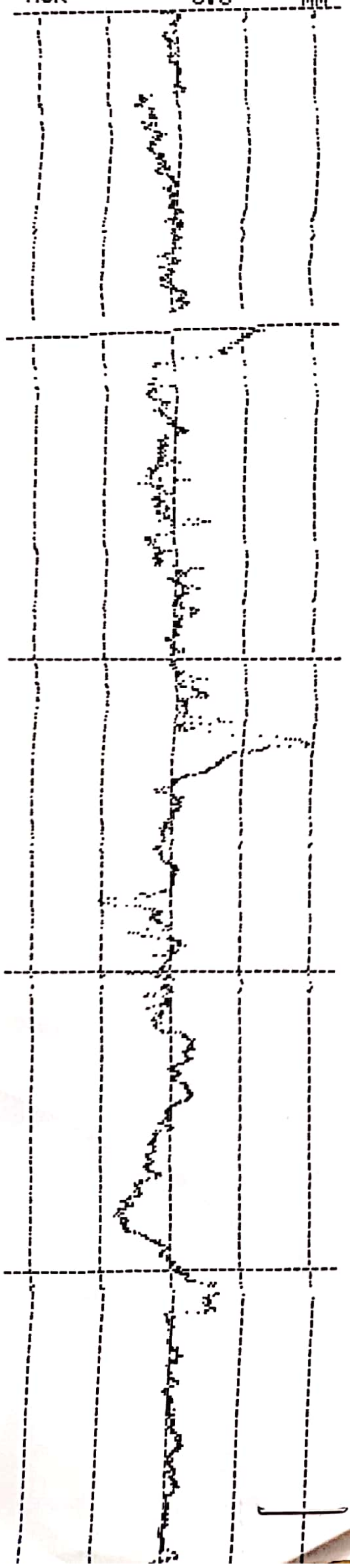


BM2 Front Center

MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF		0.8 X 5	
RA		0.21	µm
RZ		1.6	µm
RT		3.0	µm
TP	(10%)	0	%
	(15%)	0	%
	(20%)	0	%
	(25%)	1	%
	(30%)	1	%
	(40%)	2	%
	(50%)	6	%
	(60%)	19	%
	(70%)	73	%
	[illegible]	94	%
	(90%)	99	%

VER 1 µm
HOR 0.8 mm

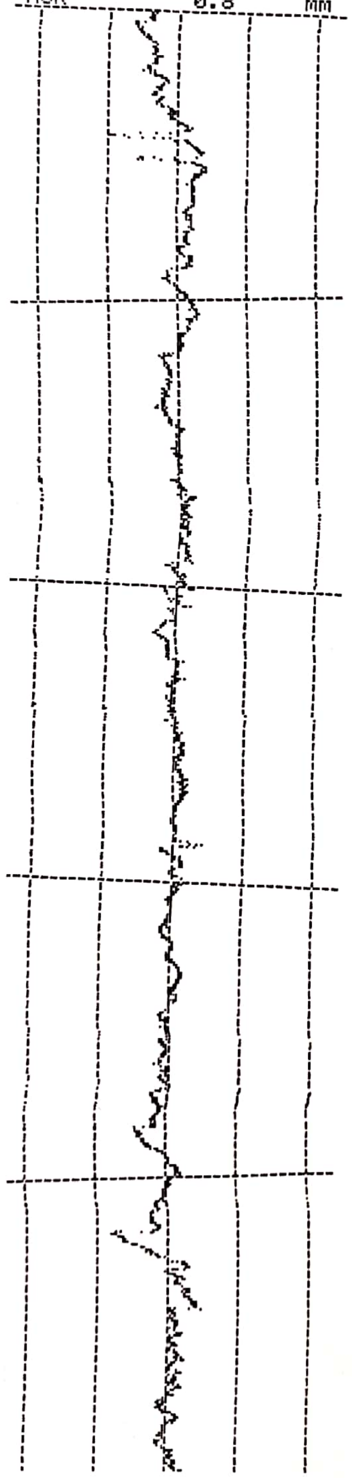


BM2 Backside center

MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF		0.8 X 5	
RA		0.14	µm
RZ		0.9	µm
RT		1.4	µm
TP	(10%)	1	%
	(15%)	3	%
	(20%)	10	%
	(25%)	24	%
	(30%)	40	%
	(40%)	74	%
	(50%)	89	%
	(60%)	[illegible]	%
	(70%)	98	%
	(80%)	99	%
	(90%)	99	%

VER 1 µm
HOR 0.8 mm

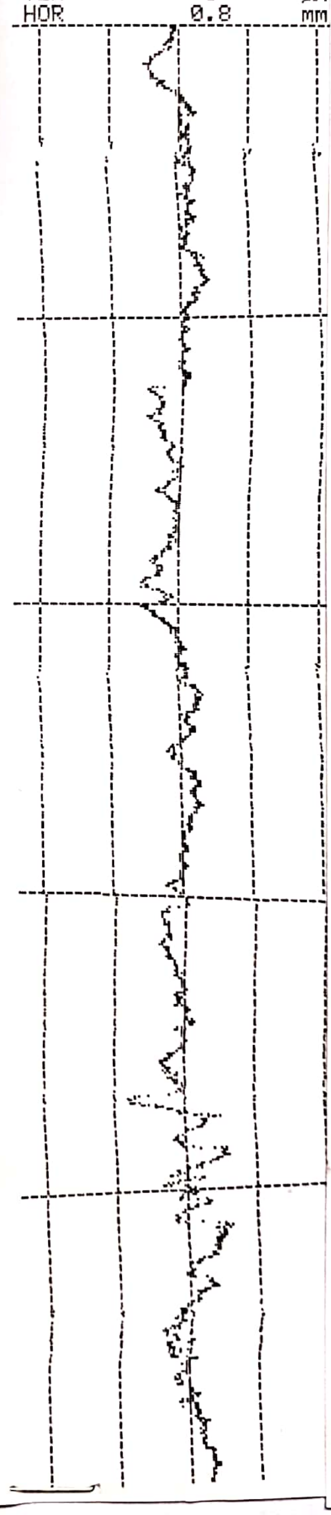


BM2 Right

MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF		0.8 X 5	
RA		0.17	µm
RZ		1.0	µm
RT		1.4	µm
TP	(10%)	1	%
	(15%)	2	%
	(20%)	3	%
	(25%)	8	%
	(30%)	16	%
	(40%)	37	%
	(50%)	65	%
	(60%)	82	%
	(70%)	94	%
	(80%)	99	%
	(90%)	99	%

VER 1 µm
HOR 0.8 mm

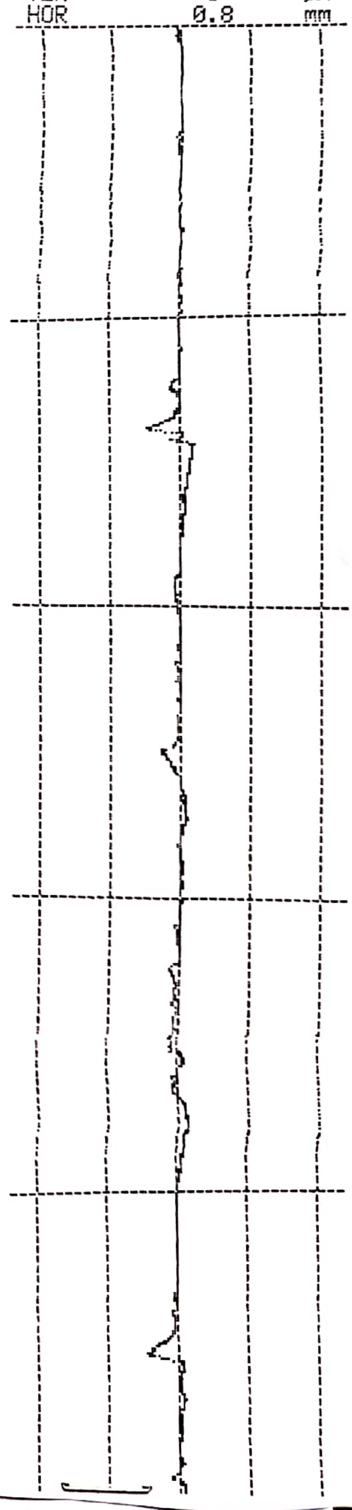


BM2 Left

MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF		0.8 X 5	
RA		0.26	µm
RZ		2.0	µm
RT		3.4	µm
TP	(10%)	3	%
	(15%)	7	%
	(20%)	15	%
	(25%)	27	%
	(30%)	56	%
	(40%)	88	%
	(50%)	96	%
	(60%)	97	%
	(70%)	98	%
	(80%)	99	%
	(90%)	99	%

VER 5 µm
HOR 0.8 mm



Test 8

Signature : [signature]

Approved : [signature]

Fatigue test log - rev 0

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	BM1
Date	24.06.2019

Stress range (ΔS)	430	Mpa	Load range ΔF	102.13	kN	ΔF=ΔS*Area/1000
Target life	1 000 000	Cycles	Max load	113.48	kN	Fmax=ΔF/(1-R)
Area	237.51	mm²	Min load	11.35	kN	Fmin=Fmax-ΔF
Cyclic rate	15	Hz	Mean load	62.42	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	62.42	51.07	± kN	F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign
24.06.2019	10.34	0	2.19 / 1.30	[signature]
— " —	11.46	9244	1.66 / 0.73 0.93	[signature]
	11.58	15643	10.49 / 10.48	[signature]
			Failure criterion:	
			complete fracture	
			N = 15643	
			ΔS = 430 MPa	

Feil fel. Tog av last & installer specimen igjen.

Visual Test Log

The visual test log was created after BM1 fatigue test was performed.

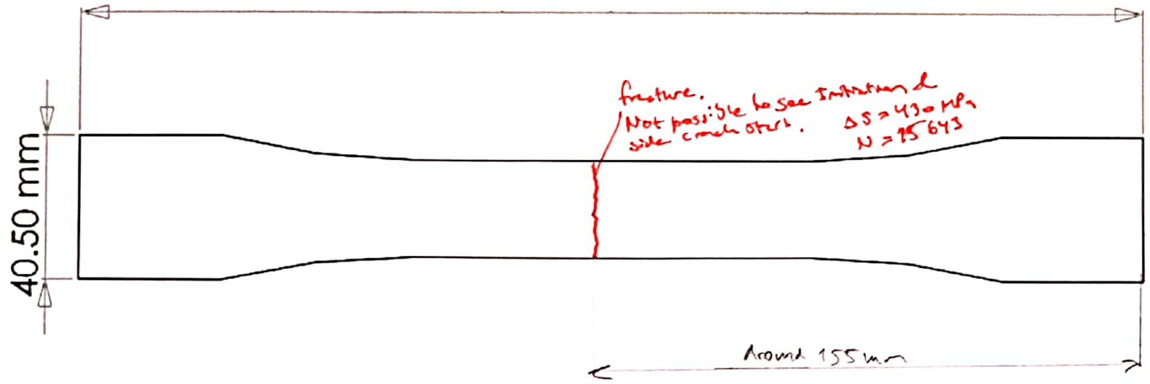
- It can be confirmed that no transverse scratches were visible & roughness was below ≤ 20 μm before testing started

Test: 8

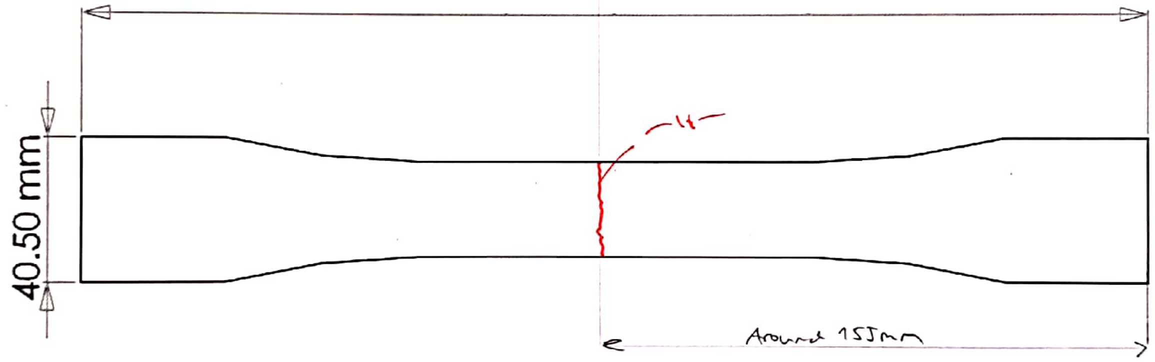
Name: BM1

Magnus Larsson

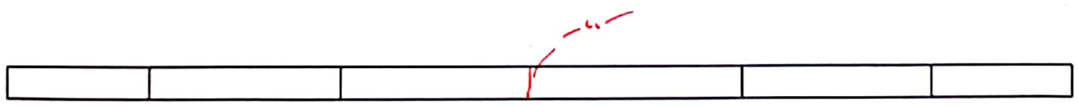
Front side



Back side



Right side

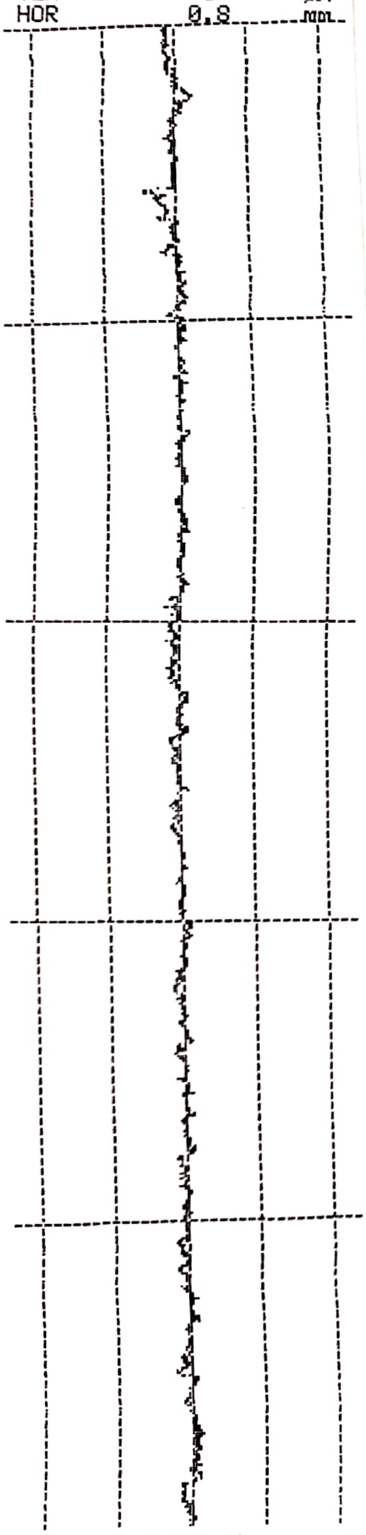


Left side

MITUTOYO SURFTEST 201
DATE 21 juni 2019
NAME BM1 Front Center

CUTOFF		0.8 X 5	
RA		0.05	µm
RZ		0.3	µm
RT		0.6	µm
TP	(10%)	0	%
	(15%)	0	%
	(20%)	1	%
	(25%)	10	%
	(30%)	25	%
	(40%)	57	%
	(50%)	88	%
	(60%)	98	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

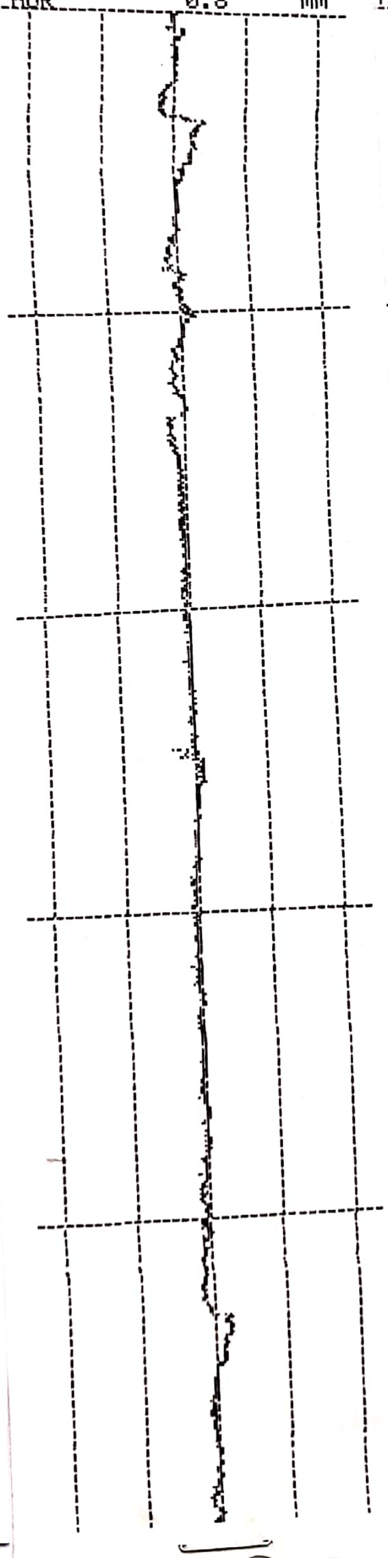
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 20.06.2019
NAME BM1 Backside center

CUTOFF		0.8 X 5	
RA		0.07	µm
RZ		0.4	µm
RT		0.7	µm
TP	(10%)	0	%
	(15%)	0	%
	(20%)	0	%
	(25%)	1	%
	(30%)	3	%
	(40%)	5	%
	(50%)	10	%
	(60%)	35	%
	(70%)	72	%
	(80%)	94	%
	(90%)	99	%

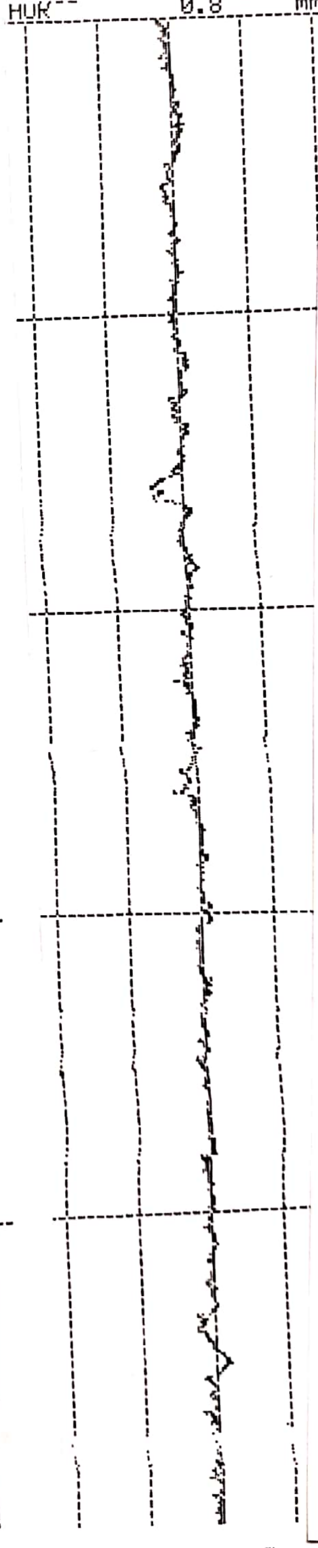
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME BM1 Right

CUTOFF		0.8 X 5	
RA		0.06	µm
RZ		0.4	µm
RT		0.6	µm
TP	(10%)	1	%
	(15%)	3	%
	(20%)	10	%
	(25%)	25	%
	(30%)	34	%
	(40%)	78	%
	(50%)	92	%
	(60%)	96	%
	(70%)	98	%
	(80%)	98	%
	(90%)	99	%

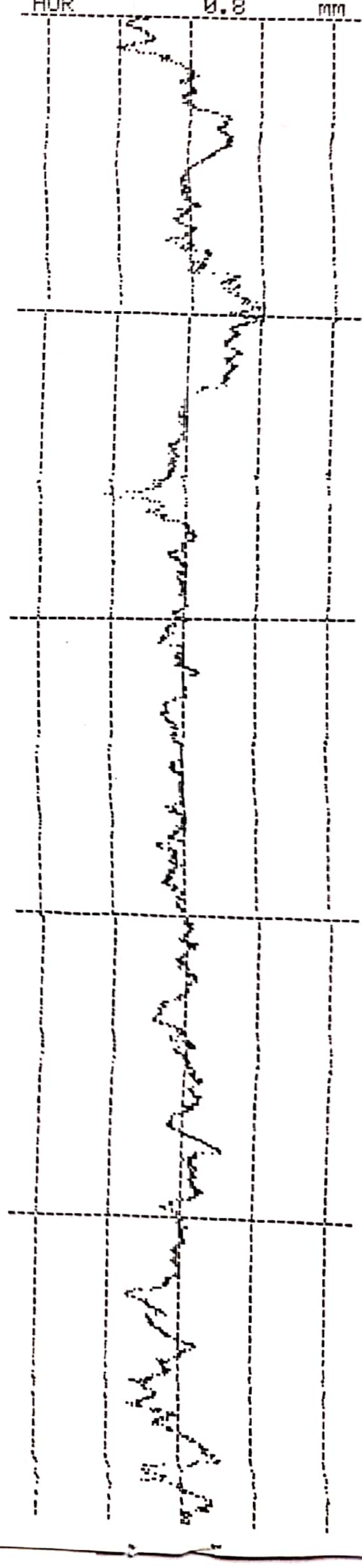
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 20.06.2019
NAME BM1 Left

CUTOFF		0.8 X 5	
RA		0.21	µm
RZ		1.4	µm
RT		2.2	µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	4	%
	(25%)	9	%
	(30%)	11	%
	(40%)	19	%
	(50%)	52	%
	(60%)	85	%
	(70%)	94	%
	(80%)	98	%
	(90%)	99	%

VER 1 µm
HOR 0.8 mm



Test (9)

Fatigue test log - rev 0

R= 0,1

Project name: BM5

Specimen ID: Larsson Master Thesis

Date: 24.06.2019

Stress range (ΔS)	400	Mpa	Load range ΔF	91.28	kN
Target life	1000 000	Cycles	Max load	101.44	kN
Area	8.45 · 27.0 = 228.23	mm²	Min load	10.14	kN
Cyclic rate	13	Hz	Mean load	55.79	kN
Test rig	MTS 809	Machine load	55.79	45.64	± kN

$\Delta F=\Delta S*Area/1000$

$F_{max}=\Delta F/(1-R)$

$F_{min}=F_{max}-\Delta F$

$F_{mean}=(F_{max}+F_{min})/2$

$F=F_{mean}\pm\Delta F/2$

Date	Time	Cycles	Observation, comments	Sign	displ.
24.06.2019	14:55	0	1.02/0.25	Mathias	0.77 mm
"	17:16	110 000	1.13/0.36	[illegible]	0.77 mm
"	19:25	242563	1.18/0.41	[illegible]	"
	20:09	294 000	1.18/0.47	[illegible]	
		426615	Fracture		
			Failure Criterion:		
			complete fracture		
			N = 426 615		
			ΔS = 400 MPa		

Visual Test log

The visual test log was created after, BM5 fatigue test was performed

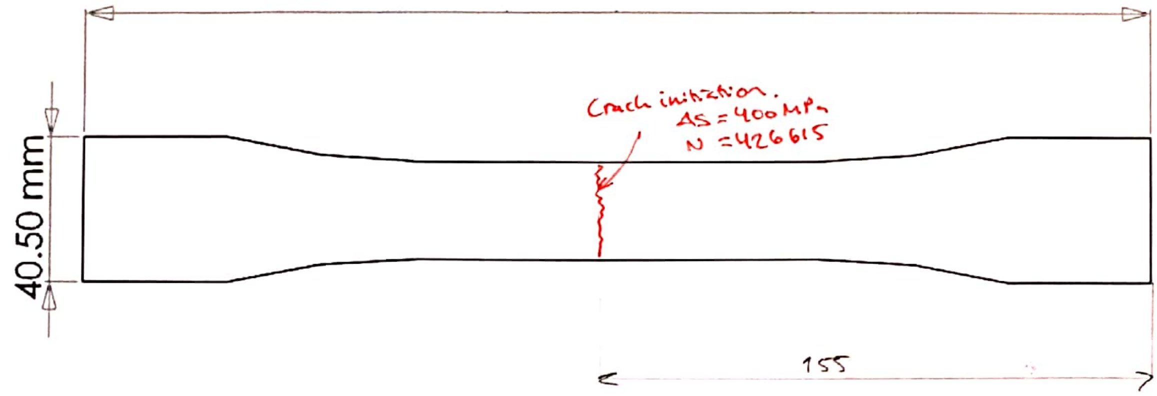
- It can be confirmed that no transverse scratches were visible & roughness was below ≤ 20 µm
- before testing was started

Test: 9

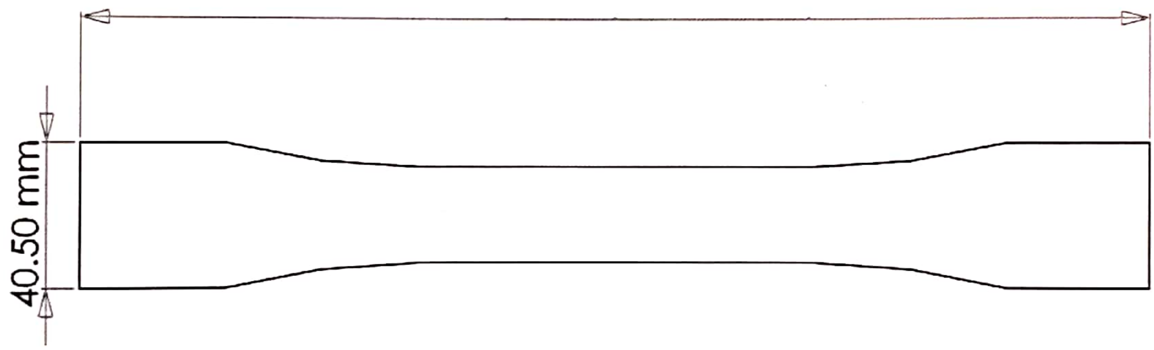
Name: BM5

Magnus Larsson

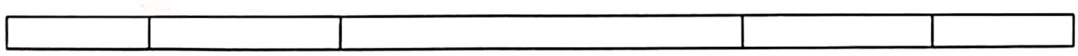
Front side · Not checked with visual test



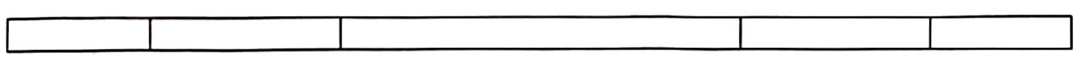
Back side



Right side



Left side



MITUTOYO SURFTEST 201

DATE 24.06.2019

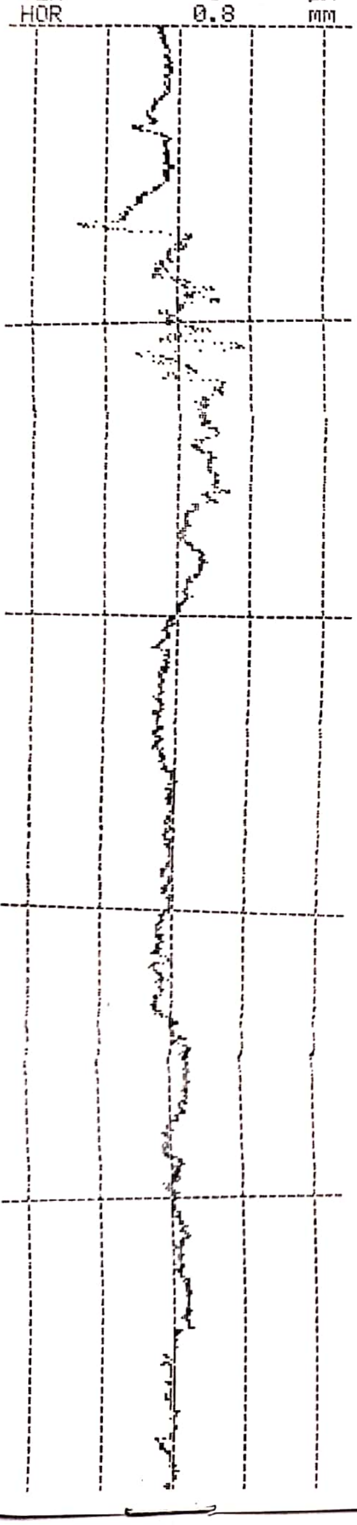
NAME BM5

FRONT SIDE

CUTOFF	0.8	X	5
RA	0.19		µm
RZ	0.9		µm
RT	2.3		µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	5	%
	(25%)	8	%
	(30%)	17	%
	(40%)	50	%
	(50%)	90	%
	(60%)	97	%
	(70%)	98	%
	(80%)	99	%
	(90%)	99	%

VER 1 µm

HOR 0.8 mm



MITUTOYO SURFTEST 201

DATE 24.06.2019

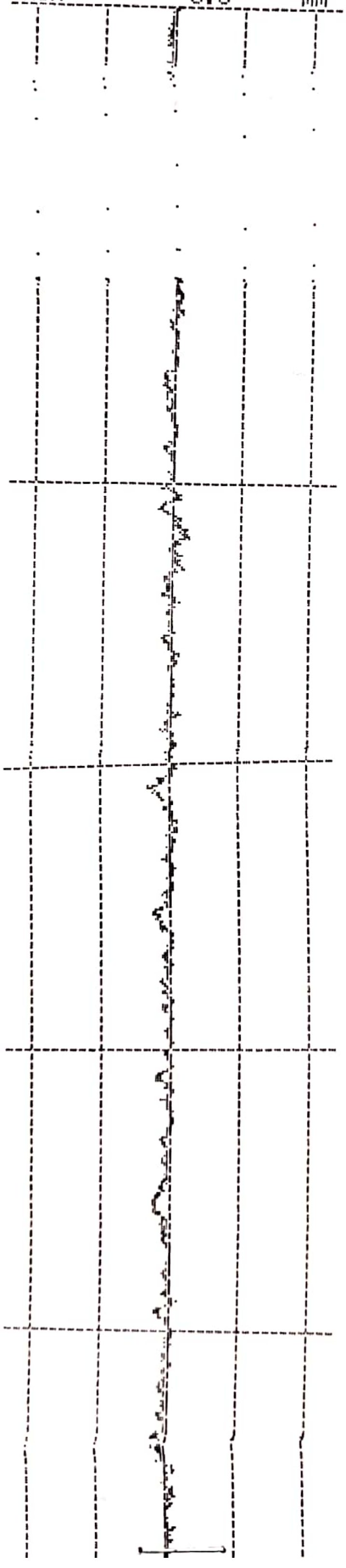
NAME BM5

BACK SIDE

CUTOFF	0.8	X	5
RA	0.05		µm
RZ	0.3		µm
RT	0.5		µm
TP	(10%)	0	%
	(15%)	0	%
	(20%)	1	%
	(25%)	2	%
	(30%)	8	%
	(40%)	22	%
	(50%)	56	%
	(60%)	84	%
	(70%)	91	%
	(80%)	97	%
	(90%)	99	%

VER 1 µm

HOR 0.8 mm



MITUTOYO SURFTEST 201

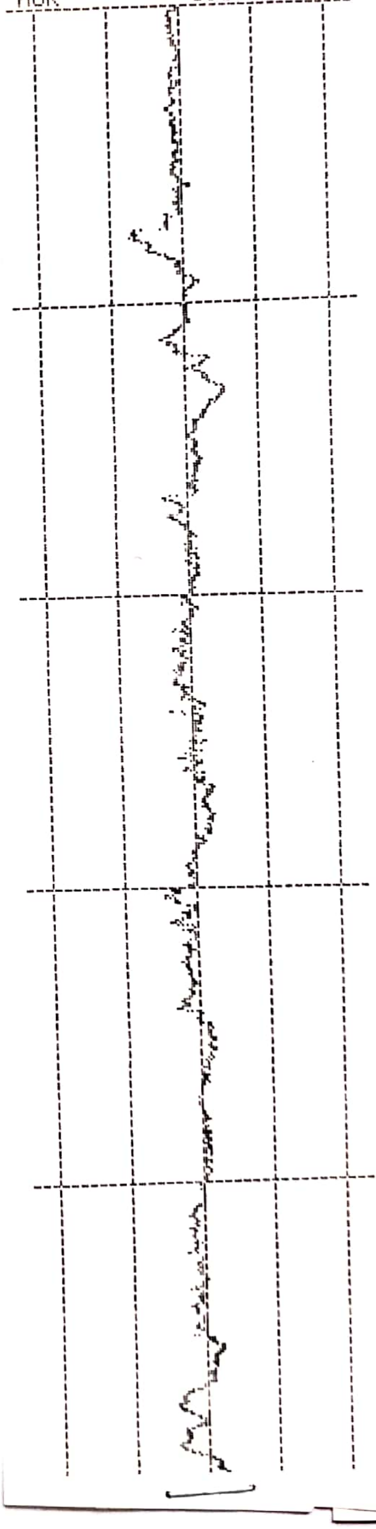
DATE 24.06.2019

NAME BM5 - RIGHT SIDE

CUTOFF	0.8	X	5
RA	0.12		µm
RZ	0.7		µm
RT	1.3		µm
TP	(10%)	1	%
	(15%)	1	%
	(20%)	2	%
	(25%)	5	%
	(30%)	9	%
	(40%)	35	%
	(50%)	73	%
	(60%)	91	%
	(70%)	97	%
	(80%)	99	%
	(90%)	99	%

VER 1 µm

HOR 0.8 mm



MITUTOYO SURFTEST 201

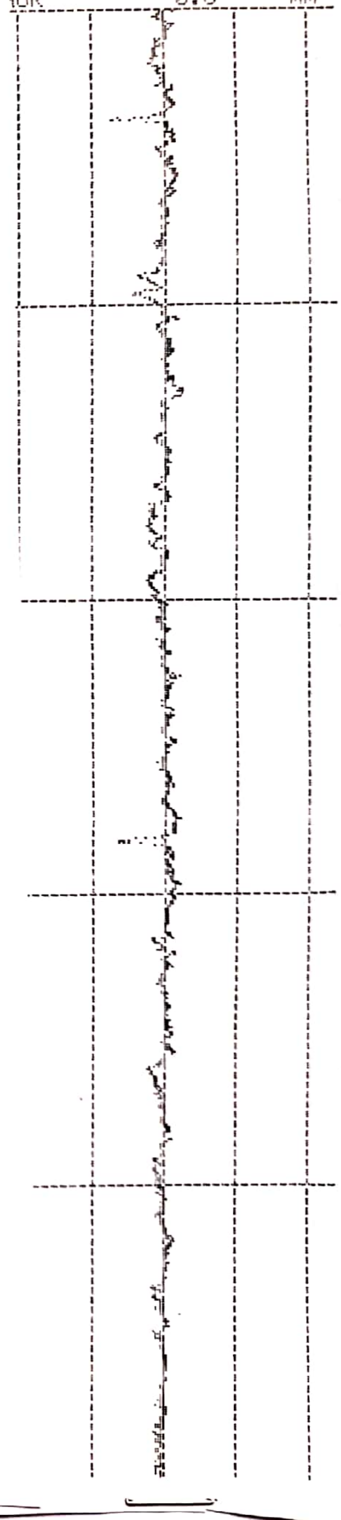
DATE 24.06.2019

NAME BM5 - LEFT SIDE

CUTOFF	0.8	X	5
RA	0.07		µm
RZ	0.6		µm
RT	1.0		µm
TP	(10%)	1	%
	(15%)	4	%
	(20%)	17	%
	(25%)	32	%
	(30%)	61	%
	(40%)	90	%
	(50%)	98	%
	(60%)	98	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

VER 1 µm

HOR 0.8 mm



Test 10

Fatigue test log - rev 0

R= 0,1

Project name	Master Thesis Larsson
Specimen ID	BM4
Date	25/6-2019

Stress range (ΔS)	375	Mpa	Load range ΔF	87.7	kN	ΔF=ΔS*Area/1000
Target life		Cycles	Max load	97.47	kN	Fmax=ΔF/(1-R)
27.2×8.6 Area	233.92	mm²	Min load	9.75	kN	Fmin=Fmax-ΔF
Cyclic rate	13	Hz	Mean load	53.61	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	53.61	43.85	± kN	F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign	displ.
25.06.2019	12:50	0	0.92/0.23	Matt	.69 mm
"	13:00	7700	0.94/0.26	"	.68 mm
"	15:00	103300	0.99/0.30	"	.69
"	16:14	160 000	1.00/0.31	[illegible]	"
"	17:40	226870	0.99/0.30	Magnus	"
"	19:18	304 000	"	Mattias	"
"	20:04	335 000	0.99/0.30	Magnus	"
26.06.2019	10:00	991 400	"	Matt	"
"	12:00	1079000	"	"	
"	14:25	1200 000	"	"	"
"	15:36	1250 000	"	"	
"	1950	1450 000	"	"	
27.06.2019	08:09	2027000	0.99/0.30	Magnus	
"	13:00	2250 000	"	Mattias	
"	1730	2470 000	"	"	
"	1830	2500 000	~~STOP~~ "	"	
28.06.2019	08:06	3143 000	1.00/0.30	Magnus	
"	1917	3666 000	0.99/0.29	Mattias	
29.06.2019	08:13	4271 000	1.00/0.30	Magnus	
"	11:47	4438000	0.99/0.30	Magnus	
30.06.2019	11:14	5540 000	0.99/0.30	Magnus	
"	20:11	5955000	1.00/0.30	Magnus	
1.07.2019	08:02	6556000	1.00/0.30	Magnus	0.70
"	13:37	6 770 000	STOP "	Mattias	
			Run out:		
			N = 6770 000		
			ΔS = 375 MPa		

Rev 1

Visual Test Log

Run out:

$\Delta S = 375$ MPa

$N = 6\ 770\ 000$

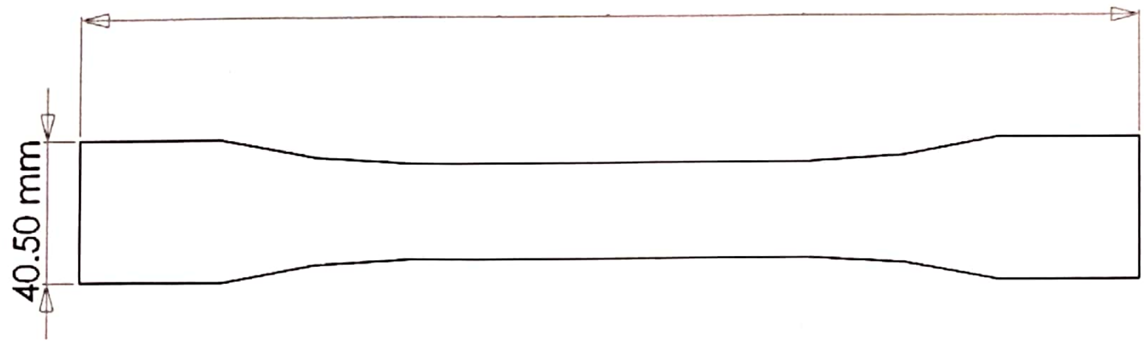
Test: 10

Name: BM4

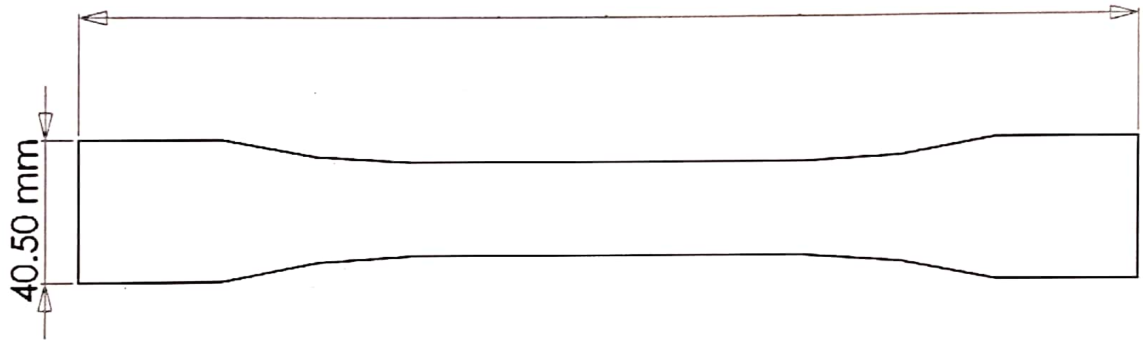
Magnus Larsson

25.06 2019

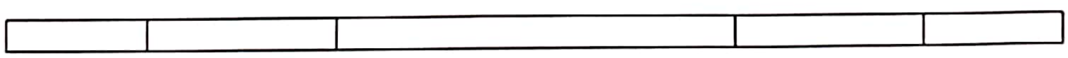
Front side - Good



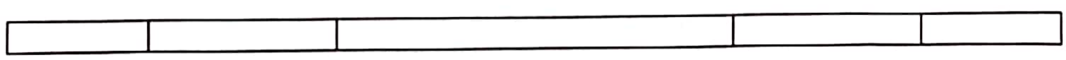
Back side - Good



Right side - Good



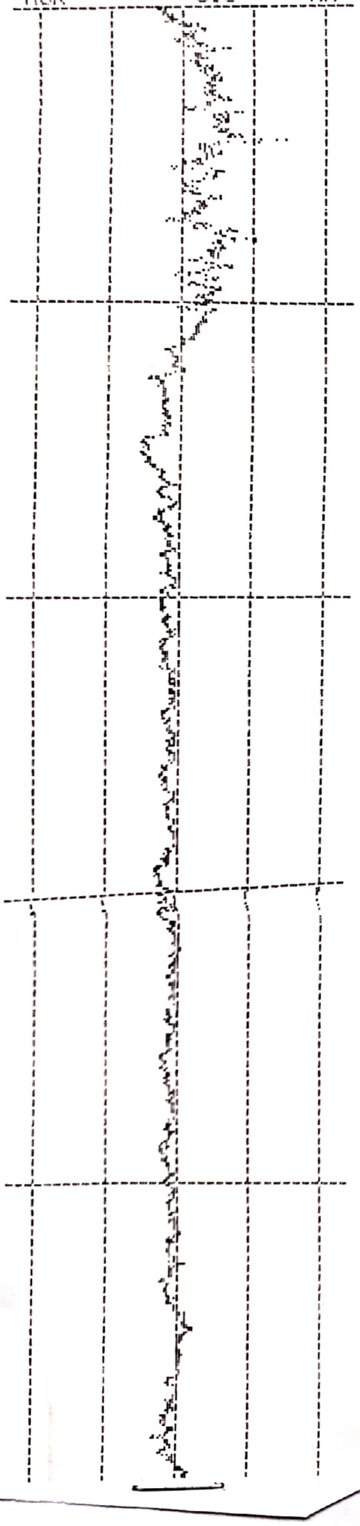
Left side - Good



MITUTOYO SURFTEST 201
DATE 25.06.2019
NAME BM4 Front side

CUTOFF		0.8	X 5
RA		0.18	µm
RZ		0.8	µm
RT		2.0	µm
TP	(10%)	0	%
	(15%)	0	%
	(20%)	0	%
	(25%)	0	%
	(30%)	0	%
	(40%)	1	%
	(50%)	6	%
	(60%)	14	%
	(70%)	23	%
	(80%)	72	%
	(90%)	97	%

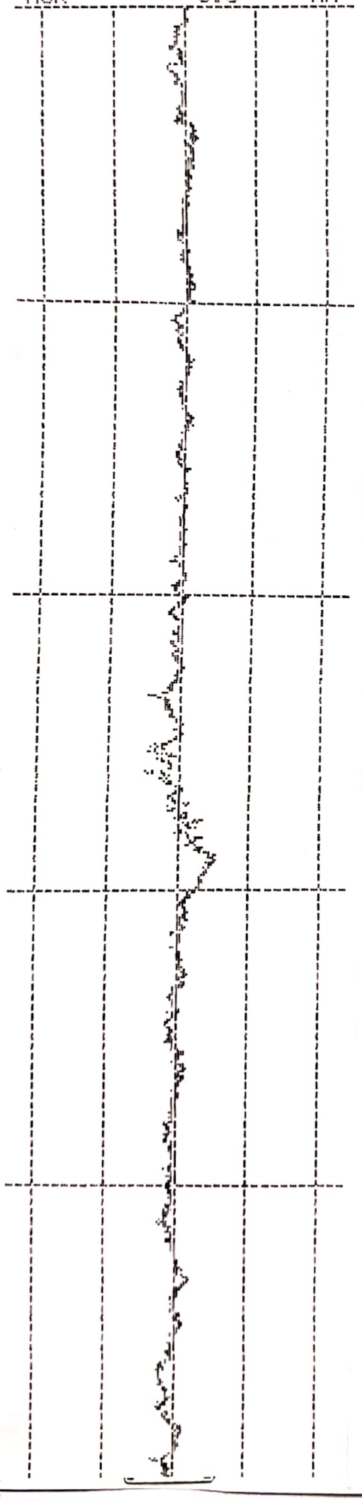
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 25.06.2019
NAME BM4 Back side

CUTOFF		0.8	X 5
RA		0.08	µm
RZ		0.5	µm
RT		1.0	µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	1	%
	(25%)	3	%
	(30%)	3	%
	(40%)	6	%
	(50%)	34	%
	(60%)	79	%
	(70%)	95	%
	(80%)	99	%
	(90%)	99	%

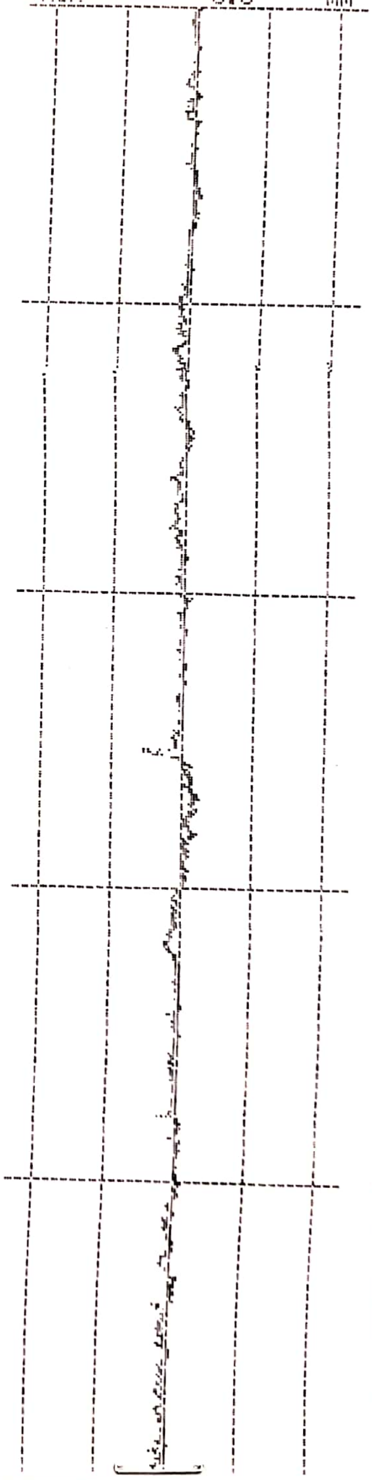
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 26.05.2019
NAME BM4 Right side

CUTOFF		0.8	X 5
RA		0.05	µm
RZ		0.4	µm
RT		0.8	µm
TP	(10%)	1	%
	(15%)	3	%
	(20%)	8	%
	(25%)	20	%
	(30%)	40	%
	(40%)	84	%
	(50%)	98	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

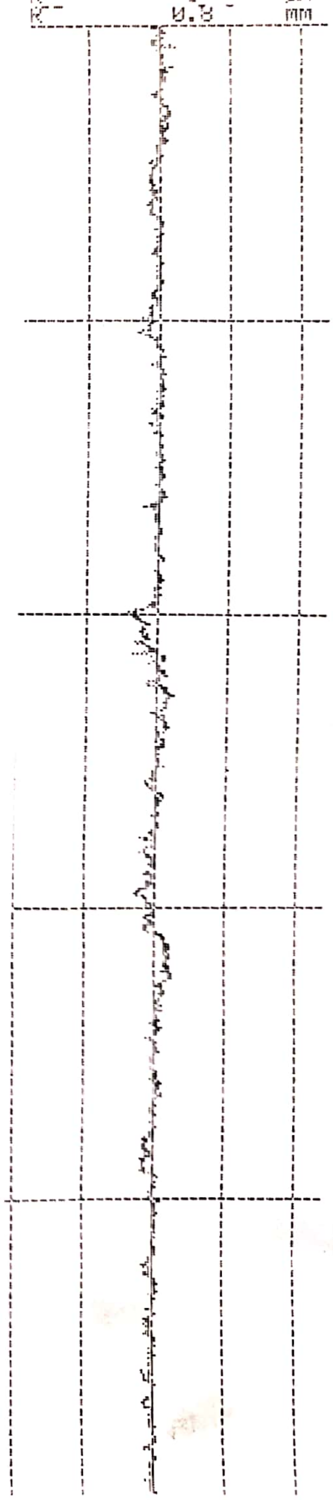
VER 1 µm
HOR 0.8 mm



UTOYO SURFTEST 201
E 26.06.2019
E BM4 Left side

OFF		0.8	X 5
		0.06	µm
		0.4	µm
		0.8	µm
	(10%)	2	%
	(15%)	4	%
	(20%)	9	%
	(25%)	20	%
	(30%)	42	%
	(40%)	79	%
	(50%)	94	%
	(60%)	97	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

R 1 µm
R 0.8 mm



(16)

Fatigue test log - rev 0

Project name: weld proximity investigation
Specimen ID: BM3
Date: 22/7-19

R= 0,1

Stress range (ΔS)	400	Mpa	Load range ΔF	96.06	kN	ΔF=ΔS*Area/1000
Target life	500 000	Cycles	Max load	106.73	kN	Fmax=ΔF/(1-R)
Area 27.32 x 8.79	= 240.14	mm²	Min load	10.67	kN	Fmin=Fmax-ΔF
Cyclic rate	13	Hz	Mean load	58.70	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	58.70	48.03	± kN	F=Fmean±ΔF/2

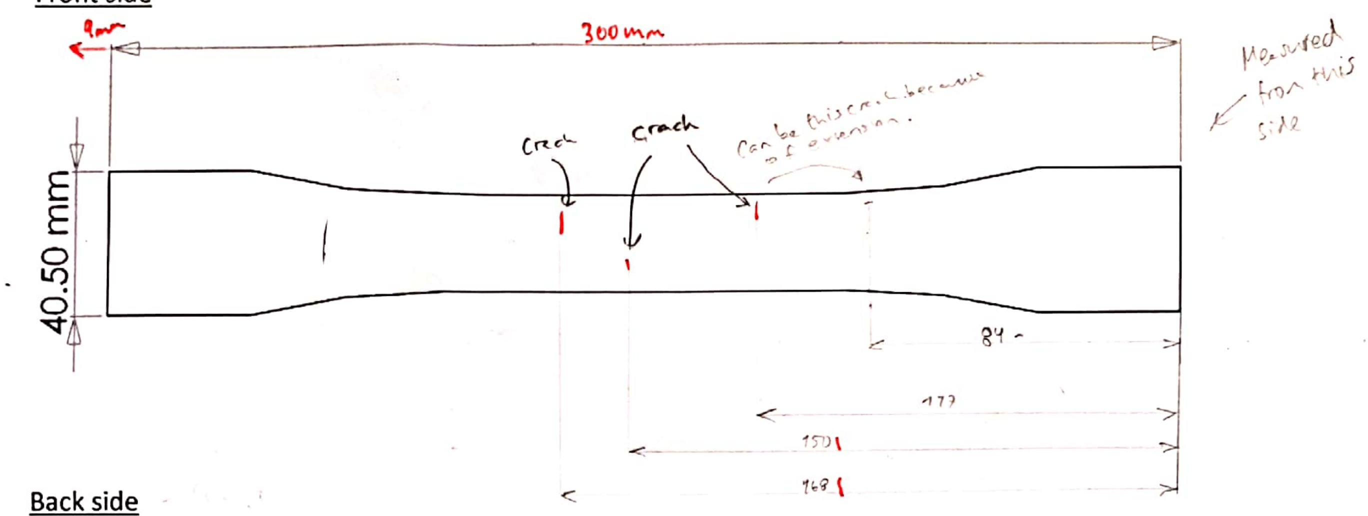
Date	Time	Cycles	Observation, comments	Temp	Sign	
22/7-19	1019	1000	6.18/5.38	23	Mattias	Δd=0.80
"	1030	5000	6.53/5.73	"	"	"
"	1045	16 000	7.41/6.60	"	"	0.82
"	1128	50 277	7.82/7.01	"	"	0.81
"	1247	111 902	7.88/7.07	"	"	
"	1426	189 226	7.90/7.09	"	"	0.81
"	1521	231 000	7.91/7.10	"	"	
"	1727	331 000	7.92/7.10	"	"	82
"	1853	394 701	Fracture in the middle		"	
			Failure criteria.			
			ΔS = 400 MPa			
			N = 394 701			
			Fracture in the middle Not			
			100% fracture 3 crack initiates			
			on the back			

Visual test log

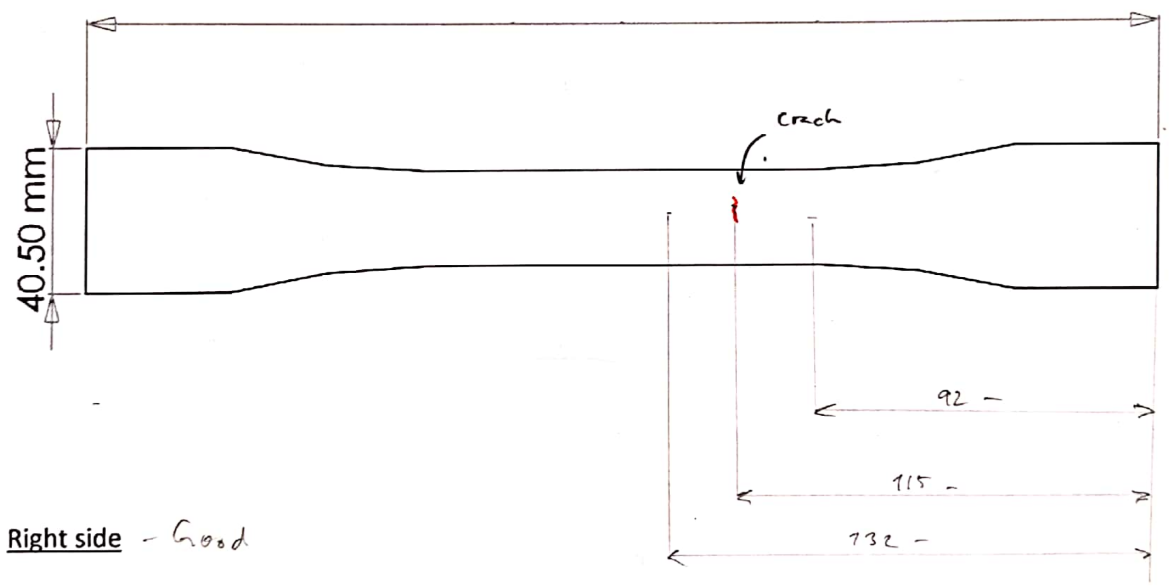
length before : 300mm
length after : 309

Test : 16
Name: BM3
Magnus Larsson
25 06.2019

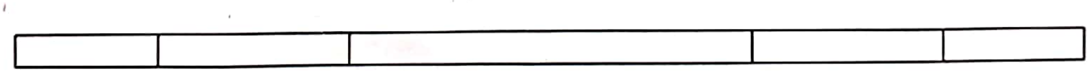
Front side



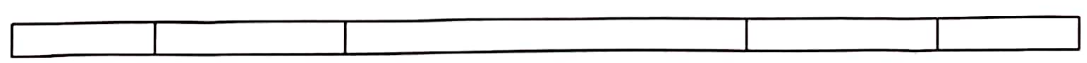
Back side



Right side - Good



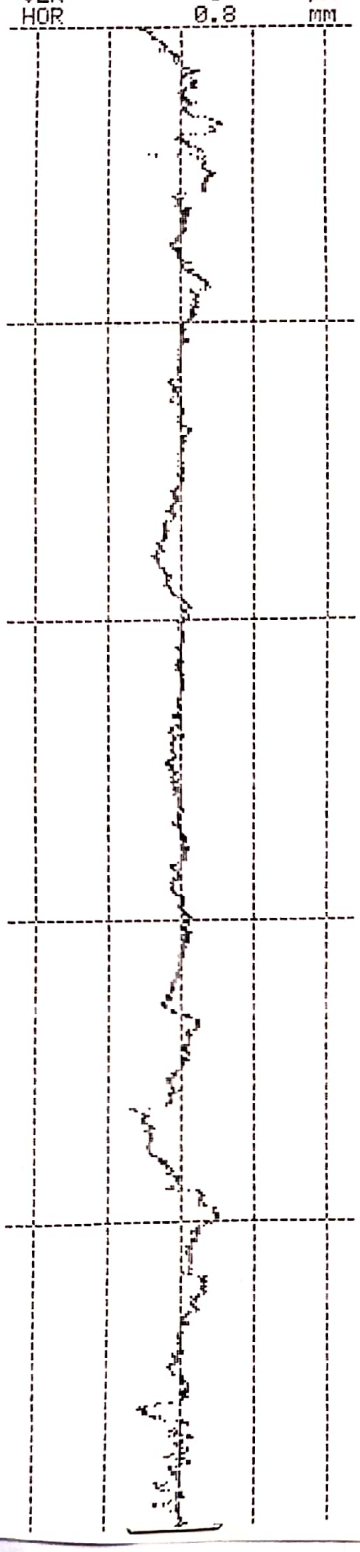
Left side - Good



MITUTOYO SURFTEST 201
DATE 19.07.2019
NAME BM3 FRONT SIDE

CUTOFF		0.8 X 5	
RA		0.13	µm
RZ		0.8	µm
RT		1.2	µm
TP	(10%)	1	%
	(15%)	2	%
	(20%)	4	%
	(25%)	8	%
	(30%)	12	%
	(40%)	28	%
	(50%)	67	%
	(60%)	86	%
	(70%)	93	%
	(80%)	97	%
	(90%)	99	%

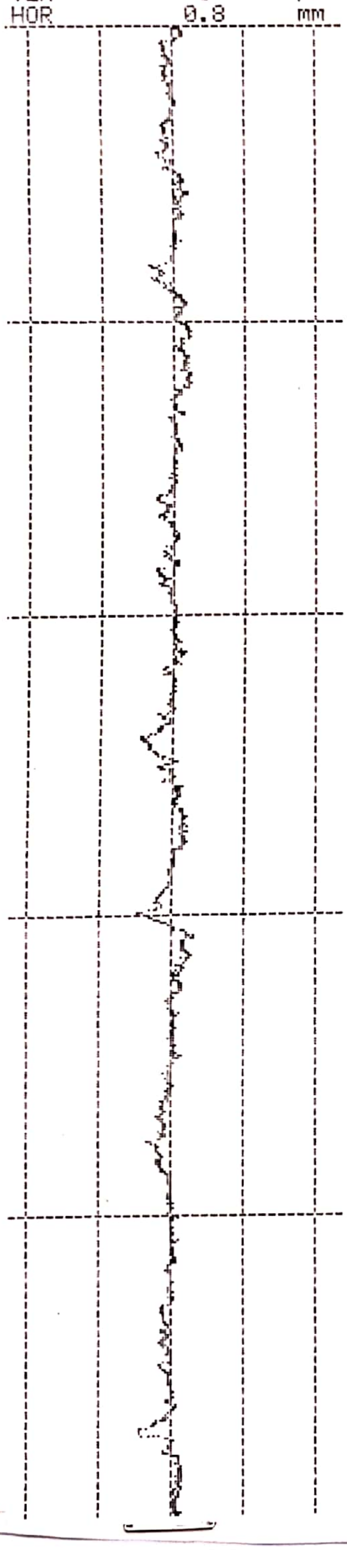
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 19.07.2019
NAME BM3 BACKSIDE

CUTOFF		0.8 X 5	
RA		0.09	µm
RZ		0.6	µm
RT		0.8	µm
TP	(10%)	0	%
	(15%)	3	%
	(20%)	7	%
	(25%)	14	%
	(30%)	24	%
	(40%)	53	%
	(50%)	76	%
	(60%)	90	%
	(70%)	96	%
	(80%)	98	%
	(90%)	99	%

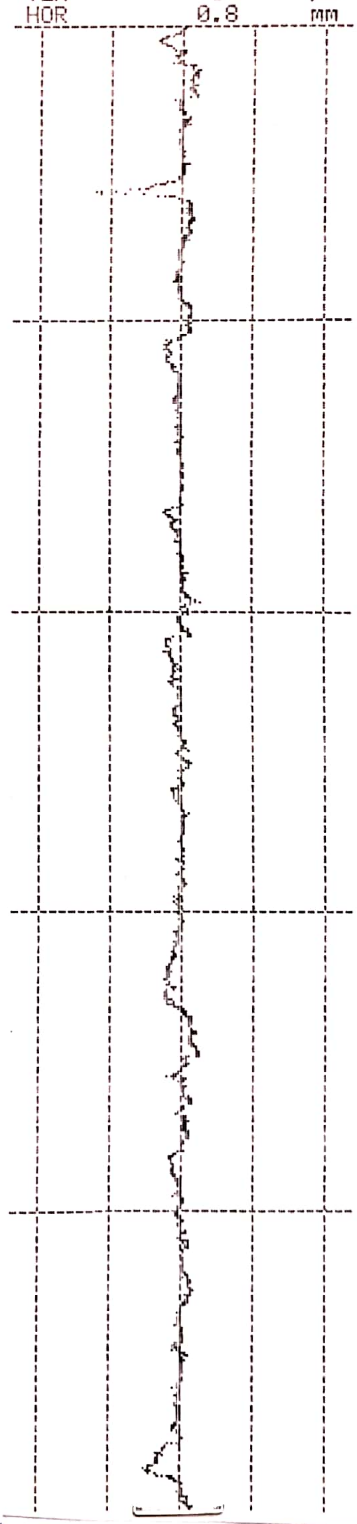
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 19.07.2019
NAME BM3 RIGHT SIDE

CUTOFF		0.8 X 5	
RA		0.08	µm
RZ		0.7	µm
RT		1.5	µm
TP	(10%)	7	%
	(15%)	26	%
	(20%)	61	%
	(25%)	85	%
	(30%)	91	%
	(40%)	98	%
	(50%)	99	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

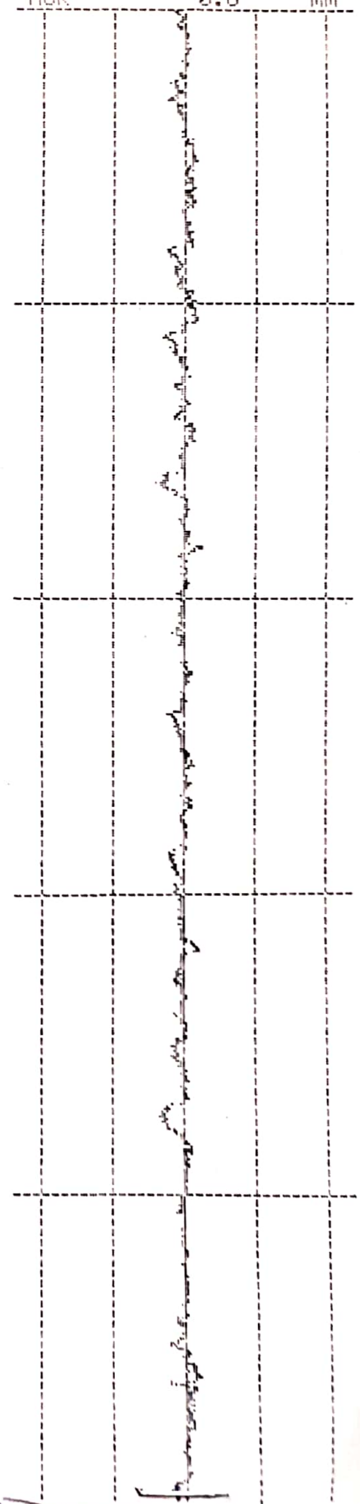
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 19.07.2019
NAME BM3 Left side

CUTOFF		0.8 X 5	
RA		0.06	µm
RZ		0.4	µm
RT		0.6	µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	1	%
	(25%)	5	%
	(30%)	14	%
	(40%)	40	%
	(50%)	77	%
	(60%)	89	%
	(70%)	95	%
	(80%)	98	%
	(90%)	99	%

VER 1 µm
HOR 0.8 mm



- Doc G703 - Fatigue test - Production test plate specimens

Test (12) & (13) Next leaf 1/2

Fatigue test log - rev 0

	R= 0,1
Project name	Master Thesis
Specimen ID	8612-2 2A (B)
Date	04.07.2019

Stress range (ΔS)	375 MPa	Mpa	Load range ΔF	87.01	kN	ΔF=ΔS*Area/1000
Target life		Cycles	Max load	96.68	kN	Fmax=ΔF/(1-R)
Area (8.60x26.98)	232.03	mm²	Min load	9.67	kN	Fmin=Fmax-ΔF
Cyclic rate	13	Hz	Mean load	53.17	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	53.17	43.51	± kN	F=Fmean±ΔF/2

Picture	Date	Time	Cycles	Observation, comments	Temp	Sign	Δ displ.
	4/7-2019	10:37	0				
	— " —	10:42	3580	0,97/0,29	23.1	Magnus	0.68
	— " —	11:13	26084	1.00/0,31	23.3	Magnus	
	— " —	11:36	45460	1.01/0,33	23.6	Magnus	
	— " —	12:27	85300	1.01/0.33	23.5	Magnus	
	— " —	14:24	176645	1,01/0.32	24.0	Magnus	
	— " —	14:52	198210	1.01/0.32	24.1	Magnus	
	— " —	15:46	240 000	1.00/0.32	24.4	Magnus	
	— " —	17:11	307 000	1,00/0.31	24.2	Magnus	
	— " —	18:19	360 000	0,99/0.31	24.1	Magnus	
	— " —	20:40	469 000	1.01/0.32	23.8	Magnus	
	5/7-2019	09:21	1 063 000	1.00/0.32	23.5	Magnus	
	— " —	10:30	1175 000	1.01/0.33	23.1	Magnus	
	— " —	11:10	1178 000	Tyckte jag såg nånt i orn del. 1.01/0.32	23.1	Magnus	
	— " —	12:02	1190 000	Bands are forming 1.01/0.33	22.8	Magnus	Se note (1) Check Error.
20190705_133003	— " —	13:30	1193 000	Bands for both welds 1.01/0.32	22.8	Magnus	
	— " —	16:30	1258 000	1.01/0.32	22.9	Magnus	
	— " —	17:40	1325 000	1.01/0.32	23.0	Magnus	
	— " —	19:07	1393 000	1.01/0.33	22.6	Magnus	
	— " —	21:23	1500 000	1.02/0.33	22.6	Magnus	
20190706_082304	6/7-2019	08:26	2019 000	Bands is the same 1.01/0.32	22.6	Magnus	
	— " —	11:07	2139 000	1.01/0.32	23.2	Magnus	
	— " —	12:59	2227 000	1.00/0.32	23.1	Magnus	
	— " —	15.50	2360 000	Bands is the same. 1.00/0.32	23.8	Magnus	
	— " —	18:56	2505 000	1.00/0,31	24.1	Magnus	
	7/7-2019	10:31	3 234 000	Bands is the same. 1.00/0.32	23.0	Magnus	
	— " —	17:06	3 543 000	1.00/0.32	23.9	Magnus	
	— " —	19:06	3 647 000	1.00/0.31	24.1	Magnus	
	8/7-2019	07:41	4 225 083	Bands is the same. 1.00/0.32	23.3	Magnus	
	— " —	19:45	4 800 000	1.00/0.32	24.4	Magnus	
	— " —	21:06	4875 000	1.00/0.32	24.3	Magnus	
	— " —	23:45	5 000 000	1.00/0.31	24.3	Magnus	0.69

(1)

Run out:
N = 5 000 000
ΔS = 375 MPa

Test (15)

Fatigue test log - rev 0

Project name	R= 0,1	Larsson Master thesis pilot
Specimen ID		8612-2 2A (B)
Date		8/7 2019

Stress range (ΔS)	400 MPa	Mpa	Load range ΔF	92.812	kN
Target life		Cycles	Max load	103.124	kN
Area	232.05	mm²	Min load	10.312	kN
Cyclic rate	12	Hz	Mean load	56.718	kN
Test rig	MTS 809	Machine load	56.718	46,406	± kN

ΔF=ΔS*Area/1000

Fmax=ΔF/(1-R)

Fmin=Fmax-ΔF

Fmean=(Fmax+Fmin)/2

F=Fmean±ΔF/2

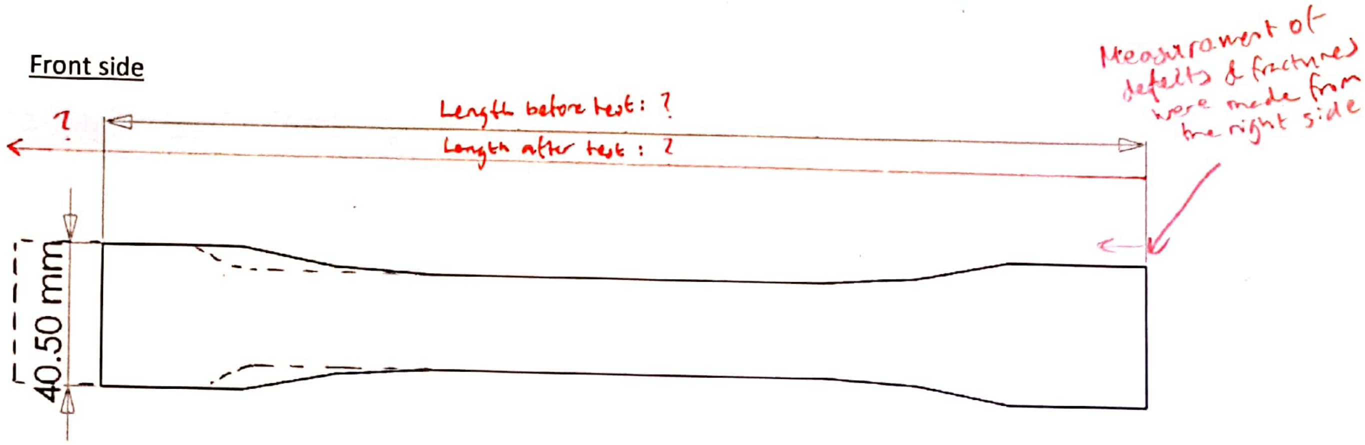
Date	Time	Cycles	Observation, comments	Sign
8/7 - 2019	23:50	0		Magnus.
9/7 - 2019	10:15	439 404	Bands on the surface had increas abot when crack occurs.	Magnus.
			• Failure Criterion:	
			Complete fracture BM	
			N = 439 404	
			ΔS = 400 MPa	

Visual Test log

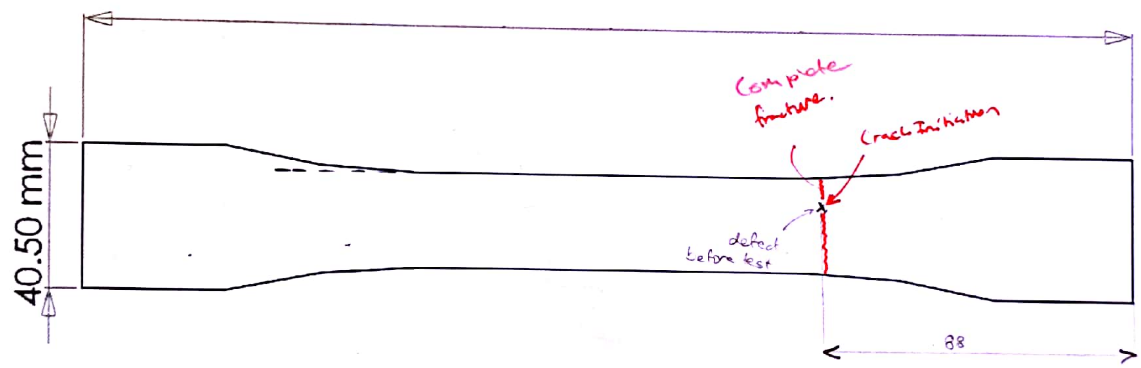
Test : 12 & 13

Name: 8612 - 2 2A (B)

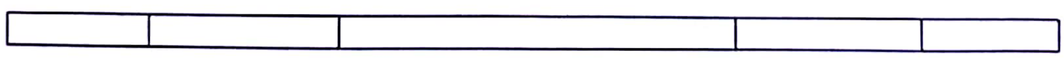
Front side



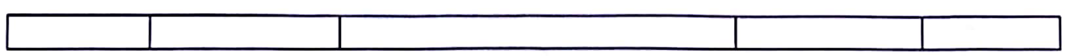
Back side



Right side



Left side

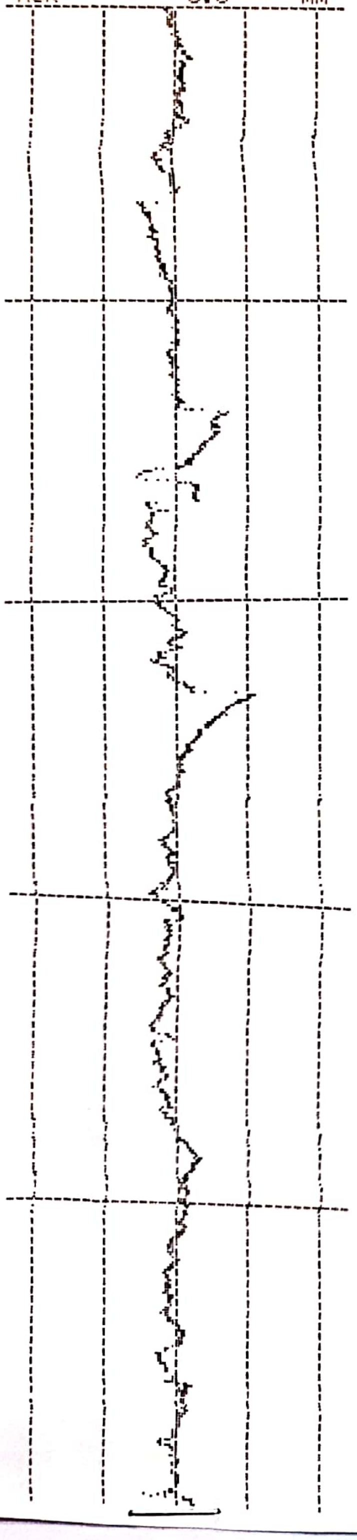


MITUTOYO SURFTEST 201

DATE 21.06.2019
NAME 8612-2 2A (B)
FRONT SIDE CENTER

CUTOFF	0.8	X 5
RA	0.16	µm
RZ	1.0	µm
RT	1.6	µm
TP (10%)	0	%
(15%)	0	%
(20%)	0	%
(25%)	1	%
(30%)	1	%
(40%)	4	%
(50%)	7	%
(60%)	18	%
(70%)	55	%
(80%)	84	%
(90%)	97	%

VER 1 µm
HOR 0.8 mm

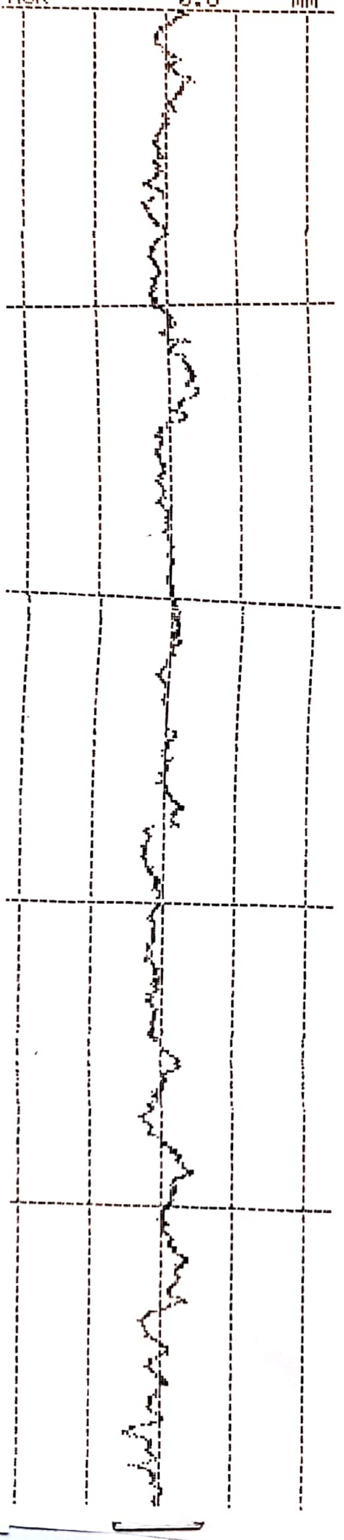


MITUTOYO SURFTEST 201

DATE 21.06.2019
NAME 8612-2 2A (B)
BACKSIDE CENTER

CUTOFF	0.8	X 5
RA	0.12	µm
RZ	0.7	µm
RT	0.9	µm
TP (10%)	1	%
(15%)	5	%
(20%)	7	%
(25%)	11	%
(30%)	16	%
(40%)	30	%
(50%)	54	%
(60%)	81	%
(70%)	95	%
(80%)	99	%
(90%)	99	%

VER 1 µm
HOR 0.8 mm

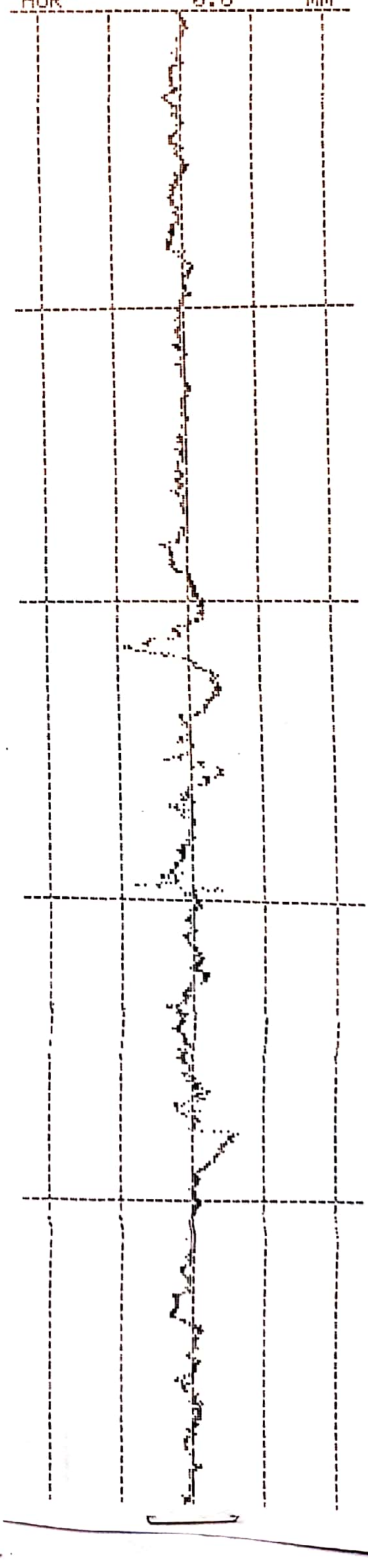


MITUTOYO SURFTEST 201

DATE 21.06.2019
NAME 8612-2 2A (B)
RIGHT SIDE

CUTOFF	0.8	X 5
RA	0.11	µm
RZ	0.7	µm
RT	1.6	µm
TP (10%)	0	%
(15%)	1	%
(20%)	3	%
(25%)	5	%
(30%)	8	%
(40%)	34	%
(50%)	65	%
(60%)	97	%
(70%)	98	%
(80%)	99	%
(90%)	99	%

VER 1 µm
HOR 0.8 mm

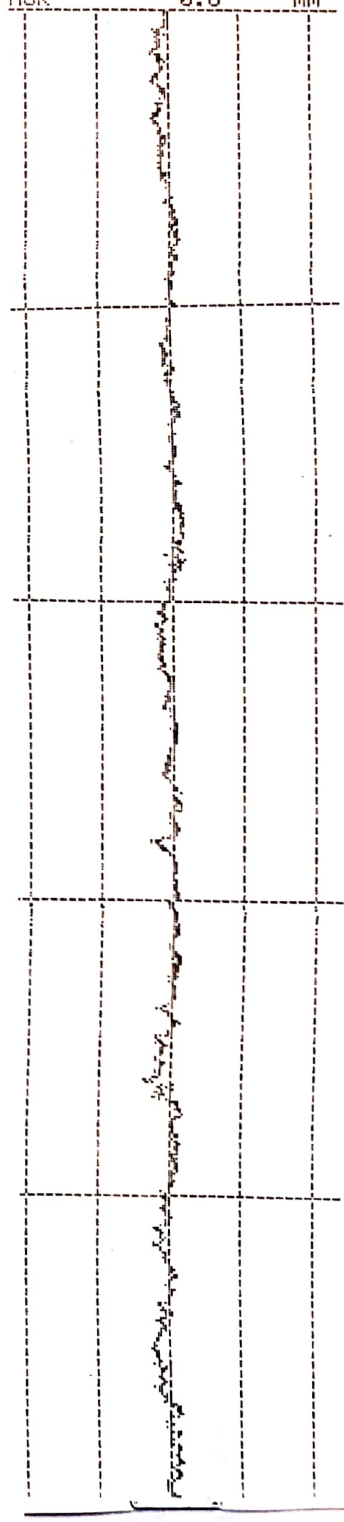


MITUTOYO SURFTEST 201

DATE 21.06.2019
NAME 8612-2 2A (B)
LEFT SIDE

CUTOFF	0.8	X 5
RA	0.07	µm
RZ	0.4	µm
RT	0.6	µm
TP (10%)	2	%
(15%)	6	%
(20%)	17	%
(25%)	23	%
(30%)	39	%
(40%)	63	%
(50%)	78	%
(60%)	92	%
(70%)	98	%
(80%)	99	%
(90%)	99	%

VER 1 µm
HOR 0.8 mm



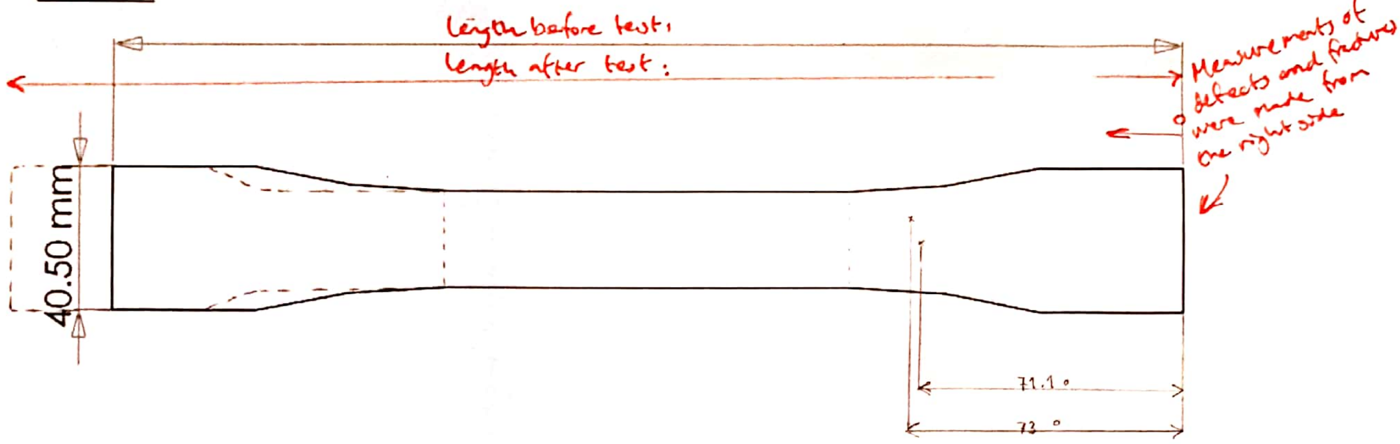
Visual test Log

Test: 14

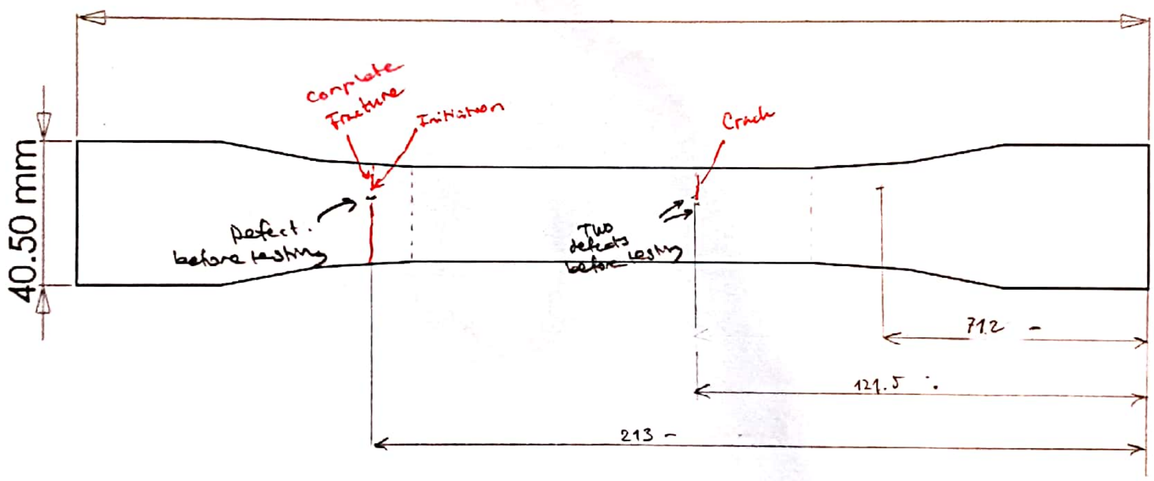
Name: 8612-3 A3

Magnus Larsson
06.07.2019

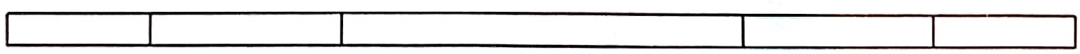
Front side



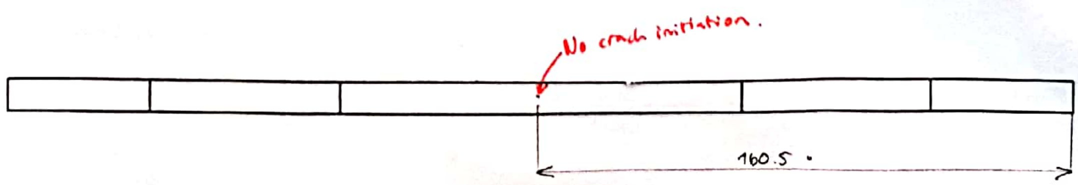
Back side



Right side - Good



Left side



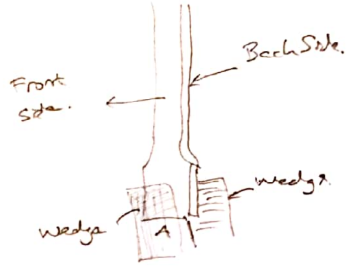
Test (14)

Fatigue test log - rev 0

UiS

R= 0,1

Project name	Larsson Master thesis pilot
Specimen ID	8612 - 3 A3
Date	9.07.2019



Stress range (ΔS)	375 MPa	Mpa	Load range ΔF	88.22	kN
Target life		Cycles	Max load	98.02	kN
27.04 × 8.70 = Area	235.248	mm²	Min load	9,8	kN
Cyclic rate	13	Hz	Mean load	53.9	kN
Test rig	MTS 809	Machine load	53.9	44.11	± kN

ΔF=ΔS*Area/1000 94.10

Fmax=ΔF/(1-R) 104.55

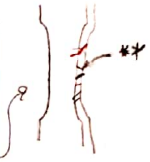
Fmin=Fmax-ΔF 10.45

Fmean=(Fmax+Fmin)/2 57.50

F=Fmean±ΔF/2 57.50 ± 47.05

Date	Time	Cycles	Observation, comments		Temp	Sign	
9/7-2019	10:10	0		0.98/0.29	23.2	Magnus	
-"-	10:22	13 800		1.02/0.33	23.4	Magnus	
-"-	12:19	105 000	See some bending right side & one on front	1.05/0.36	23.9	Magnus	
-"-	16:10	284 600		1.04/0.35	24.3	Magnus	
-"-	18:11	379 600		1.04/0.35	24.8	Magnus	
10/7-2019	08:13	1 036 000	Some extra bend.	1.05/0.35	23.5	Magnus	
-"-	12:54	1 255 600		1.05/0.36	24.2	Magnus	
-"-	16:05	1 386 000		1.04/0.35	24.9	Magnus	
-"-	18:11	1 502 700		1.04/0.34	25.4	Magnus	
-"-	19:24	1 560 000		1.03/0.34	25.2	Magnus	
11/7-2019	08:31	2 173 000	Same.	1.04/0.35	24.3	Magnus	
-"-	10:43	2 277 000		1.04/0.35	24.1	Magnus	
-"-	14:20	2 449 000		1.04/0.35	24.4	Magnus	
-"-	19:19	2 680 000		1.03/0.34	25.1	Madias	
12/7-2019	08:08	3 279 000	Some new bends	1.05/0.35	24.1	Magnus	* *
-"-	13:37	3 532 678		"	24.9	Madias	
-"-	16:59	3 693 600		1.03/0.34	24.9	Magnus	
"	19:12	3 800 000		"	"	Madias	
13/7-2019	07:34	4 375 300		1.04/0.35	24.8	Magnus	
"	18:28	4 863 979		"	"	Madias	0,69
"	19:58	4 953 349		"	"	"	0,69
"	20:03	1000	Δ 400 MPa	1.11/0.37	"	"	0,74
"	20:10	7500		2.39/1.63		"	0,76
14/7-19	06:24	483 574	Fracture		"	"	
			• Run out: We stoped at 4 953 344 cycles				
			at 375 MPa. We continued the test				
			at 400 MPa				
			• Failure Criterion:				
			Complete fracture BM				
			N = 483 574				
			ΔS = 400 MPa				

400 MPa 13 Hz

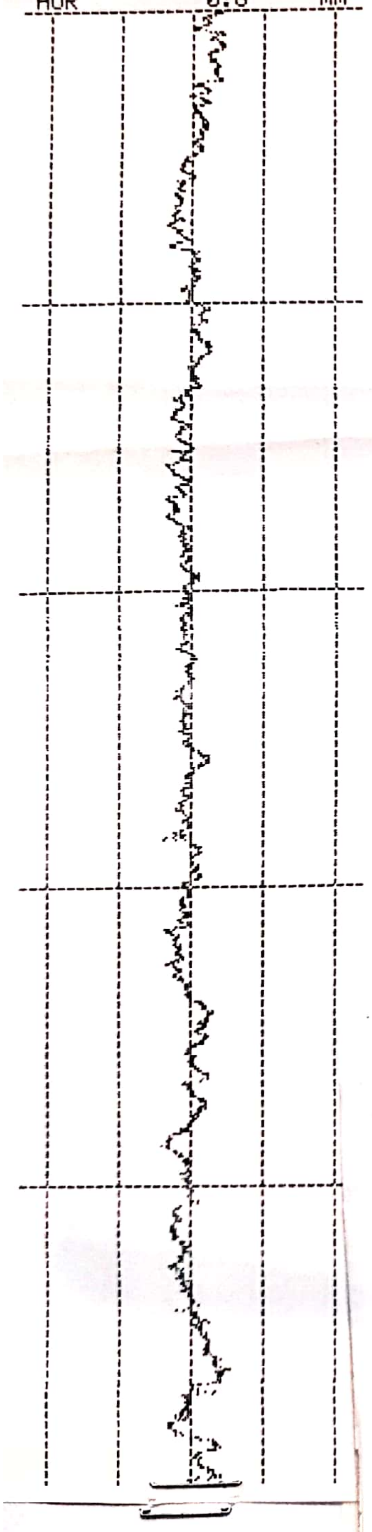


From visual inspection log: Fracture occure at the same place as reg. defect.
Crack 2 → Also here was a defect registred.

MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 A3 Front Side

CUTOFF		0.8 X 5	
RA		0.14	µm
RZ		0.7	µm
RT		0.9	µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	3	%
	(25%)	5	%
	(30%)	8	%
	(40%)	16	%
	(50%)	31	%
	(60%)	47	%
	(70%)	69	%
	(80%)	89	%
	(90%)	98	%

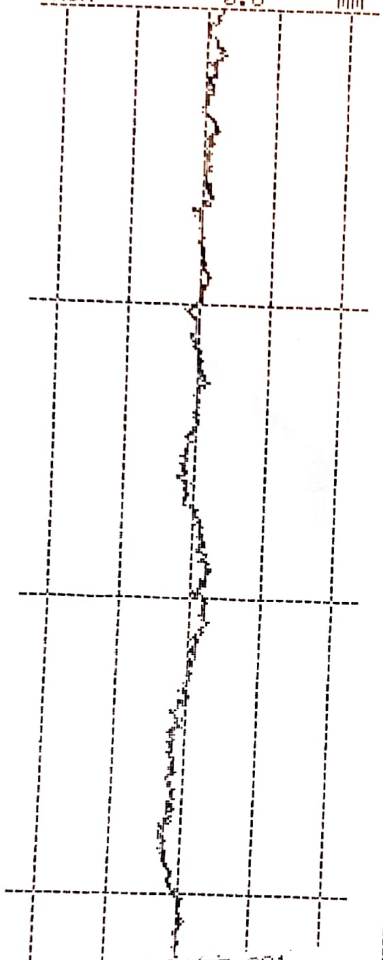
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A Backside . Between weld A & B

CUTOFF		0.8 X 5	
RA		0.16	µm
RZ		0.7	µm
RT		1.1	µm
TP	(10%)	3	%
	(15%)	4	%
	(20%)	9	%
	(25%)	16	%
	(30%)	23	%
	(40%)	49	%
	(50%)	68	%
	(60%)	81	%
	(70%)	91	%
	(80%)	93	%
	(90%)	98	%

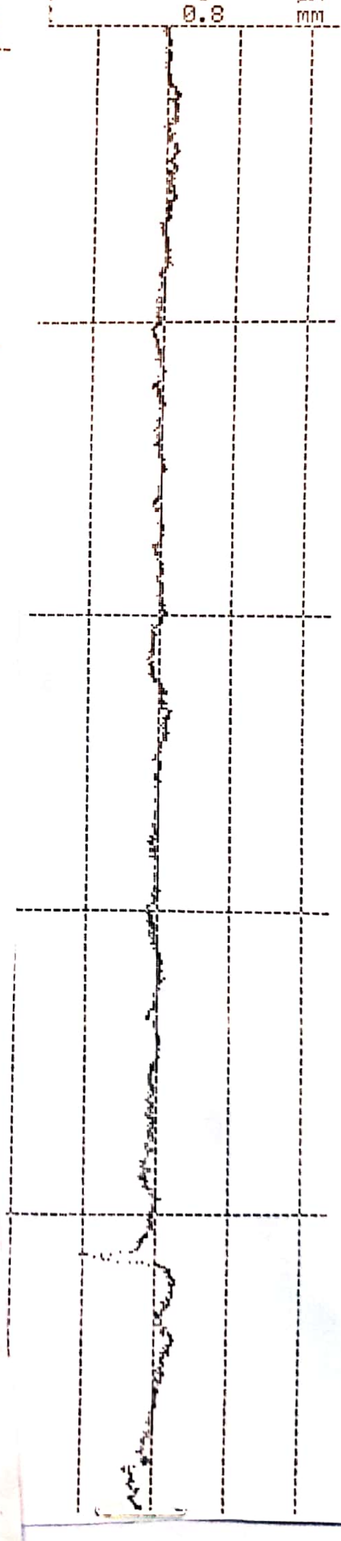
VER 1 µm
HOR 0.8 mm



JTOYO SURFTEST 201
14.07.2019
8612-3 3A Right side . Between weld A & B

OFF		0.8 X 5	
		0.08	µm
		0.5	µm
		1.3	µm
	(10%)	5	%
	(15%)	18	%
	(20%)	38	%
	(25%)	64	%
	(30%)	90	%
	(40%)	97	%
	(50%)	99	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

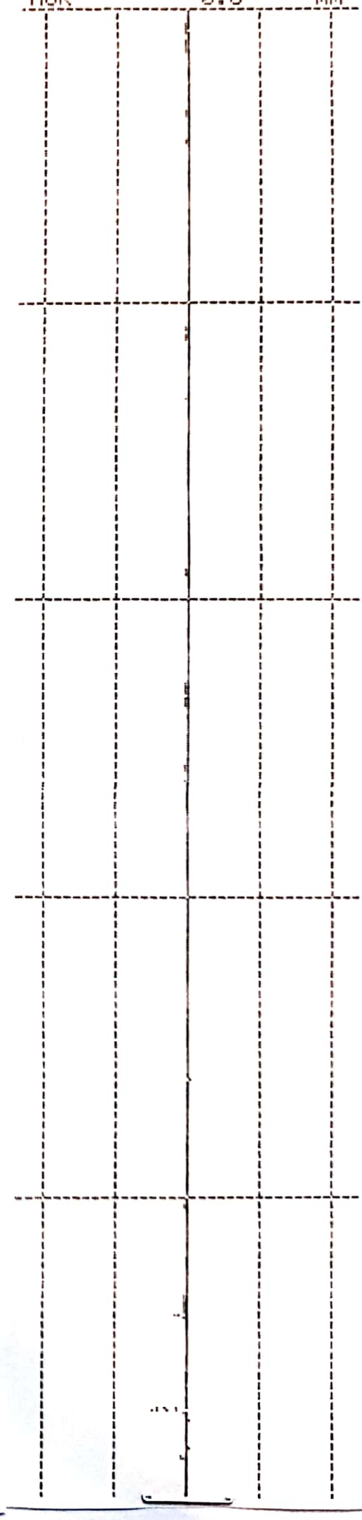
1 µm
0.8 mm



MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A Left side . Left side of weld A

CUTOFF		0.8 X 5	
RA		0.07	µm
RZ		0.7	µm
RT		2.6	µm
TP	(10%)	69	%
	(15%)	96	%
	(20%)	99	%
	(25%)	99	%
	(30%)	99	%
	(40%)	99	%
	(50%)	99	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

VER 5 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A Backside . 1mm beside crack 2

CUTOFF	0.8 X 5	
RA	0.29	µm
RZ	1.1	µm
RT	2.5	µm

MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A Backside . 1mm beside the fracture

CUTOFF	0.8 X 5	
RA	0.40	µm
RZ	1.0	µm
RT	1.9	µm

MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A Backside . 1mm beside fracture

CUTOFF	0.8 X 5	
RA	0.36	µm
RZ	0.9	µm
RT	2.0	µm

MITUTOYO SURFTEST 201
DATE 14.07.2019
NAME 8612-3 3A BACKSIDE 3mm from fracture

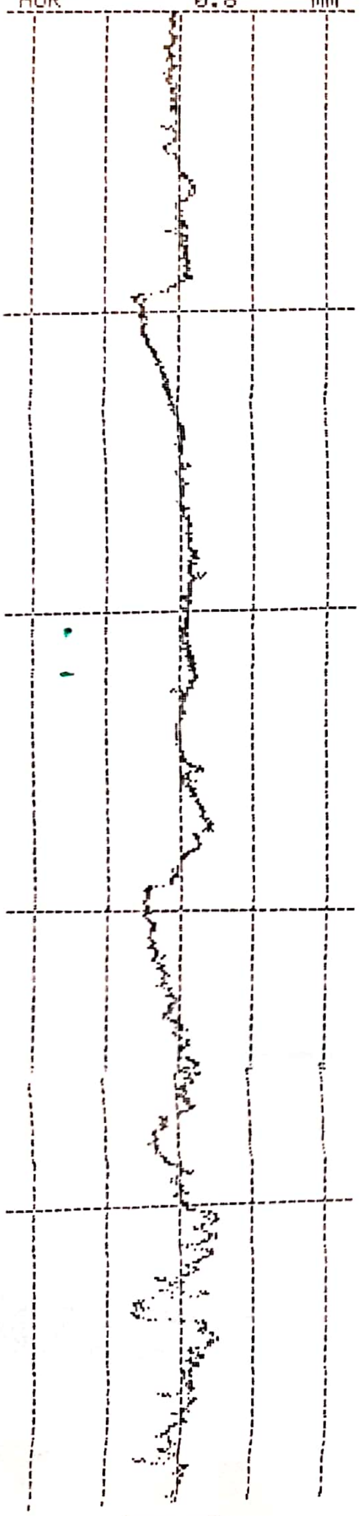
CUTOFF	0.8 X 5	
RA	0.21	µm
RZ	0.9	µm
RT	1.4	µm

8612-3 3A
After fatigue test = fracture
Note. 1 crack & 1 fracture.

MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 A3
FRONTSIDE CENTER

CUTOFF	0.8	X 5
RA	0.17	µm
RZ	0.9	µm
RT	1.2	µm
TP (10%)	1	%
(15%)	3	%
(20%)	5	%
(25%)	8	%
(30%)	13	%
(40%)	37	%
(50%)	66	%
(60%)	88	%
(70%)	87	%
(80%)	92	%
(90%)	98	%

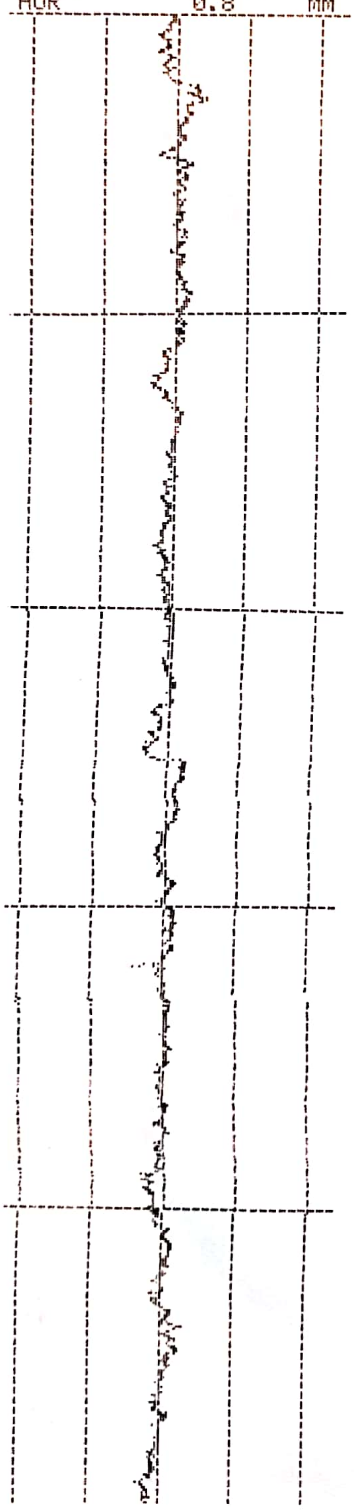
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 A3
BACKSIDE CENTER

CUTOFF	0.8	X 5
RA	0.09	µm
RZ	0.6	µm
RT	0.8	µm
TP (10%)	0	%
(15%)	1	%
(20%)	1	%
(25%)	3	%
(30%)	7	%
(40%)	24	%
(50%)	49	%
(60%)	74	%
(70%)	91	%
(80%)	97	%
(90%)	99	%

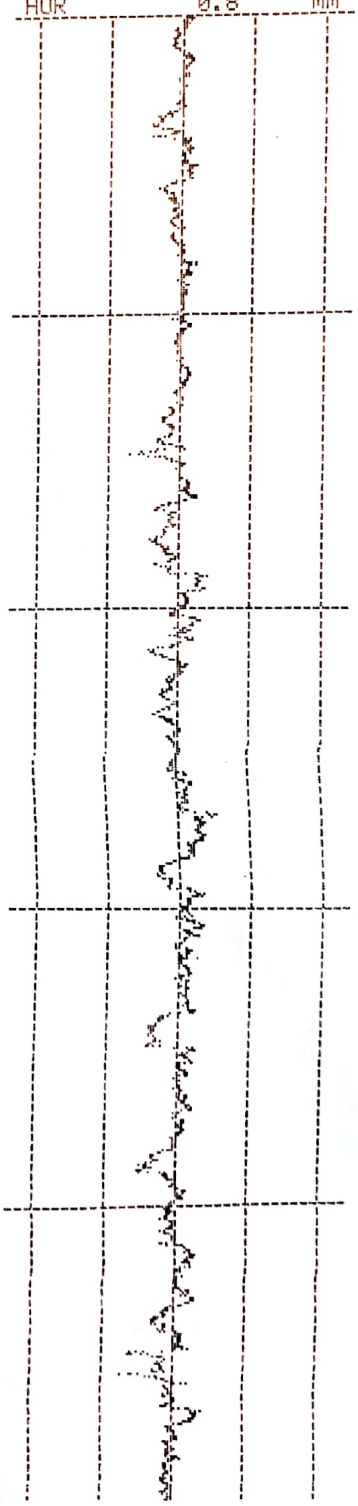
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 A3
RIGHT SIDE

CUTOFF	0.8	X 5
RA	0.12	µm
RZ	0.9	µm
RT	1.3	µm
TP (10%)	0	%
(15%)	1	%
(20%)	2	%
(25%)	5	%
(30%)	12	%
(40%)	41	%
(50%)	76	%
(60%)	91	%
(70%)	97	%
(80%)	99	%
(90%)	99	%

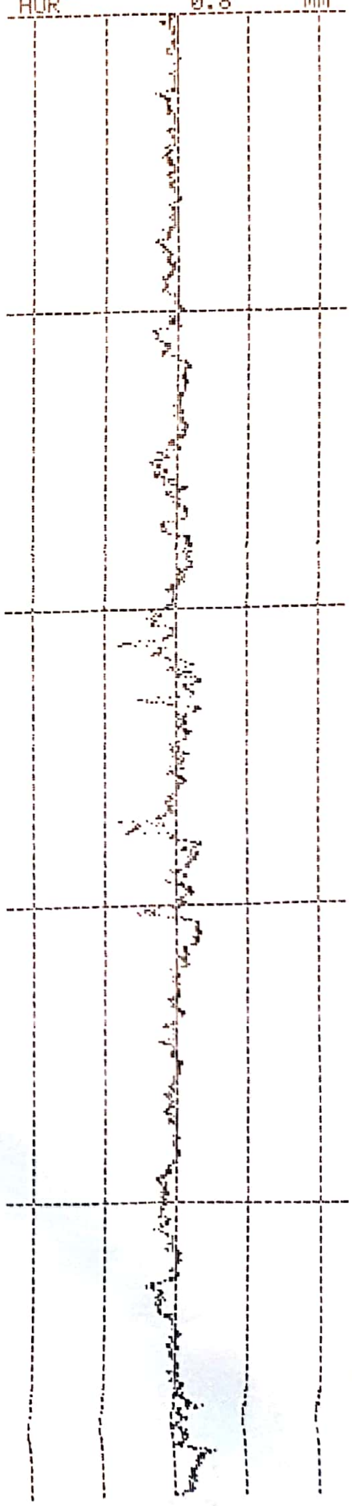
VER 1 µm
HOR 0.8 mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 A3
LEFTSIDE

CUTOFF	0.8	X 5
RA	0.12	µm
RZ	0.8	µm
RT	1.3	µm
TP (10%)	0	%
(15%)	0	%
(20%)	2	%
(25%)	6	%
(30%)	10	%
(40%)	34	%
(50%)	74	%
(60%)	93	%
(70%)	98	%
(80%)	99	%
(90%)	99	%

VER 1 µm
HOR 0.8 mm



Before fatigue test

(15)

Failure criterion
- Runout: We stopped at N=5000 000 at ΔS=375MPa
- failure Criterion: Complete fracture N = 2 084 237 ΔS = 400 MPa

Ib. Looks like weld B

Fatigue test log - rev 0

R= 0,1

Project name	Master Thesis Larssons
Specimen ID	8612-4
Date	14.07.2019

ΔS=400

Stress range (ΔS)	375MPa	Mpa	Load range ΔF	77,194	kN
Target life	+ 5 000 000 / 450 000	Cycles	Max load	85,77	kN
27.05 × 7.61 Area	205,851	mm²	Min load	8.577	kN
Cyclic rate	13	Hz	Mean load	47 174	kN
Test rig	MTS 809	Machine load	47 174	38.6	± kN

ΔF=ΔS*Area/1000 — 82.34

Fmax=ΔF/(1-R) — 91.49

Fmin=Fmax-ΔF — 9.15

Fmean=(Fmax+Fmin)/2 — 50.32

F=Fmean±ΔF/2 — 41.17

	Date	Time	Cycles	Observation, comments		TEMP	Sign		Δd
	14/7-19	1055	2200	start	0,92/0,26	23.7	Matthias		
	—"—	17:33	170 900		0,96/0,30	24.1	Magnus		
	—"—	17:42	318 300	Ceased bonds	0,95/0,29	24.8	Magnus		
	—"—	20:13	436 300		0,94/0,28	25.3	Magnus		
	15/7-19	10:08	1087 748		0,95/0,29	25.9	Matthias		
	"	14:22	1287 654		"	"	"		
	"	1810	1467129		"	25.2	"		
	"	1928	1524659		"	"	"		
	16/7-2019	08:01	2 112 000	two new bonds	0,95/0,29	24.3	Magnus		
	—"—	09:59	2 204 000		0,95/0,29	24.7	Magnus		
	—"—	12:50	2 336 000		0,95/0,29	24.6	Magnus		
	—"—	21:23	2 737 000		0,94/0,28	25.1	Magnus		
	17/7 2019	08:13	3.244 000		0,95/0,29	24.3	Magnus		
	—"—	13:22	3.485 000		0,95/0,29	24.9	Magnus		
	"	1835	3.729933		"	25.3	Matthias		
	18/7-2019	1035	4478 527		"	"	"		
	"	1642	4764335		"	"	"		
	"	2026	4938994	STOP	"	"	"		
ΔS=400MPa	"	2035	1300	ΔS=400	1.01/0.31	"	"		Δd
	"	2046	2000	"	1,05/0,34	"	"		0,71
	19/7-2019	08:37	100 000	ΔF: 91.48/9.14	2.39/1.68	23.1	Magnus	Pictures	0,71
	- " -	11.00	200 000		2.44/1.72	23.9	Matthias	Picture	0,72
	- " -	14 43	300 000		2.49/1.77	24.4	Magnus	Picture	0,72
①	"	1703	400 000	No crack visible	"	"	Matthias		
	"	1728	418 000	"	"	"	"		0,73
	"	1808	450 000	Displ. stable	2.52/1.80	"	"		0,73
	"	1858	485 000	"	"	"	"		
	"	1916	500 000	0,72	2.53/1,81	"	"		
	"	2015	545 000	"	"	"	"		
②	"	20:56	575 000		2,53/1.81	25.1	Magnus		
	20/7-19	1011	600 000	0,72	2.42/1.70	"	Matthias		
	"	1058	661 200	0,73	2.54/1.81	"	"		
	"	1208	716 000	"	2.56/1.83	"	"		
	"	1638	927 300	"	2.55/1.82	"	"		
	21/7-19	1250	2 084 237	Fracture					

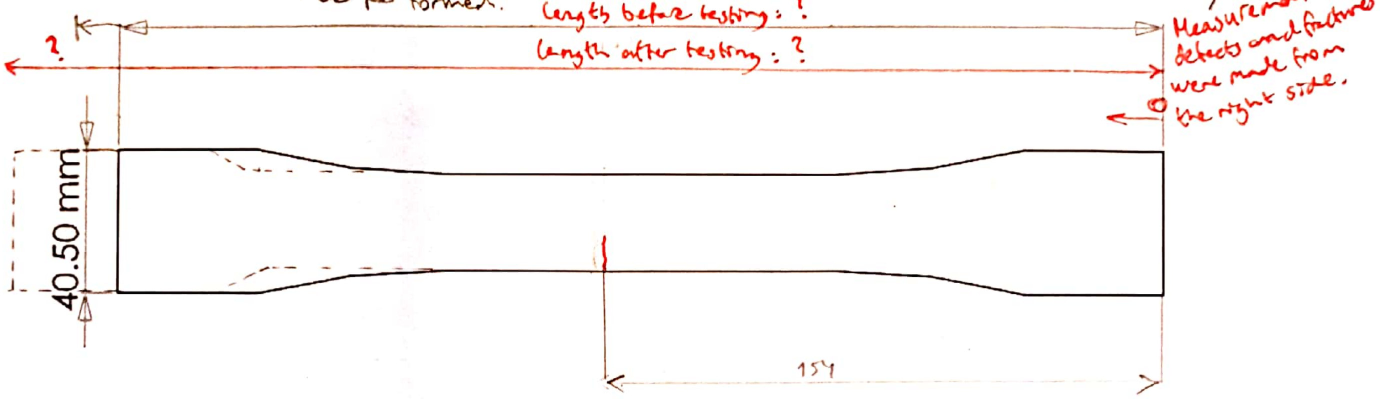
Failure Criterion: See top of page

Visual test log

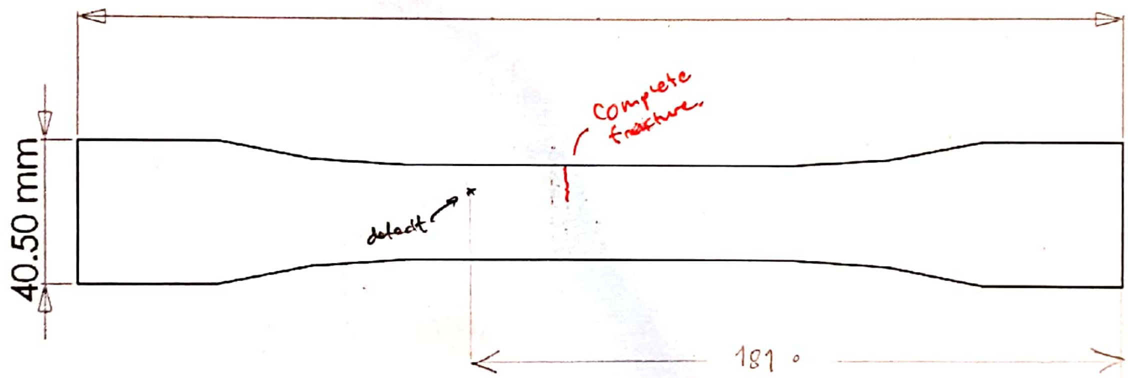
Test : 15

Name: 3612-4 (34)

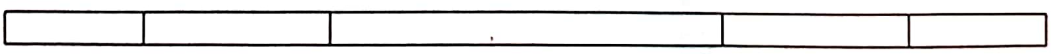
Front side – Good (A damage to the front recorded which made the test unable to performed. Front side had to be sanded down about 1 mm before testing could be performed.)



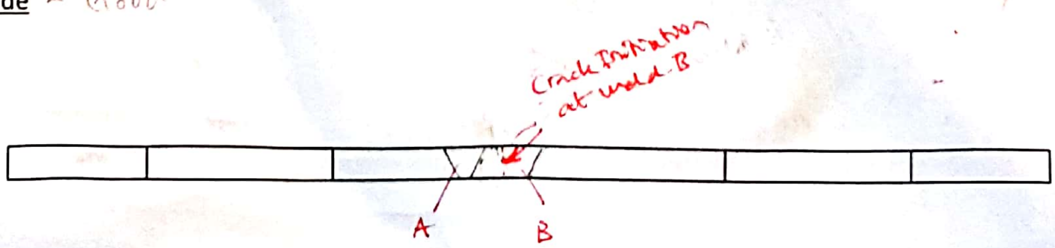
Back side



Right side – Good



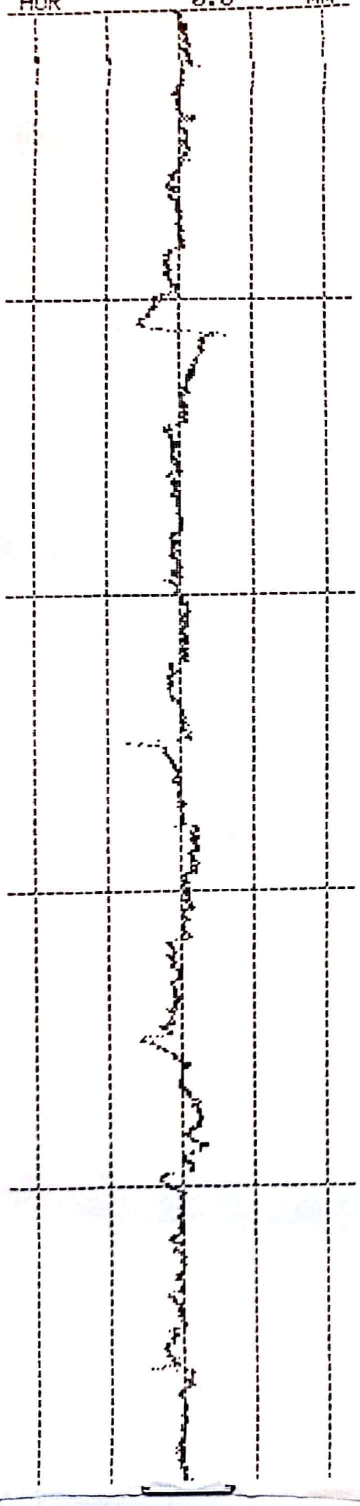
Left side – Good



MITUTOYO SURFTEST 201
DATE 10/7-2019
NAME 8612-4 FRONT SIDE

CUTOFF	0.8 X 5	
RA	0.10	µm
RZ	0.8	µm
RT	1.3	µm
TP (10%)	0	%
(15%)	0	%
(20%)	0	%
(25%)	1	%
(30%)	4	%
(40%)	20	%
(50%)	63	%
(60%)	91	%
(70%)	96	%
(80%)	98	%
(90%)	99	%

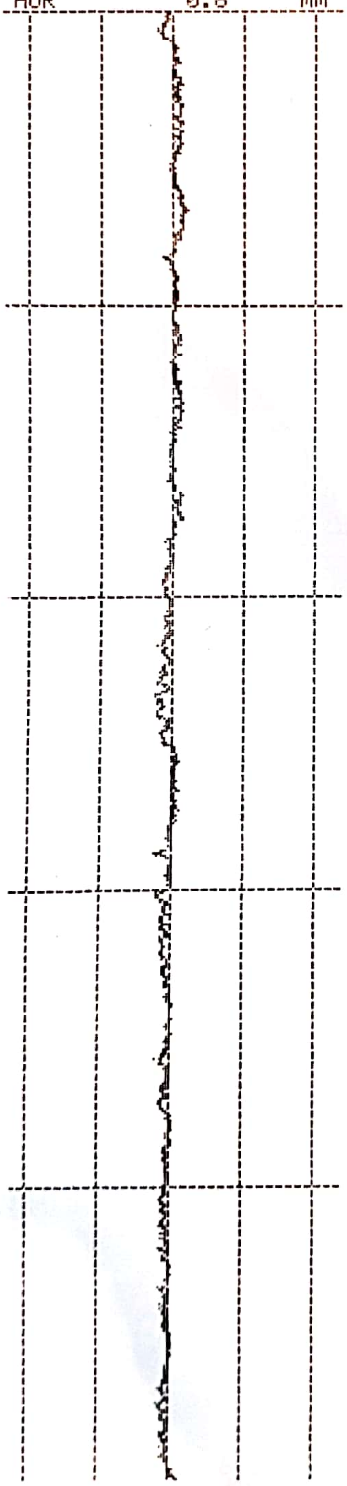
VER	1	µm
HOR	0.8	mm



MITUTOYO SURFTEST 201
DATE 10/7-2019
NAME 8612-4 BACK SIDE

CUTOFF	0.8 X 5	
RA	0.06	µm
RZ	0.3	µm
RT	0.5	µm
TP (10%)	0	%
(15%)	0	%
(20%)	5	%
(25%)	9	%
(30%)	15	%
(40%)	37	%
(50%)	53	%
(60%)	83	%
(70%)	93	%
(80%)	98	%
(90%)	99	%

VER	1	µm
HOR	0.8	mm



MITUTOYO SURFTEST 201
DATE 10/7-2019
NAME 8612-4 Right side

CUTOFF	0.8 X 5	
RA	0.05	µm
RZ	0.3	µm
RT	0.4	µm
TP (10%)	0	%
(15%)	0	%
(20%)	1	%
(25%)	1	%
(30%)	3	%
(40%)	10	%
(50%)	21	%
(60%)	39	%
(70%)	77	%
(80%)	96	%
(90%)	98	%

VER	1	µm
HOR	0.8	mm

MITUTOYO SURFTEST 201
DATE 10/7-2019
NAME 8612-4 Leftside (test 1)

CUTOFF	0.8 X 5	
RA	0.18	µm
RZ	0.9	µm
RT	1.9	µm
TP (10%)	0	%
(15%)	0	%
(20%)	1	%
(25%)	2	%
(30%)	2	%

MITUTOYO SURFTEST 201
DATE 10/7-2019
NAME 8612-4 Leftside (test 2)

CUTOFF	0.8 X 5	
RA	0.17	µm
RZ	1.3	µm
RT	2.2	µm
TP (10%)	4	%
(15%)	8	%
(20%)	18	%
(25%)	43	%
(30%)	66	%
(40%)	90	%
(50%)	97	%
(60%)	98	%
(70%)	99	%
(80%)	99	%
(90%)	99	%

VER	1	µm
HOR	0.8	mm

(17)

Fatigue test log - rev 0

R= 0,1

Project name: Master thesis
Specimen ID: 8612-2 21(BB)
Date: 22/7-19

Stress range (ΔS)	400	Mpa	Load range ΔF	97.23	kN	ΔF=ΔS*Area/1000
Target life	400 000	Cycles	Max load	108.03	kN	Fmax=ΔF/(1-R)
Area	27.25×8.92 = 243.0	mm²	Min load	10.80	kN	Fmin=Fmax-ΔF
Cyclic rate	13	Hz	Mean load	59.42	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	59.42	48.62	± kN	F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign
22/7-19	1954	600	start 3.56/7.78	Marcelas
"	2137	81 000	4.54/3.74	"
23/7-19	0249	322 187	fracture	"
			• Fracture criterion	
			Complete fracture BM (between the welds)	
			ΔS = 400 MPa	
			N = 322 187	

0.80

Visuel check before fatigue testing.

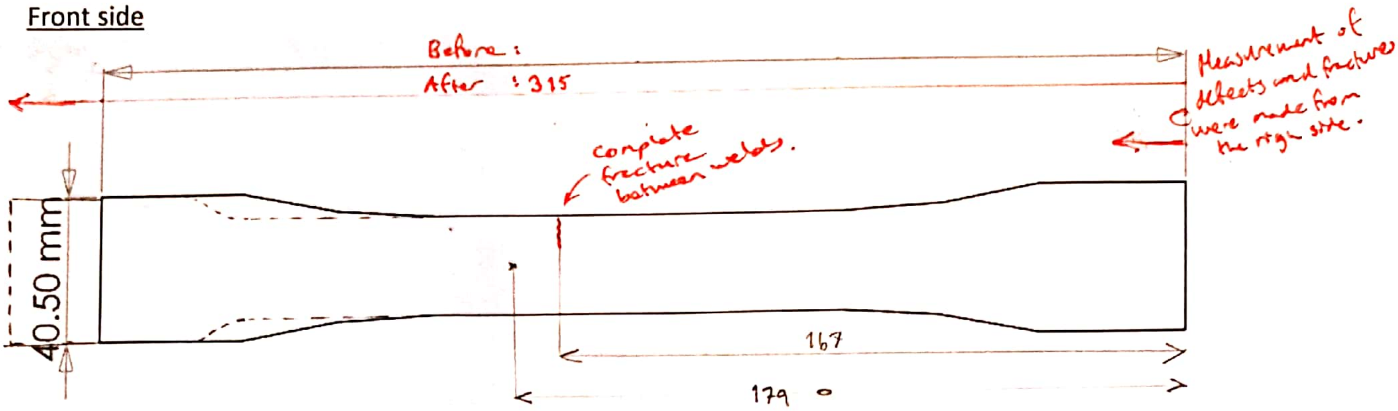
Test: 17

Name: BS12-2 2A (BB)

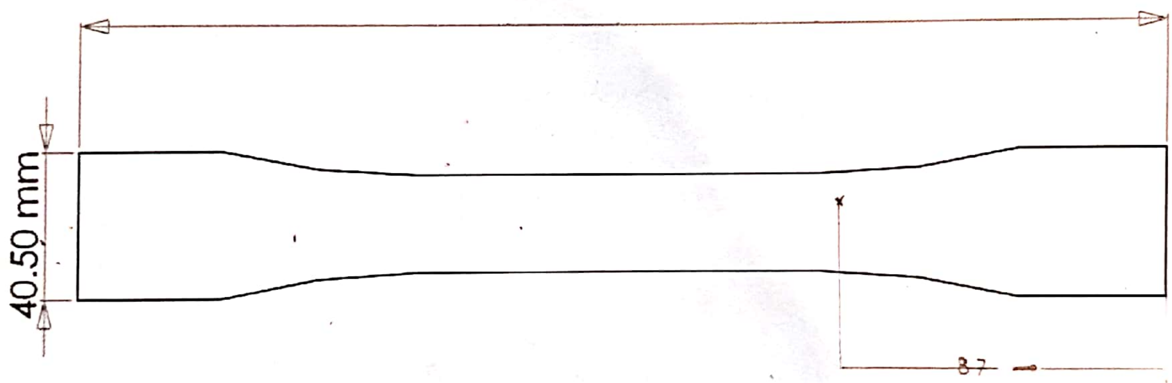
Magnus Larsson

23.06.2019.

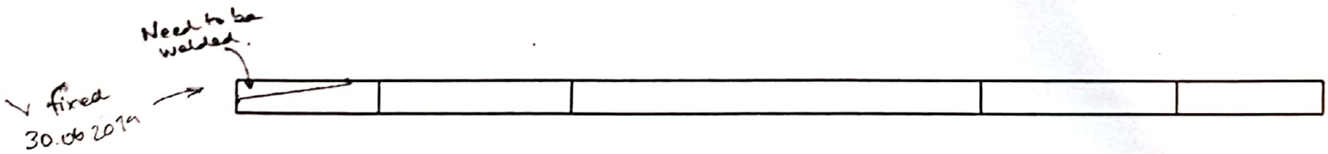
Front side



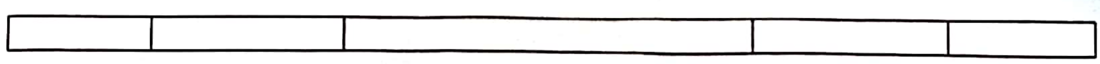
Back side - Good



Right side - Good



Left side - Good



Fatigue test log - rev 0

Project name	R= 0,1	Master Thesis
Specimen ID		8612-3 3A
Date		23/7-19

Stress range (ΔS)	400	Mpa	Load range ΔF	97.63	kN	ΔF=ΔS*Area/1000
Target life	350 000	Cycles	Max load	108.47	kN	Fmax=ΔF/(1-R)
27.27 x 8.95 Area	244.07	mm²	Min load	10.84	kN	Fmin=Fmax-ΔF
Cyclic rate	13	Hz	Mean load	59.66	kN	Fmean=(Fmax+Fmin)/2
Test rig	MTS 809	Machine load	59.66	48.82	± kN	F=Fmean±ΔF/2

Date	Time	Cycles	Observation, comments	Sign	
23/7-19	1114	600	2.72/1.94	Matteo	0.78
"	1231	60 000	4.41/3.60	"	0.81
"	1432	154 400	4.47/3.67	"	0.80
"	1646	250 000	4.45/3.65	"	0.80
"	1823	300 000	Crack initiation	"	
	1841	305 242	Crack propagation 5.62/4.90	"	
	1849	306 418	Fracture	"	
			• Failure Criterion		
			Complete fracture BM		
			N = 306 418		
			ΔS = 400 MPa		

40.5mm = 20mm

$\frac{40.5}{20} = 2.025$

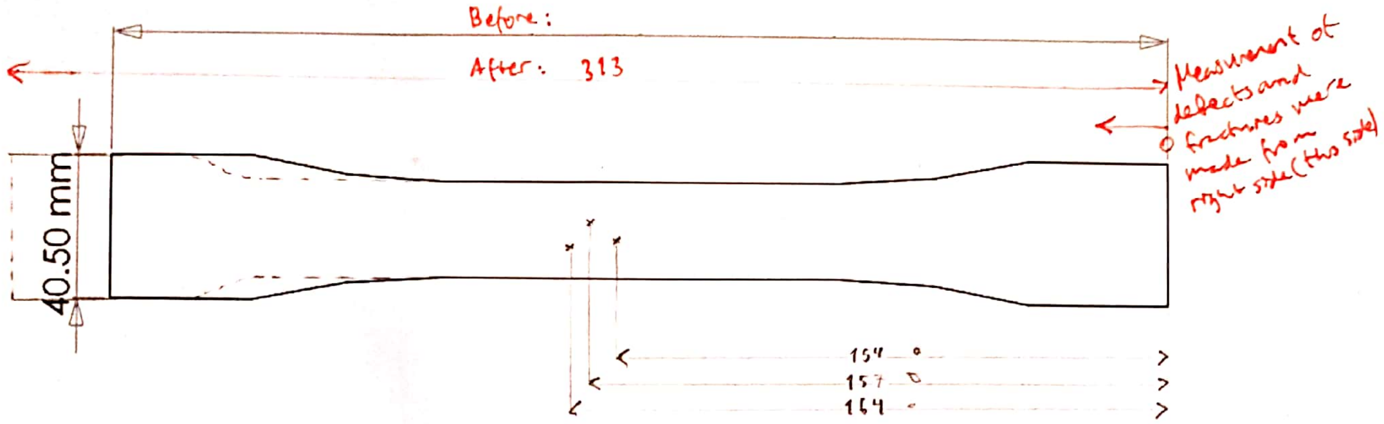
Rev 1

Test: 18

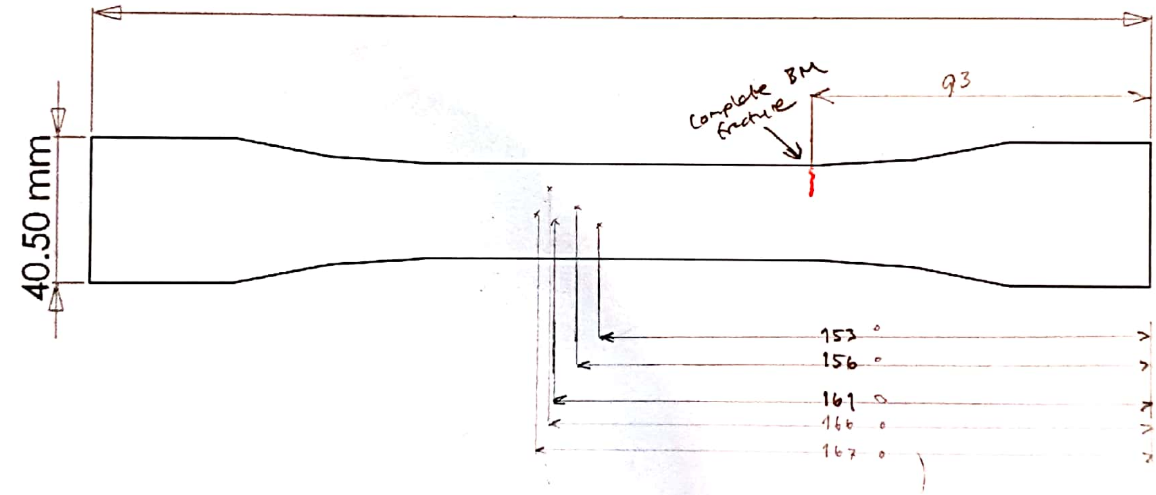
Name: 8612-3 3K

Magnus Larsson
23.06.2019.

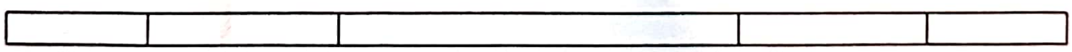
Front side



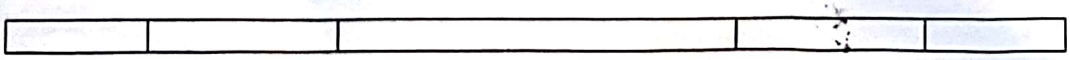
Back side



Right side Good



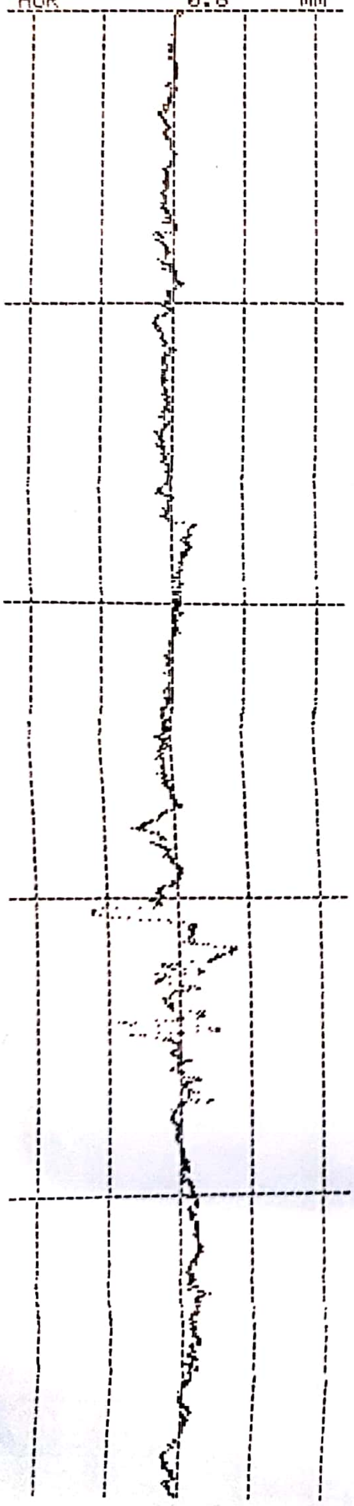
Left side - Good



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 3A
FRONT SIDE Center

CUTOFF		0.8	X 5
RA		0.13	µm
RZ		0.9	µm
RT		2.0	µm
TP	(10%)	0	%
	(15%)	1	%
	(20%)	1	%
	(25%)	2	%
	(30%)	8	%
	(40%)	37	%
	(50%)	92	%
	(60%)	98	%
	(70%)	98	%
	(80%)	99	%
	(90%)	99	%

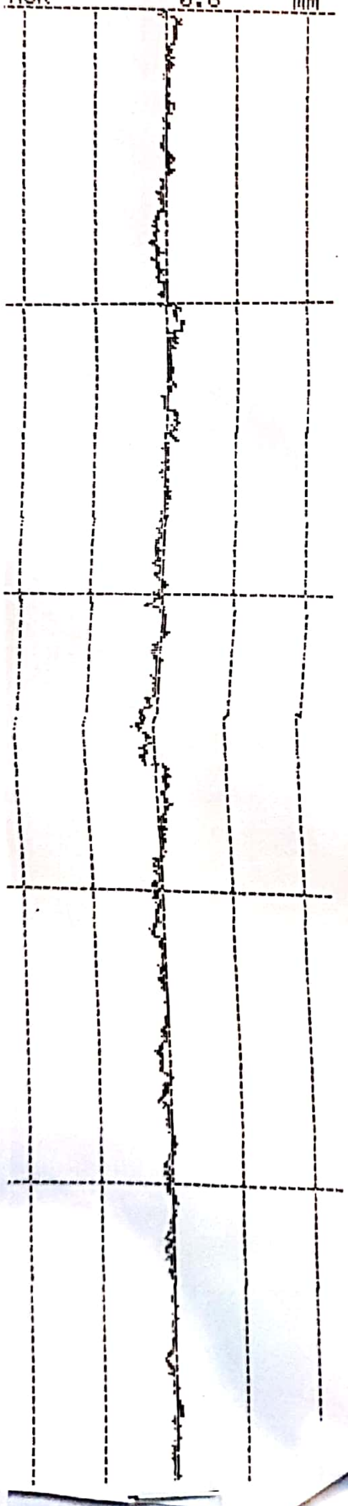
VER	1	µm
HOR	0.8	mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 3A Backside Center

CUTOFF		0.8	X 5
RA		0.06	µm
RZ		0.3	µm
RT		0.5	µm
TP	(10%)	0	%
	(15%)	3	%
	(20%)	5	%
	(25%)	9	%
	(30%)	13	%
	(40%)	33	%
	(50%)	65	%
	(60%)	87	%
	(70%)	96	%
	(80%)	99	%
	(90%)	99	%

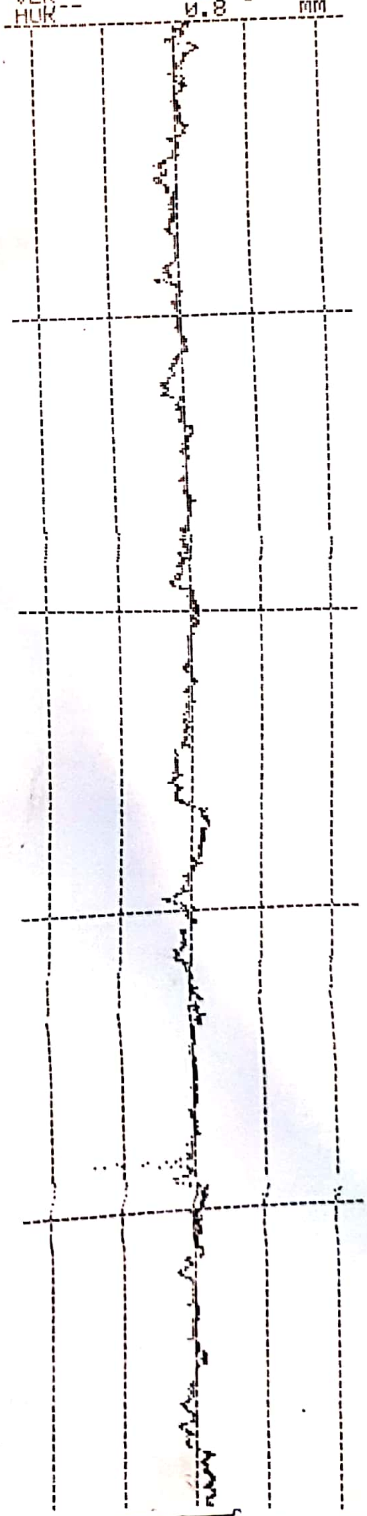
VER	1	µm
HOR	0.8	mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 3A
RIGHTSIDE

CUTOFF		0.8	X 5
RA		0.09	µm
RZ		0.7	µm
RT		1.7	µm
TP	(10%)	4	%
	(15%)	20	%
	(20%)	47	%
	(25%)	77	%
	(30%)	90	%
	(40%)	99	%
	(50%)	99	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

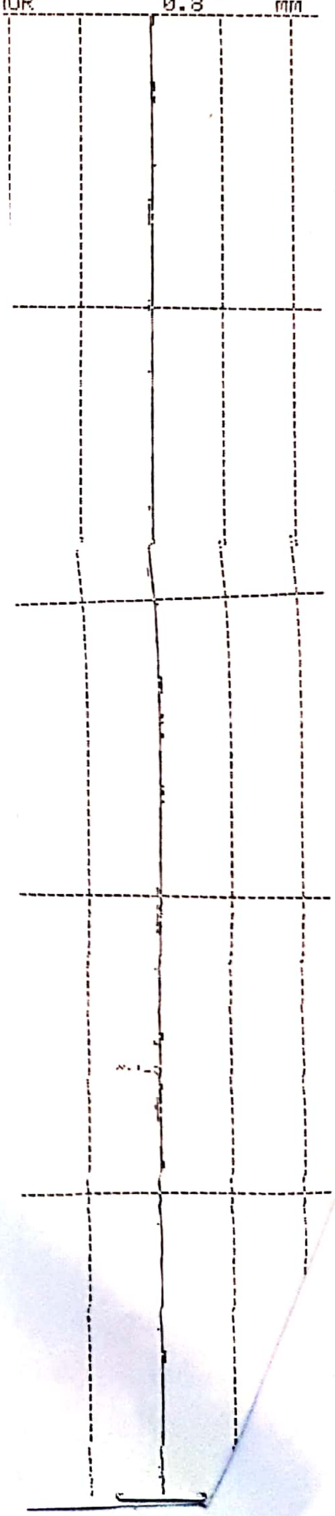
VER	1	µm
HOR	0.8	mm



MITUTOYO SURFTEST 201
DATE 21.06.2019
NAME 8612-3 3A
LEFTSIDE

CUTOFF		0.8	X 5
RA		0.08	µm
RZ		1.0	µm
RT		3.3	µm
TP	(10%)	44	%
	(15%)	95	%
	(20%)	99	%
	(25%)	99	%
	(30%)	99	%
	(40%)	99	%
	(50%)	99	%
	(60%)	99	%
	(70%)	99	%
	(80%)	99	%
	(90%)	99	%

VER	5	µm
HOR	0.8	mm



Appendix H

Residual Stress Measurements

- The chapter "Residual Stress Measurements" has no attachments.