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Abstract

MiniBars^{TM} is a kind of high-performance composite macrofibre made of BFRP. It is designed to improve the flexural tensile strength and post-cracking (residual) strength of the concrete. Moreover, it has a reputation for corrosion-free and zero conductivity. This thesis focused on the influence of the MiniBars^{TM} fiber volume fraction on the behavior of the concrete under compressive and tensile stress. A compression test and 3-point bending test were conducted on the specimens containing 0%, 0.5% and 1% of fiber by volume.

MiniBars^{TM} fiber volume fraction had a minor effect on the compressive strength of the concrete. In comparison with the plain concrete, the compressive strength decreased by 0.1% and 5.6% respectively for MiniBars^{TM} dosage of 0.5% and 1% after curing for 28 days. However, the MiniBars^{TM} fiber did improve the failure of the concrete. Fewer spalling and narrower crack occurred to the cubes reinforced by MiniBars^{TM} fiber. No remarkable change was observed in the flexural tensile strength of the concrete due to the fiber addition. But the test results showed that the addition of MiniBars^{TM} fiber significantly improved the behavior of the concrete after flexural cracking. The specimens revealed a ductile response to the tensile stress. The residual tensile strength of the MiniBars^{TM} reinforced concrete in ULS and SLS went up by 110% and 150% respectively after when the added fiber volume fraction increased from 0.5% to 1.0%. It was mainly due to the bridging action and the pulling-out resistance of the MiniBars^{TM}.

Acknowledgements

It would not be possible for me to finish thesis without the support from many people. Many thanks to my supervisor Dr. Yanyan Sha, who spent a lot of time on my thesis and gave me numerous invaluable advice on framing, experiment designing and analysis. I am grateful to his patience and generous participation in guiding. I would also like to thank the chief engineer Jarle Berge and the senior engineer Samdar Kakay for helping me with the experiment. It was a valuable experience to have the opportunity working with them. Thanks to Einar Mesloe, the I would not be able to complete the experiment without his co-operation. Lastly, I want to express my sincere gratitude to my family for their supporting and continuous encouragement during my study.

Contents

1. Introduction

1.1 Background

The history of concrete, which is the most widely used construction material, can be traced back thousands of years ago. Some of the unreinforced concrete buildings and structures have withstood both chemical and physical onslaught and are still standing, such as Colosseum and Roman Pantheon from ancient Roman times.[1] The amazingly high compressive strength of concrete made those structures become reality, and this may also be the greatest advantage of concrete. Compared to its excellent capacity for carrying the compressive load, concrete as a brittle material has low tensile strength. Fibers are then included in concrete mix to improve flexural tensile strength and fracture properties of concrete. Fiber reinforced concrete (FRC), defined by Cement and Concrete Terminology, is concrete containing dispersed randomly oriented fibers.[2] The fiber reinforced concrete has now been used in various structures worldwide. Both practical works and research have proved that the addition of fiber in the concrete matrix can significantly improve the mechanical properties of concrete, including flexural tensile strength, residual strength, abrasion and corrosion resistance, after-cracking bearing capacity, and so on. [3]

Basalt fiber is a composite material, and it is one of the most used fibers currently. [4] It is found in volcanic rocks originated from frozen lava, with a melting temperature comprised between 1500° and 1700 °C[5] Benefits from the low energy consuming and no additive during manufacturing, basalt fiber is cheaper than glass and carbon fiber. In addition, the basalt fiber reinforced concrete (BFRC) usually has much better resistance to thermal attack and corrosion than the plain concrete due to its material properties.

Tehmina Ayub et al. did experiments found out the effect of chopped basalt fiber on the mechanical properties and microstructure of high-performance fiber reinforced concrete (HPFRC). They reported that, the addition of chopped basalt fiber enhanced the tensile splitting strength and the flexural strength of the HPFRC considerably. With fiber volume fraction of 1%, 2%, and 3%, the tensile splitting strength increased by 1.64%, 5.27%, and 23.95% respectively, and the flexural strength went up by 18.15%, 36.12%, and 27.17% respectively in comparison with the plain concrete. [6] Sruthi Jalasutram et al. reported in their paper that the splitting tensile strength and the flexural tensile strength of the concrete were enhanced by 15% and 75% in maximum respectively when 2% of basalt fibers by volume were added into the concrete mix. Moreover, the flexural toughness and post-peak residual strength were improved. The deformability of the BFRC specimen was doubled compared to the plain concrete. [7] A similar experiment was conducted by Chaohua Jiang et al. and they also found that the tensile splitting strength and the flexural strength were increased significantly by addition of chopped basalt fiber. In addition, the increase was greater when longer fibers were used in the concrete mix.[8] The behavior of the BFRC exposed in different environments, for example, high temperature, chemical and physical attacks, is investigated by researchers. Weibo Ren et al. analyzed the dynamic compressive behavior of BFRC after high temperatures and concluded the strength performance, deformation capacity, and energy absorption property of concrete were improved due to the addition of basalt fiber. [9]

There are comparative studies to reveal the advantages and disadvantages of basalt fiber compared to other fibers used as reinforcement. V.Lopresto et al. did the research on the mechanical properties of the basalt fiber and the E-glass fiber. They suggested that it was possible to use basalt fiber as a substitution for the E-glass fiber. Because the basalt composite showed a 35–42% higher Young's modulus, higher compressive strength and better flexural behavior than the glass material according to the test results.

In recent years, a high-performance and non-corrosive macrofibre based on basalt fiber, MiniBars^{TM}, is used in different construction works such as marine and floating structure, infrastructure and so on. The MiniBars™ fiber is 0.70 mm in diameter and 41mm - 45mm long, with a density between 1.9 and 2.1 g/cm^3.[10] So it can disperse quickly and evenly throughout the concrete matrix. As the normal basalt fiber reinforced polymer (BFRP), MiniBars^{TM} reinforced concrete (MRC) also provides a higher flexural tensile and post-cracking strength than plain concrete.

John Branston et al. compared the mechanical behavior of two kinds of BFRC, bundled basalt fiber reinforced concrete and MiniBars^{TM} reinforced concrete by flexural and impacting test. Results showed that, the Minibars^{TM} enhanced post-cracking behavior significantly and mostly failed by pulling out, whilst the bundled basalt fibers did not influenced the post-cracking strength of concrete and failed by rupturing.[11]

Although there are many research focusing on FRC, only few of them target at MiniBars^{TM} basalt fiber reinforced concrete. Standards or guidelines available now are originally for steel fiber reinforced concrete (SFRC). For example, NS-EN 14651:2005, Test method for metallic fibre concrete: Measuring the flexural tensile strength (limit of proportionality (LOP), residual);

This thesis will conduct compressive, bending and residual strength tests on the MRC cubes and small beams, and then discuss the experimental results for the mechanical properties of MRC.

1.2 Aims and Limitations

The aim of this thesis is to study the advantages and the following mechanical properties of the MRC, including the compressive strength, tensile strength and the residual strength. Different fiber dosage rates, which are from 0% - 1% will be conducted during the experiment. Limitations exist due to number of specimens, the materials chosen for the experiment and the range of the dosage rate.

2. Concrete and MiniBars^{TM} Reinforced Concrete

2.1 Principles of Concrete

The beginning of modern concrete is often considered as the birth of Portland cement which was invented by Joseph Aspdin in 1800s. After hundreds of years' further development in proportioning and manufacturing, today's Portland cement is often blended with other materials and has better mechanical properties than that in the earlier age. Technological improvements, such as the reinforced mechanism, also contribute to the strength of the concrete. The behavior of concrete is optimized to support complicated structures and satisfy the increasing demands for sustainability and durability in different environments.

2.1.1 Material composition

Concrete is a composite material, it is usually made by using cement, aggregates, additives, water, and admixtures.

Cement

Cement is a finely grounded powder and defined as “a hydraulic binder” in NS-EN 197-1. When mixed with water, a gel-like cement paste will be formed by the hydration reactions between the cementitious substances and water and slowly solidify into a hard mass.

According to the standard, cement is divided into five main types. [12]

- CEM I Portland cement,
- CEM II Portland-composite cement
- CEM III Blast furnace cement
- CEM IV Pozzolanic cement
- CEM V Composite cement

Table 2. 1: The 27 products in the family of common cements and their main constituents. [12]

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass[a])										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						natural	natural calcined	siliceous	calca-reous				
			K	S	D[b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5
	Portland-composite cement[c]	CEM II/A-M	80-88	<------ 12-20 ------>									0-5
		CEM II/B-M	65-79	<------ 21-35 ------>									
CEM III	Blast furnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5
CEM IV	Pozzolanic cement[c]	CEM IV/A	65-89	–	<------ 11-35 ------>					–	–	–	0-5
		CEM IV/B	45-64	–	<------ 36-55 ------>					–	–	–	0-5
CEM V	Composite cement[c]	CEM V/A	40-64	18-30	–	<--- 18-30 --->		–	–	–	–	–	0-5
		CEM V/B	20-38	31-49	–	<--- 31-49 --->		–	–	–	–	–	0-5

Nowadays, the most commonly used cement in industry is the CEM I and CEM II Portland cement. However, the other types of cement, such as low heat cement, are also applied in construction with special demands, for example, mass concrete structures. Research by L.Wang et al. shows that the concrete using the low heat cement show the long-term highest compressive and splitting tensile strength, but the lowest energy consumption and CO_2 emission comparing to the moderate heat Portland cement and the type I Portland cement.[13] Huaquan Yang et al. achieved the same results in their research on the anti-crack performance of low heat Portland cement concrete.[14] One of the reasons is that the temperature cracks are controlled due to the relatively low hydration reaction heat which reduces the thermal gap between the inside and outside structure during the hardening process.

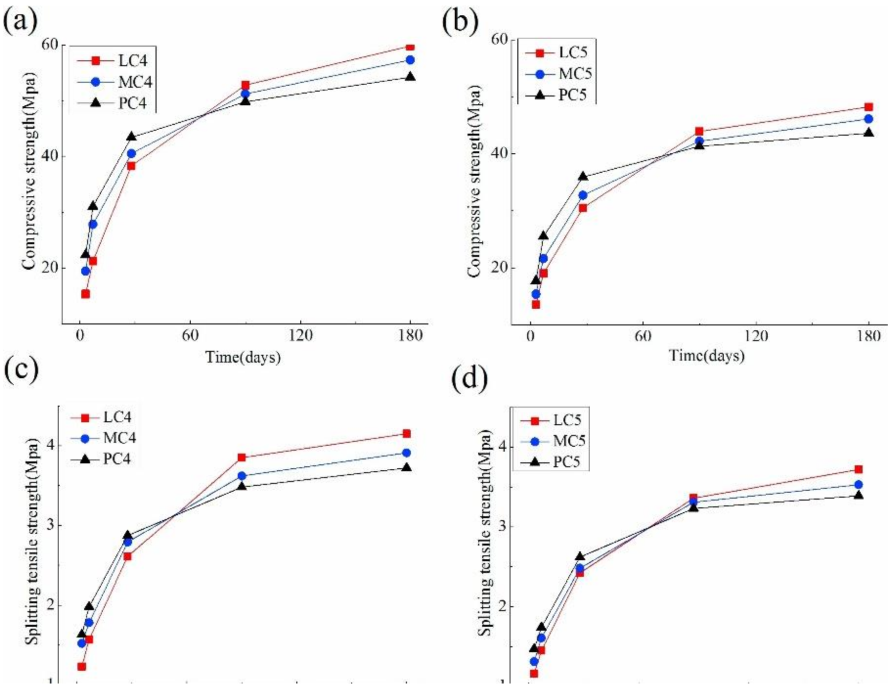


Figure 2. 1: Test results for the compressive and splitting tensile strength of concrete using low heat Portland cement (LC), moderate Portland cement (MC) and Portland cement (PC).[13]

The strength of cement is classified into three groups according to the standard strength at 28 days. Each group includes three classes of eartly strength at either 2 days or 7 days.

Table 2. 2: Cement code in NS-EN 197-1. N-Ordinary early strength; R-High early strength; L-Low early strength. [12]

Strength class	Compressive strength MPa				Initial setting time	Sound- ness (expan- sion)
	Early strength		Standard strength			
	2 days	7 days	28 days		min	mm
32,5 L[a]	-	≥ 12,0	≥ 32,5	≤ 52,5	≥ 75	≤ 10
32,5 N	-	≥ 16,0				
32,5 R	≥ 10,0	-				
42,5 L[a]	-	≥16,0	≥ 42,5	≤ 62,5	≥ 60	
42,5 N	≥ 10,0	-				
42,5 R	≥ 20,0	-				
52,5 L[a]	≥ 10,0	-	≥ 52,5	-	≥ 45	
52,5 N	≥ 20,0	-				
52,5 R	≥ 30,0	-				

a Strength class only defined for CEM III cements.

Basically, cement of different types or strength should not be mixed in concrete.

Aggregates

Aggregates are those granular materials used in concrete mix, it can be either natural (sands, moraines, etc.), manufactured (clinker, etc.) or recycled (earthquake waste, recycled concrete aggregates, etc.). In addition, materials used as aggregates should be solid, round shaped, continuously graded and have stable chemical properties. [15] It is usual that 60-75% of the concrete's volume is occupied by aggregates. The size of aggregates and the corresponding proportion are important to both fresh and hardening concrete.

Table 2. 3: Concrete applications with specification of the maximum aggregate size.[16]

<table>
<tr><th>GK [mm]</th><th colspan="2">Application</th></tr>
<tr><td>4</td><td colspan="2">Screed, fine grained components</td></tr>
<tr><td>8</td><td rowspan="2">Sprayed Concrete</td><td rowspan="3">Fiber-reinforced concrete</td></tr>
<tr><td>11</td></tr>
<tr><td>16</td><td rowspan="3">Normal concrete</td></tr>
<tr><td>22</td><td rowspan="2">Mass concrete</td></tr>
<tr><td>32</td></tr>
</table>

It is recommended by the "Norsk Betongforening" that the size of the aggregates ($d_{g,max}$) in the fiber reinforce concrete should be smaller than half of the fiber length. [4], since fiber has a great impact on concrete workability. The pictures below show how the size of aggregates influences the fiber distribution in concrete mix.

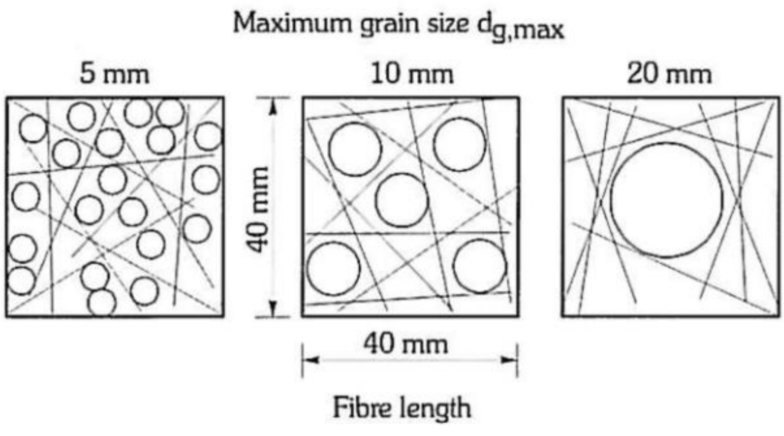


Figure 2. 2: Influence of the size of aggregates on fiber distribution. [4]

Furthermore, researches have unveiled the impact of aggregates on the mechanical properties of FRC. The impact varies according to the aggregate's constituent, gradation, packing, water absorption, etc. For example, higher fine to coarse aggregates ratio has positive effect on both compressive and tensile strength of FRC and will increase the concrete flowability in fresh state.[17] Bashar Behman described in his research that the compressive strength of fiber-reinforced lightweight concrete is inversely proportional to percent engineered aggregate by volume.[18] However, most of the experiments are conducted on steel fiber reinforced concrete (SFRC), similar study on BFRC is still deficient.

Additives

Additives can be the powdery materials added to either the cement or the aggregates. They are often used to improve the concrete properties so that it can achieve the required properties, including workability, durability, resistance to both chemical and physical attack, etc. Basically, additives materials shall not impair the properties of concrete. Special requirements are listed in the NS-EN 943-2.[15] And the total quantity shall not exceed 1.0% by mass of the cement. [12]

Admixture

Admixture is defined as a material other than water, aggregates, hydraulic cement, and fiber reinforcement in concrete that is used to modify its properties in either the fresh or after hardening state by AC1 116R. [2] They can be classified into different groups according to their application, most distinct types are: [19]

- water reduction (plasticizers)
- superplasticizers
- retardation
- acceleration
- air entrainment

There are other chemical admixtures that are designed for variety of special purposes, such as shrinkage control, anti-washout. In addition, admixtures with multiple applications, for example, accelerating water-reducing, retarding water-reducing, etc., and a combination of admixtures is also possible. In principle, the total amount of admixtures shall be limited to 5% by mass,[20] higher dosage can only be used following the recommendation from admixture producer.

In Norway, 95% of all admixtures used are either Plasticizers or Superplasticizers. Both are water reduction admixture, while Superplasticizers is considered as a special category because it provides dramatically high workability at a low water-cement ratio without undesirable adverse effects. [19]

Water

The water added in concrete mix can be divided into three types according to its roles, chemically reacted water, absorbed water and free water.[21] The hydration reaction from cementitious substance (cement) and water has an immense influence on the strength of hardened concrete. The absorbed water will cause shrinkage and creep, and the free water largely controls the porosity which will finally impair the strength and durability of concrete.
However, water is divided according to its origin in NS-EN 1008:2002. Ref.Table 2. 4. In principle, all water that damages the concrete, including the reinforcement and other constituents must be excluded.

Table 2. 4: Water classification according to NS-EN 1008:2002.[22]

Types of Water	Usability	Special Requirements
Drinking water	Can be used	
Recycled water from concrete industry	Can be used	Must satisfy the requirements listed in NS-EN 1008, Annex A

Ground water	Can be used	Must be tested
Water from natural surface and residual industrial water	Can be used	Must be tested
Seawater or brackish water	Can be used	Only in unreinforced concrete or concrete without steel reinforcement
Wastewater	Cannot be used	

2.1.2 Water-cement ratio

Water-cement ratio is defined as the ratio of mass of water to the mass of cement by ACI Committee 116.[2] The water being absorbed into the aggregates are excluded. The water-cement ratio is an important factor that effect the concrete's workability and strength. Ref. Figure 2. 3. Generally speaking, higher water-cement ratio leads to better workability of the concrete in the fresh state, whereas the compressive strength and the durability of the hardened concrete are weakened. Reason for this is that the concrete's strength is highly depended on the chemical reaction between the cementitious material and water. Research has been done to find out the optimized water-cement ratio in concrete mix. Water-reducing admixture, like plasticizers and superplasticizer are applied to increase the flowability of the fresh concrete at a low water-cement ratio. The mostly used water-cement ratio in industry is within the range of 0.45 to 0.6.

In addition, the water-cement ratio is critical to the interfacial microstructure of the concrete. It is known that the mechanical properties of a material is highly depended on the microstructure.[1], [6], [23] The residual water in the concrete, for example, cause redundant voids inside the concrete and leads to strength deterioration. Experiments were carried out on both the plain concrete and the fiber reinforced concrete. Zhenyu Pi et al. studied on the relationship between the water-cement ratio and the pullout behaviors of steel fiber by investigating the corresponding micro-mechanism. They reported that the decline of the water-cement ratio improved the fiber pullout behavior.[24]

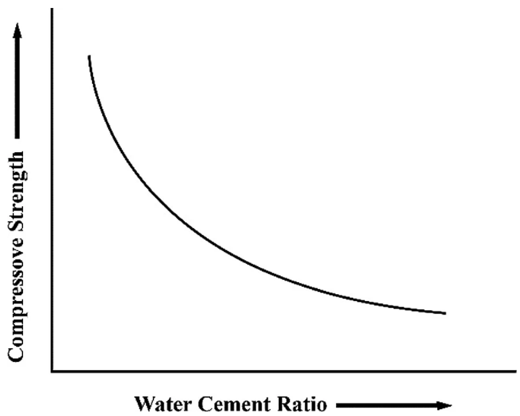


Figure 2. 3: Relationship between water-cement ratio and the compressive strength of the concrete. [23]

2.2 Fiber Reinforced Concrete

2.2.1 General

Fiber reinforced concrete(FRC) is a composite material that is characterized by an enhanced post-cracking residual tensile strength due to the capacity of the fibers to bridge the crack faces.[25] The fiber used in concrete has many advantages, including a high strength-to-weight ratio, corrosion resistance, light weight, etc. [26] It is applied to totally or partially substitute the conventional reinforcement to enhance the concrete strength, particularly the tensile strength and toughness in the cracked state.

Andrzej M. Brandt gave an overview of the development of the FRC in his study. As he concluded in his paper, the fibers dispersed into the concrete could effectively control the crack opening and propagation. Figure 2. 4 explained how the fibers contributed to crack control. The large single cracks are replaced by the microcracks. [27] Ronald F.Zollo also said that effect of the fibers is more in energy absorption and crack control rather than in increased load-transfer capacity.[28]

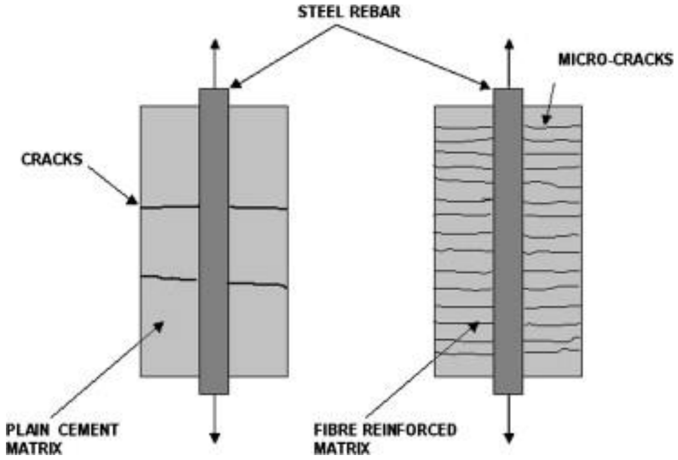
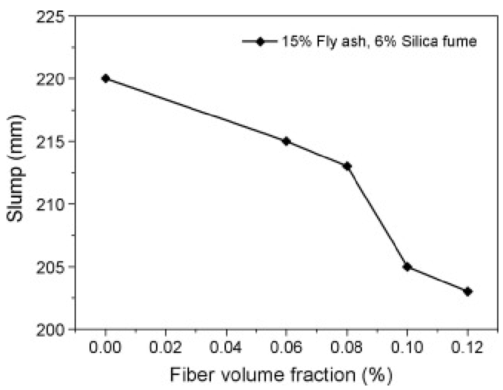


Figure 2. 4: Crack pattern in reinforced concrete (RC) and fibre reinforced concrete (FRC) elements subjected to tension. [27]

Usually, the quantity of fibers added into the concrete represented by fiber volume fraction (Vf). It is defined as the ratio of the volume of fibers present to the total volume of the layer. [29] The typically used fiber volume fraction is up to 3%. Higher fiber volume fraction may cause difficulty when mixing into the concrete due to balling. Andrzej M. Brandt pointed out that higher fiber volume fraction required special techniques to avoid the workability problem.[27] D. V. Soulioti did a research on the mechanical behavior of steel fiber reinforced concrete with different fiber geometry and volume fraction. The slump test results showed that the steel fibers caused a slump reduction higher than 50% compared to the plain concrete.[30] Peng Zhang et al. did the slump test on polypropylene fiber reinforced concrete and obtained the similar results. The fibers added decreased the workability considerably. Ref. **Figure 2. 5**.



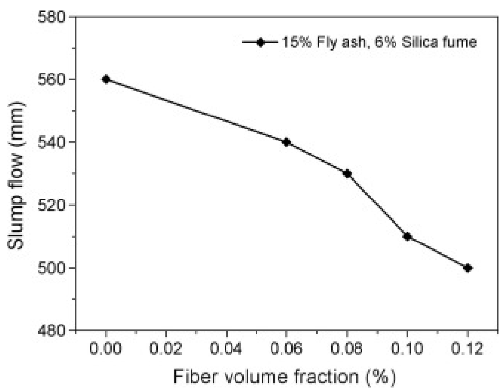


Figure 2. 5: Effect of fiber volume fraction on slump.

Different types of fiber are now applied as reinforcement, such as steel, glasses, carbon, basalts, polymeric fibers. The application and material properties will be briefly discussed in the section 2.3.2 and 2.3.3. There is a wide range of research during the last decades of years focusing on the material and mechanical properties of steel fiber and non-metallic fiber reinforced polymer (FRP) in both fresh and hardened state of the FRC.

2.2.2 Classification of FRC

Classification is an important reference for structural design. For FRC, compressive strength is not obviously influenced by the presence of fiber under a content of 1% by volume. Therefore, the classification for plain concrete defined in NS-EN 1992-1-1+NA (Eurocode 2) and NS-EN 206+NA can be used for FRC. [4], [25] See table 2.5 and 2.6. But, due to the material properties of fibers, the exposition classes described in these two standards may not be adopted to FRC.

Table 2. 5: Strength class and characteristic cylinder and cube strength for normal weight, heavy weight concrete in NS-EN 206.[20]

Norwegian Classes	**B10**	**B20**	**B25**	**B30**	**B35**	**B45**	**B55**	**B65**	**B75**	**B85**	**B95**
CEN Classes		C20/ 25	C25/ 30	C30/ 37	C35/ 45	C45/ 55	C55/ 67				
Char. Cyl. ($f_{ck,cyl}$)	10	20	25	30	35	45	55	65	75	85	95
Char. Cube.($f_{ck,cube}$)1)	12	25	30	37	45	55	67	80	90	100	110

1)For strength class B55 and higher, other values may be used, provided that the relationship between these and the reference strength for cylinders are established and documented with sufficient accuracy for the concrete mix.

Table 2. 6: Strength class and characteristic cylinder and cube strength for normal light weight concrete in NS-EN 206.[20]

Norwegian Classes	**LB12**	**LB20**	**LB25**	**LB30**	**LB35**	**LB45**	**LB55**	**LB65**	**LB75**
CEN Classes	LC12/ 13	LC20/ 22	LC25/ 28	LC30/ 33	LC35/ 38	LC45/ 50	LC55/ 60		
Char. Cyl. ($f_{ck,cyl}$)	12	20	25	30	35	45	55	65	75
Char. Cube. ($f_{ck,cube}$)1)	13	22	28	33	38	50	60	72	83

1)Other values may be used, provided that the relationship between these and the reference strength for cylinders are established and documented with sufficient accuracy for the current concrete mix.

The residual tensile strength is an important parameter when designing FRC structure. Comparing to the flexural tensile strength, fibers have apparently more influence on the residual (post-cracking) strength of concrete matrix. The reason is that the fiber reinforce mechanism is activated after flexural cracking. [25]

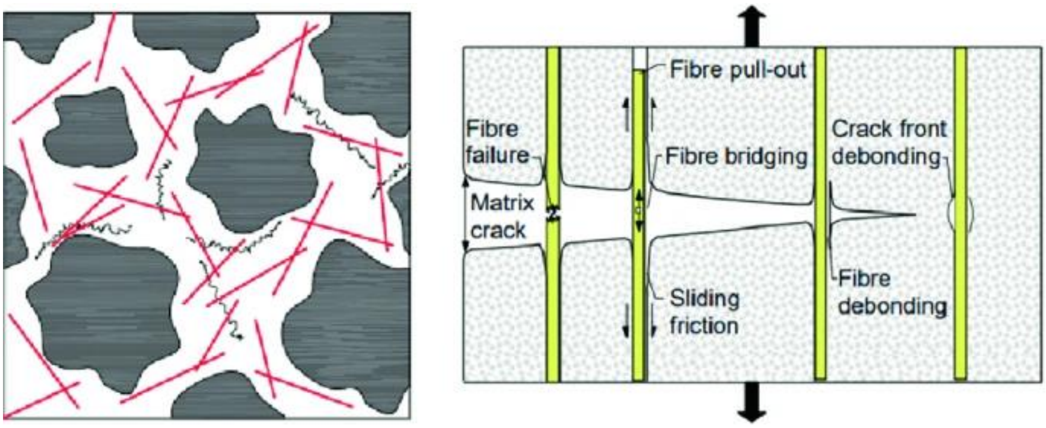


Figure 2. 6: Illustration of the fiber / matrix bridging mechanism.[31]

According to *fib* Mode Code 2010, FRC can be classified depending on its residual tensile strength which is determined from the bending tests according to EN 14651.

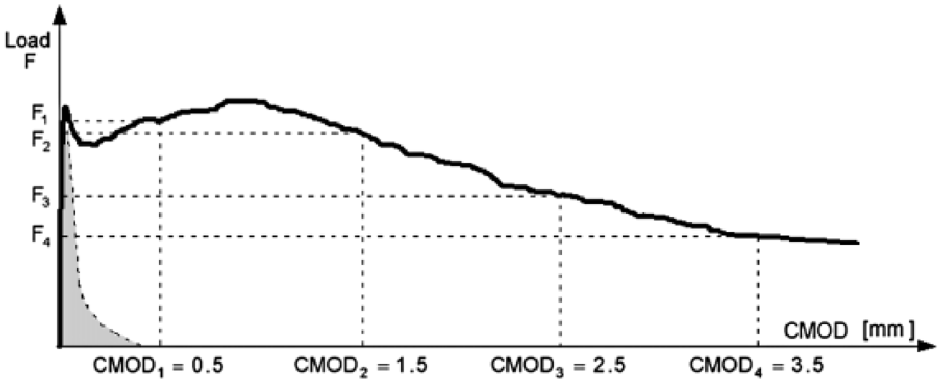


Figure 2. 7: Typical load F vs. CMOD curve for plain concrete and FRC in *fib* Mode Code 2010.

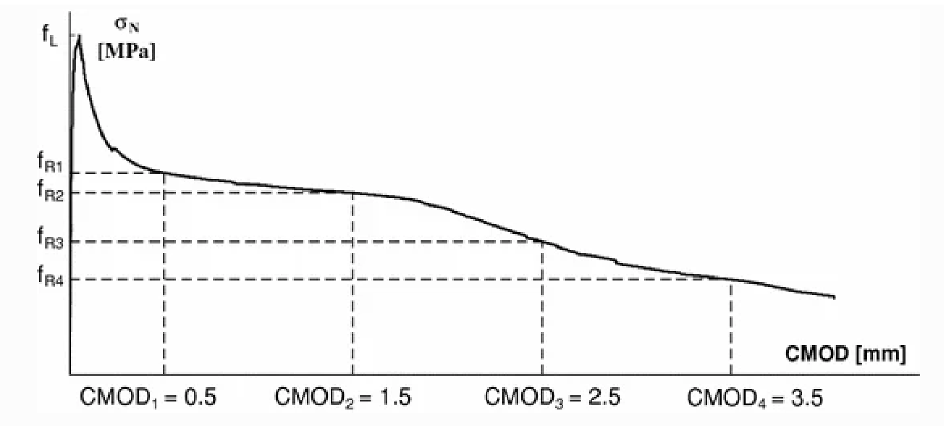


Figure 2. 8: Typical curve of the residual tensile strength vs. CMOD for plain concrete and FRC.[32]

Four residual strength values f_{R1}, f_{R2}, f_{R3}, f_{R4}, corresponding to CMOD at 0.5mm, 1.5mm, 2.5mm and 3.5mm respectively are required in the standard. Ref. Figure 2. 7, Figure 2. 8. Among them, f_{R1} and f_{R3} characterize the material behavior at the at the serviceability limit state (SLS, f_{R1k}), and at the ultimate limit state (ULS, f_{R3k}) respectively. And the classification for FRC can be determined by using the f_{R3k} / f_{R1k} ratio and the f_{R1k} class. [25]

Table 2. 7: FRC classification according to the material residual tensile strength.[25]

f_{R1k} class [MPa]:

1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0

f_{R3k} / f_{R1k} ratio:

a	$0.5 < f_{R3k} / f_{R1k} \leq 0.7$
b	$0.7 < f_{R3k} / f_{R1k} \leq 0.9$
c	$0.9 < f_{R3k} / f_{R1k} \leq 1.1$
d	$1.1 < f_{R3k} / f_{R1k} \leq 1.3$
e	$1.3 < f_{R3k} / f_{R1k}$

For example, if a material has f_{R1k} = 3.2 MPa and f_{R3k} = 2.9 MPa, then the material will be classified as "3c".

In "NB38 Fiberarmert betong i bærende konstruksjoner", published by Norsk Betongforening, f_{R1k} class is defined as the residual flexural tensile strength class of the reinforce concrete, and f_{R3k} / f_{R1k} ratio applied to describe the ductility class. The residual strength class is denoted as the following example.

R5.0c: Reinforced concrete with f_{R1k} class 5.0 and f_{R3k} / f_{R1k} ratio between 0.9 and 1.1.

Moreover, the FRC used in bearing structure should fulfill the minimum requirement to avoid the brittleness.

$f_{R3k} / f_{R1k} \geq 0.5$ in "NB38"
$f_{R3k} / f_{R1k} > 0.5$ in "*fib* Mode Code 2010"

Another way to classify the FRC is to divide it into different groups according to the percentage of fibers by volume. The method is simple, but quite useful since fiber dosage has a significant influence on the behavior of fresh and hardened concrete.

Table 2. 8: FRC classification according to the fiber amount used by volume per cent of matrix. [28]

Fiber amount by volume	FRC Class
0.1 – 1.0%	Low
1.0 – 3.0%	Moderate
3.0 – 12.0%	High

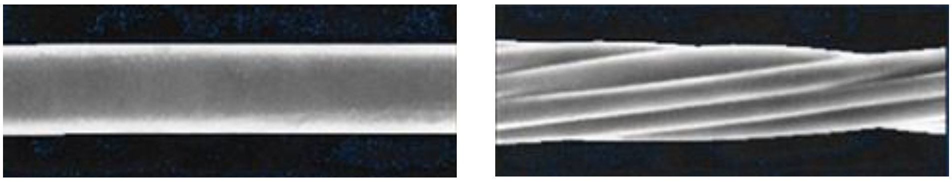
2.3 Fibers Used in FRC

2.3.1 Fiber Geometry

With the advancement of modern technology, various fibers are applied as strengthen material in concrete structures.

Figure 2. 9: A selection of reinforcing elements commercially available.[33]

Based on the fiber geometry, fibers can be firstly divided into three types on the cross-section area, prismatic, irregular and collated. Prismatic for fibers with round or polygon cross-section; irregular for fibers having various cross-section in the longitudinal direction; and collated for multifilament or monofilament fiber networks or bundles.[28]



Monofilament fiber Multifilament fiber

Figure 2. 10: Example for monofilament and multifilamentfiber.[34]

When referring to the size, fibers are classified into microfiber and macrofiber for fibers with diameter under 0.3mm (1/8 in.) and 0.3-6.5mm (1/8-2.5in.) respectively.[35] In addition, Fibers used in FRC may also have diverse shapes. Ref. Figure 2. 10.

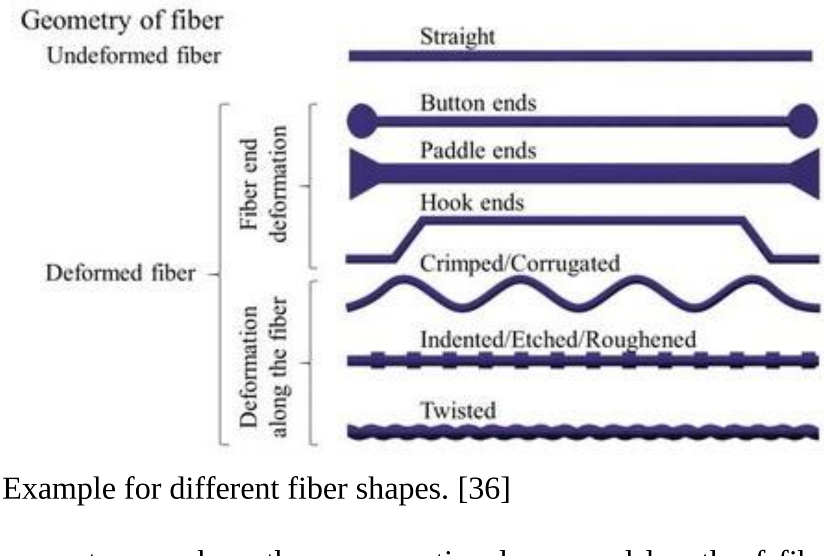


Figure 2. 11: Example for different fiber shapes. [36]

Geometrical parameters, such as the cross-sectional area and length of fiber, fiber specific surface, shape and volume fraction, are important to the mechanical properties of FRC because these parameters are greatly related to the effectiveness of fibers.

Ando et al. found that the fiber specific surface has a negative effect on the flow spread of fiber reinforced paste, and eventually causes the weaken the workability of fresh concrete. [37]

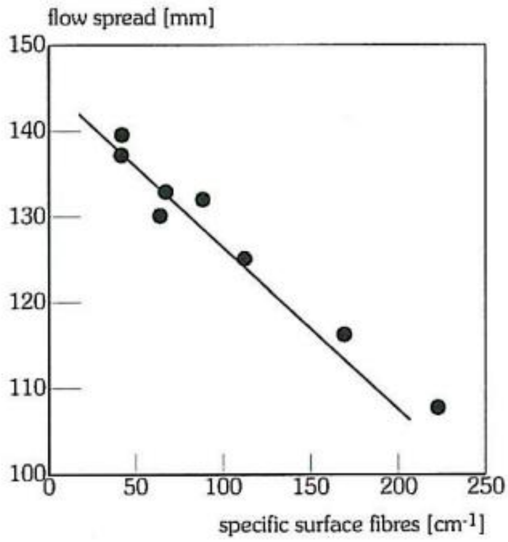


Figure 2. 12： Effect of the specific surface area of carbon fibers on the flow spread of fiber reinforced paste (Ando et al. 1990)

D. V. Soulioti et al. did an experiment on waved fibers and fibers with hooked ends. Three different fiber volume fractions of 0.5, 1 and 1.5% were used in concrete mixes. They found that the slump of fresh concrete reduced with the raising of fiber volume fraction. On the other hand, the peak strength and the residual strength are obviously improved when the fiber volume fraction grows. The results also shows that fibers with hooked ends have greater influence on FRC than wave fibers, which prove that the fiber shape does affect the mechanical properties of hardened concrete.[30] Komathi Murugan et al. achieved the similar results in their research. After investigating the flexural performance of two different hooked-end steel fiber reinforced concrete, steel fibers with one kink (3D) and two kinks (5D), they found that 5D fibers exhibit a superior performance than 3D fibers even with a slight reduction of dosage. [38]

2.3.2 Typical Reinforcing Fibers

Fibers are classified into four types based on the material by ACI Committee 544, steel, glass, synthetic and natural fiber. [35] It can also be divided simply into metallic and non-metallic fiber. Among the non-metallic fibers, glass fibers, aramid fibers and carbon fibers are most-used in the construction industry. [39], [40] Recently, basalt fiber and some newly developed types of fiber, such as PEN and PET are also available, and cause more and more attention worldwide.

Steel fiber

It is clarified by steel fibers ACI Committee 544 that steel fibers for FRC should be in short and discrete length so that fibers can be distributed in the concrete matrix randomly. [35] The commonly used steel fibers have diameters in between 0.3mm and 1.3mm and the length varies from 30 to 65mm. They can be used either as the auxiliary reinforcement or to partially/totally substitute the conventional reinforcement.

Different shapes of steel fibers have been designed to satisfy various requirements in construction.

Figure 2. 13: Steel fibers in different shapes. [16]

Each type has its own functional advantages. Basically, the popularity of steel fibers originated in its excellent performance in compensating the brittle behavior of concrete and improving its flexural strength under bearing situation, especially in statically indeterminate structures. However, steel fibers have relatively low resistance to chemical attack. [41] V. Marcos-Meson et al. did a review on the literature concerning the durability of the SFRC exposed to acid attack. It reveals that long-term and severe exposure to acid will cause larger deterioration of the residual strength of FRC compared to the other exposures.

Glass fiber

Glass fiber is quite popular in today's fiber reinforcement polymer composites market and has over 95% of the market share. [42] It is often used in sewer linings, headwalls, roof surfacing and other formworks. [43] The attraction of glass fiber firstly comes from its competitive price. Moreover, fibers have a significantly positive effect on controlling the shrinkage and enhancing the tensile strength of concrete. Research has revealed that the glass fiber reinforced polymer can achieve the same functional characteristics as steel fiber reinforced polymer, whilst the specific gravity of glass fiber was only a quarter of the steel fiber.[44] Syed Safdar Raza et al. made a comparative study on steel fiber, glass fiber and carbon fiber. As is written in the article, glass fiber reinforced concretes have higher corrosion resistance than steel fiber reinforced concrete.

Woven and random glass fiber mat

glass fibers in the bundle wound

integral glass fibers

Figure 2. 14: Example of different forms of glass fiber.

Glass fibers are produced into different forms. Practically, the strength of glass fibers varies greatly due to the method of pre-damage.[16] And the other physical or chemical properties also change depending on its processing and material composites. The picture below shows the major classification of glass fiber and its corresponding physical properties.

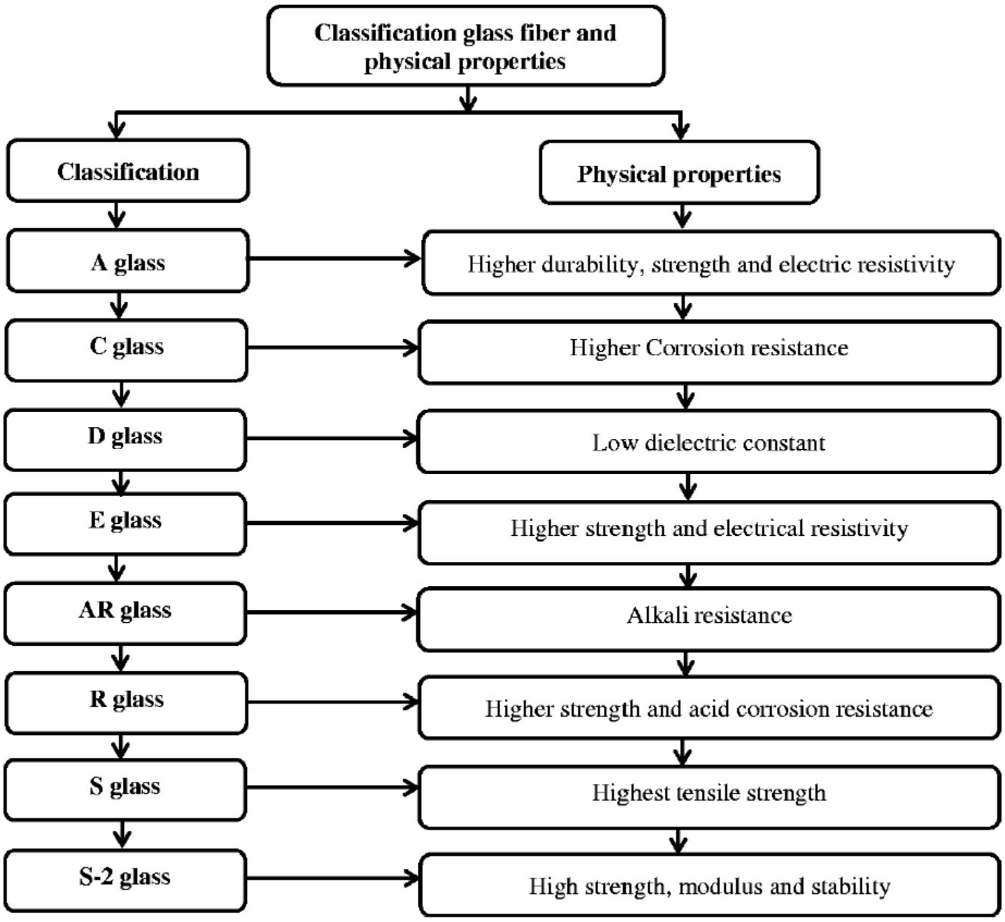


Figure 2. 15: Major classification of glass fiber and physical properties.[45]

Among the glass fibers listed in the graph, the usage of A glass and E glass are restricted since they are not compatible with the cement stone, which is strongly alkaline. These two types of glass fibers do not have the resistance to alkaline solutions. Therefore, the alkalinity of the cementitious binder will lead to a corrosion in the A-glass or E-glass FRC and cause embrittlement. [16]

Carbon fiber

The commercial use of carbon fiber can be traced back to the late 1950s. Theoretically, the tensile strength and the modulus of elasticity of carbon fiber could reach 15,000 ksi (approx. 103,421 MPa) and 145,000 ksi (approx. 1,000,000 MPa) respectively. Except the high strength, carbon fibers have superb resistance to high temperature, humidity, acid attack and so on. In addition, they are non-magnetic and have extremely low electrical conductivity. Benefitting from these material properties, carbon fiber reinforced concrete gains remarkable durability, even in severe natural environments. These advantages make carbon fiber attractive to the construction industry. It is now widely used as the strengthen reinforcement or to minimize deterioration of concrete structures, especially for the infrastructures and buildings which are exposed to hot and moist climate or under fatigue loading.[40] [46]

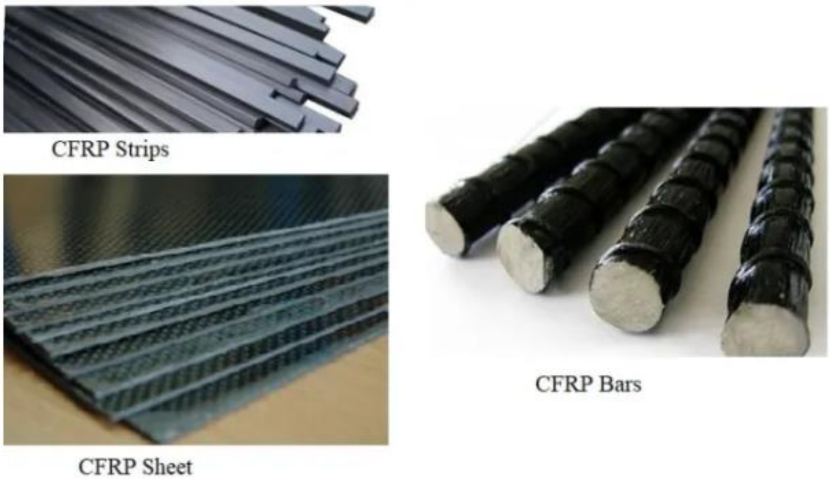
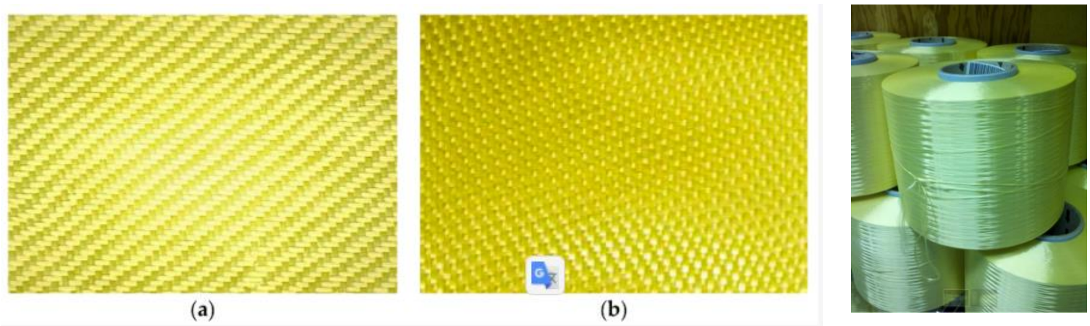


Figure 2. 16： Example of carbon fiber reinforcement products. [47]

Take the carbon fiber reinforced polymer (CFRP) strips as an example. The CFRP strips could be four times as strong as the similar products made of high-strength steel fiber, but 80% less in weight. [47]

Aramid fiber

Aramid fibers also appeared in the late 1950s. It is an organically synthesized high-tech fiber and mainly applied in aerospace and aircraft, marine and automobile, military products, and rope for offshore oil rigs.[40], [48], [49] Aramid fiber has quite high modulus and tenacity due to its chemical structure. Chen and Zhou explained the molecular structure and its mechanism in their research. They pointed out that it was the strong inter-chain bonding and high level of crystallization that led to the outstanding strength of the material. [50] Research shows that aramid fiber can have five times more strength than steel fiber. The tensile strength and shear strength of Kevlar aramid fiber is much greater than E-glass fiber, by 55% and 180% respectively.[51] Rajashekhar Siddappa Talikoti et al. found in their research that the aramid-fiber wrapping applied on the concrete structure can improve the compressive strength dramatically, by 140%. [49]



Aramid fiber reinforced polymer. (a) Front side; (b) Back side.[49] Kevlar Fiber Spool[52]

Figure 2. 17: Example of aramid fiber.

Basalt fiber

Recently, basalt fiber has attracted attention from both the industrial and academic world. It has excellent thermal properties, strength and durability. Since basalt fiber is originally made of basalt rocks, which is an inorganic, natural material, the basalt fiber is considered as the “twenty-first century nonpolluting green material”.[53]

Figure 2. 18: Basalt fiber Rebars and geo grids. [53]

Basalt fiber was first developed by the Moscow Research Institute of Glass and Plastic in the mid 1950s. However, basalt fiber caused little attention by the research institutes and the commercial market at that time. 30 years later, in 1985, the first industrial furnace was completed at the Ukraine fiber laboratory. [5] The new technologies of basalt fiber manufacturing have made the production cost equal or ever lower than the glass and carbon fibers. It is now commercially available and quite popular in the civil industry. The material composition and mechanical properties of basalt fiber will be discussed in detail in section 2.4.

2.3.3 Material Properties of Fibers

Many researchers have done the investigation on the material properties, including density, tensile strength, failure strain, etc. of the reinforcing fibers. Hwai Chung Wu et al. wrote a guide on structural design by using advanced fiber reinforce polymers (FRP). The book briefly covers the basic concepts of composite mechanics of the FRP. [40] Sruthi Jalasutram et al. did an experimental investigation on the basalt fiber reinforced concrete and listed the mechanical properties of some commonly used fibers in current structural applications in their report. Ref. Table 2. 9. Data in the table are adapted from Hwai-ChungWu et al. 2017, Sruthi Jalasutram et al. 2016 and Mehdi Derradji et al. 2018 [7], [40], [54]

Table 2. 9: Material properties of steel, glass, carbon, aramid and basalt fiber.

Fiber type	Fiber identification	Density (g/cm^3)	Young’s modulus (GPa)	Tensile strength (MPa)	Failure strain (%)
Steel	High-tensile	7.8	200	350-1,800	3.5
	Stainless	7.8	160	2,070	3
Glass	E-glass	2.58	72	3,445	4.8
	S-glass	2.48	87	4,309	5.0
	AR-glass	2.7	73	3,241	4.4
Carbon	T-300	1.76	231	3,654	1.4
	P-100	2.15	69	2,413	0.32
	AS-4	1.79	248	4,068	1.65
	IM-7	1.78	300	5,323	1.81

Aramid	Kevlar 49	1.46	131	3,620	2.8
	Technora	1.41	69	2,999	4.6
Basalt		2.63	89	2,999	3.2

2.4 Basalt Fiber Reinforced Concrete

2.4.1 Material Composition of Basalt Fiber

Basalt fiber is an inorganic fiber made from basalt rock, which can be found in volcanic rocks originating from frozen lava. SiO_2 content is far ahead of the other constituents in basalt rock. So, the basalt rock is classified according to its SiO_2 contents. Alkaline for basalt rocks with SiO_2 content lower than 42%, mildly acidic for those with SiO_2 contents between 43-46% and acidic for those with SiO_2 content above 46%. Among these three types, only the acidic basalt rocks satisfied the requirements of continuous fiber production. Table 2. 10 shows the main chemical constituents of basalt fiber. As the table reveals, SiO_2 and Fe_2O_3 together account for more than 50% of basalt fiber. Therefore, these two compounds are crucial to the fiber properties, such as density and thermal performance.

Table 2. 10: Main chemical constituents of basalt fiber. (Values are adapted from three research groups. 1. Jiri Militky et al. 2002; [55] 2. Tamas Deak et al. 2009;[56] 3. Hafsa Jamshaid et al. 2015[53])

Constituent	**Content [%]**		
	1	2	3
SiO_2	43.3-47	42.43-55.69	52.8
Al_2O_3	11-13	14.21-17.97	17.5
Fe_2O_3	<5	10.80-11.68	10.3
CaO	10-12	7.43-8.88	8.59
MgO	8-11	4.06-9.45	4.53
Na_2O	<5	2.38-3.79	3.34
TiO_2	<5	1.10-2.55	1.38
K_2O	<5	1.06-2.33	1.46

In brief, basalt fiber is produced directly from crush basalt stone which is widely available and usually has no impurities. No additives are required in production process. Thus, the production costs less, and makes the basalt fiber competitive in the commercial market. While its natural origin brings disadvantage to manufacture on large scale since it is hard to control the chemical composite of the raw material. The mechanical properties, such as density and fiber strength might be slightly uneven.

2.4.2 Material Properties of Basalt Fiber

Basalt fiber can be simply divided into two types: discrete fiber and continuous fiber. Short basalt fiber production is simply so that the price is low. But such fibers have relatively poor mechanical properties compared to the continuous ones. The object being discussed herein is the continuous basalt fiber. It is usually produced into filament forms and then it can be twisted into a yarn, plied into a multi strand roving, converted into woven or nonwoven textiles or cut into chopped fiber.[53] As mentioned before, the mechanical properties of the basalt fiber do not maintain the same since the chemical constituents may vary in the raw material. But there are still some positive features in general.

Basalt fiber has a density of 2.6 g/cm^3, which is closer to glass fiber and carbon fiber, but only one third of steel fiber. So, it can reduce the weight of the reinforced concrete significantly when being used as the substitution of the conventional reinforcement or the secondary reinforcement in the concrete structures. Meanwhile, the basalt fiber is very hard due to the hardness of basalt rock (5-9 on Mohr's scale). Even the propeller type abrader is not able to split the fiber after continuous abrasion continuous abrasion

Research has also proved some other advantages, such as excellent resistance to sound, heat and chemical attacks, and good electromagnetic properties. For example, the sound proofing for 400–1800 Hz can reach 80–95%. [53] Jongsung Sim et al. investigates the applicability of basalt fiber as a strengthening material for structural concrete members. They reported that basalt fiber has better thermal stability than glass and carbon fiber.

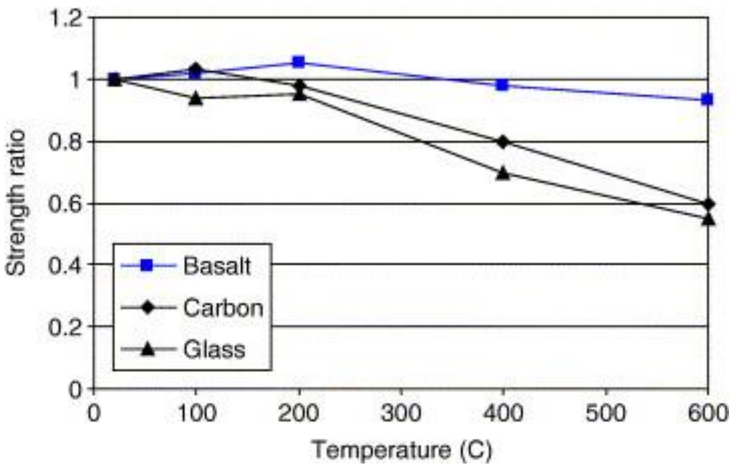


Figure 2. 19: Strength variation with respect to heat exposure.[57]

These fibers have similar behavior under 200°C. However, all three types obviously show a decreasing tendency when the temperature is over 200°C. The strength reduction is greater in the carbon and the glass fiber than that in the basalt fiber. The basalt fiber loses only about 10% strength up to 600°C, while the strength ratio of the carbon and the glass fiber drops more than 40-45%.

The resistance to the chemical attack (acid and alkaline) is determined by the change of strength after being exposed in aggressive media for some time. JongsungSim et al. observed the basalt fibers which were immersed in NaOH solution by SEM. Ref. Figure 2. 20 It is obvious that the fibers were eroded under the alkaline condition. The erosion started from the surface and finally caused the volume reduction. The non-alkali resistance glass fiber and the carbon fiber were also tested. Results show that the carbon fiber has the best alkali resistance. Ref. Figure 2. 21.

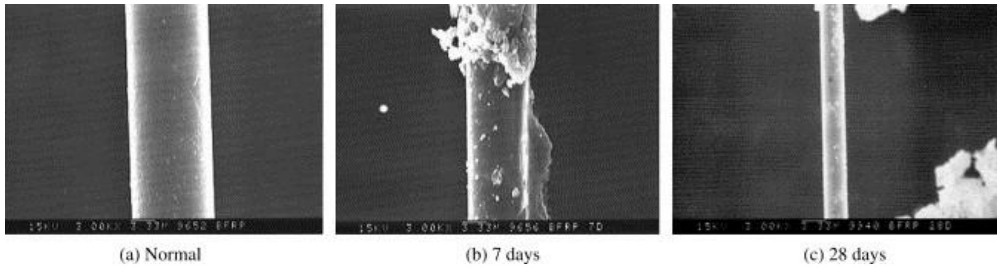


Figure 2. 20: Images of basalt fibers under NaOH solution.[57]

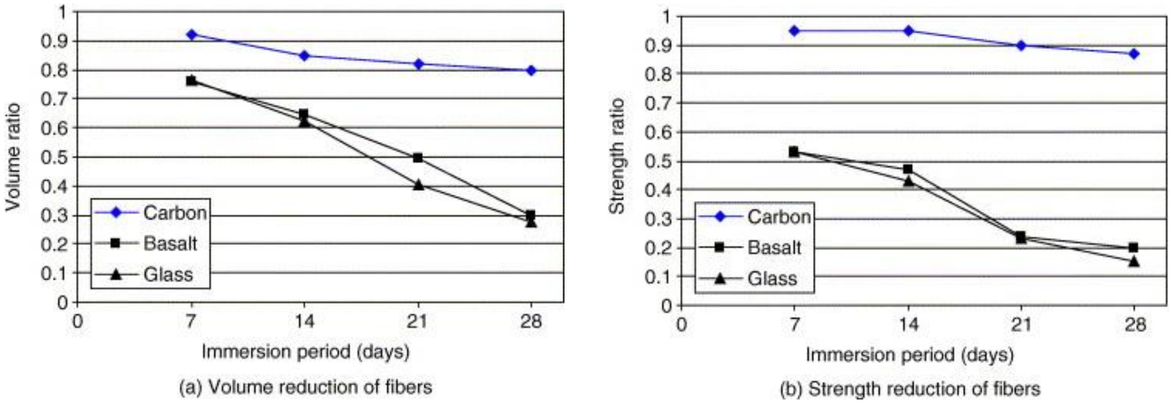


Figure 2. 21: Alkali resistance experiment results.

On the other hand, the acid resistance of basalt fiber is high. The fiber is hardly impacted by the acid solution after a short-time exposure. The long-time influence on the fiber strength is limited to 15-20%. [58]

Both basalt fiber and glass fiber have high content of SiO_2, and their production process are similar. Thus, comparative studies have been done on these two types of fibers. V.Lopresto et al. did some mechanical tests on basalt fiber and E-glass fiber to evaluate the possibility to replace E-glass fiber by basalt fiber. Ref. Figure 2. 22. Better flexural behavior as well as higher Young's modulus and compressive strength are found for basalt fiber, whereas its tensile strength is inferior to glass fiber.[59] Same results are reported by A. A. Dalinkevich et al. in their study on continuous basalt rovings.[58]

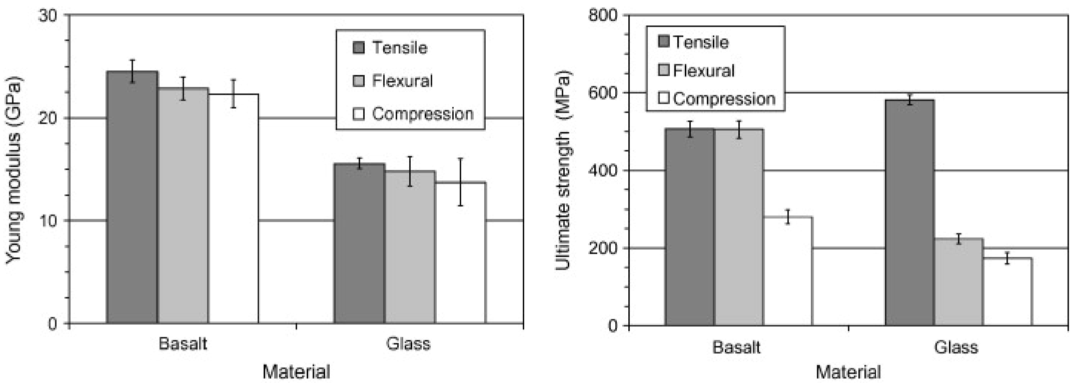


Figure 2. 22: Comparison of basalt fiber and E-glass fiber.

Same as glass fiber, the tensile strength of the basalt fiber is not only related to its chemical composites, but to the melt holding time above the crystallization temperature (1447°C) as well. [60] Figure 2. 23 reveals the relationship between tensile strength and melt holding time.

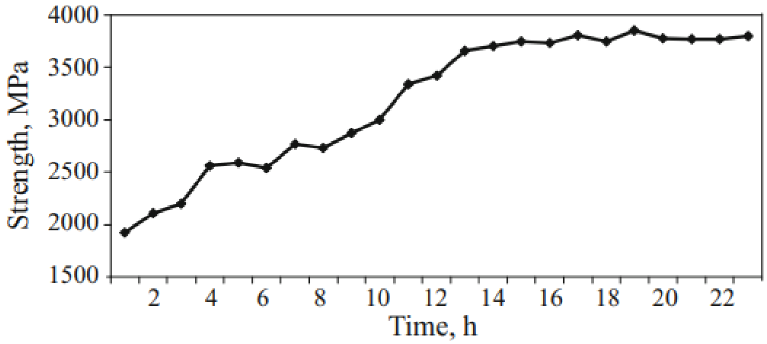


Figure 2. 23: Relationship between tensile strength and melt holding time at 1447°C.[60]

Researchers now focus on the influence of basalt fiber on reinforced concrete as well as the possibility of using basalt fiber as substitute for conventional reinforcement. Literature suggested that the benefit of basalt fiber in concrete under compressive load was not obvious, whereas the tensile strength and the post-cracking strength increased significantly. [8], [11] But the magnitude of the increase in tensile strength is hard to access due to different test methods.

2.4.3 MiniBars™

MiniBars™ is a kind of high-performance composite macrofibre made of BFRP. It is designed to provide high flexural tensile strength and post-cracking (residual) strength to the concrete. Meanwhile, it can improve the toughness and fatigue resistance, increase impact energy absorption capacity, and has a reputation for corrosion free and zero conductivity. ReforceTech AS has upgraded the form of MiniBars™ several times since it was developed. The most remarkable change from Gen 1.0 to Gen 3.1 is the reduction of diameter, by 1.5mm. Ref. Table 2. 11. Gen3.1 MiniBars™ has obtained a better balance between the tensile strength and the pull-out strength from the improvement. [61]

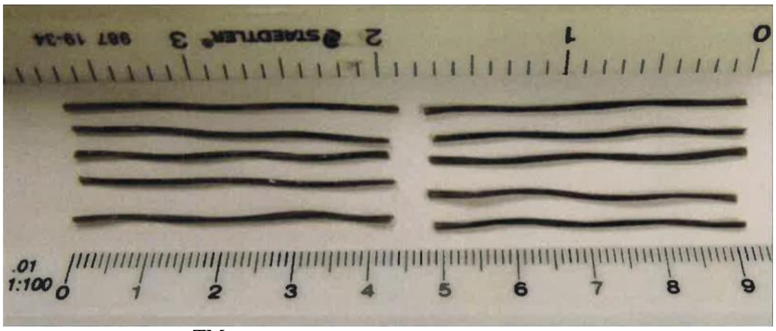


Figure 2. 24: Gen 3.1 MiniBars™ [61]

Table 2. 11: Material properties of MiniBars™ Gen 1, Gen 2 and Gen 3. (Data is collected from the product datasheet from ReforceTech.[10], [62])

MiniBars™ properties	Gen 1.0	Gen 2.0	Gen 3.1
Diameter [mm]	2.1	1.1	0.65
Length [mm]	-	-	43 +/- 2
Specific Gravity [g/cm^3]	1.9	1.9	2 +/- 0.1
E modulus [GPa]	45	60	42

Tensile Strength [MPa]	1000	1100	> 1000
Alkaline Resistance	Excellent	Excellent	Excellent

Basalt MiniBars™ is a kind of multifilament fiber which consists of 1200 fibers gluing together. The specific gravity of MiniBars™ is 1.9-2.1 g/cm^3, which is like concrete. This means the MiniBars™ has relatively high workability when mixed with wet concrete, and the MiniBars™ fiber is easier to distribute evenly after hardening. Patnaik Anil et al. reported that MiniBars™ dosage up to 4% by volume is feasible in concrete mixing process.

There is merely limited research on basalt MiniBars™ reinforced concrete. John Branston et al. tried to evaluate the effect of bundle dispersion basalt fiber and basalt MiniBars™ in the mechanical behavior of concrete. Test results showed that only the MiniBars™ enhances the post-cracking strength of concrete, and such effect is positively proportional to the fiber dosage. [11] According to the report from ReforceTech AS, MiniBars™ has been used in several countries, including Norway, Sweden, UK, USA and Canada. It is mainly applied in wall panels, marine structures, roads, raft foundations, etc. Examples for the application of MiniBars™ are listed in figure 2.21.

Pontoon in Norderney, Germany. It is corrosion free and 40% lighter than conventional reinforced concrete.

Precast Insulated wall panels of Kilenkrysset in Sweden. Both the weight and the thickness are reduced by 50%.[63]

Road in Gothenburg, Sweden. MRC is used as the 20cm top layer of road surface at tram switching and signaling intersections.

Watertight raft of the student center in Porsgrunn, Norway. 32cm steel reinforced slab with MiniBars™ to ensure crack control eliminating nets.

Figure 2. 25: Examples for the application of MiniBars™

3. Experiment Program

3.1 Materials

The concrete mix used in this study consisted of:

a) Low heat cement (Lavvarmesement CEM III/B 42,5 L-LH/SR (na)) provided by SCHWENK Norge AS. The characteristic properties of cement are given in Table 3. 1.

Table 3. 1: Chemical properties of low heat cement. (Data is collected from the technical datasheet of the low heat cement.)

Chemical properties:		Content by weight [%]
CaO		49
SiO_2		31
Al_2O_3		8.3
MgO		6.1
SO_3		2.1
Fe_2O_3		1.6
K_2O		0.6
Na_2O		0.3
Na_2Oekv		0.79
C_3A		5.3
loss on ignition (L.O.I)		0.7
Insoluble residue (i.r)		0.2
Cl^-		0.05
$Cr^{(VI)}$		< 2 mg/kg
Physical properties:		
Fineness		4700 cm^2/g
Density		2.98 g/cm^3
Bulk density		1,1g/cm^3
Proportion of slag		Approx. 70%
Binding time		230 min.
Expansion		0.3 mm
Compressive strength	7 days	36MPa
	28 days	58MPa

b) Norstone Årdal aggregates are used in the experiment. Fine aggregates with size 0-8mm in diameter and coarse aggregates with size 8-16mm in diameter.

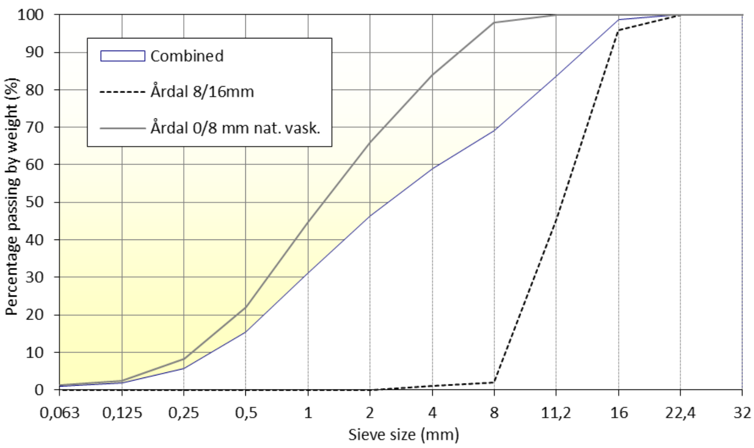


Figure 3. 1: Grading curve for concrete aggregates.

c) Superplasticizers, Mapei Dynamon SX-N. The
d) MiniBars™ produced by ReforceTech AS. These fibers were formed from crushed basalt rock, and each has 1200 fibers glutting together. Specific gravity, length and diameter reported from the producer are 2.1g/cm^3, 4.1-4.5mm and 0.65mm respectively. The mixing content of MiniBars™ was designed as 0%, 0.5% and 1%. Mechanical properties are listed in section 3.4 in this thesis.
e) Water.

3.2 Mix Proportions

In this study, three batches of concrete mix are prepared for the experiment. The percentages of MiniBars™ are 0%, 0.5% and 1.0% by volume. The water/cement ratio used is 0.39. The quantity of superplasticizers consumed for each batch is measured in site on the testing day. Plain concrete is used to determine the compressive strength and the flexural tensile strength after 7 days and 28 days respectively. Concrete with fiber content at 0.5% and 1% are used for compressive test, bending test and residual tensile strength test. Table 3. 2 summarizes the mix proportions used for each batch. Table 3. 3 details the size of specimens.

Table 3. 2: Summary of concrete mix proportions.

Mix type	Fiber content [%]	Cement [kg]	Water [kg]	Aggregate 0-8mm [kg]	Aggregate 8-16mm [kg]	Admixture [cm^3]	MiniBars™ [kg]
B1	0%	108.716	42.303	98.256	41.777	157	0
B2	0.5%	108.733	42.314	96.963	41.227	235	1.418
B3	1.0%	108.749	42.325	95.670	40.677	241	2.835

Table 3. 3: Summary of specimen sizes.

<table>
<tr><th>Fiber content [%]</th><th>Specimen</th><th>Size:
height x width x Length</th><th>Use</th></tr>
<tr><td rowspan="9">0%</td><td>B1-C1</td><td rowspan="6">100mm x 100mm x 100mm</td><td rowspan="3">28 days compressive strength</td></tr>
<tr><td>B1-C2</td></tr>
<tr><td>B1-C3</td></tr>
<tr><td>B1-C4</td><td rowspan="3">7 days compressive strength</td></tr>
<tr><td>B1-C5</td></tr>
<tr><td>B1-C6</td></tr>
<tr><td>B1-T1</td><td rowspan="3">100mm x 100mm x 500mm</td><td rowspan="3">28 days flexural tensile strength</td></tr>
<tr><td>B1-T2</td></tr>
<tr><td>B1-T3</td></tr>
<tr><td rowspan="8">0.5%</td><td>B2-C1</td><td rowspan="6">100mm x 100mm x 100mm</td><td rowspan="3">28 days compressive strength</td></tr>
<tr><td>B2-C2</td></tr>
<tr><td>B2-C3</td></tr>
<tr><td>B2-C4</td><td rowspan="3">7 days compressive strength</td></tr>
<tr><td>B2-C5</td></tr>
<tr><td>B2-C6</td></tr>
<tr><td>B2-T1</td><td rowspan="2">100mm x 100mm x 500mm</td><td rowspan="2">28 days flexural tensile strength</td></tr>
<tr><td>B2-T2</td></tr>
</table>

	B2-T3		
	B2-R1	150mm x 150mm x 550mm	28 days Residual tensile strength
	B2-R2		
	B2-R3		
1.0%	B3-C1	100mm x 100mm x 100mm	28 days compressive strength
	B3-C2		
	B3-C3		
	B3-C4		7 days compressive strength
	B3-C5		
	B3-C6		
	B3-T1	100mm x 100mm x 500mm	28 days flexural tensile strength
	B3-T2		
	B3-T3		
	B3-R1	150mm x 150mm x 550mm	28 days Residual tensile strength
	B3-R2		
	B3-R3		

3.3 Mixing and Curing Methods

Mixing

Concrete mixing is done in a 100L capacity concrete mixer in the laboratory. Ref. Figure 3. 2. Test mixing is done in a small concrete mixer a few weeks before the formal mixing to determine the highest fiber dosage used in the experiment. All the materials needed are measured and put separately into buckets with clear labels on top in advance. The test mixing and formal mixing follow the same procedure. The steps used for mixing plain concrete and MiniBars^{TM} reinforced concrete are as follows:

1) The coarse aggregates, fine aggregates and the cement are added into the mixer, followed by dry mix for one minute.
2) Add water into the concrete mixer and continue mixing for about 2 minutes. Superplasticizer is added in this step. Stop the mixer until these materials are properly mixed.
3) For batches have fiber dosages rate at 0.5% and 1%, fibers are pulled into the mixer after step 2). Balling of the fibers happens during the mixing in this stage, especially in the concrete mix containing the higher fiber dosage. Thus, more superplasticizer is added during mixing to increase the flowability of the concrete mixture. Briefly halt the machine to check if the fibers disperse in all directions.
4) Stop mixing after fibers are spread evenly.

Figure 3. 2: Concrete mixer used during the experiment.

Casting

The concrete mix is then cast into the molds carefully. Sizes and number of molds used are listed in Figure 3. 2**Figure 3. 2** Use a small hammer and knock on the side of molds to remove the air trapped in the concrete mixture. For plain concrete, compacting is conducted by rod. Cover the fresh concrete with a large plastic film to avoid drying and shrinkage.

Removing the molds

Molds are removed two days after casting. The reason for this is that the low heat cement needs more time for hardening than type I and II Portland cement,

Curing

After removing the molds, all the specimens are kept in water and left in the laboratory under room temperature at about 20°C. A plastic film is used to cover water container, so that water evaporation is eliminated, and all the specimens stay in the water until the testing day.

3.4 Test Methods

The tsest process follows the standards listed in the Table 3. 4.

Table 3. 4: Standards for tests

Tests	**Standards**
Density	NS-EN 12390-7: 2019: Testing hardened concrete - Part 7: Density of hardened concrete
Compressive strength	NS-EN 12390-3: 2019 Testing hardened concrete - Part 3: Compressive strength of test specimens
Flexural Tensile strength	NS-EN 12390-5:2019 Testing hardened concrete - Part 5: Flexural strength of test specimens
Residual strength	NS-EN 14651:2005+A1:2007 Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

3.4.1 Density

The density of concrete cube is measured two times respectively at the 7^{th} day and the 28^{th} day. The process of measuring follows the European Standard NS-EN 12390-7: 2019.

Although the molds for cubes have fixed size, which is $10cm^3$ (100mm x 100mm x 100mm), the volume of each cube is slightly different in practice. Thus, it is necessary to measure the volume and the weight of the cubes to find out the precise density of each specimen. According to the standard, formula for density is:[64]

$$D = \frac{m}{V}$$

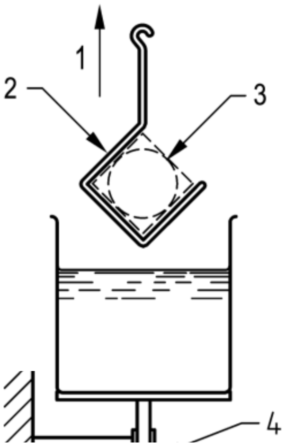
Where,

D is the density in kg/m^3;

m is the mass in kg;

V is the volume i m^3.

The concrete cubes are taken out of the water container and wiped dry just before the test. Figure 3. 3 illustrate the method for measuring the volume of the concrete cubes. A scale is used to measure the weight increase of water. The value is then considered as the volume of the cube since water has density of 1 g/cm^3. The bucket and the scale are also used for obtaining the weight of the concrete cubes. Cubes are put on the bucket instead of being put on the scale directly in order to achieve more accurate values. Null set is done before every measurement.



2) hanger
3) concrete cube
4) scale with a bucket of water on it

Figure 3. 3: Equipment for measuring the volume of concrete cubes. [64]

3.4.2 Compression Test

The compressive strength of hardened concrete is tested according to the European Standard 12390-3: 2019 at 7 and 28 days respectively. It is done after density measurement. Tests are carried out on 3 cubes of each type of mix. Ref. Figure 3. 4. The size of the cubes is 100mm x 100mm x 100mm. Machine for compression testing is prepared as NS-EN 12390-4: 2020 required.[65] During the compressive test a load with constant increasing rate is added after the initial load. The load and stress are monitored and recorded during the test process.

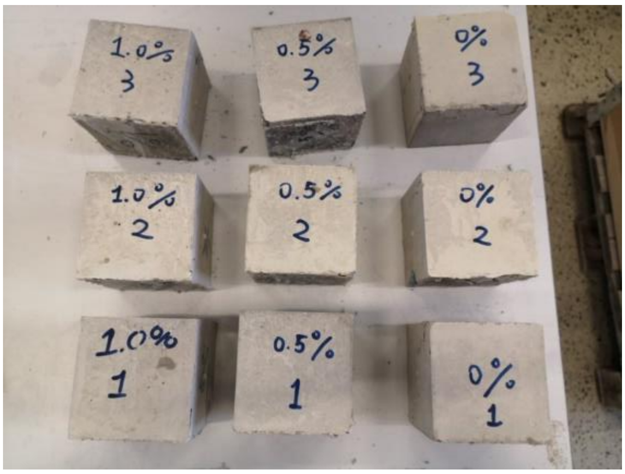


Figure 3. 4: Concrete cubes for compressive test at 7 days.

Apply the load until no greater load can be sustained by the concrete cube. All the failures as shown in Figure 3. 5 is acceptable. And the compressive strength is then given by the expression below:

$$f_c = \frac{F}{A_c}$$

where,

f_c is the compressive strength in MPa;

F is the maximum load at failure in N;

A_c is the cross-sectional area of the specimen on which the compressive force acted.

According to the NS-EN 12390-3: 2019, the results shall be expressed to the nearest 0.1 MPa.[66]

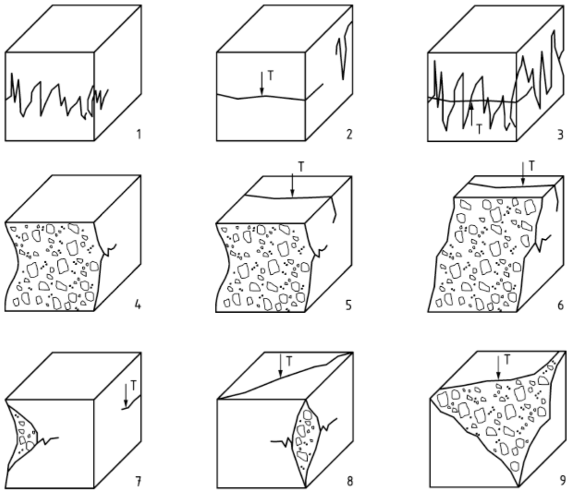
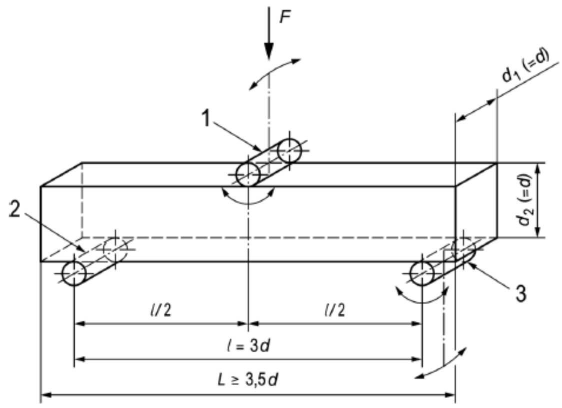


Figure 3. 5: Satisfactory failures of cube specimens according to NS-EN 12390-3: 2019.[66]

3.4.3 Flexural Tensile Strength Test

The flexural tensile strength of the MRC in this these is obtained by 3-point bending test. The test method follows the guidance of the European Standard NS-EN 12390-5:2019. Tests are conducted on three beams which have size 100mm x 100mm x 500mm for each fiber dosage at 28 days. The beam is supported by two steel rolls underneath. And one steel roll for executing the load is in the center of the upside of the beam. Location of the beam and steel rolls is shown in **Figure 3. 6**. After the application of an initial load, a gradually increasing load is applied until the failure happens. The growing rate of the load shall be constant and between 0,04 MPa/s and 0,06 MPa/s.



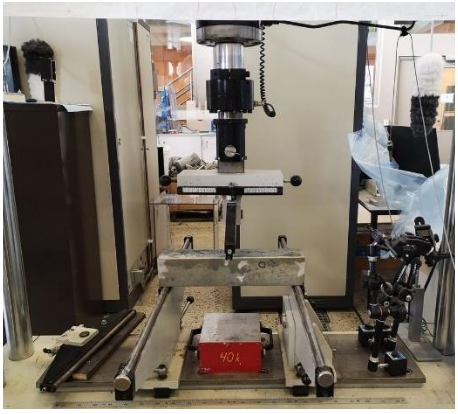


Figure 3. 6: Illustration for locating the beam on test machine.[67]

The strength of the test specimens by 3-point bending test in given by the formula according to NS-EN 12390-5:2019:

$$f_{ct,fl} = \frac{3 \times F \times l}{2 \times d_1 \times d_2^2}$$

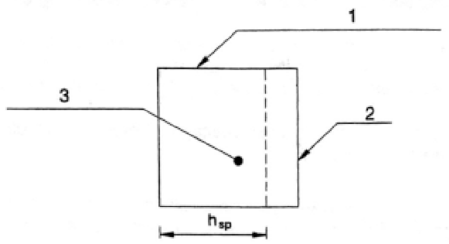
where,

$f_{ct,fl}$ is the flexural tensile strength of the specimen by bending test, in MPa;
F is maximum load, in N;
d_1 and d_2 is the dimension of the cross-sectional area, in mm;
l is the distance between the two rolls under the beam, in mm.
Test results shall be expressed to the nearest 0.1 MPa as the standard requires. [67]

3.4.4 Residual Tensile Strength Test

When referring to the residual tensile strength test, the European Standard NS-EN 14651:2005+A1:2007 for the steel fiber reinforced concrete is followed. The reason is that no special standard for basalt fiber reinforced concrete has been published until now. Size of the beams is 150mm x 150mm x 550mm. Three of each type of MRC beams with fiber volume fraction at 0.5% and 1% respectively are used for the residual tensile strength test at 29 days. The test is postponed for one day due to the time limitation.

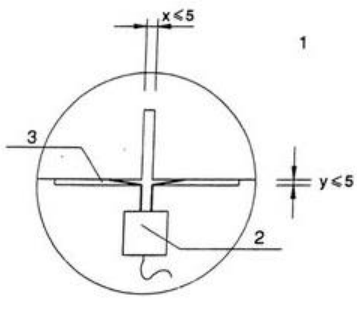
The specimens are notched four days before the test. The notch is 5mm in width and 25±1mm in depth, which means the distance h_{sp} is 125±1mm. Figure 3. 7 is the side view of the specimen after notching, h_{sp} is defined clearly by the picture. After notching, two small steel knife blades are stuck on both edges of the notch. Ref. Figure 3. 8. Wet tissues and a plastic cover are used to wrap the specimens clearly afterwards to provide a humid curing environment, while avoiding the water into the notch.



1) Top surface during casting
2) Notch
3) Cross-section of test specimen

Side view of the beam.

Figure 3. 7: Position of the notch.[68]



2) Transducer (clip gaupe)
3) Knife blades on both edges of the notch

Top view of the beam.

Figure 3. 8: Details of the notch.[68]

The residual tensile strength of the MRC is found out by 3-point bending test. Ref. Figure 3. 6. Location of the beam in the machine is illustrated by Figure 3. 9. Two transducers are used during the test. The clip gaupe is inserted in between the edges of the notch to measure the crack mouth opening displacement (CMOD) as shown in Figure 3. 9 and Figure 3. 10. The linear variable differential transformer is placed underneath the beam beside the notch for deflection. Ref. Figure 3. 10.

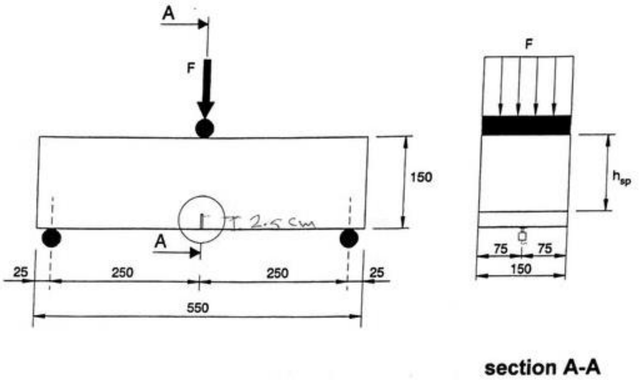


Figure 3. 9: Location of the beam.[68]

Figure 3. 10: Detail of locating the transducer.

The application of the load follows NS-EN 14651:2005+A1:2007. It can be distinguished by two stages in terms of CMOD increasing rate.

- CMOD < 0.1mm 0.05mm/min
- CMOD ⩾ 0.1mm 0.2mm/min

The loads and corresponding values of CMOD are monitored and recorded as NS-EN 14651 required. The machine is stopped when the CMOD exceeds 6mm. And the residual tensile strength is then calculated by using the equation below:

$$f_{R,j} = \frac{3F_j l}{2bh_{sp}^2}$$

Where,

$f_{R,j}$ residual flexural tensile strength corresponding with CMOD[1)] = $CMOD_j$
F_j the load corresponding with CMOD = $CMOD_j$
l the span length
b the width of the specimen
h_{sp} the distance between the tip of the notch and the top of the specimen

1) CMOD: crack mouth opening displacement.

The Limit of proportionality (LOP) and the f_{R1}, f_{R2}, f_{R3}, f_{R4}, corresponding to CMOD at 0.5mm, 1.5mm, 2.5mm and 3.5mm respectively should be found out. Basically, LOP can be obtained by using the same equation for f_{R1}, f_{R2}, f_{R3}, f_{R4}. In NS-EN 14654-1, it is denoted by the symbol $f_{cl,L}^{f}$, and the expression for is LOP is :

$$f_{cl,L}^{f} = \frac{3F_L l}{2bh_{sp}^2}$$

Where the F_L is defined as the greatest load acted on the beam within the range of CMOD from 0 to 0.05mm. $f_{cl,L}^{f}$ is simplified to f_l in this thesis.

4. Results and Discussion

The main parameters in this these are compressive strength, flexural tensile strength and residual tensile strength of the MRC. Test results will be presented in the following section. Code of the specimen and its corresponding MiniBars™ fiber dosage and size refer to Table 3. 2 and Table 3. 3.

4.1 Density

Table 4. 1 summarizes the average density of MRC cubes with different volume fraction of MiniBars™. Every average value comes from three measurements. The three batches of MRC have nearly the same average density, which means that the fibers added do not change the density. One reason for this is the similar density of these two materials. As mentioned in section 2.4.3, the specific gravity of MiniBars™ is in the range of 1.9-2.1g/cm^3 which is slightly lower than that of plain concrete. However, the MiniBars™ fibers do not disperse evenly in the concrete mix, it is hard to conclude the relationship between fiber dosage and density when only a small fraction of fiber is added.

Table 4. 1: Density

Fiber dosage (%)	Density [g/cm^3]	
	7 days	28 days
0%	2.23	2.24
0.5%	2.22	2.23
1%	2.24	2.23

4.2 Compressive Strength

Table 4. 2 exhibits the compressive strength of the specimens tested on 7 days and 28 days respectively. The coefficient of variation (CV) for the compressive strength of concrete specimens is less than 4%, indicating that the data is reliable. The concrete specimens can be categorized to B55 according to NS-EN 1992-1-1. The results revealed that the addition of MiniBars™ at a low dosage has limited influence on the hardened concrete. concrete

The concrete usually achieves its designed strength after 28 days of curing. Thus, the compressive strength of the concrete at 28 days is significantly higher than that at 7 days, increased by over 40%. A more direct view is given in Figure 4. 1. The figure shows the difference of mean compressive strength between concrete cubes at 7 days and 28 days. The greatest change was among the plain concrete cubes, where mean value for compressive strength increased by 47%. The compressive strength of concrete mix with 0.5% and 1% MiniBars™ changed relatively less, both increased by 42%.

According to the test results, it is not easy to distinguish the relationship between volume fraction of MiniBars™ and compressive strength of hardened concrete. The tendency is unclear for concrete at these two stages. For cube after curing for 7 days, the mean compressive strength fluctuated with the addition of MiniBars™. The value increased from 50.58MPa to 52.31Mpa (by 3.4%) by adding 0.5% of MiniBars™ and decreased to 49.45MPa (by 2.2%) when another 0.5% of fiber were added to the concrete. When referring to the concrete cube after curing for 28 days, a growth of MiniBars™ dosage weakened the compressive strength. Values listed in Table 4. 2 shows one common point of concrete cubes at the two curing stages. The specimens which had the highest measured compressive strength were plain concrete, while the lowest ones were concrete with 1% of MiniBars™.

Compared with the increasing volume of fiber addition, other factors such as mix proportion, material used, have a greater influence on the compressive strength of hardened concrete. Anil Patnaik et al. did the compressive test on 4-inch (101mm) diameter x 8-inch (202mm) long cylinders and got 63.7 MPa for the concrete mix with 0.5% of MiniBars™. The water cement ratio was also 0.4 in their test, but the cement type and proportion of fine and coarse aggregates are differet with tests done for this thesis. [61] JohnBranston et al. did the same test on 100mm diameter x 200mm long concrete cylinders. The compressive strength reported by them was only 20.90 MPa for the concrete mix had MiniBars™ dosage of 1%. Type GUL Portland cement was used in their test. Water cement ratio is 0.5, and the proportions of cement, fine aggregate, and coarse aggregate is 1:1.4:2.8 by mass.[11]

Table 4. 2: Compressive strength

Fiber dosage	Compressive strength [MPa]					
	7 days			28 days		
	Measured	Mean	CV (%)	Measured	Mean	CV (%)
0%	49.31 52.76 49.68	50.58	3.1	71.29 75.51 76.86	74.55	3.2
0.5%	52.26 52.70 51.98	52.31	0.6	72.99 73.87 76.55	74.47	2.0
1%	49.61 49.45 49.28	49.45	0.3	69.42 71.63 69.99	70.35	1.3

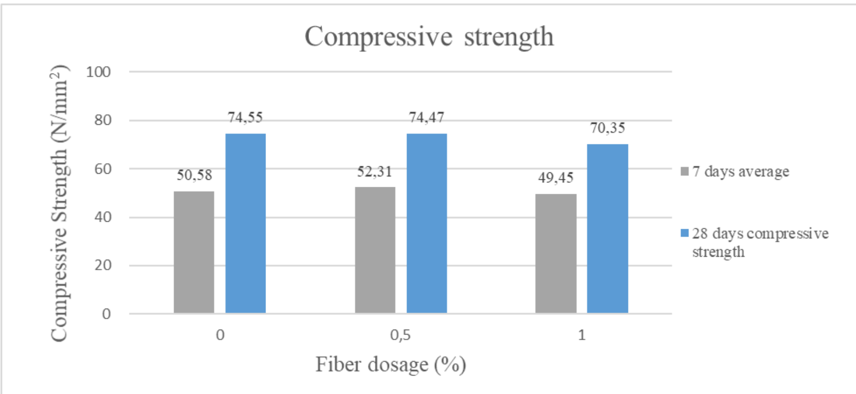


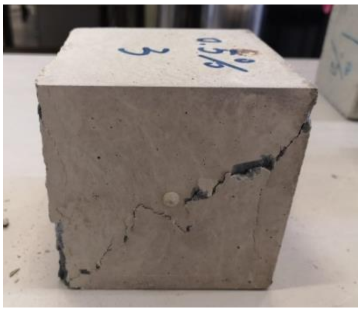
Figure 4. 1: Comparison of the mean values for the compressive strength.

Figure **4. 2** reveals the typical failures of cubes with different MiniBars™ dosage after the compression test. Compared to the satisfactory failures in NS-EN 12390-3: 2019, ref. Figure

3. 5, failures happened to the test cubes met the requirement of the European standard. Although the effect of MiniBars™ addition on the compressive strength of concrete is not obvious, the fiber can control the failure under compressive load. More serious spalling is observed in the plain concrete than in the FRC. In addition, there are also more vertical and diagonal cracks formed on the surface of the plain concrete specimens after the fracture. The FRC remained a much better appearance. Cracks were extremely narrow on the surface of cubes with 1% MiniBars™. It is maybe because the MiniBars™ added has a bridging effect on concrete. The resistance of pulling out from the fiber in concrete mix restricted the expansion under compression, thus spalling and cracks got controlled. But the distribution of fiber in concrete mix was not completely uniform, the extent of spalling and cracks width were different even in the same cube.

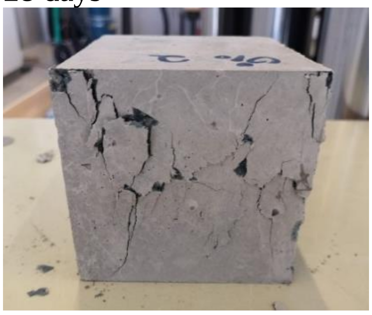
7 days


Fiber dosage 0%


Fiber dosage 0.5%


Fiber dosage 1.0%

28 days


Fiber dosage 0%


Fiber dosage 0.5%


Fiber dosage 1.0%

Figure 4. 2: Failures of concrete cubes under compressive load.

4.3 Flexural Tensile Strength

Like the compressive strength, the flexural tensile strength of hardened concrete is not proportionate to the MiniBars™ dosage. The discussion below is based on the results obtained from the 3-point bending test carried out on 28 days.

Table 4. 3 summarizes the measured and mean values of the highest flexural tensile strength of the specimens. According to the table, the mean value went down by 7% when the fiber dosage increased from 0% to 0.5%. The reason for the reduction may be the deterioration of the cementitious binding due to the adding of fibers. This impact played a more dominant role than the bridging action of MiniBars™ in the tension area. However, the further increase of fiber dosage enhanced the flexural tensile strength. For the beams with 1% MiniBars™ content, the mean value for flexural tensile strength was raised to 9.81MPa, which is 28% higher than beams with 0.5% MiniBars™ content and 20% higher than the plain concrete. The highest flexural tensile strength of beam specimen measured was 10.58MPa during the test, which nearly

doubled the lowest value (6.13MPa). Figure 4. 3 gives a clear view of the relationship between the flexural tensile strength and the addition of fiber.

Table 4. 3: Flexural tensile strength

Fiber dosage	Specimen	Flexural tensile strength [MPa]	
		Measured	Mean
0%	B1-T1	6.13	8.20
	B1-T2	9.21	
	B1-T3	9.26	
0.5%	B2-T1	7.42	7.62
	B2-T2	8.83	
	B2-T3	6.62	
1.0%	B3-T1	8.91	9.81
	B3-T2	10.58	
	B3-T3	9.94	

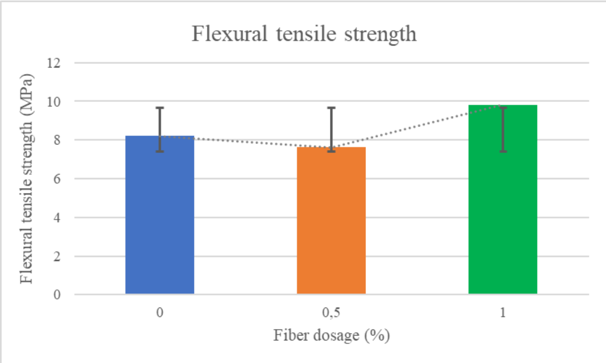


Figure 4. 3: Mean values for the flexural tensile strength of the concrete with different fiber dosage by volume.

Figure 4. 4 exhibits the behavior of the beam specimens during the 3-point bending test. The flexural tensile strength was calculated by using the equation in NS-EN 12390-5:2019. Although the trend of the ultimate flexural tensile strength with fiber dosage is indeterminate, the MiniBars^{TM} added in concrete effectively improve the behavior of the beams during the bending test. Ref. Figure 4. 5.

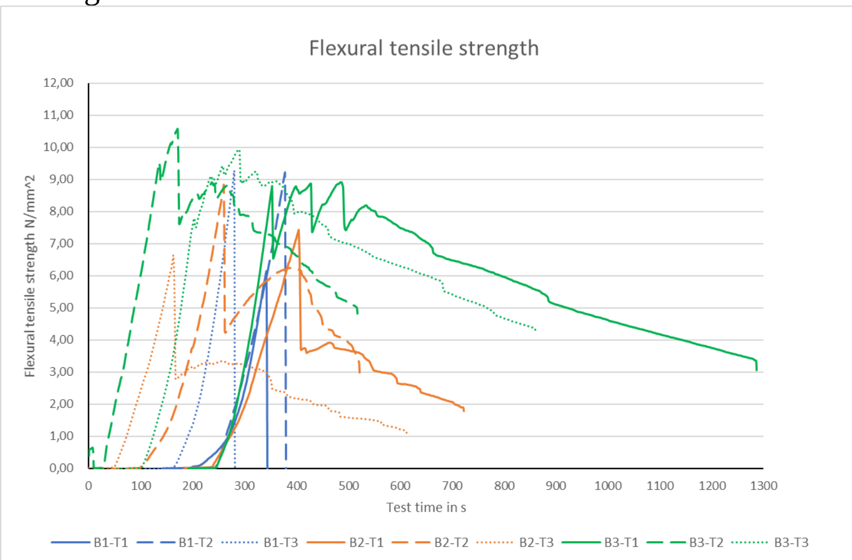
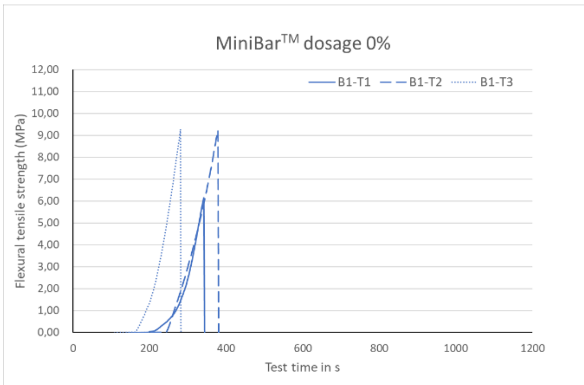
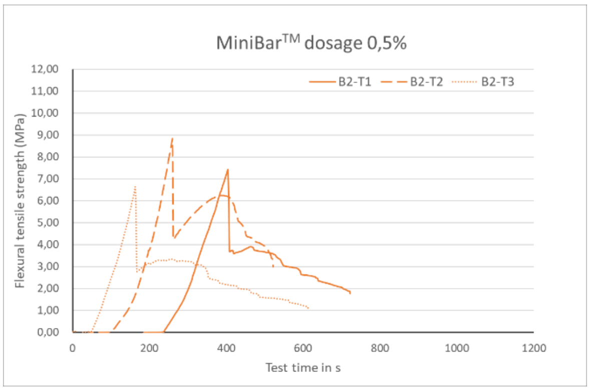


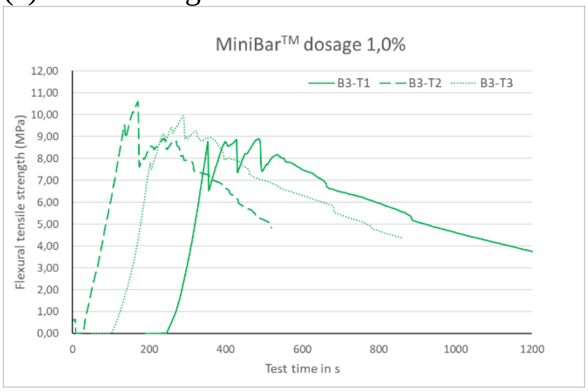
Figure 4. 4: Summary of the measured flexural tensile strength.



(a) Fiber dosage 0%



(b) Fiber dosage 0.5%



(c) Fiber dosage 1%

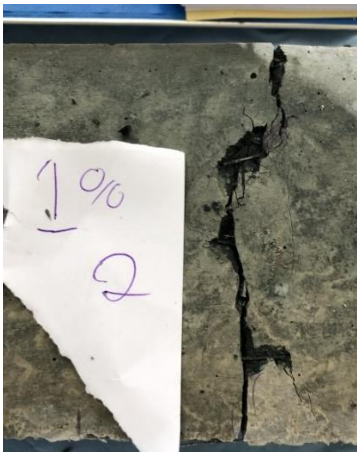
Figure 4. 5: Measured flexural tensile strength of concrete beams with different fiber dosages.

For the plain concrete, the value dropped to zero after reaching the top, indicating that the beam lost its support the load thoroughly after cracking. For MRC with 0.5% MiniBars^{TM} content, beams showed a ductile failure after the flexural crack occurred as shown in Figure 4. 5 (b). The difference originated into the fibers added into the concrete mix. The crack was restrained because the tensile stress was transferred into the fibers across the crack. The MRC with 1% MiniBars^{TM} content had a far more ductile response to the tensile stress. Unlike the other two batches of the concrete mix, the values did not rise to the top directly. The value for specimen B3-T1, for example, fluctuated quite a lot before reaching the peak stress and went gradually down afterwards. Ref. **Table 4. 4**: Flexural tensile strength of the specimen B3-T1 before reaching the peak load. It is because of the bridging action and the pulling-out resistance of the MiniBars^{TM}, which effectively improved the brittle behavior of the concrete under tensile stress. The concrete cracked first, and then tensile failure occurred to the fibers in the crack zone, few fibers were pulled out. Ref. Figure 4. 6.

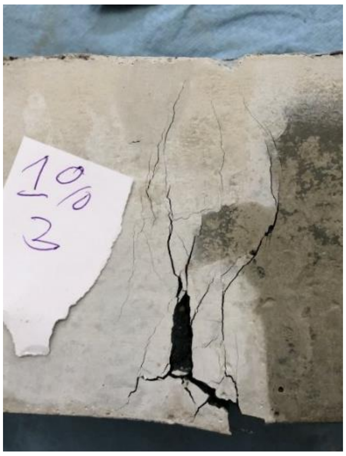
Table 4. 4: Flexural tensile strength of the specimen B3-T1 before reaching the peak load.

Time [s]	Flexural tensile strength [MPa]
353	8.78
356	6.56
425	8.83
430	7.35
485	8.91

B1-T1



B1-T2



B1-T3

Figure 4. 6: Flexural cracking of the MRC beams with 1% MiniBars™ content.

4.4 Residual Tensile Strength

Table 4. 5 summarized the peak load, LOP and residual tensile strength of each specimen measured during the experiment. Peak load is the highest value for load acted on the beam in the CMOD interval 0-6mm. f_l is the highest residual tensile strength before CMOD exceeds 0.05mm. f_{R1}, f_{R2}, f_{R3}, f_{R4} are the strength values corresponding to CMOD equals to 0.5mm, 1.5mm, 2.5mm and 3.5mm respectively. Test procedure and the calculation follow the NS-EN 14651.

Table 4. 5: Summary of the peak load, LOP and residual tensile strength measured from the test.

Spesimen	Peak load [KN]	f_l [MPa]	f_{R1} [MPa]	f_{R2} [MPa]	f_{R3} [MPa]	f_{R4} [MPa]
B2-R1	12.53	3.99	3.41	3.64	2.71	2.09
B2-R2	20.39	6.50	3.69	3.35	2.31	1.84
B2-R3	15.73	-	-	2.56	2.94	2.22
B3-R1	28.85	5.32	8.02	9.01	6.80	5.50
B3-R2	22.54	4.72	6.36	7.06	5.48	4.18
B3-R3	27.85	6.15	8.00	8.83	7.63	6.34

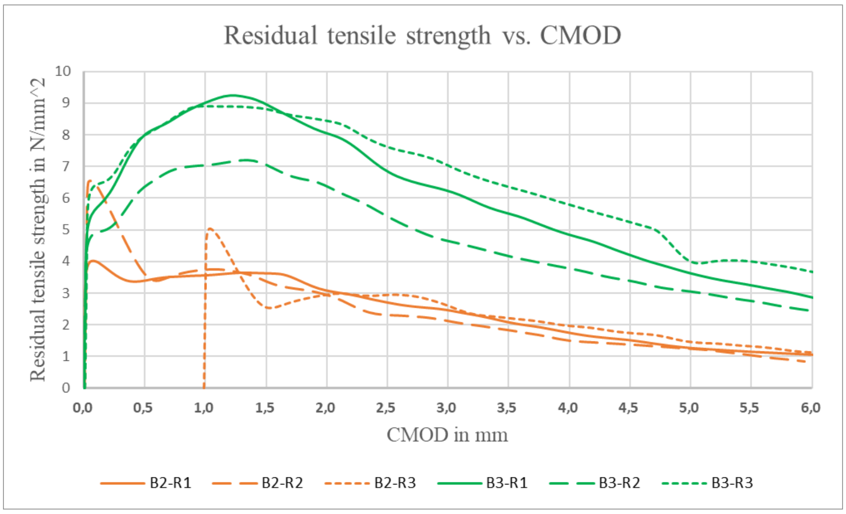


Figure 4. 7: Residual tensile strength vs. CMOD curve for MRC beam with MiniBars™ volume fraction of 0.5% and 1%.

According to *fib* Mode Code 2010, the classification of the MRC specimens can be determined depending on the f_{R1} and f_{R3} obtained from the test. Ref. Table 4. 6: Residual strength class of the MRC specimens. As listed in the table, the residual tensile strength class and the ductility class of the MRC specimens varies with each other. In general, higher fiber volume fraction leads to higher residual flexural tensile strength class and ductility class of the MRC.

Table 4. 6: Residual strength class of the MRC specimens.

Specimen	f_{R1} [MPa]	f_{R3} [MPa]	f_{R3}/f_{R1}	Classification	
				fib Mode Code 2010	NB38
B2-R1	3.41	2.71	0,7947	3b	R3.0b
B2-R2	3.69	2.31	0,626	3a	R3.0a
B2-R3	-	2.94	-	-	
B3-R1	8.02	6.80	0,8479	8b	R8.0b
B3-R2	6.36	5.48	0,8616	6b	R6.0b
B3-R3	8.00	7.63	0,9538	8c	R8.0c

The magnitude of peak load went up dramatically with the increase of MiniBars™ content. Figure 4. 8 gave a brief view of the relationship between them. The value in the graph was the average of three specimens from each batch. The percentage of increase was approximately 63%. It was because the activation of the fiber bridging mechanism after flexural cracking. Ref. Figure 2. 6. The MiniBars™ improved the beam's resistance to tension to a large extent. Meanwhile, the load applied reached its peak at different stages. Ref. Figure 4. 9. The peak load on the specimen with 0.5% fiber content showed in the primary stage which is near CMOD 0.05mm. It was equal or extremely close to the F_L for LOP. When referring to the beams with 1.0% fiber content, however, the peak load was recorded within the range of CMOD 1.0mm and 1.5mm. In addition, the load acted on B2-R1, B2-R2 and B2-R3 drop suddenly after reaching the peak value, while the decrease was steady on B3-R1, B3-R2 and B3-R3. This means that the addition of MiniBars™ can not only enhance the concrete beam's tensile strength but improve its behavior after cracking as well.

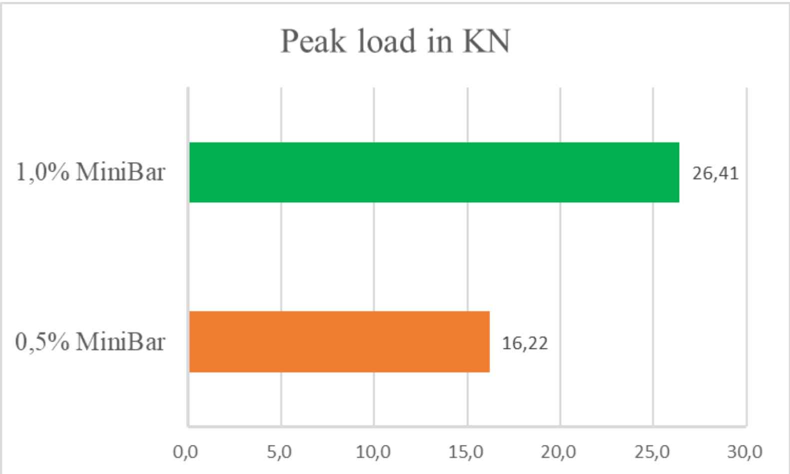


Figure 4. 8: Mean value for peak load of concrete beam with MiniBars™ volume fraction of 0.5% and 1%.

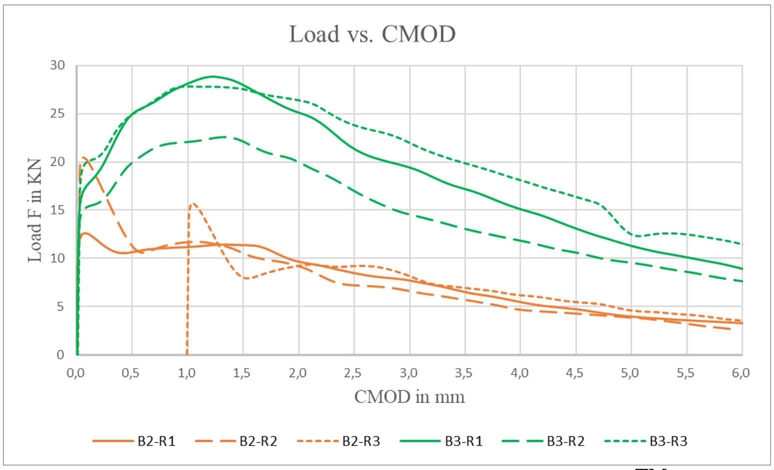
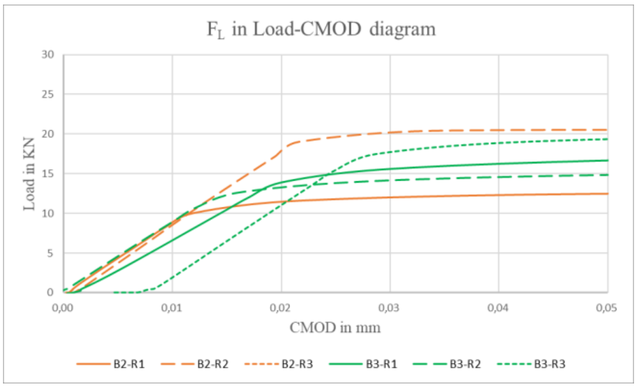
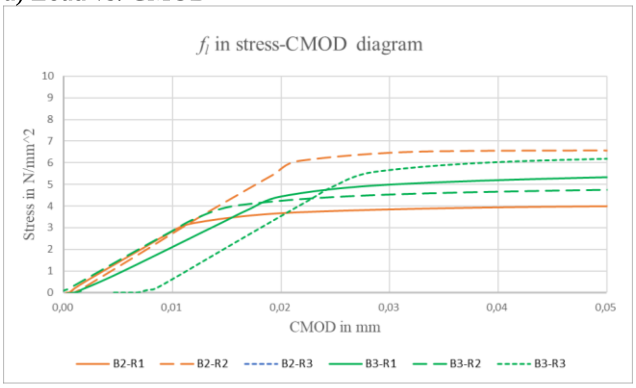


Figure 4. 9: Load vs. CMOD curve for MRC beam with MiniBars™ volume fraction of 0.5% and 1%.

The measured load and its corresponding residual tensile strength within the range of CMOD from 0 to 0.05mm was plotted in the line graph. Ref. Figure 4. 10. According to the graph, the residual tensile strength had a linear relationship with the CMOD before LOP. The value rose with the addition of MiniBars™ in concrete. Due to recording problem when testing, B2-R3 was not included in the graphs. The difference among the specimens with fiber volume fraction of 0.5% is larger as shown in the graphs. Both the highest and the lowest value were detected from the MRC with 0.5% fiber content. Furthermore, the mean values for the LOP of the concrete with 0.5% and 1.0% fiber content were close to each other, at 5.25MPa and 5.39MPa respectively, which means that the effect of fiber content on the LOP is negligible.



a) Load vs. CMOD



b) Residual tensile strength vs. CMOD

Figure 4. 10: The load and residual tensile strength within the range of CMOD from 0 to 0.05mm.

According to the test results, the concrete with fiber volume fraction of 1% has higher residual tensile strength than the concrete having 0.5% fiber content. The residual tensile strength in both ULS and SLS were increased remarkably. Ref. Figure 4. 11. As the bar chart shows, the gaps between the values for f_{R1}, f_{R2}, f_{R3} and f_{R4} of these two batches of MRC are huge. The residual tensile strength was increased by 110%, 160%, 150% and 160% respectively with only 0.5% higher volume fraction of MiniBars™ added to the concrete. The result proved that the MiniBars™ addition played an effective role in improving the post-cracking behavior of the reinforced concrete. Figure 4. 12 gives an example of the flexural crack on the beam specimen and reveals how the MiniBars™ works in concrete. The tensile fraction can be found on some MiniBars™ fibers across the crack, indicating that the fiber bridging mechanism was activated, and the tensile stress was transferred into the MiniBars™ fibers after cracking.

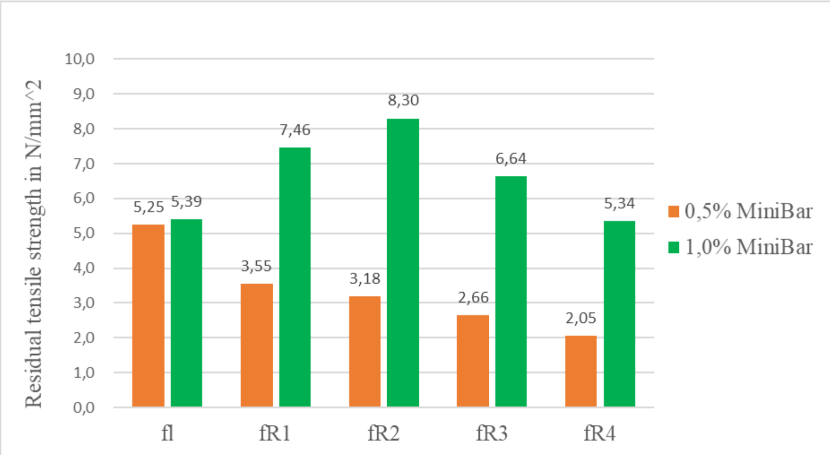


Figure 4. 11: Diagram of the mean values for LOP, and f_{R1}, f_{R2}, f_{R3}, f_{R4} of concrete with different fiber volume fraction.

(a) Rupture of the MiniBars™ fiber. (b) Pulling-out of the fiber

Figure 4. 12: Pictures of the crack on specimen B3-R3.

As to every specific MRC beam, the residual tensile strength after the peak load shows a downtrend with the growth of CMOD in general, ref. Figure 4. 7, while the decrease is steadier in the concrete with higher fiber dosage. The trend can also be represented by the f_{R3}/f_{R1} ratio in Table 4. 6: Residual strength class of the MRC specimens. The average f_{R3}/f_{R1} ratio for the MRC with MiniBars™ volume fraction of 0.5% and 1% is about 0.71 and 0.89 respectively.

5. Conclusion

In this thesis, the compression test and 3-point bending test were performed to evaluate the compressive strength, flexural tensile strength and the residual tensile strength with the change of fiber volume fraction. In addition, the density of concrete, failures due to compressive stress, peak load and LOP were analyzed according to the test results. The classification of the specimens used in the experiment were determined based on the compressive strength and the residual tensile strength.

According to the results from the compression test and the residual tensile strength test, the plain concrete and the MRC can be classified as B55 concrete. But the residual strength class varies with each other. Generally, the MRC with 1% fiber volume fraction has higher residual strength class than that with 0.5% fiber by volume.

There is a minor change of the compressive strength of the concrete with a low dosage of MiniBars^{TM} fiber added to the concrete. The compressive strength decreased by 0.1% and 5.6% respectively for fiber content of 0.5% and 1% by volume after curing for 28 days. Compared to the addition of fiber, the time for curing had a more significant influence on the compressive strength. The increase exceeded 40% for both the plain concrete and the MRC. However, the MiniBars^{TM} fiber did improve the failure of the concrete. Fewer spalling and narrower crack occurred to the cubes reinforced by MiniBars^{TM} fiber.

The flexural tensile strength of the concrete did not linearly change with the increase of MiniBars^{TM} content. The flexural tensile strength went down by 7% when the fiber volume fraction increased from 0% to 0.5%. However, further increase of fiber dosage enhanced the flexural tensile strength. The flexural tensile strength of the specimen containing 1% of MiniBars^{TM} by volume was 20% higher than that of the plain concrete. The behavior of the concrete beams under bending test was improved due to the fiber addition. The specimens exhibited a ductile response to the tensile stress because the stress was transferred into the fibers after the flexural cracking.

In general, the residual tensile strength revealed a downtrend with the rise of CMOD. The effect of the MiniBars^{TM} addition on the residual tensile strength varies in different stages. At CMOD range within 0-0.05mm, the influence was negligible. The LOP of the concrete with fiber volume fraction of 0.5% and 1.0% fiber were extremely close to each other. But the enhancement of the residual tensile strength in ULS and SLS and the peak load were remarkable due to the bridging action and the pulling-out resistance of the MiniBars^{TM}. The values were uplifted by 110%, 150% and 63% respectively.

6. Future studies

Further studies are necessary to find out a more general conclusion. More experiment studies are recommended, so that different parameters, for example, fiber size, composite materials and mix proportions of the concrete, temperature, etc. can be included to evaluate the influence of the fiber addition on the concrete strength. Experiments should be carried out on the reinforced concrete with more variable fiber dosage in order to optimize the use of basalt MiniBars^{TM} in different structures.

7. References

[1] Harvinder Singh, *Steel Fiber Reinforced Concrete: Behavior, Modelling and Design*, 1st ed. 2017. Singapore: Springer Singapore : Imprint: Springer, 2017. doi: 10.1007/978-981-10-2507-5.

[2] ACI Committee 116, '116R-00 Cement and Concrete Terminology', p. 73, Mar. 2000.

[3] Ahmet B. Kizilkanat, Nihat Kabay, Veysel Akyüncü, Swaptik Chowdhury, and Abdullah H. Akça, 'Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study', *Constr. Build. Mater.*, vol. 100, pp. 218–224, Dec. 2015, doi: 10.1016/j.conbuildmat.2015.10.006.

[4] Terje Kanstad *et al.*, 'NB38 Fiberarmert betong i bærende konstruksjoner (2020)'. Norsk Betongforening, Mar. 2020.

[5] V. Fiore, T. Scalici, G. Di Bella, and A. Valenza, 'A review on basalt fibre and its composites', *Compos. Part B Eng.*, vol. 74, pp. 74–94, Jun. 2015, doi: 10.1016/j.compositesb.2014.12.034.

[6] Tehmina Ayub, Nasir Shafiq, and M. Fadhil Nuruddin, 'Effect of Chopped Basalt Fibers on the Mechanical Properties and Microstructure of High Performance Fiber Reinforced Concrete', *Adv. Mater. Sci. Eng.*, vol. 2014, pp. 1–14, 2014, doi: 10.1155/2014/587686.

[7] Sruthi Jalasutram, Dipti Ranjan Sahoo, and Vasant Matsagar, 'Experimental investigation of the mechanical properties of basalt fiber-reinforced concrete', *Struct. Concr.*, vol. 18, no. 2, pp. 292–302, 2017, doi: 10.1002/suco.201500216.

[8] Chaohua Jiang, Ke Fan, Fei Wu, and Da Chen, 'Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete', *Mater. Des.*, vol. 58, pp. 187–193, Jun. 2014, doi: 10.1016/j.matdes.2014.01.056.

[9] Weibo Ren, Jinyu Xu, and Haoyang Su, 'Dynamic compressive behavior of basalt fiber reinforced concrete after exposure to elevated temperatures', *Fire Mater.*, vol. 40, no. 5, pp. 738–755, 2016, doi: 10.1002/fam.2339.

[10] 'MiniBars^{TM}-Datasheet.pdf'. Accessed: Apr. 09, 2022. [Online]. Available: https://reforcetech.com/wp-content/uploads/2021/06/MiniBars%E2%84%A2-Datasheet.pdf

[11] John Branston, Sreekanta Das, Sara Y. Kenno, and Craig Taylor, 'Mechanical behaviour of basalt fibre reinforced concrete', *Constr. Build. Mater.*, vol. 124, pp. 878–886, Oct. 2016, doi: 10.1016/j.conbuildmat.2016.08.009.

[12] 'Cement - Part 1: Composition, specifications and conformity criteria for common cements, NS-EN 197-1:2011'. Standard norge, Dec. 2011.

[13] L. Wang, H.Q. Yang, Y. Dong, E. Chen, and S.W. Tang, 'Environmental evaluation, hydration, pore structure, volume deformation and abrasion resistance of low heat Portland (LHP) cement-based materials', *J. Clean. Prod.*, vol. 203, pp. 540–558, Dec. 2018, doi: 10.1016/j.jclepro.2018.08.281.

[14] Huaquan Yang, Yingchun Wang, and Shihua Zhou, 'Anti-crack performance of low-heat Portland cement concrete', *J. Wuhan Univ. Technol.-Mater Sci Ed*, vol. 22, no. 3, pp. 555–559, Sep. 2007, doi: 10.1007/s11595-006-3555-7.

[15] Bjørn Normann Sandaker, Malvin Sandvik, and Bjørn Vik, *Materialkunnskap*, 1. utgave, 16. opplag. Oslo: Byggenæringens forlag AS, 2016.

[16] Bernhard Wietek, *Fiber Concrete: In Construction*. Wiesbaden: Springer Fachmedien Wiesbaden, 2021. doi: 10.1007/978-3-658-34481-8.

[17] Mohammad Iqbal Khan, Wasim Abbass, Mohammad Alrubaidi, and Fahad K. Alqahtani, 'Optimization of the Fine to Coarse Aggregate Ratio for the Workability and

Mechanical Properties of High Strength Steel Fiber Reinforced Concretes', *Materials*, vol. 13, no. 22, p. 5202, Nov. 2020, doi: 10.3390/ma13225202.
[18] Bashar Behnam, 'Designing and Proportioning of Fiber-Reinforced Lightweight Concrete Mixtures Using Engineered Aggregate', *Jordan J. Civ. Eng.*, vol. 11, no. 4, pp. 698–712, Oct. 2017.
[19] M. R Rixom and N. P Mailvaganam, *Chemical admixtures for concrete*. London: E. & F.N. Spon, 1999.
[20] 'Concrete: Specification, performance, production and conformity, NS-EN 206: 2013+A2+NA'. Standard norge, Apr. 14, 2021.
[21] Zongjin Li and Wenquan Liang, *Advanced concrete technology*. Hoboken, NJ: John Wiley & Sons, Incorporated, 2011.
[22] 'Mixing water for concrete: Specification for sampling, testing and assessing the suitability for water, including water recovered from processes in the concrete industry, as mixing water for concrete. NS-EN 1008:2002'. Standard norge, 2004.
[23] Natt Makul, *Principles of Cement and Concrete Composites*, vol. 18. Cham: Springer International Publishing, 2021. doi: 10.1007/978-3-030-69602-3.
[24] Zhenyu Pi, Huigang Xiao, Junjie Du, Changdi Li, Wei Cai, and Min Liu, 'Effect of the water/cement ratio on the improvement of pullout behaviors using nano-SiO2 modified steel fiber and the micro mechanism', *Constr. Build. Mater.*, vol. 338, p. 127632, Jul. 2022, doi: 10.1016/j.conbuildmat.2022.127632.
[25] Marco di Prisco, Matteo Colombo, and Daniele Dozio, 'Fibre-reinforced concrete in *fib* Model Code 2010: principles, models and test validation', *Struct. Concr.*, vol. 14, no. 4, pp. 342–361, Dec. 2013, doi: 10.1002/suco.201300021.
[26] Hwai-Chung Wu and Christopher D. Eamon, '1 - Introduction', in *Strengthening of Concrete Structures using Fiber Reinforced Polymers (FRP) Design, Construction and Practical Applications*, Elsevier, 2017, pp. 1–10. doi: 10.1016/B978-0-08-100636-8.00001-6.
[27] Andrzej M. Brandt, 'Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering', *Compos. Struct.*, vol. 86, no. 1, pp. 3–9, Nov. 2008, doi: 10.1016/j.compstruct.2008.03.006.
[28] Ronald F. Zollo, 'Fiber-reinforced concrete: an overview after 30 years of development', *Cem. Concr. Compos.*, vol. 19, no. 2, pp. 107–122, Jan. 1997, doi: 10.1016/S0958-9465(96)00046-7.
[29] Nassim Uddin and Nasim Uddin, *Developments in Fiber-Reinforced Polymer (FRP) Composites for Civil Engineering*. Cambridge, UNITED KINGDOM: Elsevier Science & Technology, 2013. Accessed: Jun. 05, 2022. [Online]. Available: http://ebookcentral.proquest.com/lib/uisbib/detail.action?docID=1581397
[30] D. V. Soulioti, N. M. Barkoula, A. Paipetis, and T. E. Matikas, 'Effects of Fibre Geometry and Volume Fraction on the Flexural Behaviour of Steel-Fibre Reinforced Concrete', *Strain*, vol. 47, no. s1, pp. e535–e541, 2011, doi: 10.1111/j.1475-1305.2009.00652.x.
[31] Christophe Camille, D. K. Hewage, O. Mirza, F. Mashiri, B. Kirkland, and T. Clarke, 'Post-cracking Strength Classification of Macro-synthetic Fibre Reinforced Concrete for Sleeper Application', in *Fibre Reinforced Concrete: Improvements and Innovations*, vol. 30, Pedro Serna, Aitor Llano-Torre, José R. Martí-Vargas, and Juan Navarro-Gregori, Eds. Cham: Springer International Publishing, 2021, pp. 717–729. doi: 10.1007/978-3-030-58482-5_64.
[32] Marco di Prisco, Giovanni Plizzari, and Lucie Vandewalle, 'Fibre reinforced concrete: new design perspectives', *Mater. Struct.*, vol. 42, no. 9, pp. 1261–1281, Nov. 2009, doi: 10.1617/s11527-009-9529-4.

[33] Thanasis Triantafillou and Stijn Matthys, ‘Fibre-reinforced polymer reinforcement enters *fib* Model Code 2010’, *Struct. Concr.*, vol. 14, no. 4, pp. 335–341, Dec. 2013, doi: 10.1002/suco.201300016.
[34] Jose M. Sentmanat, ‘An Overview of Synthetic Filter Media’, *Chemical Engineering*, Mar. 2022. https://chemengonline.com/an-overview-of-synthetic-filter-media/ (accessed May 06, 2022).
[35] ACI Committee 544, *Guide to design with fiber-reinforced concrete*. 2018.
[36] Navid Ranjbar and Mingzhong Zhang, ‘Fiber reinforced geopolymer composites: A review’, *Cem. Concr. Compos.*, vol. 107, p. 103498, Dec. 2019, doi: 10.1016/j.cemconcomp.2019.103498.
[37] Hedda Vikan, ‘Concrete workability and fibre content’, SINTEF Building and Infrastructure; COIN - Concrete innovation Centre, SBF BK A07029, Oct. 2007. [Online]. Available: http://hdl.handle.net/11250/2424151
[38] Komathi Murugan, Stefie J Stephen, and Ravindra Gettu, ‘Influence of Fibre Geometry on the Fracture of Steel Fibre Reinforced Concrete’, *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 936, no. 1, p. 012025, Sep. 2020, doi: 10.1088/1757-899X/936/1/012025.
[39] M.Z. Naser, R.A. Hawileh, and J.A. Abdalla, ‘Fiber-reinforced polymer composites in strengthening reinforced concrete structures: A critical review’, *Eng. Struct.*, vol. 198, p. 109542, Nov. 2019, doi: 10.1016/j.engstruct.2019.109542.
[40] Hwai-Chung Wu and Christopher D. Eamon, ‘2 - Fiber-reinforced polymer composites’, in *Strengthening of Concrete Structures using Fiber Reinforced Polymers (FRP) Design, Construction and Practical Applications*, Elsevier, 2017, pp. 11–17. doi: 10.1016/B978-0-08-100636-8.00002-8.
[41] V. Marcos-Meson, G. Fischer, C. Edvardsen, T.L. Skovhus, and A. Michel, ‘Durability of Steel Fibre Reinforced Concrete (SFRC) exposed to acid attack – A literature review’, *Constr. Build. Mater.*, vol. 200, pp. 490–501, Mar. 2019, doi: 10.1016/j.conbuildmat.2018.12.051.
[42] J. L. Thomason, ‘Glass fibre sizing: A review’, *Compos. Part Appl. Sci. Manuf.*, vol. 127, p. 105619, Dec. 2019, doi: 10.1016/j.compositesa.2019.105619.
[43] Syed Safdar Raza, Liaqat Ali Qureshi, Babar Ali, Ali Raza, and Mudasser Muneer Khan, ‘Effect of different fibers (steel fibers, glass fibers, and carbon fibers) on mechanical properties of reactive powder concrete’, *Struct. Concr.*, vol. 22, no. 1, pp. 334–346, 2021, doi: 10.1002/suco.201900439.
[44] Gul Hameed Awan, Liaqat Ali, Engr Ramzan, and Engr Ehsan, ‘EFFECT OF VARIOUS FORMS OF GLASS FIBER REINFORCEMENTS ON TENSILE PROPERTIES OF POLYESTER MATRIX COMPOSITE’, *J. Fac. Eng. Technol.*, p. 7, 2009.
[45] T. Sathishkumar, S. Satheeshkumar, and J. Naveen, ‘Glass fiber-reinforced polymer composites – a review’, *J. Reinf. Plast. Compos.*, vol. 33, no. 13, pp. 1258–1275, Jul. 2014, doi: 10.1177/0731684414530790.
[46] Xinyan Guo, Peiyan Huang, Yilin Wang, Shenyunhao Shu, and Xiaohong Zheng, ‘Flexural Performance of Reinforced Concrete Beams Strengthened with Carbon Fiber-Reinforced Polymer (CFRP) under Hygrothermal Environment Considering the Influence of CFRP–Concrete Interface’, *Acta Mech. Solida Sin.*, vol. 34, no. 3, pp. 381–392, Jun. 2021, doi: 10.1007/s10338-020-00207-7.
[47] ‘Carbon Fibre Reinforced Polymers for Concrete Construction’, *The Constructor*, Aug. 23, 2019. https://theconstructor.org/concrete/carbon-fibre-reinforced-polymers-applications/1588/ (accessed May 11, 2022).
[48] Y.-F. Li, Hsin-Fu Wang, Jin-Yuan Syu, Gobinathan Kadagathur Ramanathan, Ying-Kuan Tsai, and Man Hoi Lok, ‘Mechanical Properties of Aramid/Carbon Hybrid Fiber-

Reinforced Concrete', *Materials*, vol. 14, no. 19, Art. no. 19, Jan. 2021, doi: 10.3390/ma14195881.
[49] R. S. Talikoti and S. B. Kandekar, 'Strength and Durability Study of Concrete Structures Using Aramid-Fiber-Reinforced Polymer', *Fibers*, vol. 7, no. 2, Art. no. 2, Feb. 2019, doi: 10.3390/fib7020011.
[50] X. Chen and Y. Zhou, '6 - Technical textiles for ballistic protection', in *Handbook of Technical Textiles (Second Edition)*, A. R. Horrocks and S. C. Anand, Eds. Woodhead Publishing, 2016, pp. 169–192. doi: 10.1016/B978-1-78242-465-9.00006-9.
[51] J. Michael Pereira and Duane M. Revilock Jr, 'Ballistic Impact Response of Kevlar 49 and Zylon under Conditions Representing Jet Engine Fan Containment', *J. Aerosp. Eng.*, vol. 22, no. 3, pp. 240–248, Jul. 2009, doi: 10.1061/(ASCE)0893-1321(2009)22:3(240).
[52] 'Aramid Fibers used in Structural Reinforcement and Strengthening', *Build-on-Prince.com*. https://www.princelund.com/aramid-fibers.html (accessed May 11, 2022).
[53] H. Jamshaid and R. Mishra, 'A green material from rock: basalt fiber – a review', *J. Text. Inst.*, vol. 107, no. 7, pp. 923–937, Jul. 2016, doi: 10.1080/00405000.2015.1071940.
[54] Mehdi Derradji, Jun Wang, and Wenbin Liu, '5 - Fiber-Reinforced Phthalonitrile Composites', in *Phthalonitrile Resins and Composites*, William Andrew Publishing, 2018, pp. 241–294. doi: 10.1016/B978-0-12-812966-1.00005-6.
[55] Jiří Militký, Vladimír Kovačič, and Jitka Rubnerová, 'Influence of thermal treatment on tensile failure of basalt fibers', *Eng. Fract. Mech.*, vol. 69, no. 9, pp. 1025–1033, Jun. 2002, doi: 10.1016/S0013-7944(01)00119-9.
[56] Tamás Deák and Tibor Czigány, 'Chemical Composition and Mechanical Properties of Basalt and Glass Fibers: A Comparison', *Text. Res. J.*, vol. 79, no. 7, pp. 645–651, May 2009, doi: 10.1177/0040517508095597.
[57] Jongsung Sim, Cheolwoo Park, and Do Young Moon, 'Characteristics of basalt fiber as a strengthening material for concrete structures', *Compos. Part B Eng.*, vol. 36, no. 6, pp. 504–512, Jan. 2005, doi: 10.1016/j.compositesb.2005.02.002.
[58] A. A. Dalinkevich, K. Z. Gumargalieva, S. S. Marakhovsky, and A. V. Soukhanov, 'Modern Basalt Fibrous Materials and Basalt Fiber-Based Polymeric Composites', *J. Nat. Fibers*, vol. 6, no. 3, pp. 248–271, Aug. 2009, doi: 10.1080/15440470903123173.
[59] V.Lopresto, C.Leone, and I.De Iorio, 'Mechanical characterisation of basalt fibre reinforced plastic', *Compos. Part B Eng.*, vol. 42, no. 4, pp. 717–723, Jun. 2011, doi: 10.1016/j.compositesb.2011.01.030.
[60] A. G. Novitskii and M. V. Efremov, 'Some aspects of the manufacturing process for obtaining continuous basalt fiber', *Glass Ceram.*, vol. 67, no. 11–12, pp. 361–365, Mar. 2011, doi: 10.1007/s10717-011-9299-7.
[61] Anil Patnaik, 'Gen 3.1 MiniBars^{TM} Reinforced concrete (MRC) report', The University of Akron, ReforceTech AS, Norway, RFT-AP-MB-R03-2012 Rev.B, 2012.
[62] 'BFRP MiniBars^{TM} Patent Pending.pdf'. Accessed: May 18, 2022. [Online]. Available: http://cdnassets.hw.net/45/b1/e51887ce4ed19c9c1102cc07f717/rft-bfrp-minibars-en-120607.pdf
[63] 'Presentasions for open academic meeting in Bergen-19.04.2018.pdf'. Accessed: May 19, 2022. [Online]. Available: https://betong.net/wp-content/uploads/Presentasjon-%C3%85pent-faglig-m%C3%B8te-19.04.18..pdf
[64] 'Testing hardened concrete - Part 7: Density of hardened concrete, NS-EN 12390-7:2019'. Standard norge, Dec. 18, 2019.
[65] 'Testing hardened concrete - Part 4: Compressive strength - Specification for testing machines, NS EN-12390-4:2020'. Standard norge, 2020.

[66] ‘Testing hardened concrete - Part 3: Compressive strength of test specimens, NS EN-12390-3:2019’. Standard norge, Nov. 01, 2019.
[67] ‘Testing hardened concrete - Part 5: Flexural strength of test specimens, NS-EN 12390-5:2019’. Standard norge, Nov. 01, 2019.
[68] ‘Test method for metallic fibre concrete, Measuring the flexural tensile strength (limit of proportionality (LOP), residual), NS-EN 14651:2005+A1:2007’. Standard norge, 2007.

8. Appendix

i. Proportional sheets - Batch 1 - Fiber volume fraction: 0.0%
ii. Proportional sheets - Batch 2 - Fiber volume fraction: 0.5%
iii. Proportional sheets - Batch 3 - Fiber volume fraction: 1.0%
iv. Grading curve of aggregates
v. Test results: compression test at 7 days
vi. Test results: compression test at 28 days
vii. Test results: flexural tensile strength
viii. Test results: residual tensile strength
ix. Material data sheet: SCHWENK Low heat cement
x. Material data sheet: Dynamon SX-N superplasticizer
xi. Material data sheet: ReforceTech MiniBars^{TM}

i. Proportional sheets - Batch 1 - Fiber volume fraction: 0.0%

Proporsjonering av betong

SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 1-0.0%
Tilsiktet kvalitet	
Utført av	Einar Mesloe
Dato	05.04.2022

Initialparametre	Verdi
m = v/(c+Σkp)	0,40
Luftinnhold	2,0 %

Sementtype	Andel	ndel klinke	Andel FA	ndel slagg	[kg/m³]	Alkalier	Klorider
Norcem Industri	0,0 %	100,0 %	0,0 %	0,0 %	3130	1,4 %	0,1 %
Lavvarme	100,0 %	30,0 %	0,0 %	70,0 %	2980	0,8 %	0,1 %
	0,0 %	100,0 %	0,0 %	0,0 %	1000	0,0 %	0,0 %

Tilsetningsmaterialer	Type	ndel (av b)	k	[kg/m³]	Alkalier	Klorider
Elkem Microsilica	Silika	0,0 %	1,0	2200	0,1 %	0,1 %
Normineral flyveaske	FA	0,0 %	0,7	2200	1,0 %	0,3 %
	Slagg	0,0 %	0,6	1000	1,0 %	0,3 %

Tilsetningsstoff	% av b	[kg/m³]	Tørrstoff	[kg/m³] TS	Alkalier	Klorider
Mapei Dynamon SX-N	0,9 %	1050	16,0 %	1424	0,0 %	0,0 %
Mapei Dynamon SX-23	0,0 %	1060	100,0 %	1060	0,0 %	0,0 %
Mapeair 25 1:19	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %
	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %

Fiber	Vol %	[kg/m3]
Stålfiber	0,0 %	7800
Basaltfiber	0,0 %	2100

Matriks	Verdi
Ønsket matriksvolum [l/m³]	600
Oppnådd matriksvolum [l/m³]	600
Klinkerandel i bindemiddel	30,0 %
Total FA- andel av bindemidde	0,0 %
Total slaggandel av bindemidd	70,0 %
Volum sementlim [l/m³]	593,2
Effektivt vanninnhold [l/m³]	322,1
v/p	0,39
Effektivt bindemiddel [kg/m³]	805
Totalt bindemiddel [kg/m³]	805

Beregn

Kommentarer:
Gule felt fylles ut, grønne beregnes.
Rød bakgrunn i cellen for oppnådd matriksvolum indikerer at beregningsmakroen ikke er kjørt, og at det derfor ikke er samsvar mellom ønsket og oppnådd matriksvolum. Dette vil også gi blanke felt i reseptskjemaet.

Proporsjonering av betong

SKANSKA

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Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 1-0.0%
Tilsiktet kvalitet	0
Utført av	Einar Mesloe
Dato	05.04.2022

Masseforhold	0,40
Matriksvolum (l/m³)	600
Volum sementlim (l/m³)	593
Tilsiktet luftinnhold (%	2,0
Effektivt bindemiddel (k	805

"Oppnådd" lik "Ønsket"; Ctrl+N

Nullstill volumkorreksjon; Ctrl+K

Proporsjonert betong

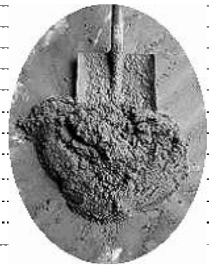
Materialer	kg/m³	Ønsket kg	Oppnådd kg	korr. luft	korr. dens	Korrigert
Norcem Industri	0,0	0,0	0,0	0,0	0,0	0,0
Lavvarme	805,3	108,7	108,7	0,0	71,9	877,2
	0,0	0,0	0,0	0,0	0,0	0,0
Elkem Microsilica	0,0	0,0	0,0	0,0	0,0	0,0
Normineral flyveaske	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Fritt vann	322,1	43,5	43,5	0,0	28,7	350,9
Absorbert vann	6,1	0,8	0,8	0,0	0,5	6,6
Årdal 0/8 mm nat. vask.	720,6	97,3	97,3	0,0	64,3	784,9
Årdal 0/2 mm nat. vask	0,0	0,0	0,0	0,0	0,0	0,0
Årdal 8/16mm	307,9	41,6	41,6	0,0	27,5	335,4
Årdal 16/22 mm	0,0	0,0	0,0	0,0	0,0	0,0
Velde 0/8 Industri S	0,0	0,0	0,0	0,0	0,0	0,0
Velde 8/16 Industri	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Mapei Dynamon SX-N	7,25	0,98	0,98	0,0	0,6	7,89
Mapei Dynamon SX-23	0,00	0,00	0,00	0,0	0,0	0,00
Mapeair 25 1:19	0,00	0,00	0,00	0,0	0,0	0,00
	0,00	0,00	0,00	0,0	0,0	0,00
Stålfiber	0,0	0,0	0,0	0,0	0,0	0,0
Basaltfiber	0,0	0,0	0,0	0,0	0,0	0,0
Prop. betongdens. (kg/m³)	2163			0,0	193,6	2356

volum ok

Fersk betong

Egenskap	
Ønsket volum (l)	135,0
Innveid volum (l)	135,0
Målt luftinnhold (%)	2,0
Målt betongdensitet (kg	2356
Effektivt v/(c+Σkp)	0,400

Aggressiver	
Kloridinnhold [% av b]	0,05 %
Alkalier [kg/m³]	6,36
Andel reakt. bergarter	0,0



Kommentarer:

Kommentarer:
Gule felt fylles ut, grønne beregnes.

Matriksvolumet inkluderer tilslagspartikler mindre en 0,125 mm.

Når fukt i tilslaget er bestemt på basis av ovnstørt tilslag skal absorbert fukt angis med målt verdi. Tilhørende densitet skal da også være basert på tørt tilslag . Dersom fukt i tilslaget er gitt på SSD-basis settes absorbert fukt lik 0. I så fall skal densitetene også angis som SSD-densitet.

Alle delmaterialer bortsett fra vann og TSS angis i tørr vekt. Ved beregning av volum, densiteter og masseforhold regnes vanninnholdet i TSS med i den fri vannmengden. Dette gjelder også korrigert resept. Dersom innveid mengde TSS avviker fra proporsjonert mengde korrigeres masseforhold og mengde fritt vann i korrigert resept automatisk.

Merk at for pozzolaner, fillere og tilsetningsstoffer oppgis tørrstoffinnhold og fukt på våt basis, for tilslag på tørr basis. Fiber regnes ikke med i matriksvolumet.

Blandeskjema SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 1-0.0%
Tilsiktet kvalitet	0

Blandevolum	135 liter
Dato:	
Tidspunkt for vanntilsetni	
Ansvarlig:	
Utført av:	

Materialer	Resept kg/m3	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Industri	0,0	0,000			0,000	
Lavvarme	805,3	108,716			108,716	
	0,0	0,000			0,000	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
	0,0	0,000			0,000	
Fritt vann	322,1	43,487		-2,003	41,484	42,303
Absorbert vann	6,1	0,819			0,819	
Årdal 0/8 mm nat. vask.	720,6	97,283	1,0	0,973	98,256	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	307,9	41,569	0,5	0,208	41,777	
Årdal 16/22 mm	0,0	0,000	0,5	0,000	0,000	
Velde 0/8 Industri S	0,0	0,000	0,0	0,000	0,000	
Velde 8/16 Industri	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	
Mapei Dynamon SX-N	7,2	0,978	84	0,822	0,978	
Mapei Dynamon SX-23	0,0	0,000	0	0,000	0,000	
Mapeair 25 1:19	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
Basaltfiber	0,0	0,000			0,000	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

ii. Proportional sheets - Batch 2 - Fiber volume fraction: 0.5%

Proporsjonering av betong

SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 2-0.5%
Tilsiktet kvalitet	
Utført av	
Dato	05.04.2022

Initialparametre	Verdi
m = v/(c+Σkp)	0,40
Luftinnhold	2,0 %

Sementtype	Andel	Andel klinker	Andel FA	Andel slagg	[kg/m³]	Alkalier	Klorider
Norcem Industri	0,0 %	100,0 %	0,0 %	0,0 %	3130	1,4 %	0,1 %
Lavvarme	100,0 %	30,0 %	0,0 %	70,0 %	2980	0,8 %	0,1 %
	0,0 %	100,0 %	0,0 %	0,0 %	1000	0,0 %	0,0 %

Tilsetningsmaterialer	Type	Andel (av b)	k	[kg/m³]	Alkalier	Klorider
Elkem Microsilica	Silika	0,0 %	1,0	2200	0,1 %	0,1 %
Normineral flyveaske	FA	0,0 %	0,7	2200	1,0 %	0,3 %
	Slagg	0,0 %	0,6	1000	1,0 %	0,3 %

Tilsetningsstoff	% av b	[kg/m³]	Tørrstoff	[kg/m³] TS	Alkalier	Klorider
Mapei Dynamon SX-N	0,9 %	1050	16,0 %	1424	0,0 %	0,0 %
Mapei Dynamon SX-23	0,0 %	1060	100,0 %	1060	0,0 %	0,0 %
Mapeair 25 1:19	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %
	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %

Fiber	Vol %	[kg/m3]
Stålfiber	0,0 %	7800
Basaltfiber	0,5 %	2100

Matriks	Verdi
Ønsket matriksvolum [l/m³]	600
Oppnådd matriksvolum [l/m³]	600
Klinkerandel i bindemiddel	30,0 %
Total FA- andel av bindemidde	0,0 %
Total slaggandel av bindemidd	70,0 %
Volum sementlim [l/m³]	593,3
Effektivt vanninnhold [l/m³]	322,2
v/p	0,39
Effektivt bindemiddel [kg/m³]	805
Totalt bindemiddel [kg/m³]	805

Beregn

Kommentarer:
Gule felt fylles ut, grønne beregnes.
Rød bakgrunn i cellen for oppnådd matriksvolum indikerer at beregningsmakroen ikke er kjørt, og at det derfor ikke er samsvar mellom ønsket og oppnådd matriksvolum. Dette vil også gi blanke felt i reseptskjemaet.

Proporsjonering av betong

SKANSKA

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Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 2-0.5%
Tilsiktet kvalitet	0
Utført av	0
Dato	05.04.2022

Masseforhold	0,40
Matriksvolum (l/m³)	600
Volum sementlim (l/m³)	593
Tilsiktet luftinnhold (%	2,0
Effektivt bindemiddel (k	805

"Oppnådd" lik "Ønsket"; Ctrl+N

Nullstill volumkorreksjon; Ctrl+K

Proporsjonert betong

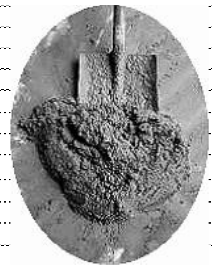
Materialer	kg/m³	Ønsket kg	Oppnådd kg	Volumkorreksjon korr. luft	korr. dens	Korrigert
Norcem Industri	0,0	0,0	0,0	0,0	0,0	0,0
Lavvarme	805,4	108,7	108,7	0,0	73,1	878,5
	0,0	0,0	0,0	0,0	0,0	0,0
Elkem Microsilica	0,0	0,0	0,0	0,0	0,0	0,0
Normineral flyveaske	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Fritt vann	322,2	43,5	43,5	0,0	29,2	351,4
Absorbert vann	6,0	0,8	0,8	0,0	0,5	6,5
Årdal 0/8 mm nat. vask.	711,1	96,0	96,0	0,0	64,5	775,7
Årdal 0/2 mm nat. vask	0,0	0,0	0,0	0,0	0,0	0,0
Årdal 8/16mm	303,9	41,0	41,0	0,0	27,6	331,4
Årdal 16/22 mm	0,0	0,0	0,0	0,0	0,0	0,0
Velde 0/8 Industri S	0,0	0,0	0,0	0,0	0,0	0,0
Velde 8/16 Industri	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Mapei Dynamon SX-N	7,25	0,98	0,98	0,0	0,7	7,91
Mapei Dynamon SX-23	0,00	0,00	0,00	0,0	0,0	0,00
Mapeair 25 1:19	0,00	0,00	0,00	0,0	0,0	0,00
	0,00	0,00	0,00	0,0	0,0	0,00
Stålfiber	0,0	0,0	0,0	0,0	0,0	0,0
Basaltfiber	10,5	1,4	1,4	0,0	1,0	11,5
Prop. betongdens. (kg/m³)	2160			0,0	195,6	2356

volum ok

Fersk betong

Egenskap	
Ønsket volum (l)	135,0
Innveid volum (l)	135,0
Målt luftinnhold (%)	2,0
Målt betongdensitet (kg	2356
Effektivt v/(c+Σkp)	0,400

Aggressiver	
Kloridinnhold [% av b]	0,05 %
Alkalier [kg/m³]	6,36
Andel reakt. bergarter	0,0



Kommentarer:

Kommentarer:
Gule felt fylles ut, grønne beregnes.

Matriksvolumet inkluderer tilslagspartikler mindre en 0,125 mm.

Når fukt i tilslaget er bestemt på basis av ovnstørt tilslag skal absorbert fukt angis med målt verdi. Tilhørende densitet skal da også være basert på tørt tilslag . Dersom fukt i tilslaget er gitt på SSD-basis settes absorbert fukt lik 0. I så fall skal densitetene også angis som SSD-densitet.

Alle delmaterialer bortsett fra vann og TSS angis i tørr vekt. Ved beregning av volum, densiteter og masseforhold regnes vanninnholdet i TSS med i den fri vannmengden. Dette gjelder også korrigert resept. Dersom innveid mengde TSS avviker fra proporsjonert mengde korrigeres masseforhold og mengde fritt vann i korrigert resept automatisk.

Merk at for pozzolaner, fillere og tilsetningsstoffer oppgis tørrstoffinnhold og fukt på våt basis, for tilslag på tørr basis. Fiber regnes ikke med i matriksvolumet.

Blandeskjema

SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batch 2-0.5%
Tilsiktet kvalitet	0

Blandevolum	135 liter
Dato:	Onsdag 3 uker før påske
Tidspunkt for vanntilsetni	
Ansvarlig:	
Utført av:	Einar Mesloe

Materialer	Resept kg/m^3	Sats kg	Fukt* %	Korr. kg	Oppveid** kg	
Norcem Industri	0,0	0,000			0,000	
Lavvarme	805,4	108,733			108,733	
	0,0	0,000			0,000	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
	0,0	0,000			0,000	
Fritt vann	322,2	43,493		-1,987	41,506	42,314
Absorbert vann	6,0	0,808			0,808	
Årdal 0/8 mm nat. vask.	711,1	96,003	1,0	0,960	96,963	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	303,9	41,022	0,5	0,205	41,227	
Årdal 16/22 mm	0,0	0,000	0,5	0,000	0,000	
Velde 0/8 Industri S	0,0	0,000	0,0	0,000	0,000	
Velde 8/16 Industri	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	
Mapei Dynamon SX-N	7,2	0,979	84	0,822	0,979	
Mapei Dynamon SX-23	0,0	0,000	0	0,000	0,000	
Mapeair 25 1:19	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
Basaltfiber	10,5	1,418			1,418	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

iii. Proportional sheets - Batch 3 - Fiber volume fraction: 1.0%

Proporsjonering av betong

SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batche 3-1.0%
Tilsiktet kvalitet	
Utført av	
Dato	05.04.2022

Initialparametre	Verdi
m = v/(c+Σkp)	0,40
Luftinnhold	2,0 %

Sementtype	Andel	ndel klinke	Andel FA	ndel slagg	[kg/m³]	Alkalier	Klorider
Norcem Industri	0,0 %	100,0 %	0,0 %	0,0 %	3130	1,4 %	0,1 %
Norcem lavvarme	100,0 %	30,0 %	0,0 %	70,0 %	2980	0,8 %	0,1 %
	0,0 %	100,0 %	0,0 %	0,0 %	1000	0,0 %	0,0 %

Tilsetningsmaterialer	Type	ndel (av b)	k	[kg/m³]	Alkalier	Klorider
Elkem Microsilica	Silika	0,0 %	1,0	2200	0,1 %	0,1 %
Normineral flyveaske	FA	0,0 %	0,7	2200	1,0 %	0,3 %
	Slagg	0,0 %	0,6	1000	1,0 %	0,3 %

Tilsetningsstoff	% av b	[kg/m³]	Tørrstoff	[kg/m³] TS	Alkalier	Klorider
Mapei Dynamon SX-N	0,9 %	1050	16,0 %	1424	0,0 %	0,0 %
Mapei Dynamon SX-23	0,0 %	1060	100,0 %	1060	0,0 %	0,0 %
Mapeair 25 1:19	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %
	0,0 %	1000	100,0 %	1000	0,0 %	0,0 %

Fiber	Vol %	[kg/m3]
Stålfiber	0,0 %	7800
Basaltfiber	1,0 %	2100

Matriks	Verdi
Ønsket matriksvolum [l/m³]	600
Oppnådd matriksvolum [l/m³]	600
Klinkerandel i bindemiddel	30,0 %
Total FA- andel av bindemidde	0,0 %
Total slaggandel av bindemidd	70,0 %
Volum sementlim [l/m³]	593,4
Effektivt vanninnhold [l/m³]	322,2
v/p	0,39
Effektivt bindemiddel [kg/m³]	806
Totalt bindemiddel [kg/m³]	806

Beregn

Kommentarer:
Gule felt fylles ut, grønne beregnes.
Rød bakgrunn i cellen for oppnådd matriksvolum indikerer at beregningsmakroen ikke er kjørt, og at det derfor ikke er samsvar mellom ønsket og oppnådd matriksvolum. Dette vil også gi blanke felt i reseptskjemaet.

Proporsjonering av betong

SKANSKA

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Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batche 3-1.0%
Tilsiktet kvalitet	0
Utført av	0
Dato	05.04.2022

Masseforhold	0,40
Matriksvolum (l/m³)	600
Volum sementlim (l/m³)	593
Tilsiktet luftinnhold (%	2,0
Effektivt bindemiddel (k	806

"Oppnådd" lik "Ønsket"; Ctrl+N

Nullstill volumkorreksjon; Ctrl+K

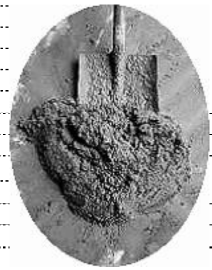
Proporsjonert betong

Materialer	kg/m³	Ønsket kg	Oppnådd kg	Volumkorreksjon korr. luft	korr. dens	Korrigert
Norcem Industri	0,0	0,0	0,0	0,0	0,0	0,0
Norcem lavvarme	805,6	108,7	108,7	0,0	74,3	879,8
	0,0	0,0	0,0	0,0	0,0	0,0
Elkem Microsilica	0,0	0,0	0,0	0,0	0,0	0,0
Normineral flyveaske	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Fritt vann	322,2	43,5	43,5	0,0	29,7	351,9
Absorbert vann	5,9	0,8	0,8	0,0	0,5	6,5
Årdal 0/8 mm nat. vask.	701,7	94,7	94,7	0,0	64,7	766,4
Årdal 0/2 mm nat. vask	0,0	0,0	0,0	0,0	0,0	0,0
Årdal 8/16mm	299,8	40,5	40,5	0,0	27,6	327,5
Årdal 16/22 mm	0,0	0,0	0,0	0,0	0,0	0,0
Velde 0/8 Industri S	0,0	0,0	0,0	0,0	0,0	0,0
Velde 8/16 Industri	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
	0,0	0,0	0,0	0,0	0,0	0,0
Mapei Dynamon SX-N	7,25	0,98	0,98	0,0	0,7	7,92
Mapei Dynamon SX-23	0,00	0,00	0,00	0,0	0,0	0,00
Mapeair 25 1:19	0,00	0,00	0,00	0,0	0,0	0,00
	0,00	0,00	0,00	0,0	0,0	0,00
Stålfiber	0,0	0,0	0,0	0,0	0,0	0,0
Basaltfiber	21,0	2,8	2,8	0,0	1,9	22,9
Prop. betongdens. (kg/m³)	2157			0,0	197,6	2356
	volum ok					

Fersk betong

Egenskap	
Ønsket volum (l)	135,0
Innveid volum (l)	135,0
Målt luftinnhold (%)	2,0
Målt betongdensitet (kg	2356
Effektivt v/(c+Σkp)	0,400

Aggressiver	
Kloridinnhold [% av b]	0,05 %
Alkalier [kg/m³]	6,36
Andel reakt. bergarter	0,0



Kommentarer:

Kommentarer:
Gule felt fylles ut, grønne beregnes.

Matriksvolumet inkluderer tilslagspartikler mindre en 0,125 mm.

Når fukt i tilslaget er bestemt på basis av ovnstørt tilslag skal absorbert fukt angis med målt verdi. Tilhørende densitet skal da også være basert på tørt tilslag . Dersom fukt i tilslaget er gitt på SSD-basis settes absorbert fukt lik 0. I så fall skal densitetene også angis som SSD-densitet.

Alle delmaterialer bortsett fra vann og TSS angis i tørr vekt. Ved beregning av volum, densiteter og masseforhold regnes vanninnholdet i TSS med i den fri vannmengden. Dette gjelder også korrigert resept. Dersom innveid mengde TSS avviker fra proporsjonert mengde korrigeres masseforhorld og mengde fritt vann i korrigert resept automatisk.

Merk at for pozzolaner, fillere og tilsetningsstoffer oppgis tørrstoffinnhold og fukt på våt basis, for tilslag på tørr basis. Fiber regnes ikke med i matriksvolumet.

Blandeskjema	SKANSKA

Prosjekt	Basaltfiber reinforced concrete
Reseptnummer	Batche 3-1.0%
Tilsiktet kvalitet	0

Blandevolum	135 liter
Dato:	
Tidspunkt for vanntilsetni	
Ansvarlig:	
Utført av:	

Materialer	**Resept** kg/m^3	**Sats** kg	**Fukt*** %	**Korr.** kg	**Oppveid**** kg	
Norcem Industri	0,0	0,000			0,000	
Norcem lavvarme	805,6	108,749			108,749	
	0,0	0,000			0,000	
Elkem Microsilica	0,0	0,000	0,0	0,000	0,000	
Normineral flyveaske	0,0	0,000			0,000	
	0,0	0,000			0,000	
Fritt vann	322,2	43,500		-1,972	41,528	42,325
Absorbert vann	5,9	0,797			0,797	
Årdal 0/8 mm nat. vask.	701,7	94,723	1,0	0,947	95,670	
Årdal 0/2 mm nat. vask	0,0	0,000	0,0	0,000	0,000	
Årdal 8/16mm	299,8	40,475	0,5	0,202	40,677	
Årdal 16/22 mm	0,0	0,000	0,5	0,000	0,000	
Velde 0/8 Industri S	0,0	0,000	0,0	0,000	0,000	
Velde 8/16 Industri	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	
Mapei Dynamon SX-N	7,2	0,979	84	0,822	0,979	
Mapei Dynamon SX-23	0,0	0,000	0	0,000	0,000	
Mapeair 25 1:19	0,0	0,000	0	0,000	0,000	
	0,0	0,000	0	0,000	0,000	
Stålfiber	0,0	0,000			0,000	
Basaltfiber	21,0	2,835			2,835	

*Se fotnote på delark "Resept" ** NB! Våte mengder, også for silikaslurry

Fersk betong					
Tid etter vanntilsetning					
Synkmål					
Utbredelsesmål					
Luft					
Densitet					

Prøvestykker (antall)					
Utstøpningstidspunkt					
Terninger					
150x300 sylindre					
100x200 sylindre					

iv. Grading curve of aggregates

Sammensatt tilslag

Fraksjon	Navn	Densitet [kg/m3]	Abs. fukt [%]	Alk. reakt. Sv[%]	Klorider [%]	Andel volum	Andel vekt	Bruk
I	Årdal 0/8 mm nat.	2650	0,5	0,0	0,00	0,703	0,700	ok
II	Årdal 0/2 mm nat.	2650	0,5	0,0	0,00	0,000	0,000	
III	Årdal 8/16mm	2680	0,8	0,0	0,00	0,297	0,300	ok
IV	Årdal 16/22 mm	2700	0,5	0,0	0,00	0,000	0,000	
V	Velde 0/8 Industri	2700	2,1	0,0	0,00	0,000	0,000	
VI	Velde 8/16 Industr	2700	1,0	0,0	0,00	0,000	0,000	
VII		2700	0,0	0,0	0,00	0,000	0,000	
VIII		2700	0,0	0,0	0,00	0,000	0,000	
IX		2700	0,0	0,0	0,00	0,000	0,000	
X		2700	0,0	0,0	0,00	0,000	0,000	
Sammensatt		2659		0,0	0,00	1,000	1,000	

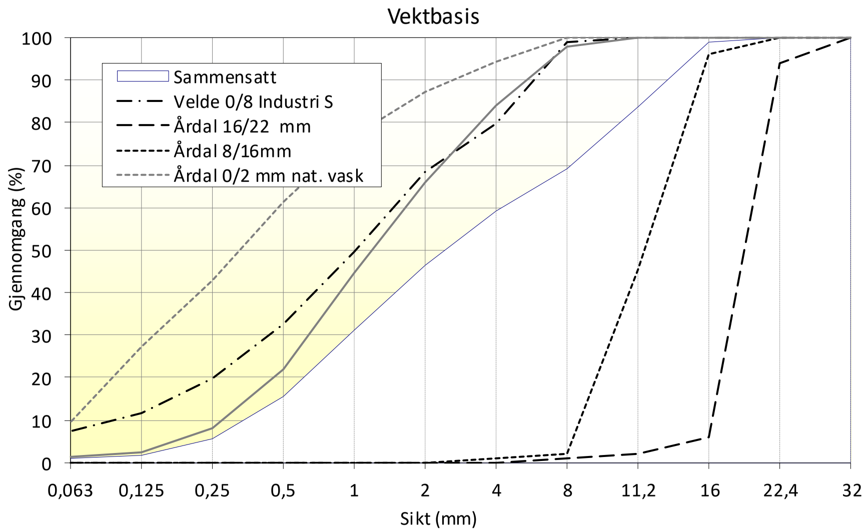
Finhetsmoduler	
FM_{vekt} =	4,23
FM_{vol} =	4,22
FM_{ref} =	4,71
FMg =	5,55

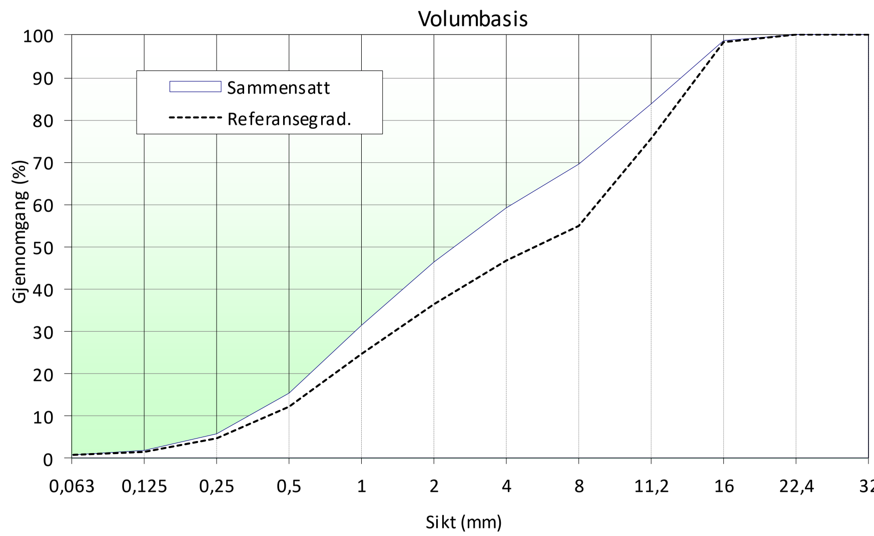
Tilpass til ref. gradering, Ctrl T

Sett ref. gradering, Ctrl R

Tilpass til FMg, Ctrl F

Åpning	Gjennomgang vol. [%]	Gjennomgang vekt [%]	Ref. grad. [vol. %]	Vekt ved tilpasning
32	100,0	100,0	100,0	1
22,4	100,0	100,0	100,0	1
16	98,8	98,8	98,2	1
11,2	83,8	83,7	75,7	1
8	69,4	69,1	55,1	1
4	59,3	59,1	46,9	1
2	46,5	46,3	36,6	1
1	31,3	31,2	24,7	2
0,5	15,5	15,4	12,2	2
0,25	5,8	5,8	4,6	2
0,125	1,8	1,8	1,4	2
0,063	0,9	0,9	0,7	2

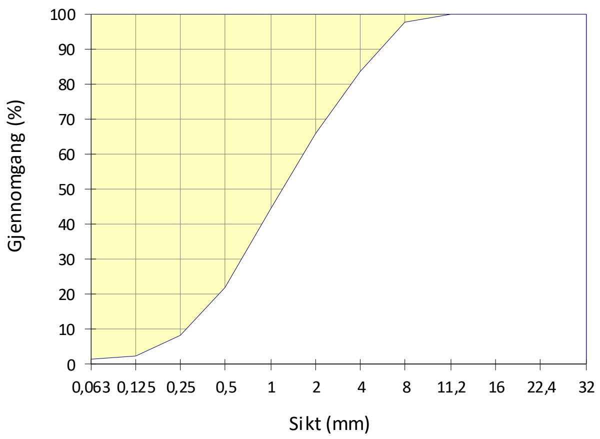




Fraksjon I

Type:	Årdal 0/8 mm nat. vask.
Dato:	#########
FM =	3,26

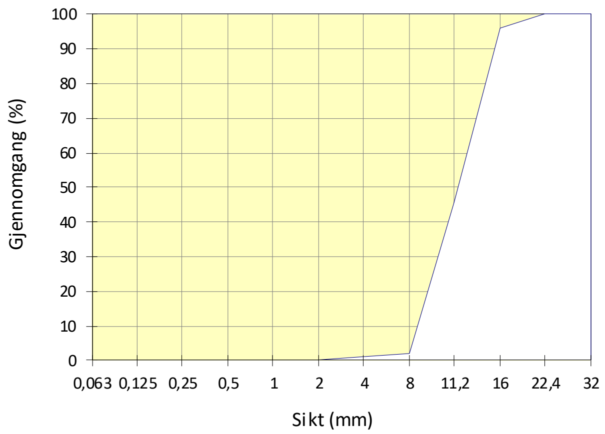
Åpning	Sikterest (g) 1	Sikterest (g) 2	Sikterest (%)	Gjennom-gang (%)
32	0	0	0,0	100,0
22,4	0	0	0,0	100,0
16	0	0	0,0	100,0
11,2	0	0	0,0	100,0
8	8,5	12,3	2,1	97,9
4	69	91,7	16,1	83,9
2	155,2	183,9	33,9	66,1
1	261,3	292,8	55,4	44,6
0,5	379,5	400,5	78,0	22,0
0,25	453,4	463,9	91,7	8,3
0,125	485,5	489,4	97,5	2,5
0,063	492,6	494,5	98,7	1,3
Bunn	500	500		



Fraksjon III

Type:	Årdal 8/16mm
Dato:	#########
FM =	6,51

Åpning	Sikterest (g) 1	Sikterest (g) 2	Sikterest (%)	Gjennom-gang (%)
32	0	0	0,0	100,0
22,4	0	0	0,0	100,0
16	3	5	4,0	96,0
11,2	55	54	54,5	45,5
8	98	98	98,0	2,0
4	99	99	99,0	1,0
2	100	100	100,0	0,0
1	100	100	100,0	0,0
0,5	100	100	100,0	0,0
0,25	100	100	100,0	0,0
0,125	100	100	100,0	0,0
0,063	100	100	100,0	0,0
Bunn	100	100		



v. Test results: compression test at 7 days

Toni Technik

Simple standard protocol

24.05.2022

Parameter table:

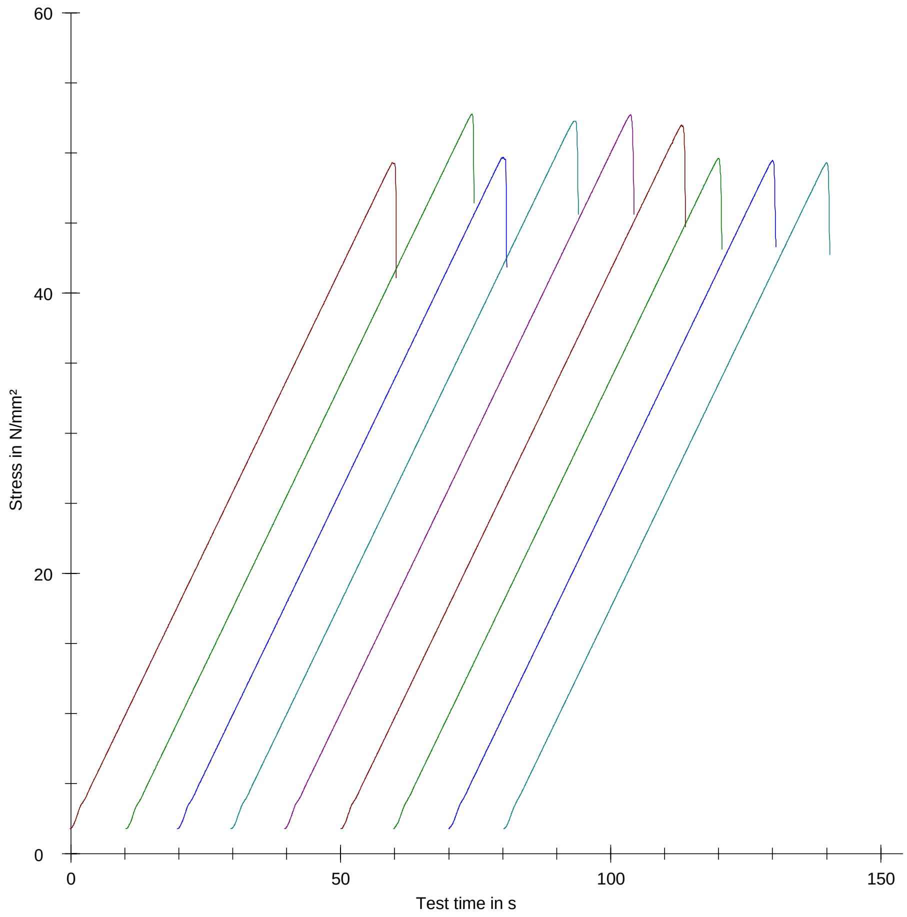
Test protocol :
Tester : UiS
Customer :
Test standard : EN-NS-12390-3
Strength grade:
Other :

Type strain extensometer:
Machine data :

Results:

Nr	Date	ID	a mm	b mm	Gauge length mm	F_m kN	σ_m N/mm²
1	05.04.2022	#1-0% fiber	100,0	100,0	50	493,11	49,31
2	05.04.2022	#1-0% fiber	100,0	100,0	50	527,55	52,76
3	05.04.2022	#1-0% fiber	100,0	100,0	50	496,79	49,68
4	05.04.2022	#2-0.5% fiber	100,0	100,0	50	522,59	52,26
5	05.04.2022	#2 -0.5% fiber	100,0	100,0	50	527,05	52,70
6	05.04.2022	#2-0.5% fiber	100,0	100,0	50	519,78	51,98
7	05.04.2022	#3-1% fiber	100,0	100,0	50	496,10	49,61
8	05.04.2022	#3-1% fiber	100,0	100,0	50	494,48	49,45
9	05.04.2022	#3-1% fiber	100,0	100,0	50	492,85	49,28

Series graphics:



vi. Test results: compression test at 28 days

Simple standard protocol 29.04.2022

Parameter table:

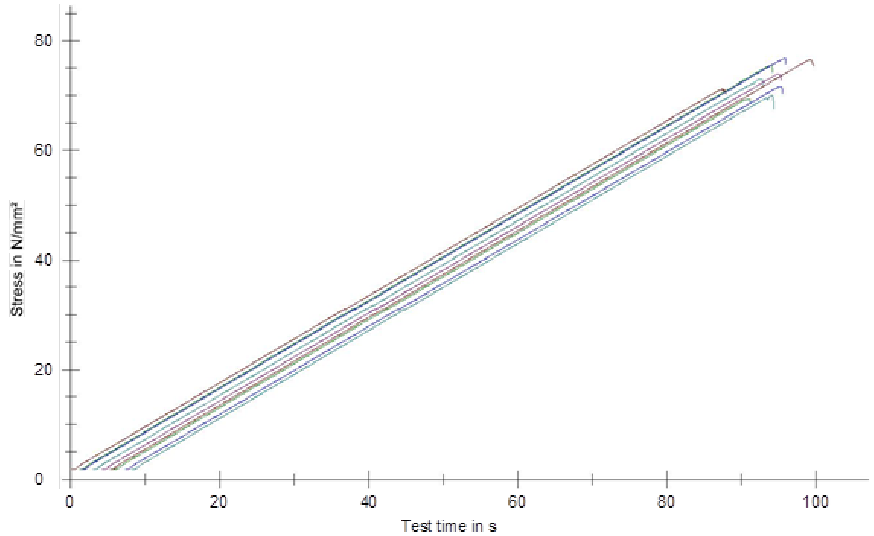
Test protocol : Compression test for cubes
Tester : Einar Mesloe, Shenyi Shen
Customer :
Test standard : NS-EN 12390-3:2019
Strength grade:
Creation date : 5 April 2022
Age : 28 T
Other :

Type strain extensometer:
Machine data : Controller TT0322
PistonStroke
LoadCell 3 MN

Results:

Nr	Date	ID	a mm	b mm	A mm²	h mm	F_m kN	σ_m N/mm²
1	26.04.2022	0% 1 28days	100,0	100,0	10000,0	100,0	712,86	71,29
2	26.04.2022	0% 2 28days	100,0	100,0	10000,0	100,0	755,07	75,51
3	26.04.2022	0% 3 28days	100,0	100,0	10000,0	100,0	768,61	76,86
4	26.04.2022	0,5% 1 28days	100,0	100,0	10000,0	100,0	729,92	72,99
5	26.04.2022	0,5% 2 28days	100,0	100,0	10000,0	100,0	738,69	73,87
6	26.04.2022	0,5% 3 28days	100,0	100,0	10000,0	100,0	765,47	76,55
7	26.04.2022	1% 1 28days	100,0	100,0	10000,0	100,0	694,25	69,42
8	26.04.2022	1% 2 28days	100,0	100,0	10000,0	100,0	716,28	71,63
9	26.04.2022	1% 3 28days	100,0	100,0	10000,0	100,0	699,94	69,99

Series graphics:



Statistics:

Series n = 9	a mm	b mm	A mm²	h mm	F_m kN	σ_m N/mm²
$\bar{x}$	100,0	100,0	10000,0	100,0	731,23	73,12
s	0,0	0,0	0,0	0,0	27,62	2,76
ν	0,00	0,00	0,00	0,00	3,78	3,78

vii. Test results: flexural tensile strength

Simple standard protocol **29.04.2022**

Parameter table:

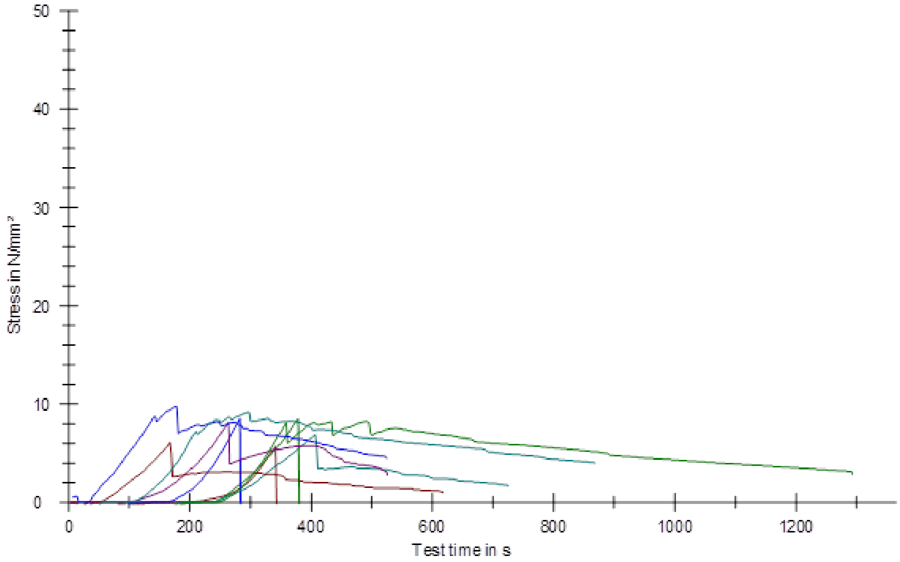
Test protocol : Flexural tensile test
Tester : Einar, Shenyi
Customer :
Test standard : NS-EN 12390-5:2019
Strength grade :
Creation date : 5 April 2022
Age : 28 T
Other :

Type strain extensometer :
Machine data : Controller TT 1412
PistonStroke
LoadCell 250 kN

Results:

Nr	Date	ID	a mm	b mm	A mm²	h mm	F_m kN
1	26.04.2022	0% specimen 1	100,0	500,0	50000,0	100,0	8,17
2	26.04.2022	0% specimen 2	100,0	500,0	50000,0	100,0	12,29
3	26.04.2022	0% specimen 3	100,0	500,0	50000,0	100,0	12,35
4	26.04.2022	0.5% specimen 1	100,0	500,0	50000,0	100,0	9,90
5	26.04.2022	0.5% specimen 2	100,0	500,0	50000,0	100,0	11,77
6	26.04.2022	0.5% specimen 3	100,0	500,0	50000,0	100,0	8,83
7	26.04.2022	1.0% specimen 1	100,0	500,0	50000,0	100,0	11,88
8	26.04.2022	1.0% specimen 2	100,0	500,0	50000,0	100,0	14,11
9	26.04.2022	1.0% specimen 3	100,0	500,0	50000,0	100,0	13,25

Series graphics:



Statistics:

Series n = 9	a mm	b mm	A mm²	h mm	F_m kN
x	100,0	500,0	50000,0	100,0	11,39
s	0,0	0,0	0,0	0,0	2,00
	0,00	0,00	0,00	0,00	17,59

Page 1/1

viii. Test results: residual tensile strength

Toni Technik

Simple standard protocol **29.04.2022**

Parameter table:

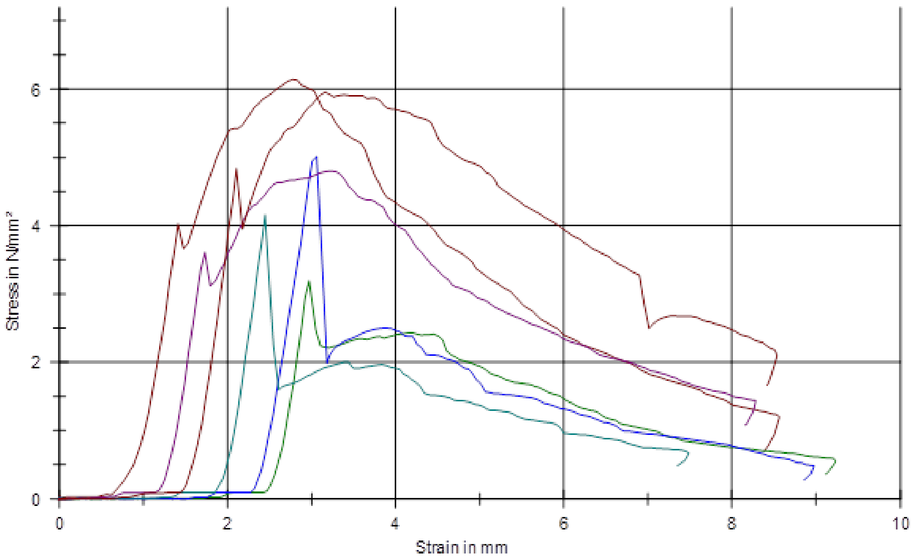
Test protocol :
Tester :
Customer :
Test standard : NS-EN 12390-5-2019
Strength grade : B70
Creation date : 05.03.2022
Age : 28 T
Other :

Type strain extensometer :
Machine data : Controller TT1412
PistonStroke
LoadCell 250 kN

Results:

Nr	ID	a mm	b mm	A mm²	h mm	F_m kN
1	1% specimen 1	150,0	550,0	90000,0	150,0	27,62
2	0,5% specimen 1	150,0	550,0	90000,0	150,0	14,34
3	0,5% specimen 2	150,0	550,0	90000,0	150,0	22,57
4	0,5% specimen 3	150,0	550,0	90000,0	150,0	18,71
5	1% specimen 2	150,0	550,0	90000,0	150,0	21,60
6	1% specimen 3	150,0	550,0	90000,0	150,0	26,81

Series graphics:



ix. Material data sheet: SCHWENK Low heat cement

SCHWENK

Teknisk datablad

Lavvarmesement

CEM III/B 42,5 L-LH/SR (na)

Rüdersdorf

Sammensetning:	Slaggsement
Bruk:	Til bruk i betongproduksjon. Elementindustri, ferdigbetong og injeksjon.
Egenskaper:	Lav varme- og herdeutvikling. Lavt CO2 avtrykk.

Tilfredsstiller kravene ihht. EN 197-1: CEM III/B 42,5 L-LH/SR (na)
Produktet er sertifisert (CE-merket) ihht. EN 197-1 av VDZ, Tyskland

Typiske data:

Fysiske data

Finhet(blaine)		4700 cm²/g
Densitet		2,98 g/cm³
Bulkdensitet		1,1g/cm³
Andel slagg		Ca 70%
Bindetid		230 min
Ekspansjon		0,3 mm
Trykkfasthet		
	2d	28 Mpa
	7d	36 MPa
	28d	58 MPa
	56d	64 MPa

Kjemiske data

		vekt %
Kalk	(CaO)	49
Silisium	(SiO_2)	31
Aluminium	(Al_2O_3)	8,3
Magnesium	(MgO)	6,1
Sulfat	(SO_3)	2,1
Jern	(Fe_2O_3)	1,6
Kalium	(K_2O)	0,6
Natrium	(Na_2O)	0,3
Alkali ekv.	(Na_2Oekv)	0,79
(C_3A)		5,3
Glødetap	(L.O.I)	0,7
Uløselig rest	(i.r)	0,2
Vannnløslig klorid	(Cl^-)	0,05
Vannnløslig krom	$Cr^{(VI)}$	< 2 mg/kg

CE
0840

CEMEX Zement GmbH
Werk Rüdersdorf
Frankfurter Chaussee
15562 Rüdersdorf

0840-CPD-5520-340595-16
EN 197-1
CEM III/B 42,5 L-LH/SR (na)

Teknisk spørsmål:
Lars Busterud, tel 908 90 668
- E-Mail lars.busterud@schwenk.no

Versjon August 2019

SCHWENK Norge AS
Grønland 70A, 3045 Drammen
Telefon: +47 31 02 10 11
E-Mail: info@schwenk.no · www.schwenk.no

x. Material data sheet: Dynamon SX-N superplasticizer

MAPEI

Dynamon SX-N

Superplastiserende tilsetningsstoff

BESKRIVELSE
Dynamon SX-N er et svært effektivt superplastiserende tilsetningsstoff basert på modifiserte akrylpolymerer. Produktet tilhører **Dynamon-systemet** basert på den Mapei-utviklede DPP-teknologien (DPP = Designed Performance Polymers), der tilsetningsstoffenes egenskaper skreddersys til ulike betongformål. **Dynamon-systemet** er utviklet på basis av Mapeis egen sammenstilling og produksjon av monomerer.

BRUKSOMRÅDER
Dynamon SX-N er et tilnærmet allround-produkt som er anvendelig i all betong for å øke støpeligheten og/eller redusere tilsatt vannmengde.

Noen spesielle bruksområder er:

- Vanntett betong med krav til høy eller svært høy fasthet og med strenge krav til bestandighet i aggressive miljøer.
- Betong med særlige krav til høy støpelighet; i konsistensklasser S4 og S5 etter NS-EN 206.
- Selvkomprimerende betong med ønske om lengre åpentid. Om nødvendig kan SKB stabiliseres med en viskositetsøker - **Viscofluid** eller **Viscostar**.
- Til produksjon av frostbestandig betong - da i kombinasjon med luftinnførende tilsetningsstoffer - **Mapeair**. Valg av type luftinnførende stoff gjøres ut fra egenskapene til de andre delmaterialer som er tilgjengelige.
- Til golvstøp for å oppnå en smidig betong med bedret støpelighet. Store doseringer og lave temperaturer kan retardere betongen noe.

EGENSKAPER
Dynamon SX-N er en vannløsning av aktive akrylpolymerer som effektivt dispergerer (løser opp) sementklaser.

Denne effekten kan prinsipielt utnyttes på tre måter:

1. For å redusere mengden tilsatt vann, men samtidig beholde betongens støpelighet. Lavere v/c-forhold gir høyere fasthet, tetthet og bestandighet i betongen.
2. For å forbedre støpeligheten sammenlignet med betonger med samme v/c-forhold. Fastheten forblir dermed den samme, men muliggjør forenklet utstøping.
3. For å redusere både vann og sementmengde uten å forandre betongens mekaniske styrke. Gjennom denne metoden kan en blant annet redusere kostnadene (mindre sement), redusere betongens svinnpotensial (mindre vann) og redusere faren for temperaturgradienter på grunn av lavere hydratasjonsvarme.
   Spesielt er denne siste effekten viktig ved betonger med større sementmengder.

Dynamon SX-N

KOMPATIBILITET MED ANDRE PRODUKTER
Dynamon SX-N lar seg kombinere med andre Mapei tilsetningsstoffer, som f.eks størkningsakselererende stoffer som **Mapefast** og størkningsretarderende stoffer som **Mapetard**.
Produktet lar seg også kombinere med luftinnførende tilsetningsstoffer, **Mapeair**, for produksjon av frostbestandig betong.

Valg av type luftinnførende stoff gjøres ut fra egenskapene til de andre delmaterialer som er tilgjengelige.

DOSERING
Dynamon SX-N tilsettes for å oppnå ønsket resultat (styrke, bestandighet, støpelighet, sementreduksjon) ved å variere doseringen mellom 0,4 og 2,0 % av sement + flyveaske + mikrosilika. Ved økt dosering økes også betongens åpentid, dvs. tiden betongen lar seg bearbeide. Større doseringsmengder og lave betongtemperaturer gir en retardert betong. Vi anbefaler alltid prøvestøper med aktuelle parametere.

Til forskjell fra konvensjonelle melamineller naftalenbaserte superplastiserende tilsetningsstoffer, utvikler **Dynamon SX-N** maksimal effekt uavhengig av tilsettingstidspunkt, men tilsetningstidspunktet kan påvirke nødvendig blandetid.

Dersom **Dynamon SX-N** tilsettes etter at minst 80 % av blandevannet er inne vil blandetiden generelt være kortest. Det er likevel viktig med utprøvinger tilpasset eget blandeutstyr.

Dynamon SX-N kan også tilsettes direkte i automikser på bygg- eller anleggsplass. Betongen bør da blandes med maksimal hastighet på trommelen i ett minutt pr. m^3 betong i lasset, men minimum 5 minutter.

EMBALLASJE
Dynamon SX-N leveres i 25 liters kanner, 200 liters fat, 1000 liter IBC-tanker og i tank.

LAGRING
Produktet må oppbevares ved temperaturer mellom +8°C og +35°C. I lukket emballasje bevarer produktet sine egenskaper i minst 12 måneder. Hvis produktet utsettes for direkte sollys, kan det føre til variasjoner i fargetonen uten at dette påvirker egenskapene til produktet.

SIKKERHETSINSTRUKSJONER FOR KLARGJØRING OG BRUK
For instruksjon vedrørende sikker håndtering av våre produkter, vennligst se siste utgave av sikkerhetsdatablad på vår nettside www.mapei.no

PRODUKT FOR PROFESJONELL BRUK.

MERK
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Dynamon SX-N

TEKNISKE DATA (typiske verdier)

PRODUKTBESKRIVELSE	
Form:	væske
Farge:	gulbrun
Viskositet:	lettflytende; < 30 mPa·s
Tørrstoffinnhold (%):	18,5 ± 1,0
Densitet (g/cm³):	1,06 ± 0,02
pH:	6,5 ± 1
Kloridinnhold (%):	< 0,05
Alkaliinnhold (Na_2O-ekvivalenter) (%):	< 2,0

6392-07-2017(NO)

MAPEI®
BUILDING THE FUTURE

xi. Material data sheet: ReforceTech MiniBars™

ReforceTech
Creating Opportunities

PRODUCT DATA SHEET

MiniBars™

HIGH PERFORMANCE COMPOSITE MACROFIBER FOR CONCRETE REINFORCEMENT

DESCRIPTION

MiniBars™ solution is a high-performance composite macrofibre, based on an alkali-resistant glass fibre or basalt and engineered to provide high post-cracking strength to concrete while at the same time increasing toughness, impact, and fatigue resistance of concrete. MiniBars™ macrofibre can be used as secondary and/or as primary reinforcement. MiniBars™ fibre disperses quickly and evenly throughout the concrete matrix, due to their specific gravity being similar to concrete. This promotes uniform performance throughout the concrete mass.

BENEFITS

- Improves post-cracking mechanical properties of hardened.
- Concrete Fast and uniform dispersion during mixing.
- Does not affect concrete pumpability when following recommended practices.
- Allows for high dosages with minimum effect on processability. (mix dependent)
- Does not corrode.
- No additional water demands.
- Easy to handle.

APPLICATIONS

MiniBars™ solution has been specifically designed to reduce or replace secondary and/or primary steel reinforcement in many structural applications requiring flexural tensile and post-crack performance (wall panels, pipes, water tanks, tunnel segments, marine structures, raft foundations, etc.)

HOW TO USE

MiniBars™ fibres can be added to the wet mix at the batching plant or into the concrete truck at site. For optimum dispersion and performance, it is recommended to add the fibre gradually.

Dosage rates are dependent on the application and desired performance levels.

PACKAGING AND STORAGE

MiniBars™ fibres in the 43mm length are packed in 10 kg (22 lbs) cardboard boxes. MiniBars™ solution should be stored away from heat and moisture in their original packaging.

Optimum conditions are temperatures between 10°C (50ºF) and 35°C (95ºF) and relative humidity between 25% and 65%.

QUALITY STANDARDS – CERTIFICATION

MiniBars™ fibres are manufactured under a quality Management System approved to ISO 9001.

Basalt MiniBars ETA-20/0599, Cem-Fil MiniBars™ ETA19/0246. Ref Environmental ReforceTech Product Declaration (EPD) available.

MINIBARS™

HIGH PERFORMANCE COMPOSITE MACROFIBER

TECHNICAL CHARACTERISTICS

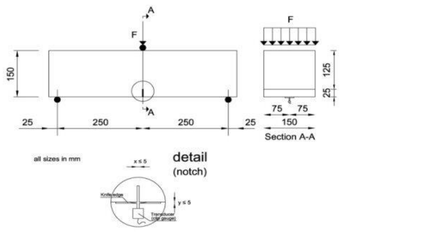
Material	Fiber Length	Fiber Diameter	Specific Gravity	Modulus of Elasticity	Tensile Strength
Alkali-resistant glass+ thermoset resin	43 +/-2 mm* 1.7 +/- 0.08 in.	0.70 mm 0.03 in.	2.0 ± 0.1	42 GPa 6,091,585 psi	> 1000 MPa / 145,038 psi

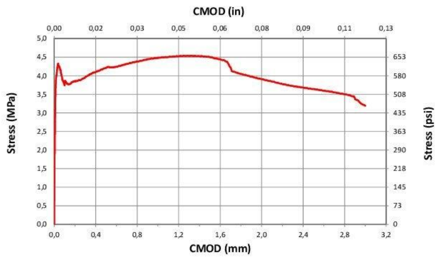
* Shorter or longer fibers are available on request

MECHANICAL PERFORMANCE

The fundamental mechanical performance of fiber reinforced concrete can be obtained from a three-point bending test performed on a prismatic beam of 150×150×550mm (6×6×22in.) including a notch at mid-span (EN 14651). The displacement-controlled testing system introduces a specific deflection or CMOD (Crack Mouth Opening Displacement) rate, and records load and displacement up to a CMOD limit of 3.5 mm (0.14 in). The fiber reinforced concrete performance is evaluated by means of residual flexural strength values at 0.5, 1.5, 2.5, and 3.5mm (0.02, 0.06, 0.10, and 0.14in.) of CMOD, namely f_{R1}, f_{R2}, f_{R3} and f_{R4}, respectively.

According to the fib Model Code 2010, the constitutive law of the material in tension is defined by means of the tensile stresses f_{Fts} and f_{Ftu}, calculated from f_{R1} and f_{R3} for service and ultimate limit state, respectively.





The sketch shows the basic configuration of the test.

The following curve shows a typical Load-CMOD response of a C30/37 concrete
(4400 psi) reinforced with 10 kg/m³ (17 lbs/yd³) of MiniBars™. The table presents the mean values of residual strength.

Concrete Description :
EN206-1 C30/37 XC3/XC4 Dmax20 S4 CL 1.00, Slump=22 cm
ACI 211| 4400 PSI Concrete, C1/F1 exposure class, 8 ½" max. aggregate, 8 ¾" slump

Mean flexural performance (prism 100x100x400mm | 4x4x16 in)	MPa (mean)	psi (mean)
f_c (100 mm / 4 in cube)	46.9	6800
f_L	4.35	631
f_{R1}	3.67	532
f_{R2}	3.99	579
f_{R3}	3.61	524
f_{R4}	3.12	453
ARS= (f_{R1}+ f_{R2}+f_{R3}+ f_{R4})/4	3.60	520

Note: using a 100×100×400mm (4x4x16 in), f_{R1}, f_{R2}, f_{R3}, and f_{R4}, are calculated at 0.4, 1.2, 2.0, and 2.8mm of CMOD, respectively

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