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Abstract

Slipforming is a construction method for concrete and it is especially suited for tall constructions with simple geometry. This method have occasionally caused lifting cracks and other surface damages, due to the friction between the slipform panel and the concrete has become to high.

The thesis will look at how the choice of material composition in concrete mixes in the combination of a given slipform rate would affect the friction between the slipform panel and concrete. The goal is also to verify that the test rig will reproduce the same results with the same concrete mix. In addition there will be tested ultra-high performance concrete to see if it can be used in slipforming.

A total of 10 concrete mixes have been tested in the slipform rig, a reference mix, increased content of silica, air entrainment mix and a mix with lowered water binder ratio, in addition ultra-high performance concrete.

The results indicate that the slipform rig is able to reproduce results.

The max net static and kinetic lifting stress is increased with a higher silica content and with a lower water binder ratio. With increased air content the max net static and kinetic lifting stress is lowered. When compared to the reference mix..

Preface

This master thesis is written in the spring of 2016, as a final part of a two-year master's program at the Department of Structural Engineering and Materials Science, University of Stavanger (UiS).

I would especially like to thank my supervisor Kjell Tore Fosså, for his help and for the suggestion about the choice of topic. Also, his PhD thesis on slipforming have been an extremely important inspiration and have been the main source of information that my thesis is based on.

In addition, I would like to thank Jarle Berge for his many hours of help in the laboratory. Without his help the testing would not have been possible.

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1. Introduction

Slipforming has gradually become a conventional construction method over the years and has proven to be effective for production of tall vertical concrete structures such as silos, tall foundations, stairwells etc. It have however been found that slipforming have occasionally caused lifting cracks and other surface damages, this is due to that the friction between the slipform panel and concrete has become too high.

The thesis will look at how the choice of material composition in concrete mixes in combination of a given slipform rate would affect the friction between the slipform panel and concrete.

There will be performed a literature review of existing literature on experiences made with slipforming. A laboratory program will also be executed where a new slipform rig at UiS will be used to test how the composition of concrete affects the friction in slipforming. The goal is also to verify that the test rig will reproduce the same results with the same concrete mix. In addition there will be tested to see if ultra-high performance concrete can be used in slipforming.

In chapter 2 the relevant findings from the literature review is presented. The slipform rig at UiS is described in chapter 3. Chapter 4 describes the laboratory program, materials used and how the testing of concrete was performed. The results are presented in chapter 5 and discussed. And lastly chapter 6, the conclusion.

2. Literature review

2.1. Slipforming

2.1.1. Description of slipforming

Slipforming is a construction method for concrete and it is especially suited for tall constructions with simple geometry.

With slipforming one utilizes the concrete setting time to create a homogeneous layer. This is achieved by pouring concrete layer by layer into a form, which is lifted upwards gradually by a hydraulic jacking system. This allows the concrete layers to merge into each other and create good adhesion and one gets a homogeneous layer.

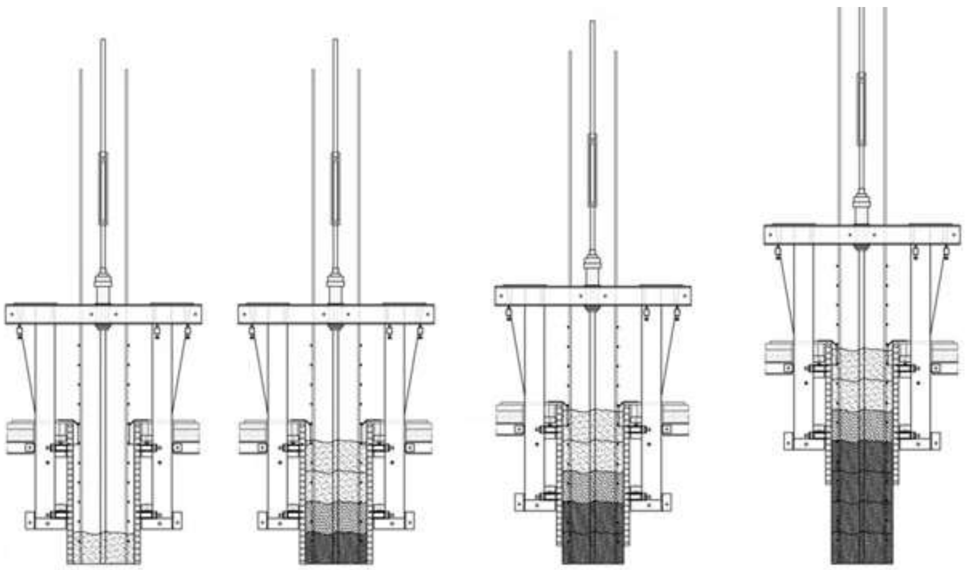

Figure 1- Principle of slipforming

The form is build around yoke frames, these holds the slipform in place and the rest of the form stiff. The hydraulic jacks are placed at the top of the horizontal cross beams, and uses climbing/ jacking rods to lift the form. The slipform panel is what holds the fresh concrete in place, and slides against the concrete when the form is lifted. To ease the detachment of the concrete from the panel it is mounted with a small inclination. The slipform panel has normally a height of 1 to 1.3 m. [1,2]

2.1.2. Conical slipforming

Slipforming can also be performed with a more complex geometry than a simple structure with constant cross section. Conical slipforming is performed where the structural geometry changes over the entire or part of the structure's height. The structure's wall thickness, radius and angle of inclination can be changed.

In extreme cases the slipforming can have an angle of inclination up to 35 degrees, but it is not recommended to exceed 20 degrees. The curvature should be max 100mm per meter, and 50-80 mm is recommended as a practical upper limit. For conical slipforming diameter smaller than 1.5 m should be avoided, due to lack of space. [2]

Figure 2 - Conical slipforming, Troll A

2.1.3. Typical constructions

Slipforming is normally a construction method for high constructions. Typical constructions are:

- Silos.
- Machinery towers.
- Tanks and basins.
- Water towers.
- Chimneys.

- Oil platform legs.
- Civil buildings.

[3]

2.1.4. Pros and cons with slipforming

Pros:

- No horizontal construction joints.
- Casting of thin concrete layers and with a low lifting rate provides favourable conditions for vibrating the concrete.
- No need for spacers in the nominal cover.
- When the construction process is planned carefully it is possible to achieve a high production rate.
- The progress is relatively independent of weather conditions.
- There is good visual control of the placement and compaction of the concrete.
- For higher structures there is showed to be a cost advantage with the use of slipforming.
- The concrete that is left exposed when the form is lifted allows it to be finished.

Cons:

- The nominal cover is constantly affected by the lifting of the form from it is poured until it hardens. This can give surface damages.
- Lump formation and materials sticking to the panel will give vertical damages.
- Vibrating on the reinforcement could give cavities along the reinforcement and poor adhesion.
- There is a time pressure on the steel fixers on placing and tying the reinforcements.
- The work must continue regardless of whether the weather gets bad.
- With slipforming it is required a greater alertness and control than other methods.
- Unforeseen delay in supply of concrete could possible stop the slipform.

[4]

2.2. Surface damage

Surface damages is one of the main concerns related to slipforming. From the concrete is poured until it leaves the form there is a higher probability of surface damages if the stress induced from the lifting of the slipform panel exceeds the concrete strain capacity.

Surface damages related to slipforming can be grouped in lump formation, concrete collapse, delamination and lifting cracks.

When slipforming there can sometimes be a thin concrete layer sticking to a small area on the panel. It will eventually start to grow and become a lump. This will eventually increase the friction and one will get a tear in the nominal cover where the lump displaces the concrete higher up in the form. The formation of lumps is believed to have a connection with a high ambient temperature, static friction and poorly maintained panels.

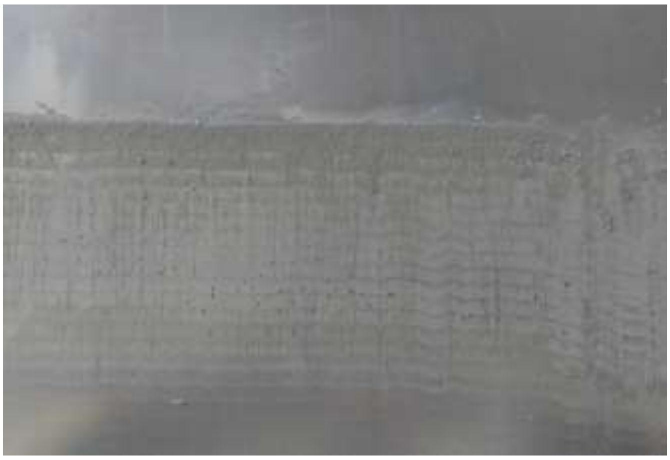

Figure 3 - Beginning growth on slipform panel

If the slipform rate have been too high or the concrete haven't set, and it leaves the form with a concrete strength that is too low to carry its own weight there will be backsliding of concrete or concrete collapse.

If the concrete is separated or displaced from the substrate in the cover zone it is called delamination. If visible, it can be seen in the cover zone as a crack parallel to the reinforcement. It has been seen to have a relation to problems in the start up, when the geometry of the slipform changes, areas above embedment plates and block out and slipform not in level.

Lifting cracks can be seen as cracks perpendicular to the lifting direction with varying depth and width, but the cracks will be limited by the reinforcement. These cracks are unfortunate because of the weakened zone and it will create favourable conditions for degradation mechanisms that will reduce the life of the structure if they are not repaired. Lifting cracks are created when there is long intervals between lifting of the panel so that adhesion between concrete and panel occurs. If the friction between the concrete and panel becomes too large there will be created cracks in the concrete when the panel is lifted. [1,2]

2.2.1. Friction

Leonardo Da Vinci (1452-1519) made the first scientific observation of friction. Da Vinci discovered that different materials moved with different efforts, and concluded that it was a result of material roughness, so smoother materials will have less friction. He stated that the areas in contact have no effect on friction and that if the load of an object is doubled, its friction will also be doubled. He never published his theories.

Later Guillaume Amontons(1663-1705) rediscovered the laws of friction and came up with an original set of theories. Amontons first law states that the frictional force is directly proportional to the normal load.

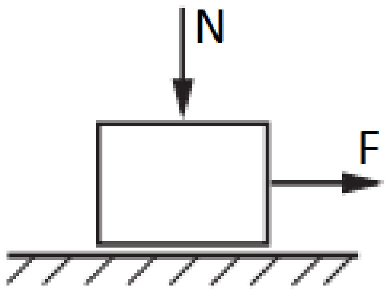

Figure 4 - Illustration of Amontons first law of friction

Eq. 1 $F = \mu * N$

Where $F: Friction\ force$

$N: Normal\ force$

$\mu: Friction\ coefficient, a\ constant\ defining\ the\ linear\ proprtion$

The second law was that the force of friction is independent of the apparent area of contact. A third law of classical friction was added by Charles-Augustuin de Coulomb(1736-1806) after detailed experimental investigations, saying that the kinetic friction is independent of the sliding velocity.

He stated that in order to set an object in motion laying on an even surface in a state of rest one need to overcome a critical force, the force of static friction, F_S, and is roughly proportional to the normal force, N.

Eq. 2 $F_S = \mu_S * N$

Where $F_S: Force\ of\ static\ friction$

$\mu_S: Coefficient\ of\ static\ friction$

After the force of static friction has been overcome, it is the resting force, F_k, kinetic friction, which act on the body. Coulomb also determined that the kinetic friction is proportional to the normal force, N.

Eq. 3 $F_k = \mu_k * N$

$F_k: Force\ of\ kinetic\ friction$

$\mu_k: Coefficient\ of\ kinetic\ friction$

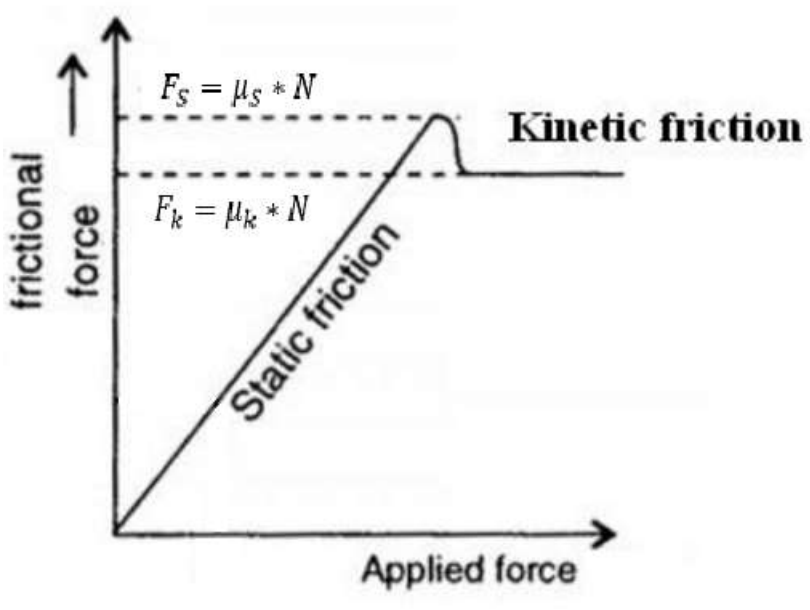

Figure 5 - Illustration of static and kinetic friction

Eq. 4 $\mu_S > \mu_k$

[5,6,7]

These friction laws applies to dry friction, but it can also be adapted for use with concrete. Only the solid particles in the fresh concrete is able to resist shear stress and contribute to friction, therefore the effective pressure replaces the normal pressure.

Eq. 5 $\sigma' = \sigma - u$

Where σ': $Effective\ pressure\ [Pa]$

σ: $Normal\ pressure\ [Pa]$

u: $Pore\ water\ pressure\ [Pa]$

Eq. 6 $F = \mu * \sigma' = \mu * (\sigma - u)$

[1]

2.2.2. Slipforming rate

The slipform rate is what that decides the effectiveness of the slipforming. Numerous things influence the slipform rate.

Absolute max slipforming rate is influenced by the site organization and the time of the concrete hardening. Such as how the slipform is designed, or rather the height of the slipform panel. How fast the workers are able to pour in concrete and how quickly the reinforcement is placed and tied without increasing the risk or lowering the quality. It is also important to take into consideration what the risks of unintentional stops are.

Also influencing the slipform rate is the setting time of the concrete. If the concrete sets too quickly there will be poor adhesion between layers, and if it sets to late the concrete will collapse when it leaves the form. This can be changed either by adding retarding or accelerating admixtures to the concrete.

The effect of some of these factors can be expressed by this equation for calculating the slipform rate.

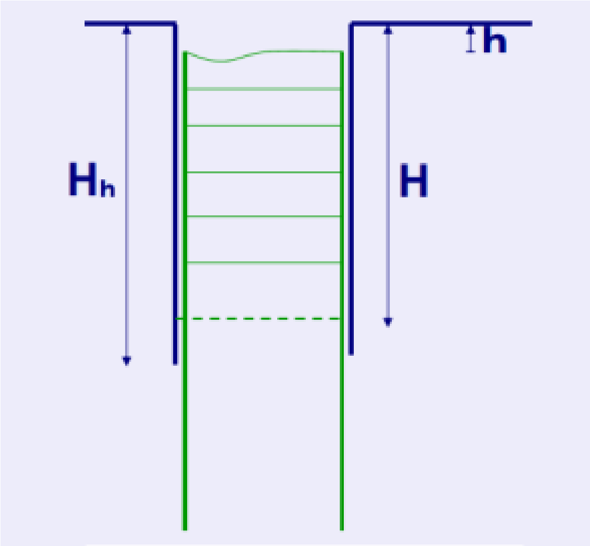

Figure 6 - Illustration of parameters affecting the slipform rate

Eq. 7 $V_S = \frac{H-h}{t_s-t_t}$

Where $V_S: Slipform\ rate\ [cm/h]$

$t_S: Setting\ time\ [h]$

$t_t: Time\ from\ mixing\ concrete\ to\ placing\ [h]$

$H: Distance\ from\ the\ top\ of\ the\ panel\ to\ the\ curing\ front\ [cm]$

$h: Distance\ from\ the\ top\ of\ the\ slipform\ panel\ to\ the\ freeboard\ [cm]$

Eq. 8 $H < H_h$

Where $H_h: Height\ of\ slipformpanel\ [cm]$

Another important factor that have an important impact on the slipform rate is friction. Experiments have shown that shorter times between lifting gives a lower maximum net lifting stress, especially static. [1]

	VT148	VT144	VT145	VT150	VT151	VT146	VT147
Period between the lifts [min]	5	8	8	15	15	30	30
Maximum net sliding lifting stress[kPa]	6,5	6,1	5,8	6,3	6,9	12,1	12,8
Maximum net static lifting stress[kPa]	7,6	7,0	7,3	12,7	13,7	23,8	27,7

Table 1 - Effect of period between lifting

The effect of lifting height is shown in table 2, where one can see that the friction is decreasing with higher lifting height.

	VT152	VT159	VT150	VT151	VT153	VT221	VT223
Lifting height [mm]	5	5	10	10	20	20	20
Maximum net sliding lifting stress[kPa]	13,9	16,6	6,3	6,9	4,6	5,4	4,9
Maximum net static lifting stress[kPa]	22,7	27,8	12,7	13,7	6,8	9,9	7,2

Table 2 - Effect of lifting height

This means that with a higher slipform rate there will be less friction acting between the slipform panel and the concrete.

[1]

2.2.3. Surface of panel

The slipform panel surface is normally made out of smooth steel plates that are attached to wooden or steel frames. As shown in table 3, smooth surfaces gives a lower friction than panels with a higher roughness.

Formwork	Very smooth pannel	Smooth panel	Wooden board	Very rough panel
Panel friction	3,4 kN/m	4,0 kN/m	6,8 kN/m	10,0 kN/m
Roughness r =	0,02255 mm	0,0625 mm	0,49 mm	1,44 mm

Table 3 - Effect of roughness

[1]

3. Description of slipform rig

Figure 7 - Slipform rig

The main objective with the slipform rig is to identify how the different components in the concrete affects the friction between the slipform panel and concrete.

All measurements are logged at 10 Hz

3.1. Concrete container

The concrete container is 1000mm high, 300mm deep and 600 mm wide. This gives it at maximum capacity of 180L. In testing, 75L and 70L have been used due to the capacity of the mixer.

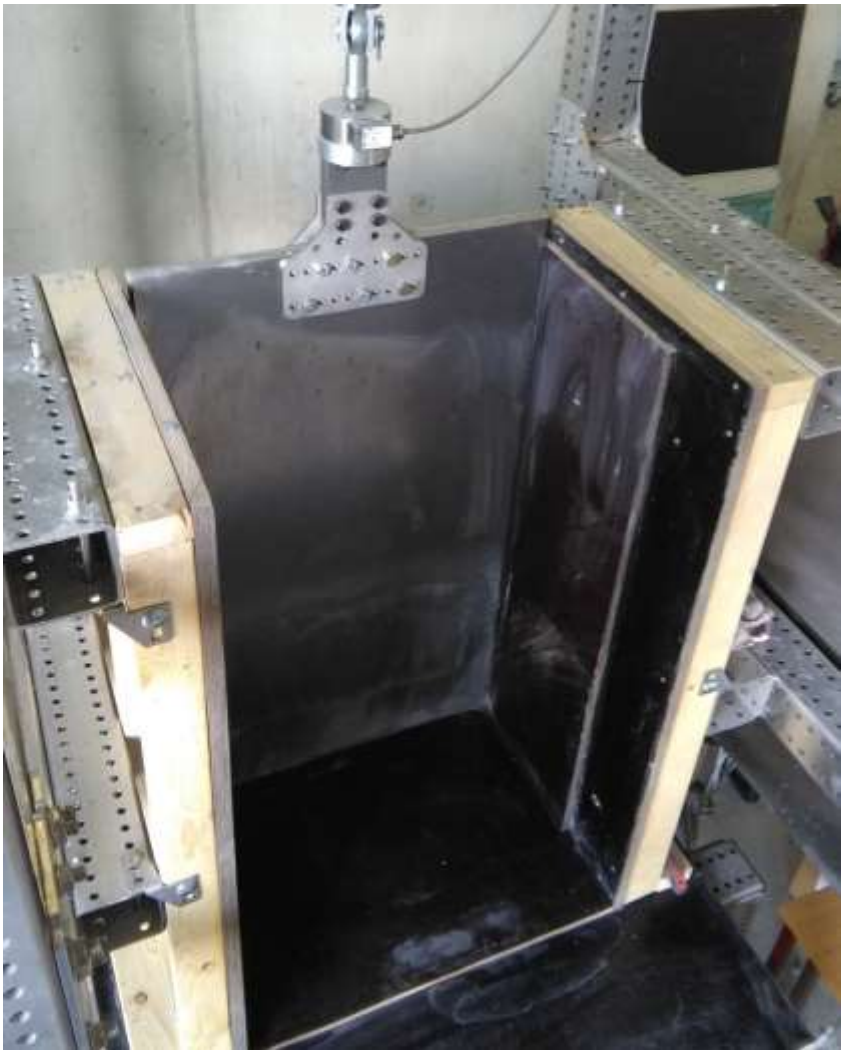

Figure 8 - Concrete container

3.2. The slipform panel

The slipform panel is made out of a plywood board covered with a steel plate, it has a length of 2000mm and width 600mm. This makes the maximum height the slipform panel can be lifted 1000mm, but due to necessary margins the panel is not lifted higher than 930mm.

An electric engine lifts the panel with the desired frequency and height with precision. The slipform panel was under testing lifted 12mm and then lowered 2mm to imitate the locking mechanism of jacks used in slipforming. The panel was lifted every 15 minutes, giving the rig a slipform-rate of 40mm/h.

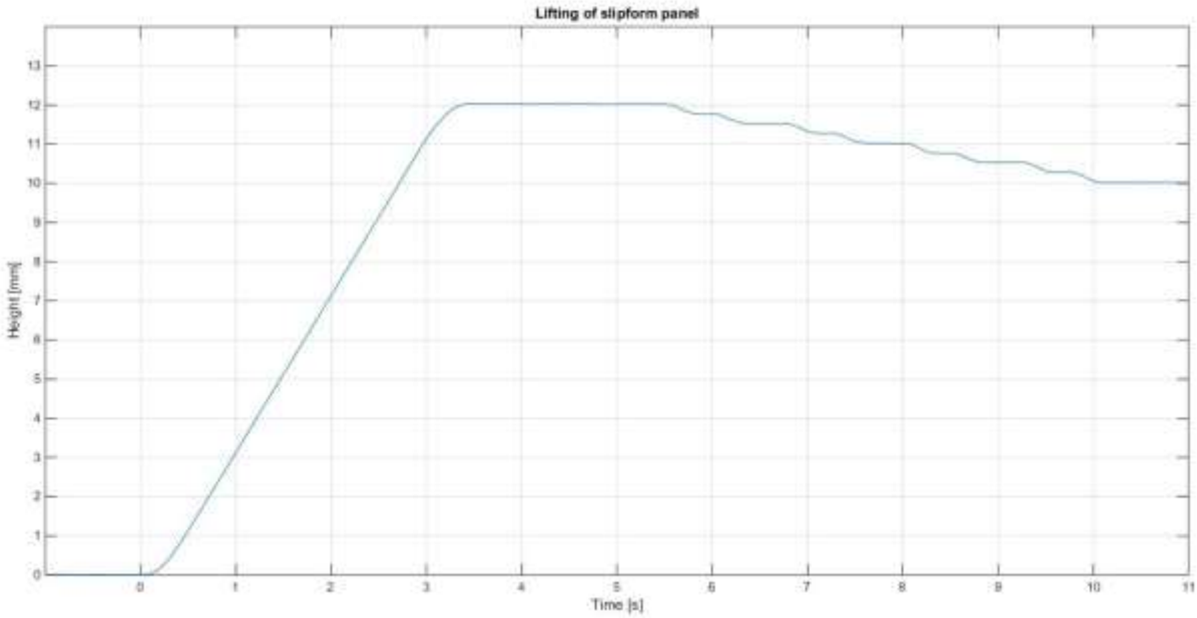

Figure 9 - Illustration of slipform panel lifting

3.3. Force measurements

Between the panel and the engine there is installed a force transducer measuring the lifting force, with a measuring range of 20kN.

Figure 10 - Force transducer measuring the lifting force

Behind the panel there are 4 force transducers with rollers measuring the concrete pressure acting on the slipform panel, with a measuring range of 5kN each. They are placed in two rows with two transducers each, centred 400mm apart. The first row is located 70mm over the lowest point of the concrete container and the second row is placed 580mm over the first row.

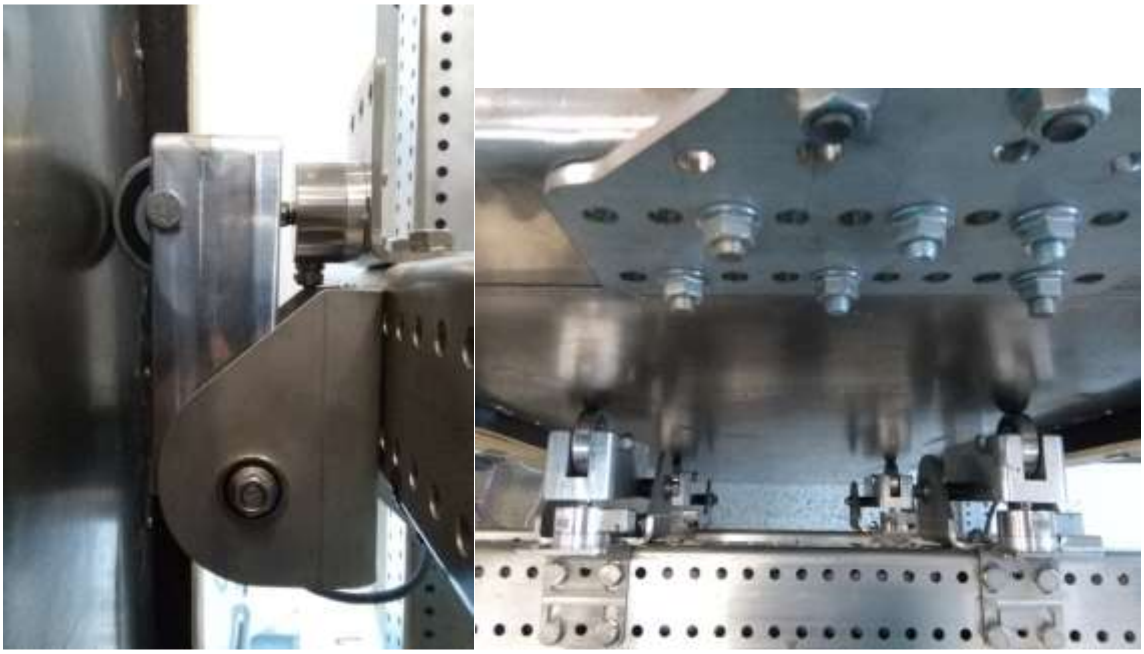

Figure 11 a/b - Illustration of placement of the force transducers measuring the normal pressure

4. Laboratory program

All of the laboratory work have been performed at the concrete laboratory at the University of Stavanger (UiS). The program consists of two main types of concrete mixes, ultra-high performance concrete and normal concrete.

The goal of the laboratory work is to identify how the different components in the concrete affects the friction between the panel and the concrete. Reproducibility of results and measurement accuracy is also in focus.

4.1. Materials

4.1.1. Portland cement

Norcem Anleggsement FA

For the normal concrete mixes, Norcrem Anleggsement FA is being used. It’s a special cement designed for civil works. The cement can be used in all exposure, resistance and strength classes. It is specially adapted to Norwegian environment for use in durability class M45 and MF45 or higher.

Properties:

- Well adapted for constructions with requirements on high end strength.
- Can be used in combination with alkali reactive aggregates.
- Relatively low heat development.
- Well suited for use in massive constructions.
- Very good workability and durability.

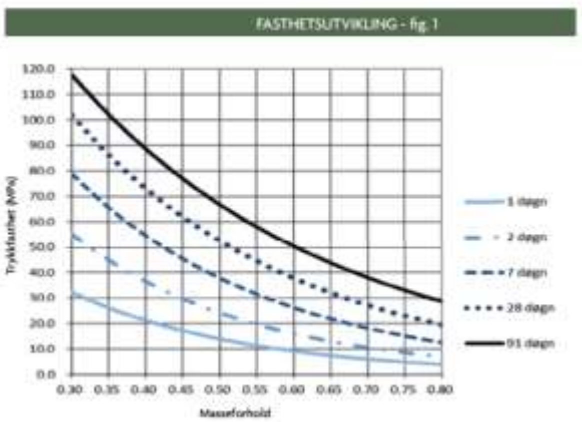

Figure 12 - Development of compression strength

	Norcem Anlegg FA
Type	CEM II/A-V 42.5 N
$Sulfate, SO_3$ [%]	≤ 3.5
$Chloride, Cl^-$ [%]	≤ 0.085
$Water\ soluble\ chromium, Cr^{6+}[ppm]$	≤ 2
$Alkalies, Na_2O_{ekv}[\%]$	0.6
$Cllincer$ [%]	83
$Fly\ ash$ [%]	17
Physical properties:	
$Fineness\ [m^2/kg]$	390
$Specific\ weight\ [kg/dm^3]$	3,02
$Initial\ set\ [min]$	165

Table 4 - Production value

[8,9]

4.1.2. Aggregate

Aggregate is an important part in concrete, it consists of sand, gravel and stones, and takes up 65 to 75 % of the volume of concrete. The aggregate has an effect on both the fresh and cured concrete properties.

In the normal concrete mix, two types of aggregate from Velde was used, fine aggregate with grading 0/8mm and coarse graded 8/16mm.

Figure 13 a/b - Aggregate 0/8mm and 8/16mm

Sieve curves for aggregates used presented in figure 14 and 15

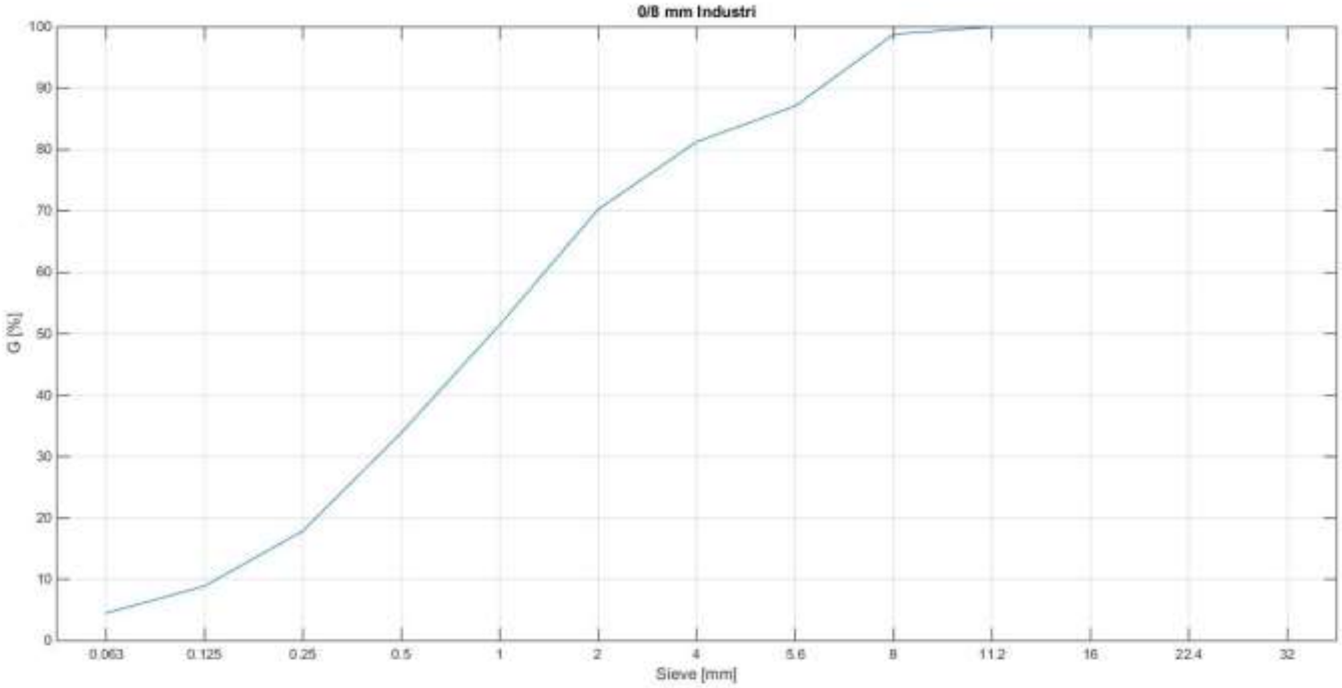

Figure 14 - Sieve curve for 0/8mm aggregate

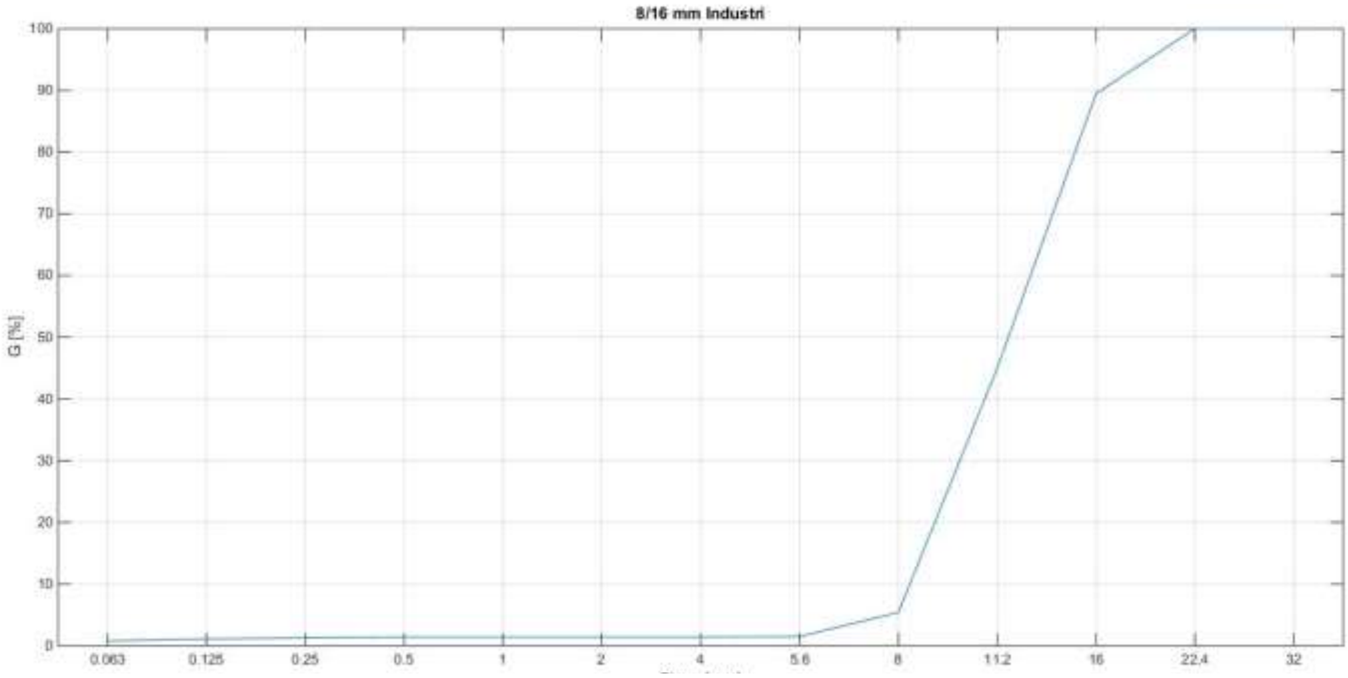

Figure 15 - Sieve curve for 8/16mm aggregate

4.1.3. Pozzolan

Pozzolans are a material that react with water and calcium hydroxide and creates compounds possessing cementitious properties. They are often by-products from industry that are added to the concrete to reduce the quantity of cement in the mix. Two regular pozzolans used in concrete are fly ash and silica.

$$2SiO_2 + 3Ca(OH)_2 \rightarrow 3CaO * 2SiO_2 * 3H_2O$$

$$2S + 3CH \rightarrow C_3S_2H_3$$

$$Silica + calcium\ hydroxide \rightarrow C - S - H$$

The cement used in the normal concrete mix contains 17% fly ash. Fly ash is a very fine powdery material that is a by-product from coal plants. It increases the workability of the concrete and provides a higher long-term strength. Because of its reduced hydration heat compared to portland cement it can therefore be helpful for concreting large structures where the temperature can be so high that it causes cracking.

Microsilica is also used in the concrete mix. It is very fine grained, much finer than fly ash and have a grainsize of one percentage of cement. This means that it has an effect as filler because it can fill the empty space between the larger cement particles. The toughness of the concrete increases, which will reduce separation and prevent formation of water pockets under the rebar and coarse aggregate. [10]

4.1.4. Admixtures

Admixtures is materials that are added during mixing in small amounts relative to the amount of cement to modify the properties of fresh or hardened concrete. Regular admixtures are plasticizer and superplasticizer, air entraining, accelerating and retardation.

In the normal concrete mixes Dynamon SN-X is used, a superplasticizer based on modified acrylic polymers. It is added to the concrete primarily to maintain workability.

For one of the mixes Sika Aer-S was added. This is an air entraining admixture, based on synthetic surfactants. It forms a finely distributed air pore system in the concrete cement paste.

The air pores serves as expansion chamber when the moisture/ water in the cured concrete expands upon freezing. [11]

4.2. Concrete mixes

In the testing 5 different concrete mixes was used, 4 with normal concrete and one ultra-high performance concrete. To be able to identify how the materials affected the friction only one of the parameters was variated for each new mix.

Mix		Reference	W/B	Silica	Air
w/b ratio		0,4	0,35	0,4	0,4
S/C	[%]	5	5	15	5
Binder content	$\left[\frac{l}{m^3}\right]$	343	343	343	343
Norcem Anlegg FA	$\left[\frac{kg}{m^3}\right]$	385	413,5	332,8	385
Water	$\left[\frac{kg}{m^3}\right]$	169,4	159,2	173	169,4
Dynamon SX-N	$\left[\frac{kg}{m^3}\right]$	4,6	4,96	3,99	4,62
SikaAer-S	$\left[\frac{kg}{m^3}\right]$	-	-	-	0,12
Elkem Microsilica	$\left[\frac{kg}{m^3}\right]$	19,3	20,7	49,9	19,3
Velde 0-8mm	$\left[\frac{kg}{m^3}\right]$	952,7	952,7	952,7	952,7
Velde 8-16mm	$\left[\frac{kg}{m^3}\right]$	844,9	844,9	844,9	844,9

Table 5 - Concrete mixes tested

The UHPC mix was provided by another master student doing his thesis in UHPC. It is presented in appendix A.

Each of the mixes was tested twice, to verify the results.

4.3. Mixing

For normal concrete 80L mix was used, and 75L for the UHPC. A total of 10 tests were performed, in addition a few test mixes was tried to find a concrete with suitable good workability.

All of the dry materials were weighted the day before, so for the 0/8mm aggregate the moisture content was tested with a moisture tester the day of mixing, according to the procedure recommended by the producer as shown in appendix D, and the weight was corrected. For 8/16 it was assumed that the moisture was 0. All concrete mixes used is presented in appendix A.

Figure 16 - Moisture tester

Mixing procedure:

- Mixer moisturized.
- Dry materials are added to the mixer. Cement, aggregates and pozzolan.
- Dry mixed for 2-3 minutes
- Water is added and mixed for 2 minutes
- Admixtures added and mixed for 1 minute

4.4. Testing of fresh concrete

All tests performed on fresh concrete were made in accordance with NS-EN 12350-1:2009 [12]

4.4.1. Slump-flow test

The slump-flow test gives an indication on the consistence of the concrete. The test was performed accordingly to NS-EN 12350-2:2009.

Figure 17 - Slump cone

Slump cone and surface are wetted, and the slump cone is placed on the horizontal surface. The cone is held fixed and filled with concrete. The concrete was not tamped because of the use of self-compacting concrete. When the slump cone is full it is carefully lifted vertically upwards within 2 to 5 seconds. Slump and flow are then recorded. [13]

Class	Slump in mm
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5	220

Table 6 - Slump class

Class	Slump-flow in mm
SF1	550 to 650
SF2	660 to 750
SF3	760 to 850

Table 7 - Slump-flow class

4.4.2. Measuring of air content

For the concrete mix with air entraining agent the air content was measured with the pressure gauge method described in NS-EN 12350-7:2009.

In the case of self-compacting concrete, the container shall be filled in one operation and no mechanical compaction shall be applied during filling or after the container is filled. After the container is filled, strike off level and smooth the surface with the steel trowel. The flanges of the container and cover assembly are thoroughly cleaned. The cover assembly is clamped, sealing the container. Using a syringe, water is injected through one of the two open valves until water emerge from the other valve. Air bleeder valve is closed and air is pumped into the chamber until the hand on the pressure gauge is on the initial pressure line. After tapping on the container, stabilize the hand on the pressure gauge is on the initial pressure line by further pumping in or bleeding off air. At last the main valve is opened and read the apparent percentage of air. [14]

Figure 18 - Air content measurer

4.5. Casting

4.5.1. Cubes

A total of 5 cubes were made for every mix of concrete according to NS-EN 12390-2:2009. The dimensions of the cubes were 100x100x100 mm. The moulds were coated with form oil to prevent adhering to the mould. Due to the use of self-compacting concrete the mould is filled in one operation and no mechanical compaction is applied during filling or after the mould is filled. The surface is levelled with a steel trowel and covered in plastic. The specimens are left in the mould over night at a temperature of 20±5ºC and are then removed from the mould. The specimens are then cured in water at a temperature of 20±2ºC for a total of 28 days [15]

Figure 19 - Moulds for cubes

Figure 20 - Cubes

4.5.2. Slipform rig test

Before the test was performed, all the surfaces of the test rig were cleaned and any loose particles are removed. The concrete container is coated with form oil (with exception of the panel) to ease the removal of the concrete block after the test. The sensors are then zeroed and the registration is started. The concreate is poured into the container and hand compacted to make sure of good casting. Two temperature gauges are placed into the concrete, approximately 100mm under the surface. A bolt is placed in the concrete to be able to lift it out after the test.

The slipform lifting program is started. The test is then in progress to the next day. When the panel is lifted to the top, the registration is manually stopped and the data is saved. The concrete block is then lifted out of the rig with the help of a forklift. The container and panel is cleaned.

Figure 21 - Cured concrete block in the slipform rig

4.6. Compression strength test of cured concrete

The compressive strength is tested accordingly to NS-EN 12390-3:2009. After 28 days of curing the cubes were compression strength tested. All bearing surfaces on the test machine are wiped clean and any loose particles or foreign objects that may come in contact with the pressure plates are removed from the specimen surface. Any excess moisture on the specimen surface is dried and placed into the test machine. The cubes are placed so that the load is applied perpendicularly to the casting direction. The load is applied uniform until fracture of the cube. [16]

Figure 22 a/b - Testing of compression strength and tested cube

Eq. 10 $$f_c = \frac{F}{A_c}$$

Where $f_c: Compressive\ strenght\ [MPa]$

$F: Fracture\ force\ [N]$

$A_c: Cross - sectional\ area\ resisting\ pessure\ load\ [mm^2]$

5. Results and discussion

5.1. Slump-flow and air content

Results presented in table 8 and figure 23 shows that all the mixes are characterized as self-compacting concrete.

Mix	Slump [mm]	Flow [mm]	Air content [%]
Ref no.1	270	700	-
Ref no.2	250	600	-
15%S no.1	260	550	-
15%S no.2	250	550	-
Air no.1	270	700	6,25
Air no.2	245	600	2,5
W/B no.1	265	650	-
W/B no.2	250	600	-
UHPC no.1	280	700	-
UHPC no.2	-	800	-

Table 8 - Slump, flow and air content

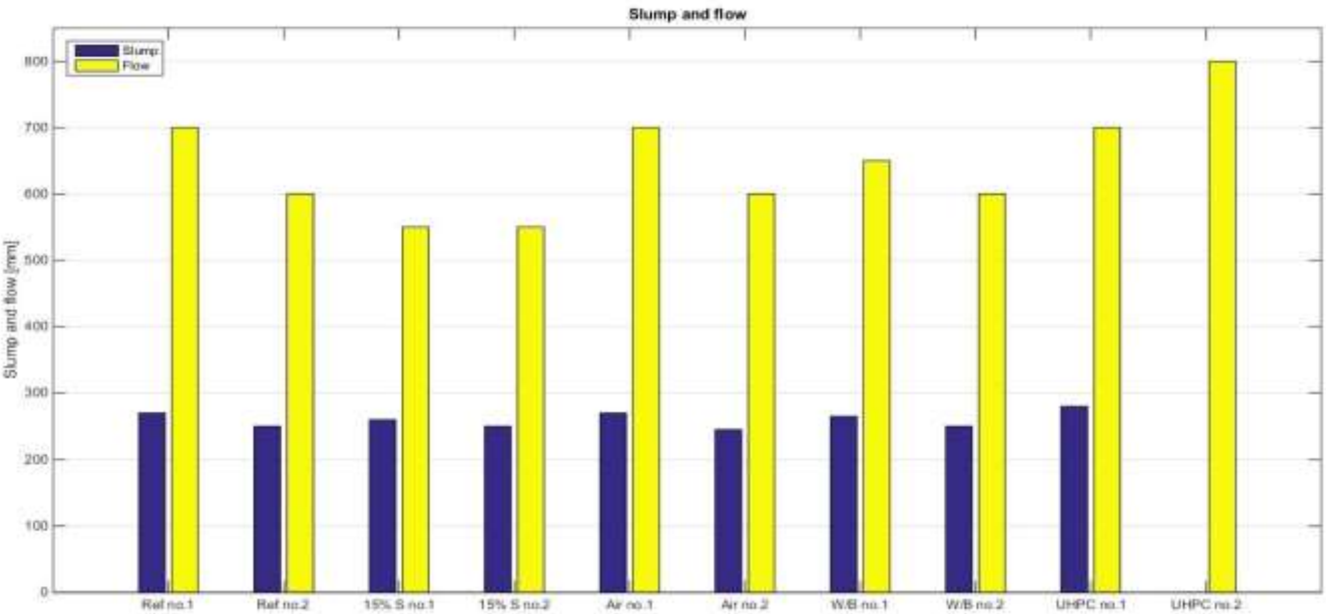

Figure 23 - Slump-flow

5.2. Compression strength

The compression strength for all mixes are presented in table 9 to 16 and compered in figure 24.

Reference no.1:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	695,57	711,86	71,19
2	683,01	702,81	70,28
3	696,11	713,87	71,39
4	694,07	707,81	70,78
5	703,87	716,50	71,65
Min	683,01	702,81	70,28
Max	703,87	716,5	71,65
Average	694,53	710,57	71,06
Standard devation			0,5386743
Coefficient of var.			0,7580769

Table 9 - Reference no.1 Compression strength

Reference no.2:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	741,90	758,75	75,88
2	771,14	786,05	78,60
3	745,83	764,81	76,48
4	768,35	781,32	78,13
5	739,39	750,64	75,06
Min	739,39	750,64	75,06
Max	771,14	786,05	78,6
Average	753,32	768,31	76,83
Standard devation			1,4983991
Coefficient of var.			1,9502787

Table 10 - Reference no.2 Compression strength

15% Silica no.1:

Results lost

15% Silica no.2:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	690,89	703,24	70,32
2	671,96	692,14	69,21
3	690,72	709,52	70,95
4	686,40	702,92	70,29
5	642,56	655,76	65,58
Min	642,56	655,76	65,58
Max	690,89	709,52	70,95
Average	676,51	692,72	69,27
Standard devation			2,16
Coefficient of var.			3,11

Table 11 - 15% Silica no.2 Compression Strength

Air entrainment no.1:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	400,31	418,26	41,83
2	421,77	435,57	43,56
3	397,21	413,54	41,35
4	420,03	435,07	43,51
5	410,35	428,71	42,87
Min	397,21	413,54	41,35
Max	421,77	435,57	43,56
Average	409,93	426,23	42,62
Standard devation			0,9968851
Coefficient of var.			2,3387884

Table 12 - Air entrainment no.1 Compression strength

Air entrainment no.2:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	485,93	504,59	50,46
2	487,21	504,75	50,47
3	476,84	496,22	49,62
4	479,20	493,40	49,38
5	500,01	509,84	50,98
Min	476,84	493,40	49,38
Max	500,01	509,84	50,98
Average	485,84	501,76	50,18
Standard devation			0,6625858
Coefficient of var.			1,3203656

Table 13 - Air entrainment no.2 Compression strength

W/B 0.35 no.1:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	898,35	914,42	91,44
2	914,49	926,84	92,68
3	905,78	920,31	92,03
4	888,45	904,69	90,47
5	876,47	893,04	89,30
Min	876,47	893,04	89,30
Max	914,49	926,84	92,68
Average	896,71	911,86	91,18
Standard devation			1,3302744
Coefficient of var.			1,4588902

Table 14 - W/B 0.35 no.1 Compression strength

W/B 0.35 no.2:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	877,78	892,09	89,21
2	877,45	893,97	89,40
3	892,07	904,19	90,42
4	870,41	883,99	88,40
5	916,11	931,78	93,18
Min	870,41	883,99	88,40
Max	916,11	931,78	93,18
Average	886,76	901,20	90,12
Standard devation			1,85
Coefficient of var.			2,06

Table 15 - W/B 0.35 no.2 Compression strength

Ultra-high performance concrete no.1:

Master student testing UHPC performed this test.

Average compression strength 112.3 MPa

Ultra-high performance concrete no.2:

Cube no.	F_b [kN]	F_m [kN]	f_c [MPa]
1	1121,66	1137,02	113,70
2	1397,59	1421,75	142,17
3	1385,02	1435,37	143,54
Min	1121,66	1137,02	113,70
Max	1397,59	1435,37	143,54
Average	1301,42	1331,38	133,14
Standard devation			16,846579
Coefficient of var.			12,653599

Table 16 - Ultra-high performance concrete no.2 Compressive strength

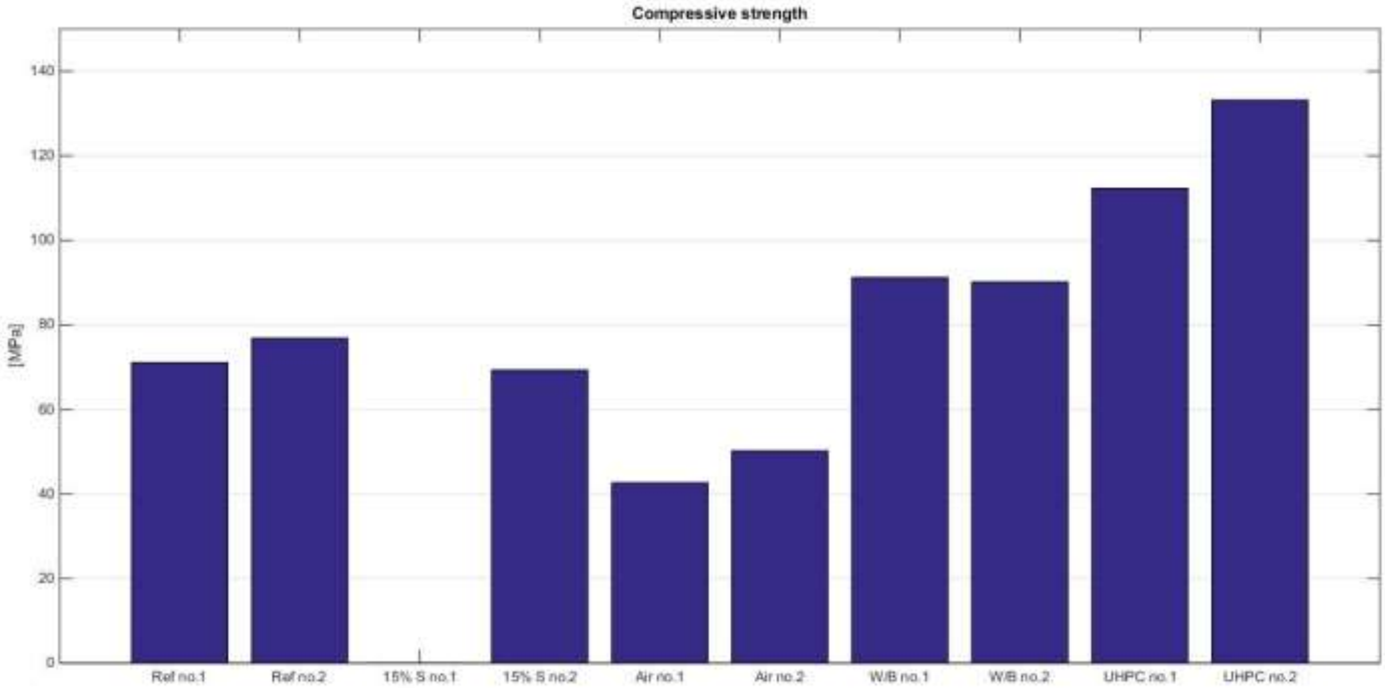

Figure 24 - Comparison of average compressive strength of tested concrete mixes

The results displayed in Figure 24 shows that similar concrete mixes produces similar compressive strength. It is assumed that the compressive strength of 15% Silica no.1 is similar to no.2.

5.3. Slipform rig tests

To get a correct friction one need to subtract the rig friction from the lifting force.

Eq. 11 $F_{NS} = F_S - F_R$

Eq. 12 $F_{NK} = F_K - F_R$

Where $F_{NS}: Net\ static\ lifting\ force\ [N]$

$F_{NK}: Net\ kinetic\ lifting\ force\ [N]$

$F_S: Measured\ static\ friction\ force\ [N]$

$F_K: Measured\ kinetic\ friction\ force\ [N]$

$F_R: Rig\ friction\ [N] = 150\ N$

Eq. 13 $F_{SS} = \frac{F_{NS}}{A}$

Eq. 14 $F_{SK} = \frac{F_{NK}}{A}$

Where $F_{SS}: Net\ static\ lifting\ stress\ [Pa]$

$F_{SK}: Net\ kinetic\ lifting\ stress\ [Pa]$

$A: Contact\ area\ of\ the\ concrete\ and\ slipform\ panel$

Eq.15 $\sigma = \frac{N}{A}$

Where $N: Normal\ force\ [N]$

$A: Contact\ area\ of\ the\ concrete\ and\ slipform\ panel$

The contact area of the concrete and slipform panel was for the normal concrete mixes $42cm * 60cm = 2520cm^2$ and for the UHPC $39cm * 60cm = 2340cm^2$.

The weight of the slipform panel is taken into account when the force transducers are zeroed.

5.3.1. Temperature

Figure 25 to 34 displays how the temperature develops during the test in relation to the net lifting stress.

Reference no.1:

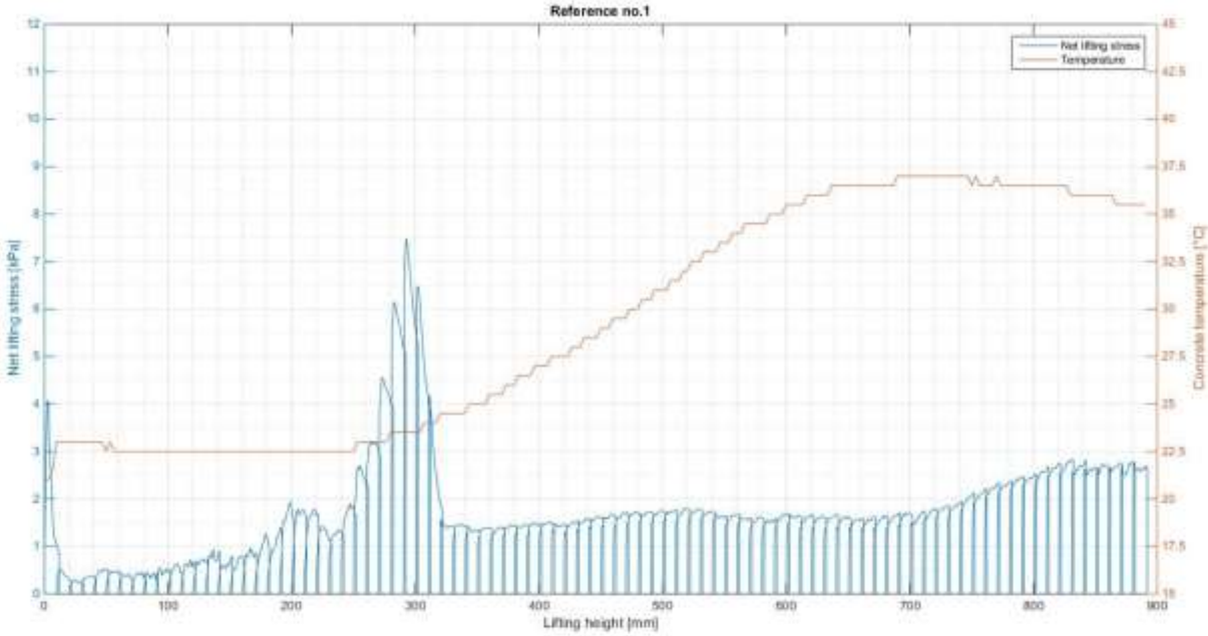

Figure 25 - Reference no.1 Temperature development

Reference no.2:

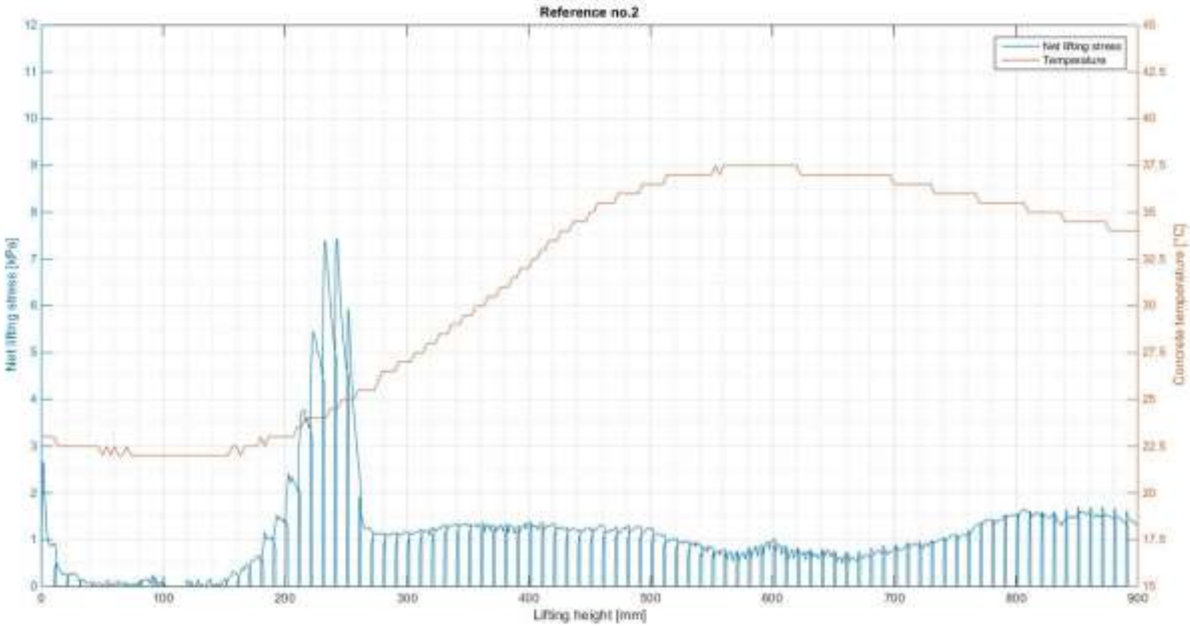

Figure 26 - Reference no.2 Temperature development

15% Silica no.1:

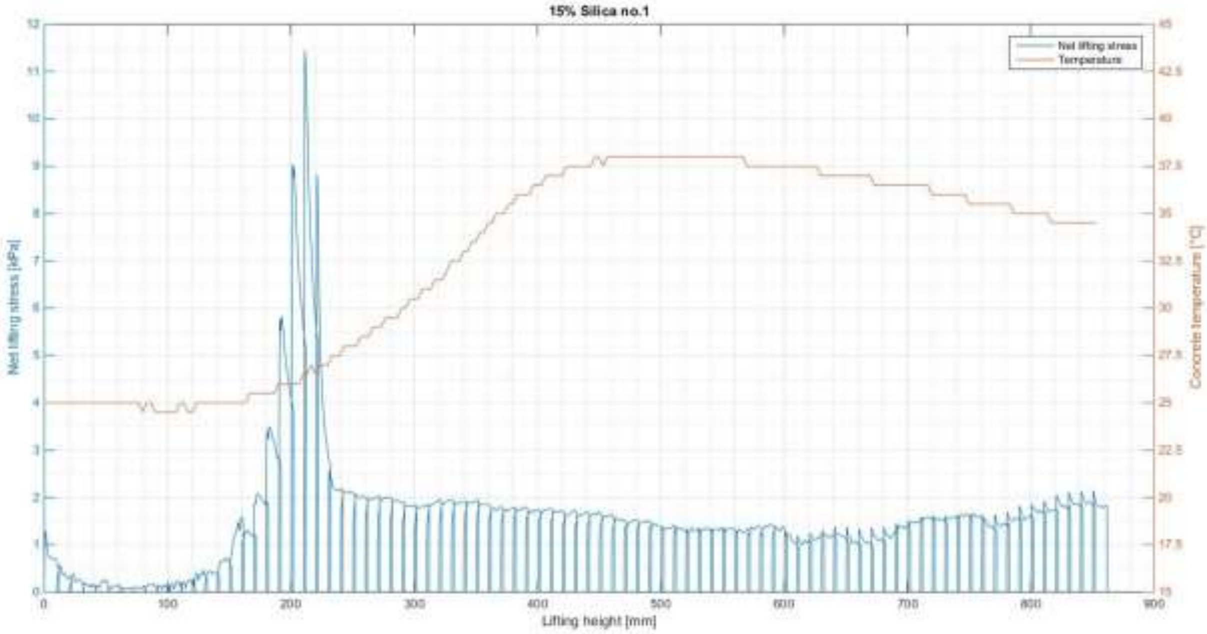

Figure 27 - Silica no.1 Temperature development

15 % Silica no.2:

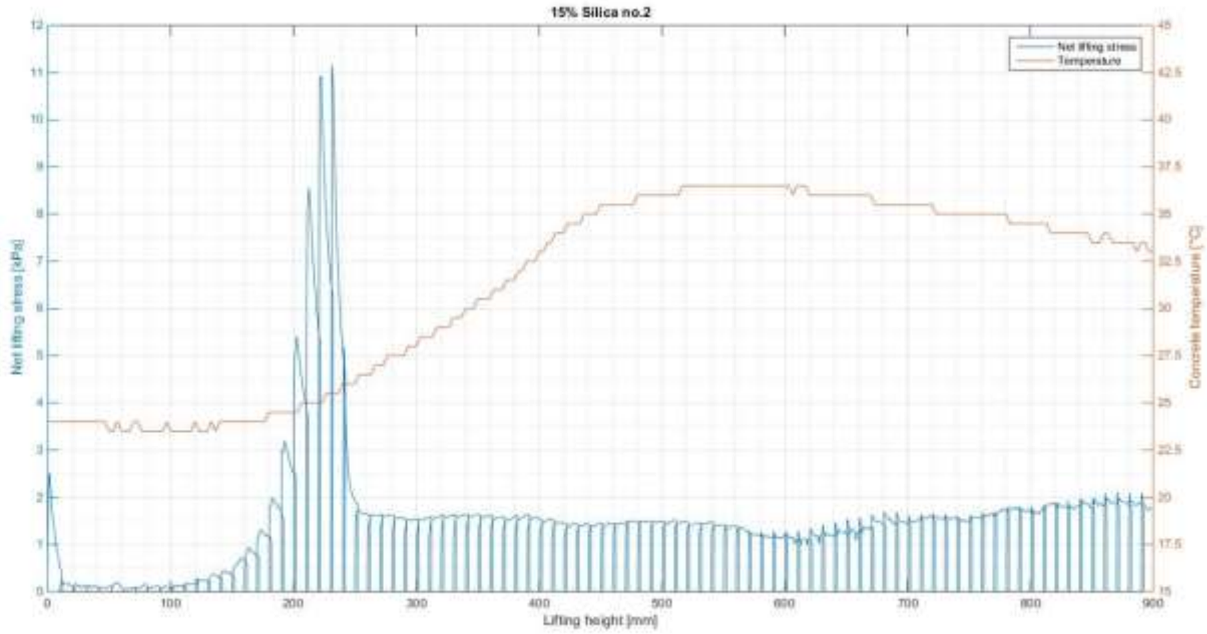

Figure 28 - Silica no.2 Temperature development

Air entrainment no.1:

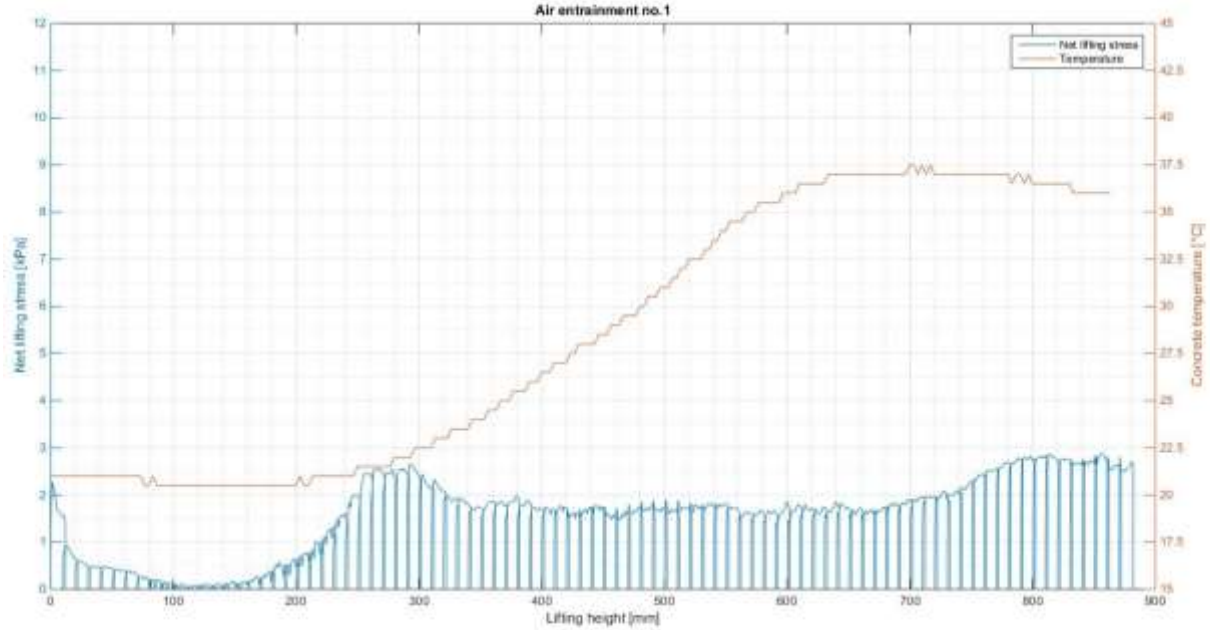

Figure 29 - Air entrainment no.1 Temperature development

Air entrainment no.2:

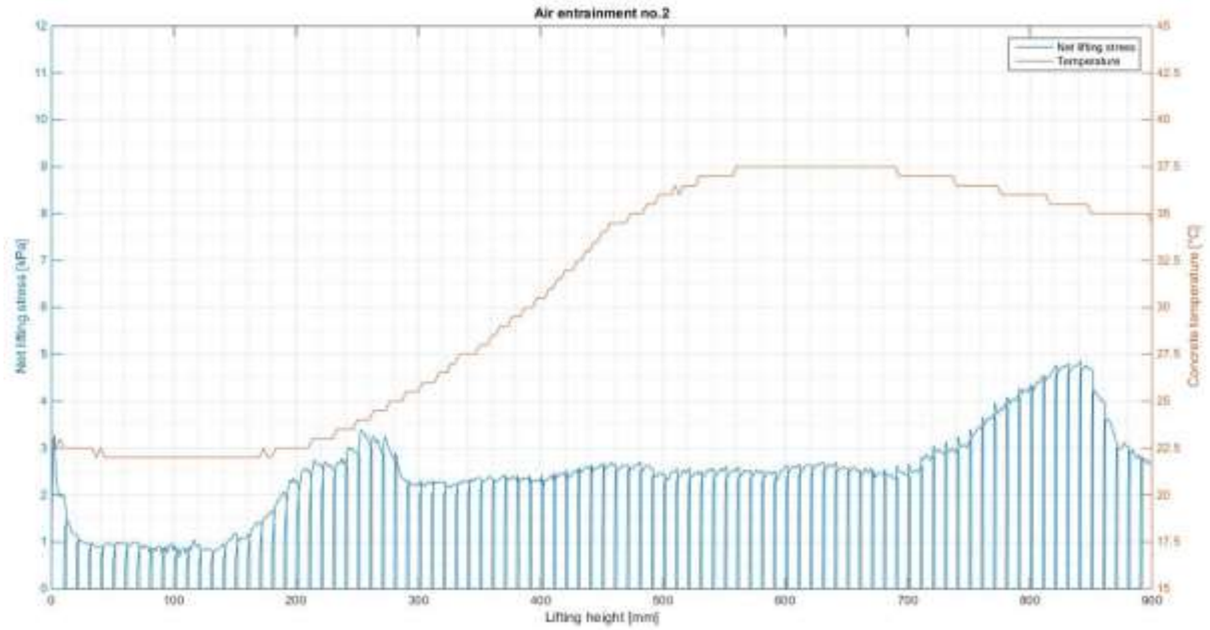

Figure 30 - Air entrainment no.2 Temperature

W/B 0.35 no.1:

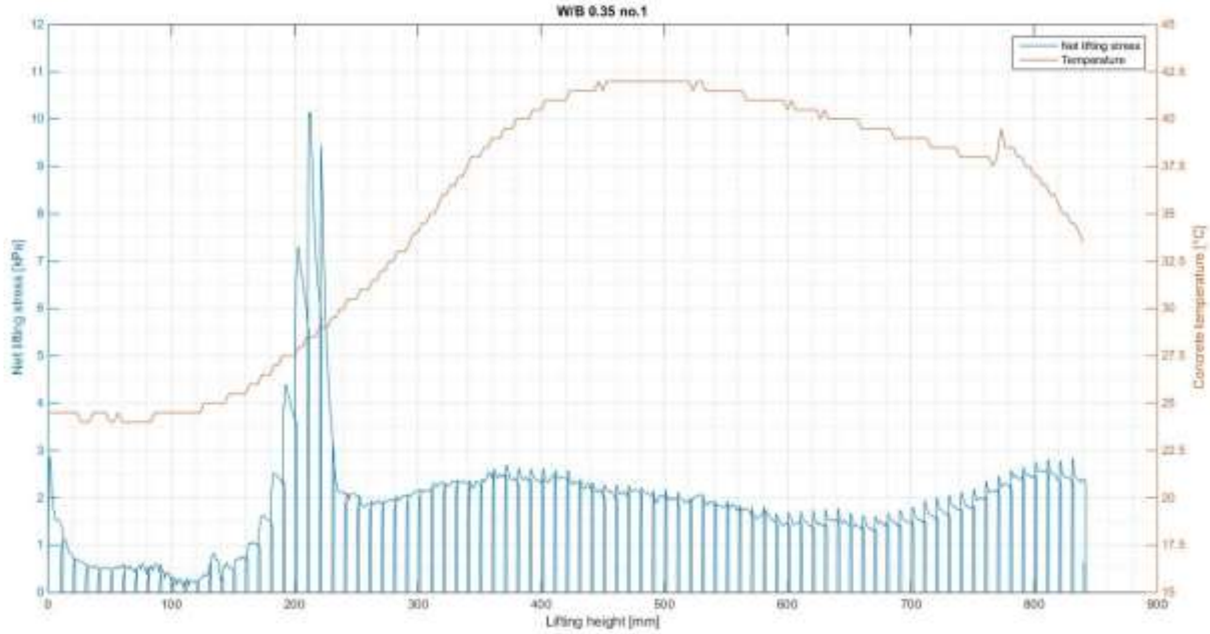

Figure 31 - W/B 0.35 no.2 Temperature development

W/B 0.35 no.2:

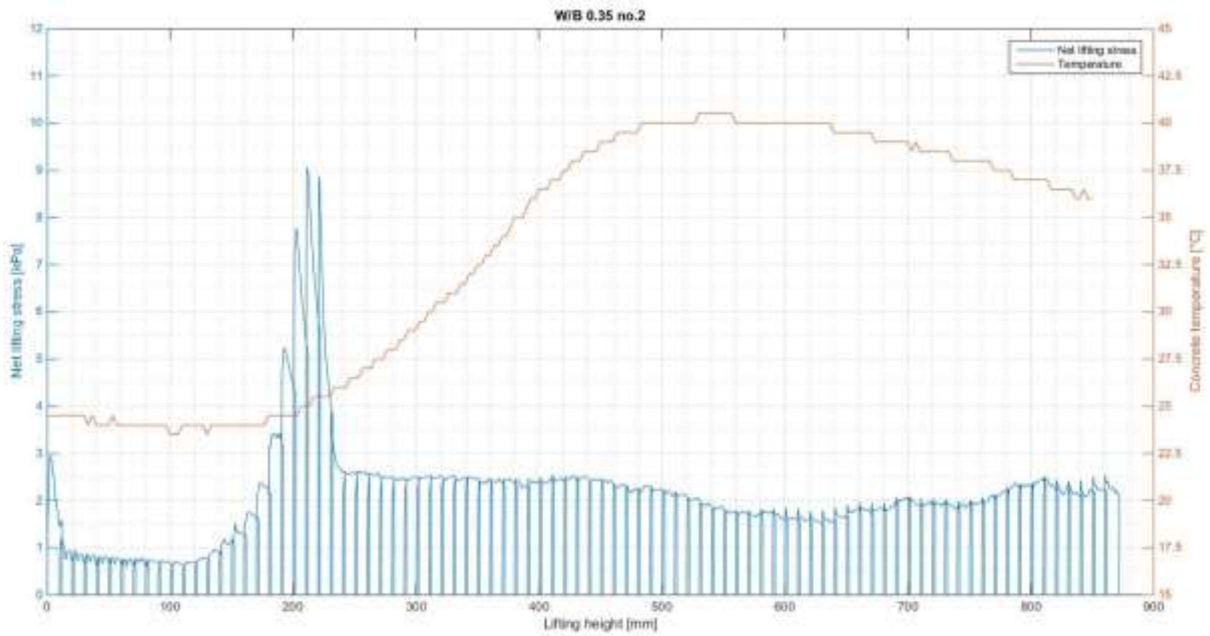

Figure 32 - W/B 0.35 no.2 Temperature development

Ultra-high performance concrete no.1:

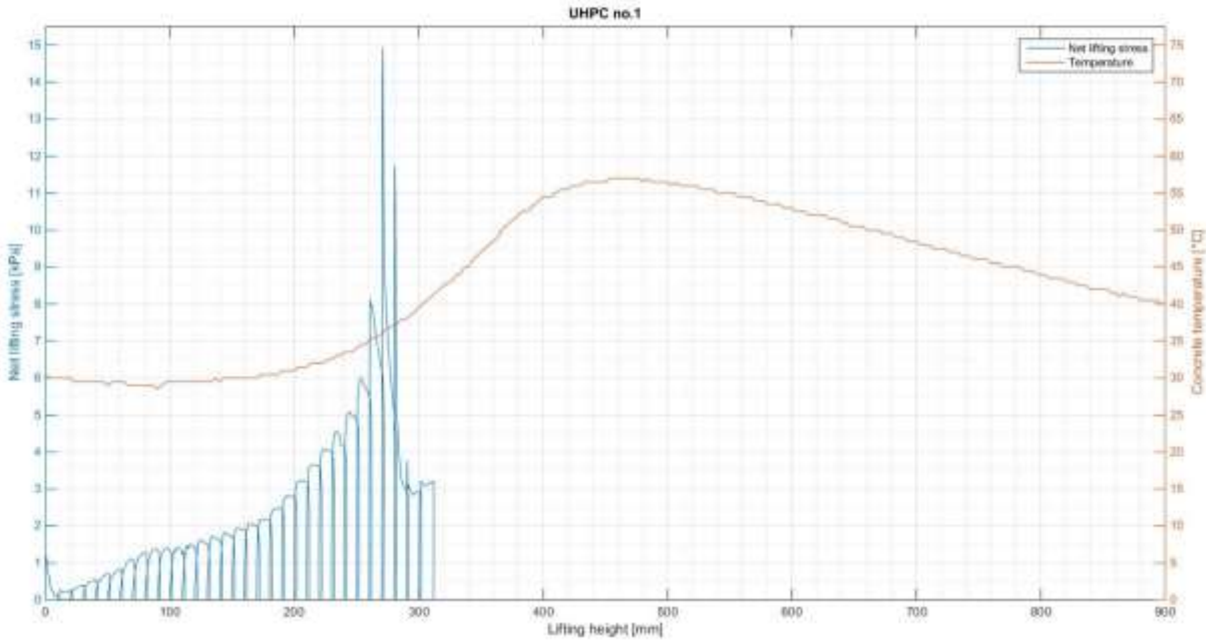

Figure 33 - Ultra-high performance concrete no.1 Temperature development

Ultra-high performance concrete no.2:

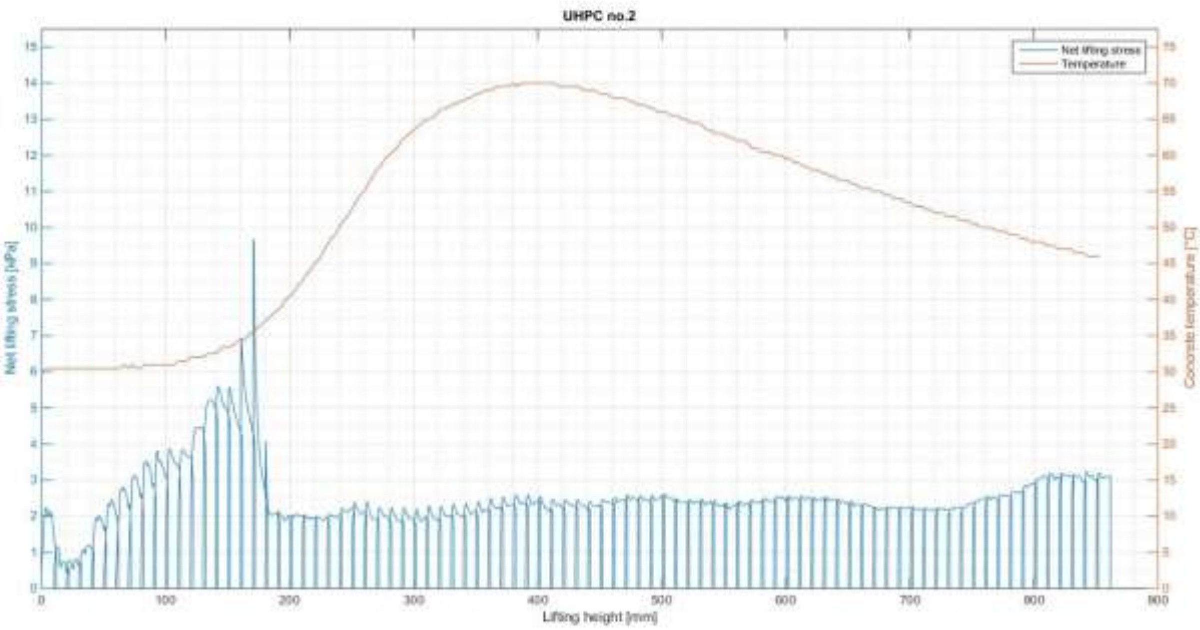

Figure 34 - Ultra-high performance concrete no.2 Temperature development

When the temperature in the concrete starts to increase it is an indication of initial set. Simultaneously one can see the lifting stress increases. These results shows a correlation between the initial set and the development of friction. The temperature development is approximately similar for all the normal concrete mixes.

5.3.2. Normal pressure

Figure 35 to 44 displays how normal pressure during the test in relation to the net lifting stress.

Reference no.1:

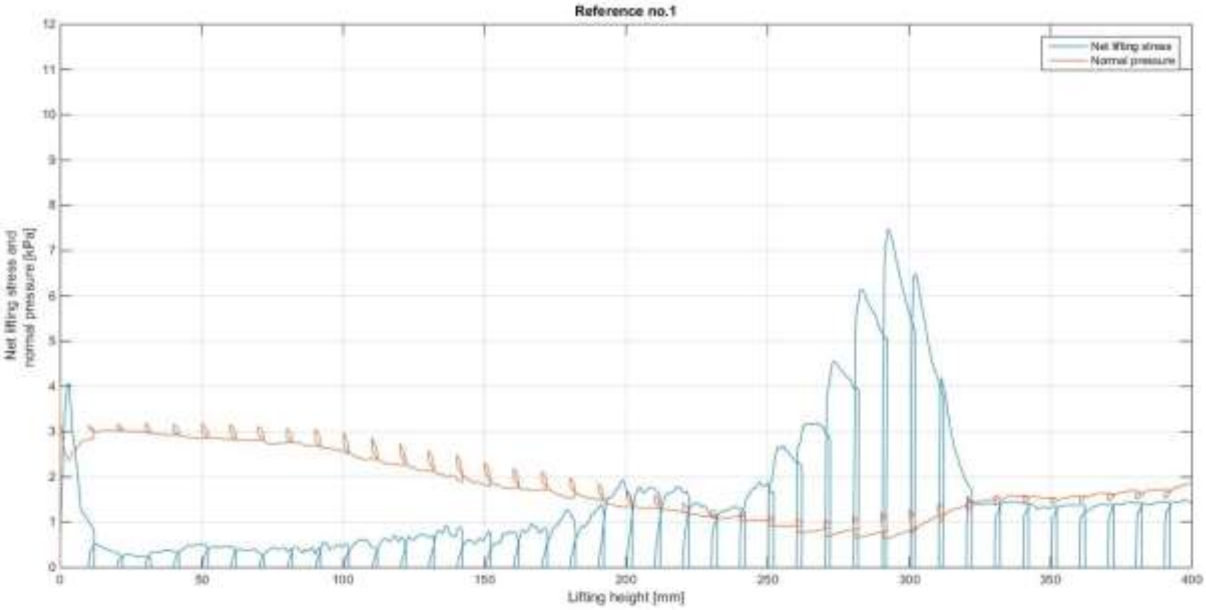

Figure 35 - Reference no.1 Normal pressure

Reference no.2:

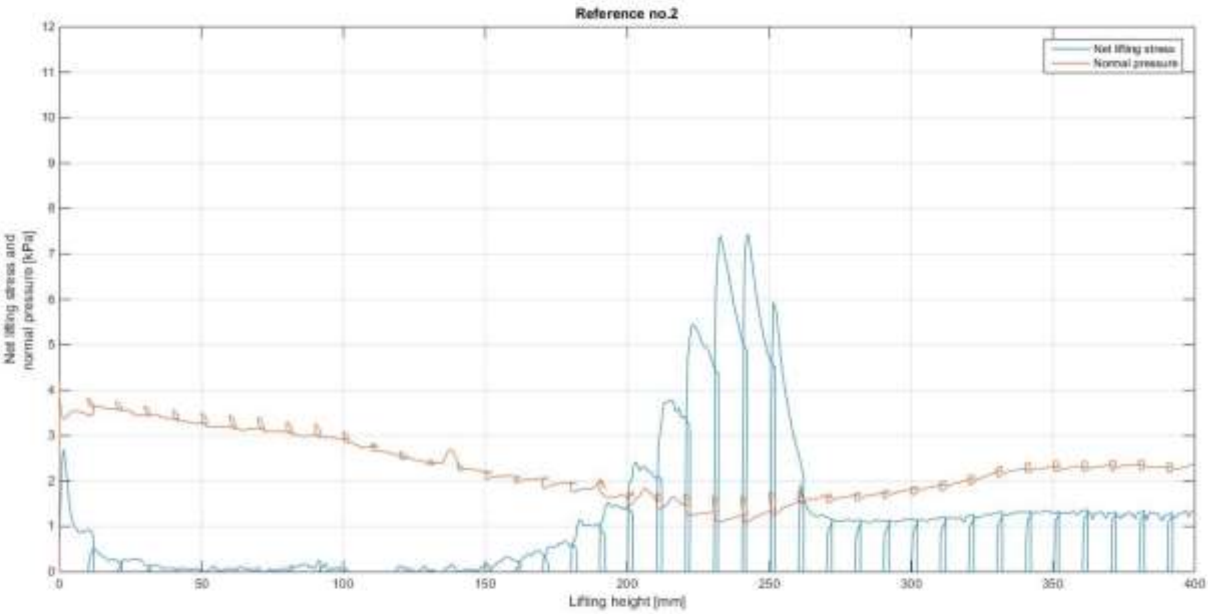

Figure 36 - Reference no.2 Normal pressure

15% Silica no.1:

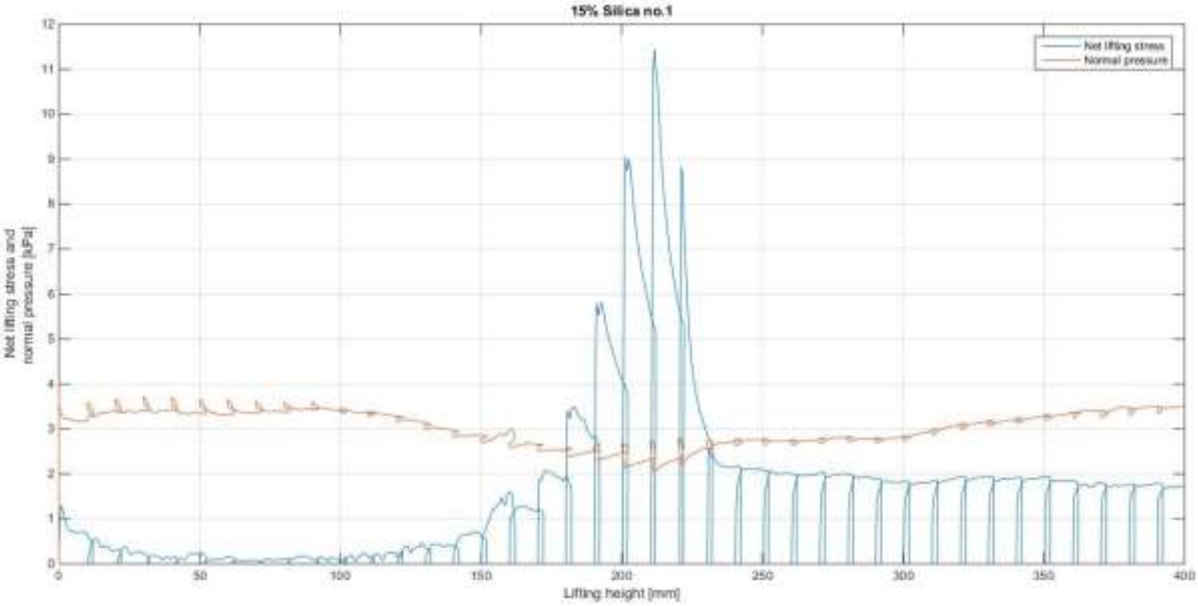

Figure 37 - 15% Silica no.1 Normal pressure

15% Silica no.2:

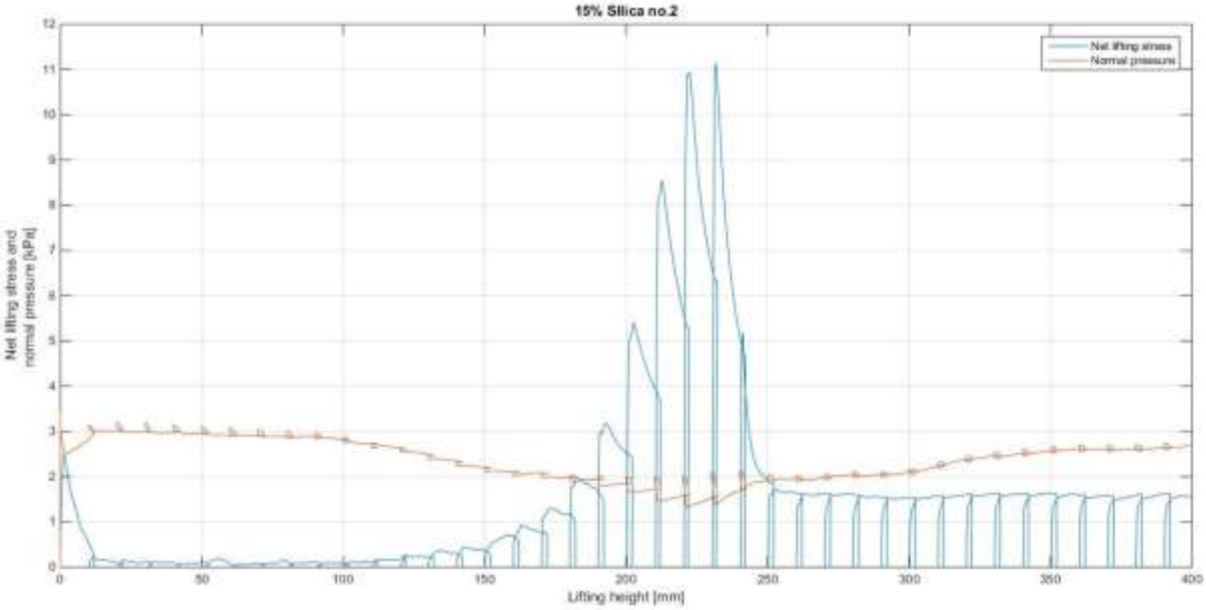

Figure 38 - 15% Silica no.2 Normal pressure

Air entrainment no.1:

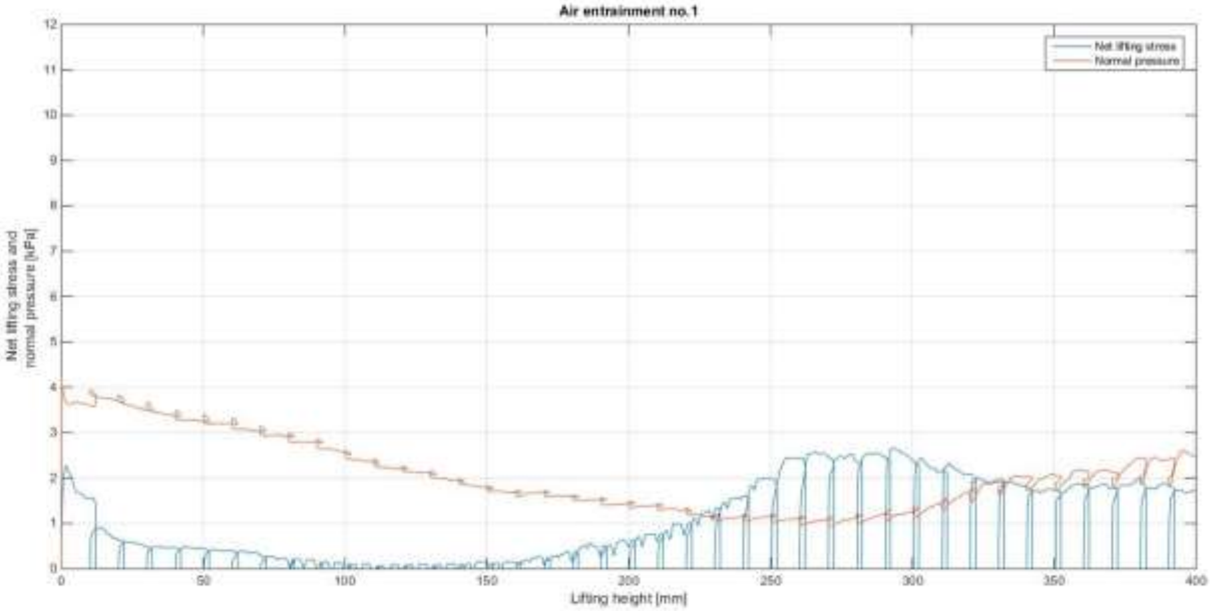

Figure 39 - Air entrainment no.1 Normal pressure

Air entrainment no.2:

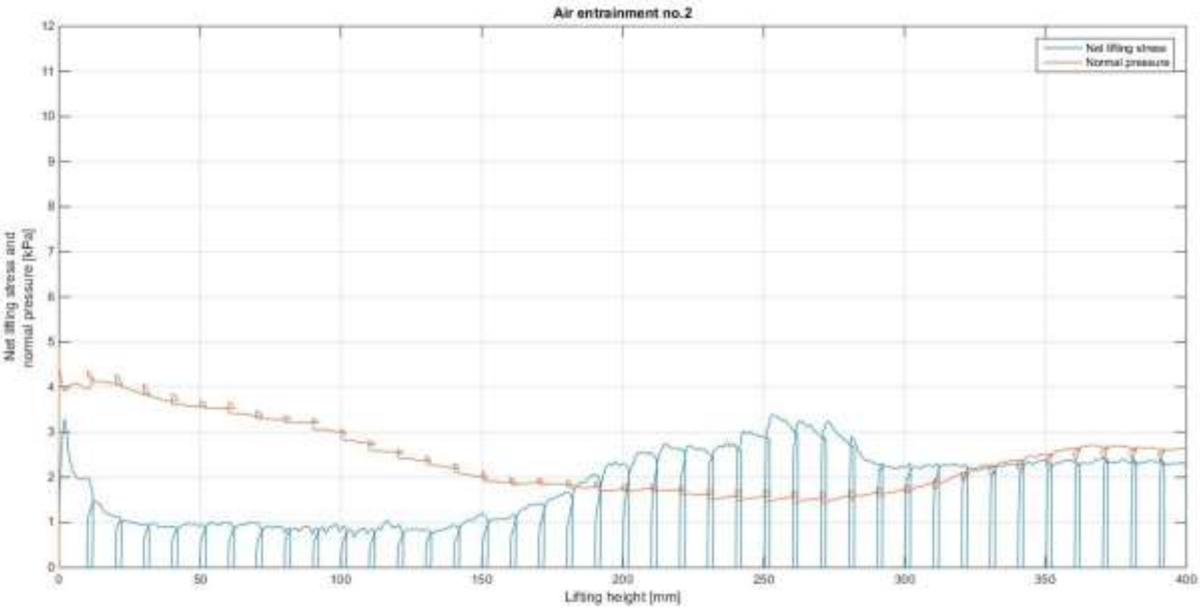

Figure 40 - Air entrainment no.2 Normal pressure

W/B 0.35 no.1:

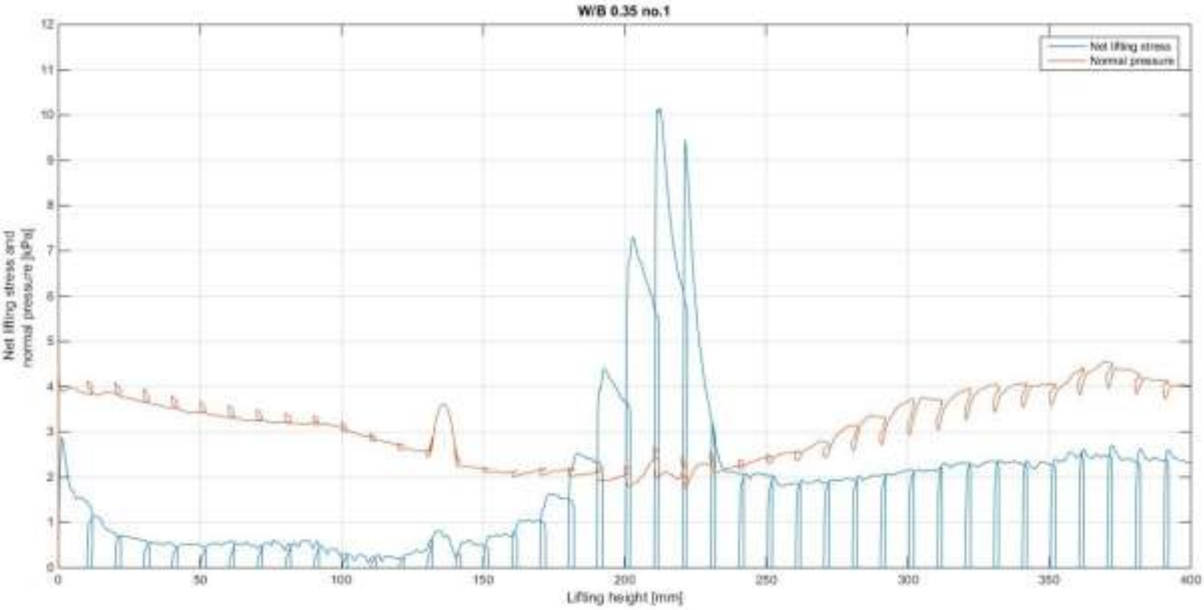

Figure 41 - W/B 0.35 no.1 Normal pressure

W/B 0.35 no.2:

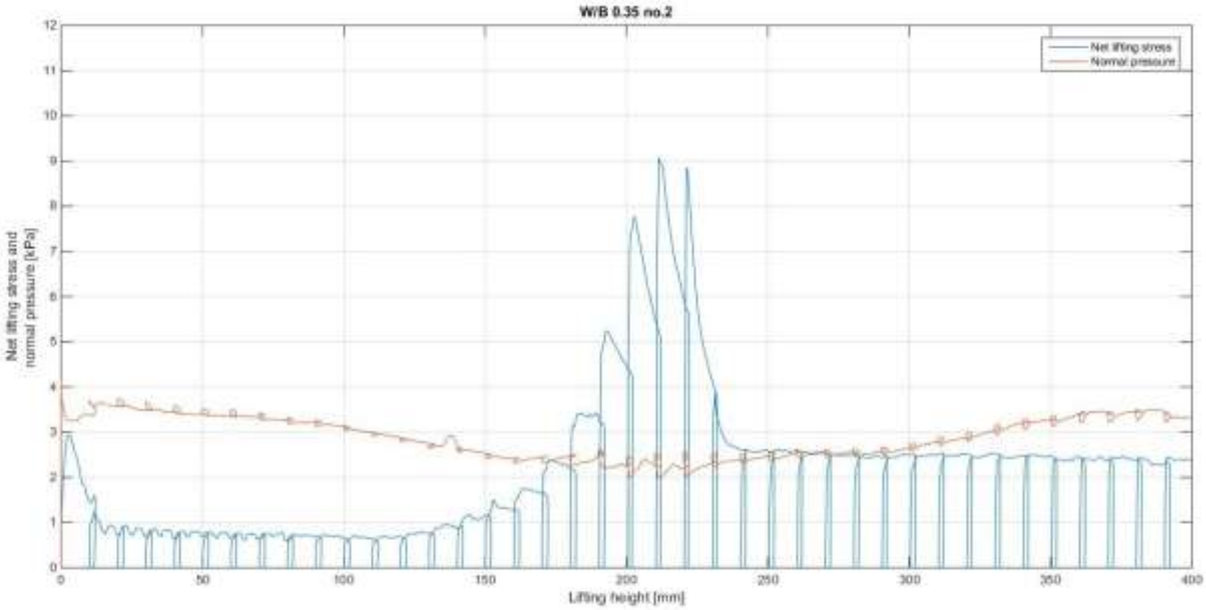

Figure 42 - W/B 0.35 no.2 Normal pressure

Ultra-high performance concrete no.1:

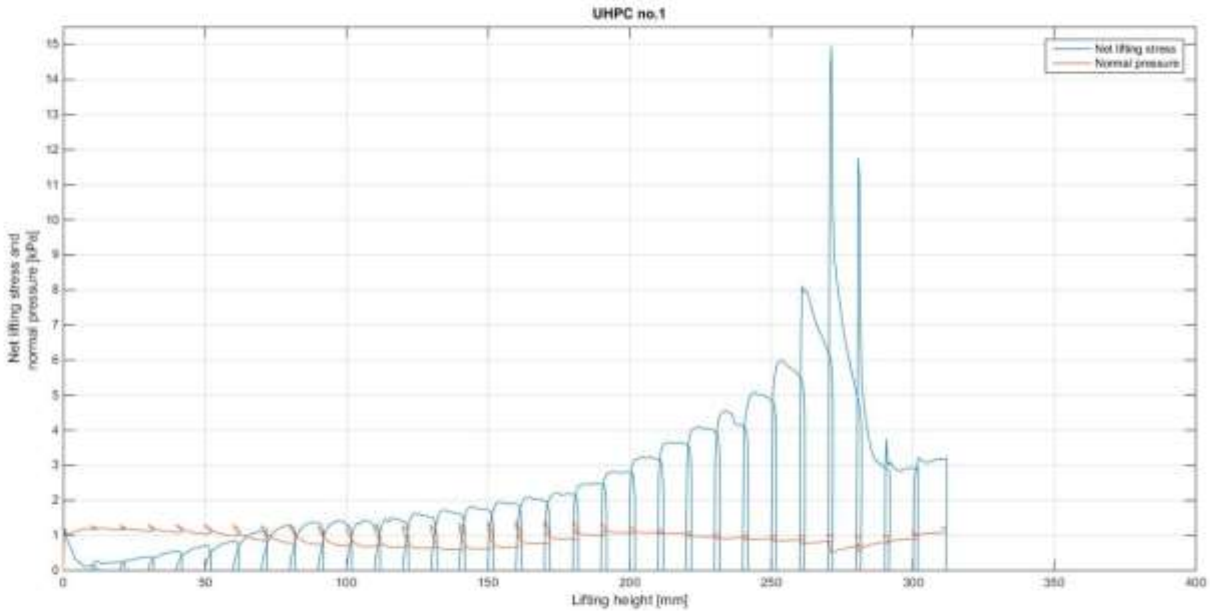

Figure 43 - Ultra-high performance concrete no.1 Normal pressure

Ultra-high performance concrete no.2:

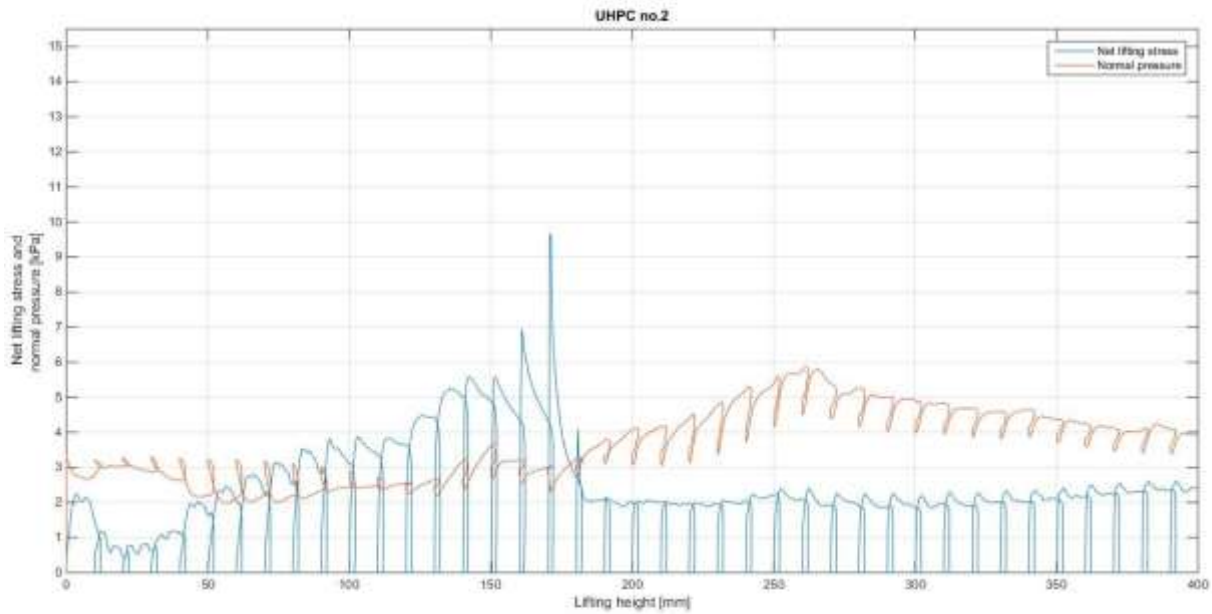

Figure 44 - Ultra-high performance concrete no.2 Normal pressure

The normal pressure immediately starts to decrease, before it eventually starts to flatten and starts to increase. This is because the concrete starts to get elastic properties. I addition one can see that when the normal pressure is at its lowest when the lifting stress is at its highest. The normal pressure seems also to be similar for all mixes, with the exception of UHPC no.1.

5.3.3. Net static and kinetic lifting stress

Figure 45 to 54 displays the development of the net static and kinetic lifting stress.

Reference no.1:

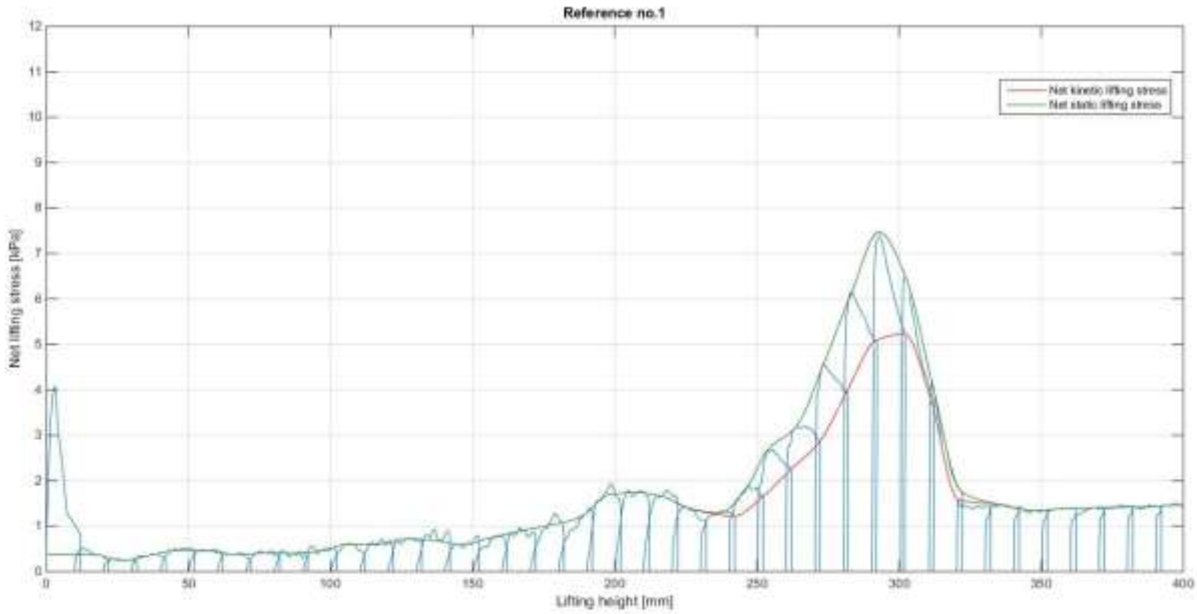

Figure 45 - Reference no.1 Net lifting stress

Reference no.2:

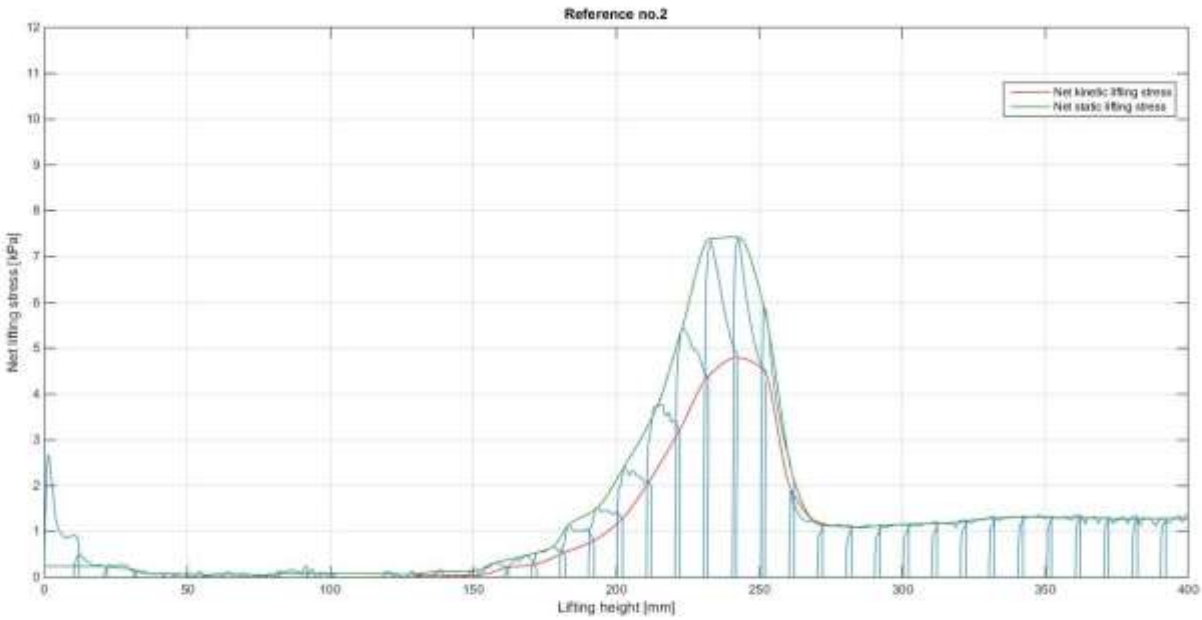

Figure 46 - Reference no.2 Net lifting stress

15% Silica no.1:

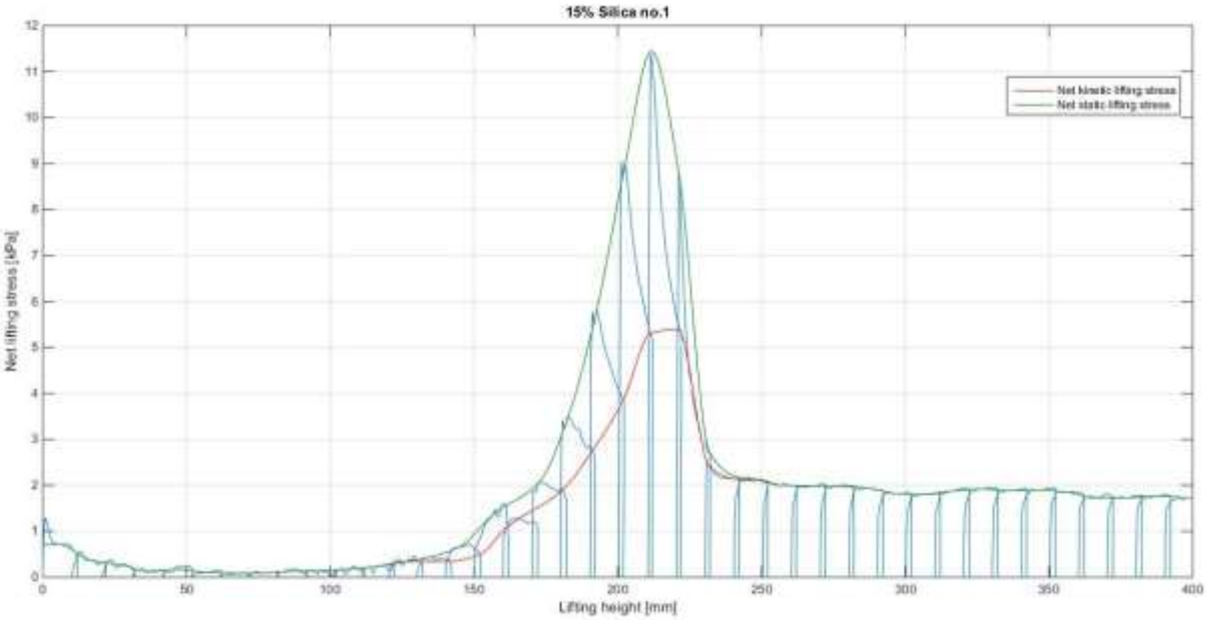

Figure 47 - 15% Silica no.1 Net lifting stress

15% Silica no.2:

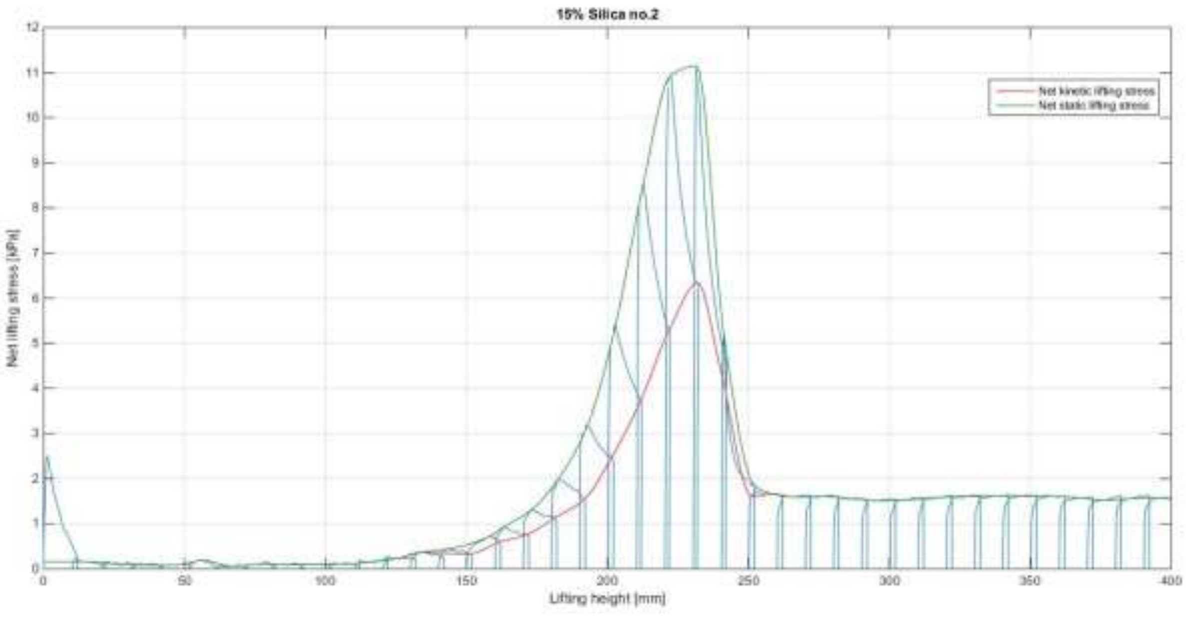

Figure 48 - 15% Silica no.2 Net lifting stress

Air entrainment no.1:

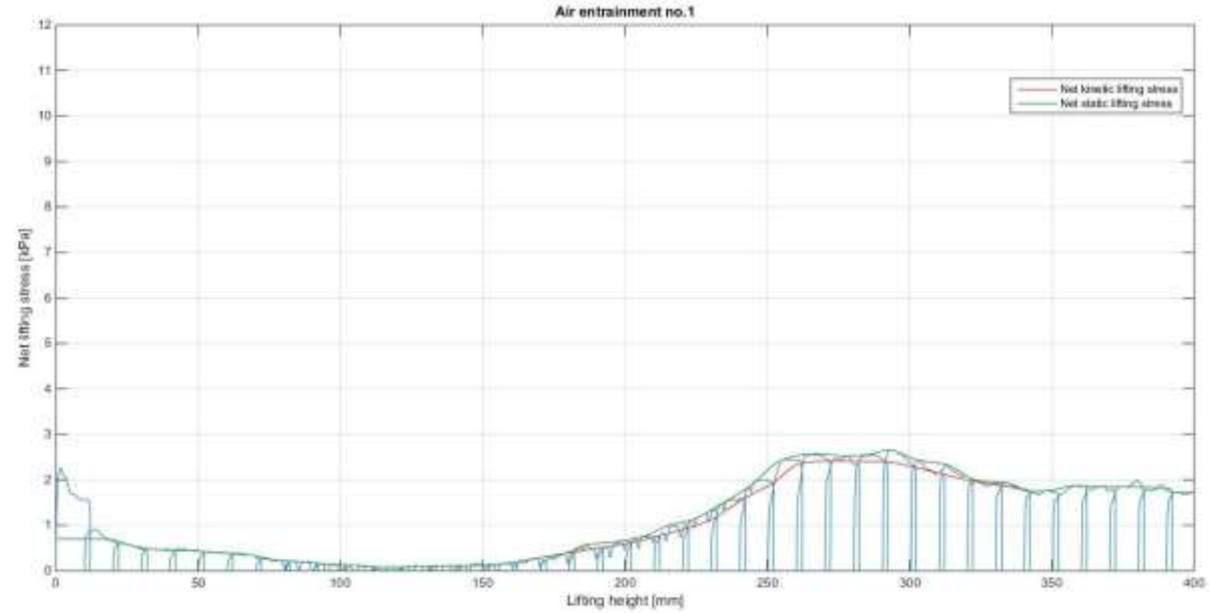

Figure 49 - Air entrainment no.1 Net lifting stress

Air entrainment no.2:

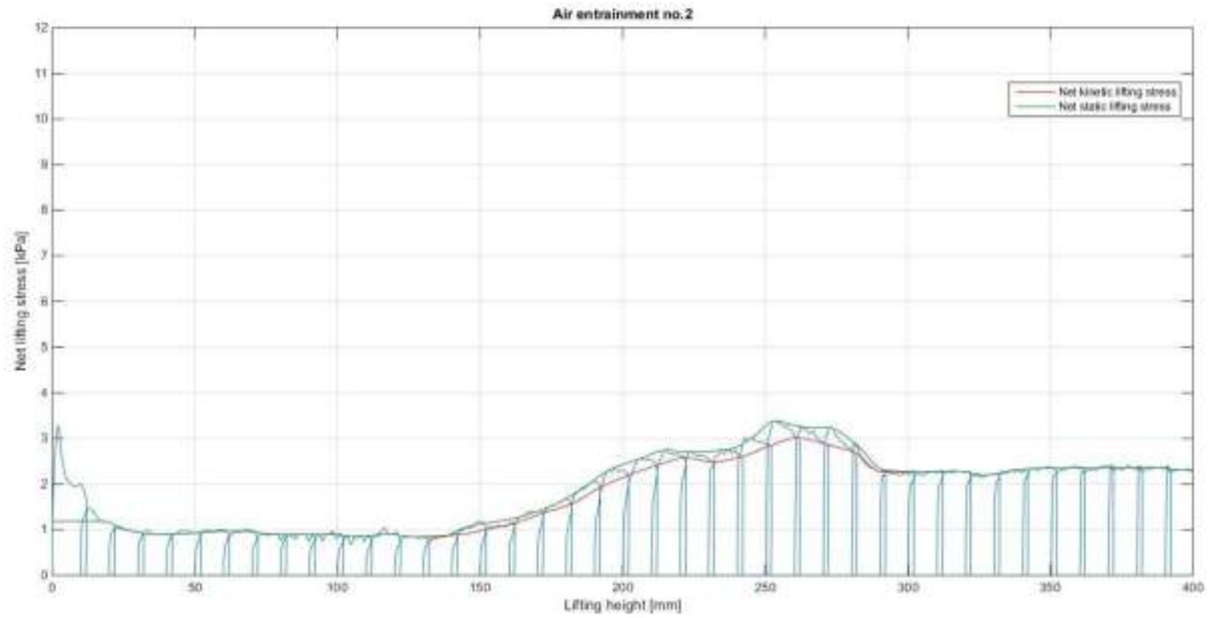

Figure 50 - Air entrainment no.2 Net lifting stress

W/B 0.35 no.1:

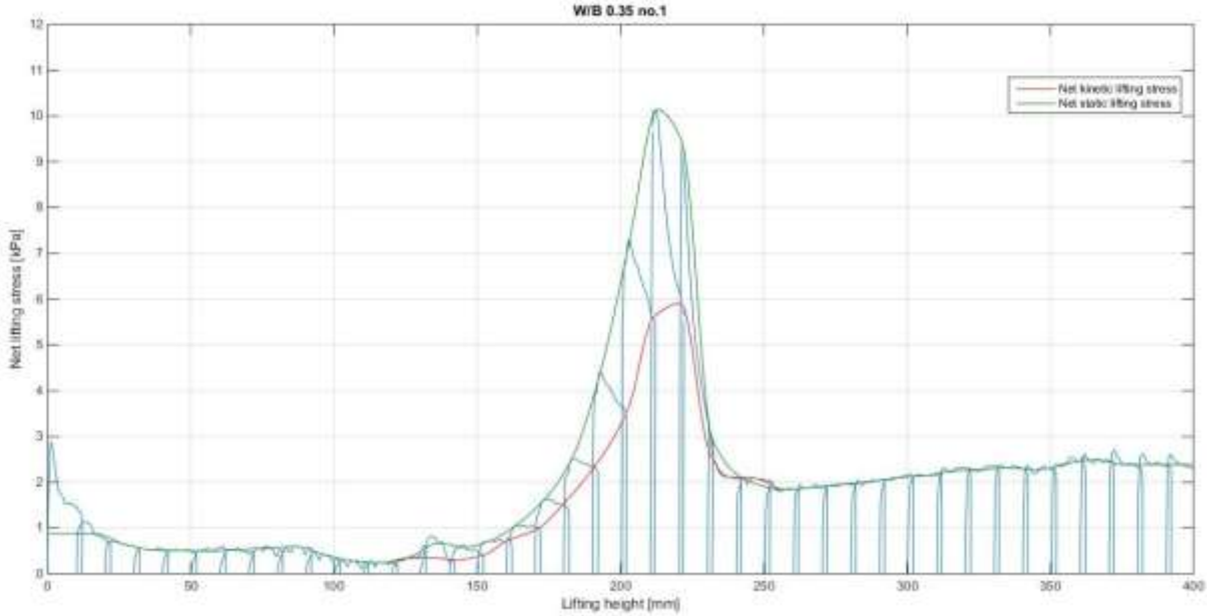

Figure 51 - W/B 0.35 no.1 Net lifting stress

W/B no0.35 no.2:

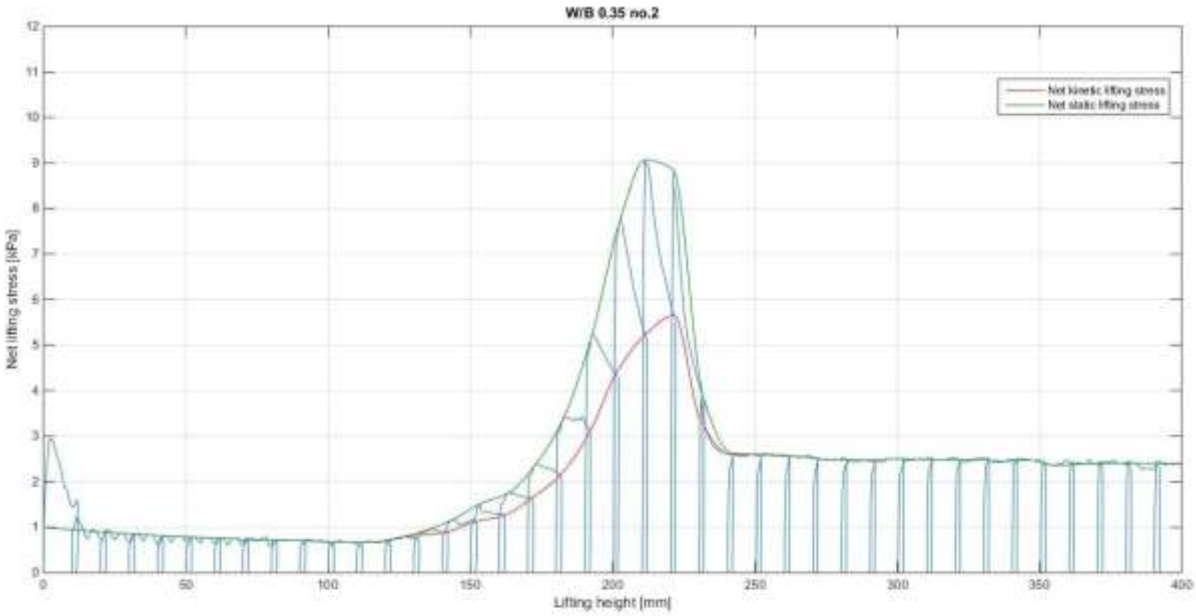

Figure 52 - W/B 0.35 no.2 Net lifting stress

Ultra-high performance concrete no.1:

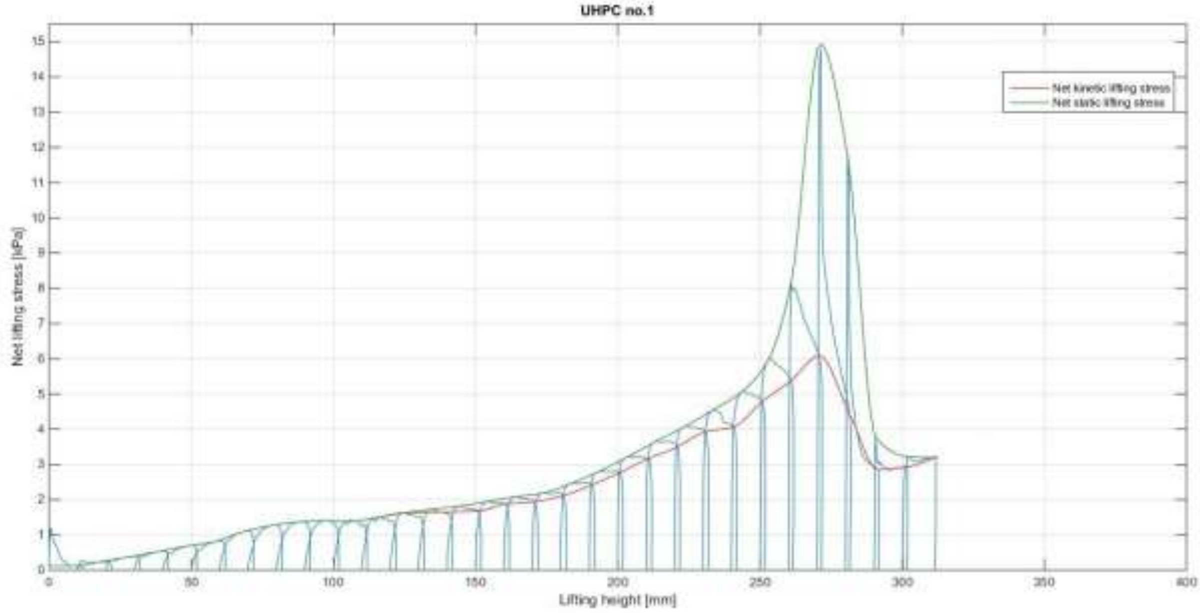

Figure 53 - Ultra-high performance concrete no.1 Net lifting stress

Ultra-high performance concrete no.2:

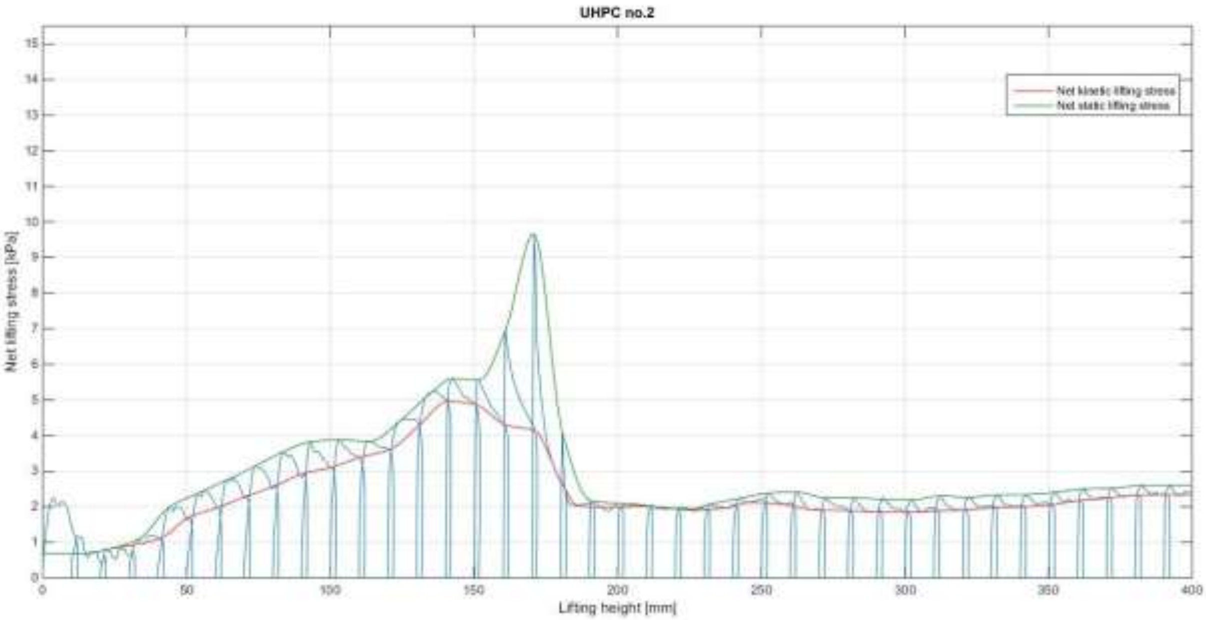

Figure 54 - Ultra-high performance concrete no.2 Net lifting stress

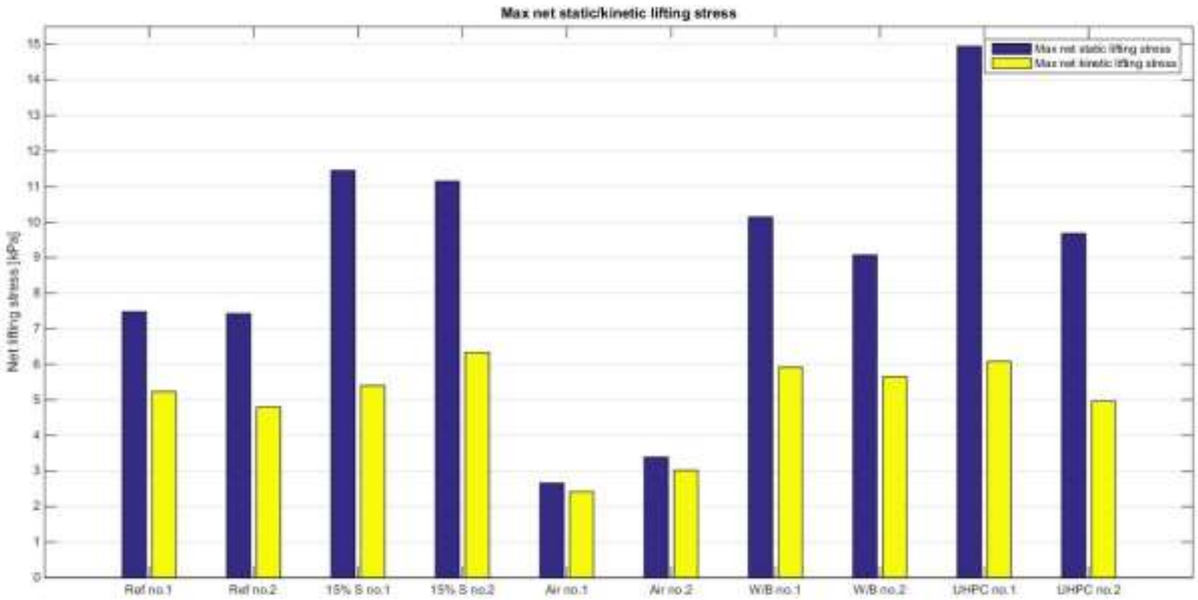

Figure 55 - Comparison of Max net static and kinetic lifting stress

Figure 55 shows the comparison of max net static and kinetic lifting stress. From the results one can see that for the normal concrete mixes there is a reasonably correlation for the similar mixes. There is also a clear difference of the net lifting stress for the different concrete mixes.

For the ultra-high performance concrete however there was not a clear correlation. This might be explained by that for the first mix there was a problem with the loss of workability and it became extremely sticky. There was also a problem with the data registration for UHPC no.1 as it suddenly stopped logging, this is unknown if effected the reading that was stored, but most likely didn’t have any effect on the data. However, one can see that the normal pressure is very low for that test, and most likely not true.

6. Conclusion

The purpose of this thesis was to, determine how the materials in concrete affected the friction between the slipform panel and the concrete, verify that the slipform rig would reproduce results with the same concrete mix, and in addition look at the possibility of use of ultra-high performance concrete in slipforming.

From the results presented in chapter 5, one can conclude with:

- The slipform rig is able to reproduce results.
- Increased content of silica in the concrete mix will give a clearly higher max net static lifting stress and a slightly increased max net kinetic lifting tress, when compared to the reference mix.
- A lower water binder ratio will give a higher max net static lifting stress and a slightly increased max net kinetic lifting stress, when compared to the reference mix.
- With a higher air content will both the max net static and kinetic lifting stress be lowered, when compared to the reference mix.
- The results can indicate that the use of ultra-high performance concrete in slipforming seems to be possible as long as the problem with the workability is handled. To be able to give a more conclusive answer more testing needs to be done with this type of concrete.

Bibliography

[1] K. T. Fosså, Slipforming of Vertical Concrete Structures – Friction between concrete and slipform panel, June 2001

[2] Norsk Betongforening, NB 25 Veiledning for prosjektering og utførelse av konstruksjoner ustøpt med glideforskaling.

[3] T. Dinescu and C. Râdulescu, Slip Form Techniques, Abacus Press 1992.

[4] Veglaboratoriet, Intern rapport no1669 Bruk av glideforskaling kontra klatreforskaling, 1994

[5] B. Basu and M. Kalin, Tribology of ceramics and composites – Materials Science Perspective, October 2011

[6] V. L. Popov, Contact Mechanics and Friction – Physical Principles and Applications, Springer 2010

[7] B.N.J Persson, Sliding Friction – Physical Principles and Applications, Springer 2000

[8] Product information Norcem Anleggsement FA, http://www.norcem.no/system/files_force/assets/document/produktinfo_anleggsement_fa_no.pdf?download=1 (.pdf)

[9] Product data sheet Norcem Anleggsement FA, http://www.norcem.no/system/files_force/assets/document/62/68/product_data_sheet_anlfa_1side_eng_k1_20august_0.pdf?download=1 (.pdf)

[10] S. Johansen, Concrete technology, 2009

[11] NS-EN 934-2:2009 Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling

[12] NS-EN 12350-1:2009 Testing fresh concrete – Part 1: Sampling

[13] NS-EN 12350-2:2009 Testing fresh concrete – Part 2: Slump-test

[14] NS-EN 12350-7:2009 Testing fresh concrete – Part 7: Air content – Pressure methods

[15] NS-EN 12390-2:2009 Testing hardened concrete – Part 2: Making and curing specimens for strength tests

[16] NS-EN 12390-3:2009 Testing hardened concrete – Part 3: Compressive strength of test specimens

Appendix

A. Concrete mixes

B. Dynamon SX-N

C. SikaAer-S

D. Moisture Test Procedure

Appendix A - Concrete mixes

Prosj./id.:	Reference no.1

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	Resept kg/m³	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Anlegg FA	385,0	30,803			30,803	
Elkem Microsilica	19,3	1,540	0	0,000	1,540	
	0,0	0,000	0	0,000	0,000	
Fritt vann	169,4	13,553		-1,599	11,955	*12,674*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm.	952,7	76,219	1,7	1,296	77,515	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,6	0,370	82	0,303	0,370	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	**Reference no.2**

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Anlegg FA	385,0	30,803			30,803	
Elkem Microsilica	19,3	1,540	0	0,000	1,540	
	0,0	0,000	0	0,000	0,000	
Fritt vann	169,4	13,553		-1,370	12,183	*12,902*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm	952,7	76,219	1,4	1,067	77,286	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,6	0,370	82	0,303	0,370	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	**15% Silica no.1**

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Anlegg FA	332,8	26,622			26,622	
Elkem Microsilica	49,9	3,993	0	0,000	3,993	
	0,0	0,000	0	0,000	0,000	
Fritt vann	173,0	13,843		-3,158	10,685	*11,404*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm	952,7	76,219	3,8	2,896	79,116	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,0	0,319	82	0,262	0,319	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	**15% Silica no.2**

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Anlegg FA	332,8	26,622			26,622	
Elkem Microsilica	49,9	3,993	0	0,000	3,993	
	0,0	0,000	0	0,000	0,000	
Fritt vann	173,0	13,843		-1,634	12,209	*12,928*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm	952,7	76,219	1,8	1,372	77,591	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,0	0,319	82	0,262	0,319	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	Air entrainment no.1

Blandevolum:	87 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	Resept kg/m³	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Anlegg FA	385,0	33,497			33,497	
Elkem Microsilica	19,3	1,675	0	0,000	1,675	
	0,0	0,000	0	0,000	0,000	
Fritt vann	169,4	14,739		-0,339	14,400	*15,182*
Absorbert vann	9,0	0,782			0,782	
Velde 0/8 mm	952,7	82,889	0,0	0,000	82,889	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	73,505	0,0	0,000	73,505	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,6	0,402	82	0,330	0,402	
Sika AER-S	0,1	0,010	91	0,009	0,010	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	**Air entrainment no.2**

Blandevolum:	87 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Anlegg FA	385,0	33,497			33,497	
Elkem Microsilica	19,3	1,675	0	0,000	1,675	
	0,0	0,000	0	0,000	0,000	
Fritt vann	169,4	14,739		-0,339	14,400	*15,182*
Absorbert vann	9,0	0,782			0,782	
Velde 0/8 mm.	952,7	82,889	0,0	0,000	82,889	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	73,505	0,0	0,000	73,505	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	4,6	0,402	82	0,330	0,402	
Sika AER-S	0,1	0,010	91	0,009	0,010	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	**W/B 0.35 no.1**

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m³	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Anlegg FA	413,5	33,081			33,081	
Elkem Microsilica	20,7	1,654	0	0,000	1,654	
	0,0	0,000	0	0,000	0,000	
Fritt vann	159,2	12,736		-1,240	11,496	*12,215*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm	952,7	76,219	1,2	0,915	77,134	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	5,0	0,397	82	0,326	0,397	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Prosj./id.:	W/B 0.35 no.2

Blandevolum:	80 liter
Dato:	
Tidspunkt for vanntilsetning	
Ansvarlig:	
Utført av:	

Materialer	Resept kg/m³	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Anlegg FA	413,5	33,081			33,081	
Elkem Microsilica	20,7	1,654	0	0,000	1,654	
	0,0	0,000	0	0,000	0,000	
Fritt vann	159,2	12,736		-1,240	11,496	*12,215*
Absorbert vann	9,0	0,719			0,719	
Velde 0/8 mm	952,7	76,219	1,2	0,915	77,134	
	0,0	0,000	0,0	0,000	0,000	
Velde 8/16mm	844,9	67,591	0,0	0,000	67,591	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
	0,0	0,000	0,0	0,000	0,000	
Dynamon SX-N	5,0	0,397	82	0,326	0,397	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
	0,0	0,000	100	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
PP-fiber	0,0	0,000			0,000	

Ultra-high performance concrete	
Liter	*75,00*
Material	**Planned**
Anleggssement	59,63
Elkem Microsilica	11,790
Water	13,360
Milsil W12	16,110
Quartzsand H33	75,930
Defoamer	0,033
BASF ACE 430	3,167
w/c	0,224

Appendix B – Dynamon SX-N

MAPEI

Dynamon SX-N

Superplasticising admixture

PRODUCT DESCRIPTION
Dynamon SX-N is a very efficient liquid superplasticising admixture, based on modified acrylic polymers.
The product belongs to the **Dynamon System** based on the DPP (Design Performance Polymers) technology, a new chemical process that can model the admixture's properties in relation to specific performances required for concrete. The process is developed by means of a complete design and production of monomers (an exclusive Mapei know-how).

AREAS OF APPLICATION
Dynamon SX-N is an all-round product to be used in nearly all types of concrete to improve the workability and/or reduce the amount of water needed.

Some specific applications are:

- Concrete with reduced permeability with specifications as to very high mechanical strength and to long durability in aggressive environments.
- Concrete with high levels of workability (consistency classes S4 or S5 - according to EN 206)
- Self-compacting concrete where high slump retention is required. If extra stabilisation is needed, a viscosity enhancing agent, **Viscofluid** or **Viscostar** can be used.
- Production of frost resistant concrete - in combination with air entraining agents (AEA), **Mapeair**. The correct type and amount of AEA is dependent on the properties of the other available ingredients.
- Concrete for flooring where a smooth concrete with high workability is aimed for. Larger dosages and lower tempe ratures may increase the retardation.

TECHNICAL PROPERTIES
Dynamon SX-N is an aqueous solution of active acrylic polymers that very efficiently disperses clusters of cement grains.

This effect can in principle be used in the following three ways:

1. To reduce the amount of added water, yet retain the same workability. Lower water to cement ratio means higher mechanical strength, reduced permeability and increased durability.
2. To increase workability compared to concrete with equal water to cement ratio. With the same mechanical strength the casting is facilitated.
3. To reduce both the amount of water and the amount of cement without changing the concrete's mechanical strength. In this way it is possible to

reduce the total cost of the concrete (less cement), reduce the concrete's shrinkage potential for (less water) and reduce the possibility of cracks due to temperature gradients (less hydration heat). Especially with concretes that normally have high amounts of cement, this effect is very important.

COMPATIBILITY WITH OTHER PRODUCTS
Dynamon SX-N can be combined with other admixtures from Mapei; such as a set-accelerating admixture, **Mapefast** or a set-retarding admixture, **Mapetard**. The product is also compatible with air entraining admixtures to produce frost resistant concrete, **Mapeair**.

The choice of admixture is done after an evaluation of the properties of the other ingredients in the mix.

DOSAGE
To obtain the prescribed properties (i.e. strength, durability, workability, cement reduction), **Dynamon SX-N** is added in dosages between 0.4 and 2.0% of the amount of cement + fly ash + microsilica. Increased dosages will also increase the slump retention, i.e. the time to be able to work with the concrete.

Higher dosages and lower temperatures will delay the setting of the concrete. To obtain correct knowledge, tests with actual parameters are advisable, especially before larger pours.

As opposed to traditional superplasticisers based on melamines or naphtalenes, the maximum effect of **Dynamon SX-N** is obtained regardless of when it isaddes during the mixing procedure it is added, but the time of addition can influence the mixing time. If at least 80 % of the mixing water is added before **Dynamon SX-N** the required mixing time will generally be shortest. It is nevertheless important to perform using the actual mixing equipment.

Dynamon SX-N can also be added directly into the truck on site. The concrete should then be mixed at full speed at least for one minute pr m³ of concrete, and never shorter than 5 minutes.

PACKAGING
Dynamon SX-N is available in 25 liter cans, 200 liter drums, 1000 liter IBC tanks and in tank.

STORAGE
The product must be stored at temperatures between +8 and +35°C, and will retain its properties for at least one year if stored unopened in its original packaging. If the product is exposed to direct sunlight, colour variation may occur, but this will not affect the technical properties of the product.

SAFETY INSTRUCTIONS FOR PREPARATION AND USE
Dynamon SX-N is not considered dangerous according to European regulations regarding classification of chemicals. It is recommended to wear gloves and goggles and to take usual precautions for handling of chemicals.

For further and complete information about safe use of our product, please refer to our latest version of the Safety Data Sheet.

PRODUCT FOR PROFESSIONAL USE

WARNING
Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above - information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the technical data sheet, available from our web site www.mapei.no

All relevant references for the product are available upon request and from www.mapei.no

Dynamon SX-N

TECHNICAL DATA (typical values)

PRODUCT IDENTITY	
Appearance:	liquid
Colour:	yellowish brown
Viscosity:	easy flowing: < 30 mPa·s
Solids content (%):	18.5 ± 1.0
Density (g/cm³):	1.06 ± 0.02
pH:	6.5 ± 1
Chloride content (%):	< 0.05
Alkali content (Na_2O-equivalents) (%):	< 2.0

10.03.2015 GB

MAPEI®
BUILDING THE FUTURE

Appendix C – SikaAer-S

Produktdatablad
Dato: 06/2006
SikaAer® -S

Construction

SikaAer® -S

Luftinnførende tilsetningsstoff for betong og mørtel

Produktbeskrivelse	SikaAer®-S er et luftinnførende tilsetningsstoff basert på syntetisk tensider. SikaAer®-S danner et finfordelt luftporesystem i betongens sementpasta. Luftporene fungerer som ekspansjonskammer når fukten/vannet i den herdnede betongen utvider seg ved frysing. Luftporene vil også gjøre betongen mer lettarbeidelig og smidig.
Anvendelsesområder	SikaAer®-S anvendes i betong for å øke frostbestandigheten i konstruksjoner som er utsatt for frysing/tining i nedfuktet tilstand. SikaAer®-S kan også anvendes for å forbedre betongens støpelighet eller betongens stabilitet og dermed redusere faren for bleeding og separasjon.
Produktegenskaper	SikaAer®-S forbedrer betongens egenskaper som følger: ▪ Forbedret bearbeidelighet ▪ Økt frostbestandighet ▪ Økt vanntetthet ▪ Gir mulighet for å styre luftinnføring i betong. ▪ Gir stabilt luftinnhold i betong, også egnet til betong med flyveaske eller flyveaskesement ▪ God stabilitet i varmbetong.

Produktdata

Tekniske data	▪ **Type:**	Væske på basis av syntetisk tensider
	▪ **Farge:**	Gul
	▪ **Densitet:**	1,02 ± 0,01 kg/l
	▪ **Viskositet:**	Lettflytende
	▪ **Tørrstoff:**	9,0 ± 1 %
	▪ **pH:**	7 ± 1 %
	▪ **Kloridinnhold (Cl-):**	< 0,10 % (vekt)
	▪ **Alkaliinnhold (Na2O ekv.):**	< 0,10 % (vekt)
	▪ **Normaldosering:**	0,01 – 0,08 % av sementvekt For å oppnå mer nøyaktig dosering anbefales at SikaAer®-S fortynnes med vann for eksempel i forholdene 1:9, 1:19 eller lignende avhengig av doseringsbehov og vektkapasitet. Tilsett først vannet, deretter SikaAer®-S (konsentrat). Nødvendig dosering for å oppnå spesifisert luftinnhold avhenger av sementtype, blandertype, tilslagets gradering, innholdet av fint materiale (< 0,25 millimeter), betongens konsistens og temperatur, Innenfor temperaturområdet +10 °C - +30 °C avtar effekten noe med økende temperatur. For optimal dosering anbefales forforsøk.
Doseringstidspunkt	SikaAer®-S tilsettes sammen med blandevannet. SikaAer®-S kan også tilsettes i automikser. Beregn minimum 5 minutter blandetid på full hastighet.	

Kombinasjoner	SikaAer®-S kan kombineres med andre produkter fra Sika som følger: ■ Plastiment® BV-40 ■ SP-stoff i Sikament eller ViscoCrete-serien ■ Sika Stabilizer ■ Sika® Pump ■ Sika® Rapid 2 og 3 ■ Sika® Retarder ■ Sika® Ferrogard 901
Bivirkninger	Overdosering reduseres betongens trykkfasthet.
Godkjenninger	SikaAer®-S er omfattet av samsvarserklæring 1257-CPD-701 og er CE-merket som angitt nedenfor. SikaAer®-S er tildelt miljømerket EQ-Seal av den Europeiske tilsetnings-stofforeningen EFCA. Miljømerket tildeles produkter som ikke har negative effekter på menneske og miljø. CE 1274 **Sika Sverige AB** **Veddestavägen 15-20** **S-175 06 Järfälla, Sverige** 04 1274-CPD-701 **Sika Aer-S** Luftinnførende tilsetningsstoff for betong EN 934-2:2001: T5 **Maks. kloridinnhold: < 0,1 %** **Maks. alkali-innhold: < 0,1 % Na_2O-ekv.** Produktet er merket IRRITERENDE se tilhørende HMS-datablad
Emballasje	SikaAer®-S leveres i kanner à 5, 10 og 25 liter, fat à 200 liter, container à 1000 liter eller med tankbil.
Oppbevaring, holdbarhet og avfallshåndtering	Ved frostfri lagring i uåpnet emballasje, er holdbarheten min. 9 måneder fra produksjonsdato. Produktet er ikke klassifisert som spesialavfall. For avfallshåndtering, se tilhørende HMS-datablad. Sika Norge AS er med på Materialreturordningen, og betaler gebyr for all produkt- og forsendelsesemballasje. Vi anbefaler at all tomemballasje leveres til gjenvinning.
Helse, Miljø og Sikkerhet	Se tilhørende HMS-datablad.
	Produktet er produsert i en bedrift som er sertifisert i henhold til ISO 9001:2000 og ISO 14001. Ønskes ytterligere opplysninger, står våre konsulenter samt vår kundeservice til din disposisjon. Forespørsel om HMS-datablad kan rettes til vår HMS-ansvarlig, eller gå inn på våre internettsider: www.sika.no

Produktansvar

Denne informasjonen og i særdeleshet anbefalingene i forbindelse med anvendelse av Sika-produkter er gitt i god tro, basert på Sikas inneværende kunnskap og erfaring med produktene når de er riktig lagret, behandlet og anvendt under normale forhold.

I praksis vil forskjellene i materialer, underlag og lokale forhold være av en slik karakter at verken denne informasjonen, andre skriftlige anbefalinger eller noen annen form for råd kan innebære noen garanti med hensyn til det bearbeidede produktets omsetnings-potensial eller egnethet for et bestemt formål, ei heller noen annen form for juridisk ansvar.

Tredjeparts eiendomsrett må respekteres.

Enhver ordre aksepteres i henhold til Sikas gjeldende salgs- og leveringsbetingelser. Brukere skal alltid forholde seg til sist oppdaterte versjon av produktdatablad og HMS-datablad for det aktuelle produktet. Kopier av gjeldende versjoner finnes på Sika Norges internettsider: www.sika.no.

Sika Norge AS
Industriveien 22
Postboks 76
1483 SKYTTA
Norge
Tel. 67 06 79 00
Fax 67 06 15 12
www.sika.no

Appendix D – Moisture Test Procedure

Large Size Speedy – Moisture Test Procedure

The test procedure is simple to follow and takes a just few minutes for most materials. To ensure accurate and consistent results the procedure should be followed precisely.

1. **Clean the Speedy Vessel.** Prior to using the speedy tester ensure that the inside of the Speedy cap and vessel are empty and clean. Use the bristle brush to remove any residues from previous tests as shown.

2. **Select and prepare the sample.** Ensure that the sample to be weighed and placed in the Speedy is representative of the material that is under investigation. Some materials, such as free-flowing powders and sands, need no preparation whereas others may need to be ground prior to testing or pulverised during the test – please refer to the Sample Preparation Table for further information.

3. **Weigh the sample.** Place the empty measuring beaker on the electronic scale and zero the scale – Refer to the electronic balance user instructions for further details. Add small amounts of material from the sample until the correct sample weight is reached. The sample weight is determined by the size and measurement range of the Speedy that is being used as detailed below:

Part No.	Vessel Size	Measurement Range H_2O%W/W	Sample weight (g)
L2000C	Large	0 – 10	40g
L2000D	**Large**	**0 – 20**	**20g**
L2000G	Large	0 – 50	8g

4. **Add the sample to the Speedy vessel.** Pour the sample into the chamber of the Speedy vessel as shown. Place pulverising balls into the chamber if required – refer to Sample Preparation Table.

5. **Add the reagent to the Speedy cap.** Using the metal scoop, add a minimum of two full scoops of reagent to the Speedy cap cavity as shown.

6. Seal **the Speedy.** Hold the Speedy horizontally and position the cap as shown. Swing the stirrup into position and tighten the top screw to seal.

7. **Mix the sample with the reagent.** Hold the Speedy vertically with the pressure gauge facing the ground and shake vigorously for 5 seconds. Rotate the Speedy through 180° so that the pressure gauge faces the sky, tap the sides of the Speedy to ensure the sample falls into the cap cavity and prop or hold the Speedy in this position for 1 – 2 minutes.

   Alternatively, if the pulverising balls are being used, hold the Speedy horizontally and shake it in an orbital motion to make the balls spin around the inside of the Speedy vessel. Do this for 20 seconds and then rest for 20 seconds. Repeat this process two or three times. The spinning balls pulverise the sample to give a more reliable measurement.

8. **Take the reading.** Hold the Speedy horizontally and at eye level and take the moisture content reading directly from the pressure gauge.

9. **Release the pressure.** Hold the Speedy vertically with the pressure gauge facing the ground. Locate the arrow on the flange of the cap and point this away from yourself and other people in your vicinity. Unscrew the top screw slowly to vent the gas that may have been generated within the Speedy.

10. **Remove the sample and reagent.** Tip the contents of the Speedy directly into a clean and dry open container and dispose of in accordance with **Section 13** of the Calcium Carbide **Material Safety Data Sheet**.

11. **Clean the Speedy.** Clean the Speedy vessel and cap and measuring beaker in preparation for the next moisture measurement.