THE EFFECT OF BASALT FIBRE ON THE PROPERTIES OF NORMAL-WEIGHT CONCRETE

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Annotation

In Estonia, fibre-reinforced concrete is most widely used in floors – approximately 90% of them are made of it. Metallic fibres are the most common type of fibres used in floors, but polypropylene, plastic and glass fibres are also used if necessary. These days, another fibre type is trying to enter the market – basalt fibre. In Estonia, it has been used very little and due to that, there is a lack of detailed knowledge of how it behaves. The present article is about an experimental investigation of the effects of basalt fibre on normal-weight concrete, which has been compared with more common metallic and polymer fibres. The study handles the effects of fibres on the consistency of concrete, the air content, shrinkage and compression and flexural tensile strength. The research is based on the Master's thesis of Martin Trossek, which has been defended in Tallinn University of Technology in 2015.

Key words: *basalt fibre; mechanical strength; mechanical testing.*

1. Introduction

Concrete is by its nature fragile and has a very small tensile strength. The mechanical properties of concrete, e.g. the flexural tensile strength, the impact resistance, fatigue and toughness can be improved by using randomly oriented fibres (Chaohua et al. 2014; Mohammadi et al. 2008; Yazici et al. 2007). The use of fibres also prevents the development, propagation and merging of cracks (Felekoglu et al. 2009; Banthia and Sappakittipakorn 2007). Fibre reinforced concrete is made of Portland cement, containing fine and course aggregate and discontinuous discrete fibres. Various types of fibres can be used to reinforce the concrete, such as metallic, organic, glass, asbestos and polypropylene fibres, which are sometimes also mixed together. Fibre reinforced concrete is used e.g. in airport taxiways, highways and especially in military buildings.

Basalt fibres have become a potential alternative for other types of fibres, because among other things they have a high elastic modulus and strength and they are resistant to high temperatures and chemicals (Tumadhir 2013; Barashykov et al. 2012; Gulik and Biland 2012; Huang and Deng 2010; Jiang et al. 2010). Credit for the basalt fibre production process has to be given to Paul Dhé, who in 1923 got a US patent for extruding filaments from basalt. Despite of that, more active research on basalt fibres was started after World War II. It is known that scientific research of basalt in the Soviet Union was started in the 50's and in the 60's intense scientific research and development was also started in the USA. However, basalt became more widely known after the fall of the Soviet Union when the research and development that was concentrated in Ukraine, was taken into use in the field of civil engineering. (Sonjoy 2013)

Basalt is the most common rock in the earth's crust. The rock itself has an extremely big density and strength and has also good thermal properties (Abbas 2013). From the chemical composition, basalt is quite similar to glass. In nature, basalt can be found with different chemical compositions. The main component of basalt is SiO_2. The colour of basalt varies from brown to faded green and depends on the content of iron, which in turn defines the thermal resistance. The mechanical properties of the fibres depend on the content of SiO_2 and Al_2O_3. Basalt fibres do not contain any additives, which makes production cheap and gives an additional advantage in price. It is possible to produce different length and diameter of basalt fibres, depending on the required properties. Basalt fibres are manufactured by melting basalt rock. There are two production methods: short fibres are produced using the Junkers method and continuous fibres using the Spinneret method.

Basalt's properties and behaviour in concrete (Fiore et al. 2015; Dhand et al. 2015; Chaohua et al. 2014; Kabay 2014; Smitri 2014; Ayub et al. 2014; Abbas 2013; Dias and Deak and Czigany 2009; Thaumaturgo 2005; Sim et al. 2005):

- Basalt has a very wide operating temperature range. The temperature where concrete loses most of its strength is still a suitable environment for basalt. Thermal stability tests done in the Reykjavik University showed, that after a two-hour heating at 1200°C and one-day cooling, the carbon fibres had lost most of their strength, glass fibres some of their strength and for the basalt no changes were observed. The suitable temperature range for basalt is from -200°C to +820°C.
- Concrete reinforced with basalt has a high corrosion and chemical resistance, high resistance to weathering, high frost resistance and water tightness. Thus, basalt fibres extend the life cycle of concrete.
- The densities of basalt and concrete are similar, thus basalt spreads more evenly in fresh concrete and does not sink to the bottom or rise to the top while hardening.
- Basalt has good mechanical properties – a high elastic modulus and strength. Tests have shown that basalt fibre, independent of the dosage, does not affect concretes' compressive strength. However, basalt does affect the flexural tensile strength and toughness, allowing bigger deformations and making it less sensitive to cracking.
- For larger dosages, the probability of balling is bigger, leaving voids in the concrete matrix. In addition, part of the cement may stay in its powder state, which is caused by the water intake of the fibres and thus there may not be enough water for the hydration of cement minerals.
- Basalt is a notable isolator for noise, heat and vibrations and has good electrical properties.
- Environmentally friendly, biologically inactive, non-poisonous and extracts very little toxic gasses when heated.

The technical properties of basalt (Nulk 2014; Sonjoy 2013):

- Density: 2,6-2,8 kg/m^3
- Diameter of the filament: 9-23 µm
- Tensile strength: 3200-4840 MPa
- Modulus of elasticity: 89 GPa
- Elongation at break: 3,1%
- Compressive strength: 3800 MPa
- Melting temperature: 1450°C
- Operating temperature range: -260°C…+820°C
- Thermal conductivity: 0,035 W/(mk)
- Moisture absorption: <0,1%
- Sound absorption: 0,90-0,99%

2. Theory and methods

Many publications have come out, where the results of researches on basalt fibres and their effect on concrete have been presented (Ayub et al. 2014; Chaohua et al. 2014; Alani et al. 2013; Sonjoy 2013; Manikandan et al. 2012; Fiore et al. 2011; Silvakumar et al. 2009; Sim et al. 2005; Dias and Thaumaturgo 2005).

Fibre reinforced concrete is variable by its nature, in addition to its dependence of the concrete content it depends on the type and content of fibre, their properties, orientation and distribution. The properties of fibre reinforced concrete depend mostly on the content of fibres, i.e. the dosage. However, the amount of fibres, their specific surface area and the spacing pay also an important role. The convenient numerical parameter to describe the fibres is the aspect ratio, i.e. the relation of length to diameter. In addition to the fibres' own strength and elasticity parameters, its effectiveness also relies on its anchorage in the concrete matrix, which is also the basis for toughness. The anchoring depends mostly on the shape of the fibre. The even distribution and scattering of the fibres is also important, because it affects the improvement of mechanical properties. The random distribution assures that the stress is distributed over the whole specimen improving concretes' properties in all directions.

The effect of fibres on the static bending strength (the flexural tensile strength of concrete itself) is not very significant. It can be said, that the purpose of using fibres is not to increase the flexural tensile strength of concrete itself (with short microfibers also that is possible), but to control the cracking and ensure toughness after the development of cracks, which makes the concrete behave plastically and eliminates brittle failure (Dias and Thaumaturgo 2005). So in order to benefit from the addition of fibres, their effect on the post-cracking strength has to be taken into consideration (Abbas 2013).

When plain concrete reaches its maximum flexural tensile strength it is not plastic and failure occurs without any warning. Reinforcing with fibres changes the failure mode completely. The energy that originates from the loading and shrinking of fibre reinforced concrete is passed on to the fibres. Distribution of that energy is dependent on the amount of fibres – the more fibres there are the more homogeneous will the distribution of energy be. In addition to the amount of fibres, the even distribution and closeness of fibres is also important, which affect the distribution of energy, which in turn affects the probability of the generation of cracks. In the beginning stages of micro cracking, the fibres going through the crack prevent and control the opening and growth of cracks with the objective not to let the micro-cracks evolve bigger. Before the specimens' deflection can be seen, the stress-strain diagram turns non-linear and when studying it microscopically, a lot of small cracks can be identified. The addition of fibres regularly does not affect the force at which the first crack arises. When the flexural tensile strength of concrete is exceeded, then thanks to the fibres in the concrete, the structure will not collapse. The randomly orientated fibres will start to take on load, prevent further cracking and hence hold the specimen together. The critical amount of fibres will determine the carrying capacity, or the increase or decrease of it, after the development of cracks. The critical amount of fibres is such, which holds the load level after cracking similar as it was before cracking. When the load increases, the concrete will enter a state, where the fibres will start to deform and the carrying capacity will start to decrease. The deformation will result in the breaking of fibres or their pulling out of the concrete and that will cause the failure of the concrete.

The main tool for estimating the toughness (energy absorbed by the beam that is caused by the load induced flexural deflection) is the stress-strain curve. For normal-weight concrete, after the ultimate load has been reached, the toughness decreases and deflection increases. Adding fibres into the concrete does not increase the flexural tensile strength of concrete itself, but increases the toughness. The longer the fibres and the bigger the slenderness ratio, the bigger the toughness will be. The toughness can also be raised by increasing the concrete strength class. The effect fibres have to the failure of concrete is illustrated in Fig. 1.

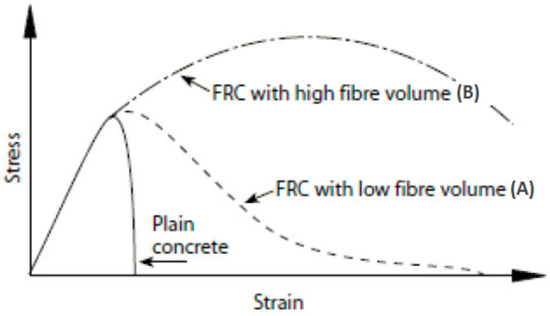


Fig. 1. Stress-strain curve (Abbas 2013)

Fibre reinforced concrete is characterized by a linear increase in stress until the first crack opening. When the fibre volume is low, failure occurs according to diagram A. When the flexural tensile strength of concrete is reached, the loadbearing capacity decreases according to how the fibres start working in the cracked cross-section. Thanks to those fibres, concrete will not fail completely. The extent of how much the loadbearing capacity will decrease, depends of many factors among which the main one is the amount of fibres. When the load increases, the fibres that are in the crack will start straightening and breaking up, and with that comes the loss of carrying capacity (the so-called softening branch). But when the fibre volume is high, failure occurs according to diagram B. After the flexural tensile strength of concrete has been reached, a crack develops and the fibres that are in the cracked cross-section start working. Thanks to the cracking, more fibres start working and the load-bearing capacity increases. That is followed by reaching the ultimate strength after which, failure occurs similarly to diagram A.

3. EXPERIMENTAL INVESTIGATION

3.1. Description of the concrete mix

Three different recipes were used for the concrete mixes (Table 1). The materials correspond to the following standards:

- EN 12620:2002+A1:2008 Aggregates for concrete
- EN 934-2:2009+A1:2012 Admixtures for concrete, mortar and grout - Part 2: Concrete admixtures - Definitions, requirements, conformity, marking and labelling
- EN 197-1:2011 Cement - Part 1: Composition, specifications and conformity criteria for common cements

- EN 1008:2002 Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete

Table 1

Material contents of recipes 1-3

Recipe nr.	Material[2)]	Fraction	Content (%)	Weight of dry material (kg/m^3)	Amount
1	Fine aggregate	0/2	11,3	209	-
		0/4	40,2	743	-
	Coarse aggregate	4/16	48,5	897	-
	Cement[1)]	-	-	-	325 kg/m^3
	Water	-	-	-	180 l/m^3
	Water-cement ratio	-	-	-	0,554
2	Fine aggregate	0/2	24	444	-
		0/4	32	592	-
	Coarse aggregate	4/16	44	814	-
	Cement[1)]	-	-	-	325 kg/m^3
	Water	-	-	-	180 l/m^3
	Water-cement ratio	-	-	-	0,554
3	Fine aggregate	0/2	18	315	-
		0/4	33	582	-
	Coarse aggregate	2/8	10,5	183	-
		4/16	33	583	-
	Limestone filler		5,5	101	-
	Cement[1)]	-	-	-	349 kg/m^3
	Water	-	-	-	190 l/m^3
	Water-cement ratio	-	-	-	0,545

Remarks:
1) Cement: CEM II/B-M (T-L) 52,5N
2) Plasticizer: Mapei Dynamon Xtend

The fibres were chosen according to what is most common on the Estonian market. Two types of metallic fibres (HE 75/50 ja Tabix 90/35), two types of polymer fibres (Barchip 48 class II and Eurofiber Ref 512 class I) and one type of basalt fibre (Chopped Basalt Fiber RBR-18-T10) were used. The lengths of chopped basalt fibres were 12 mm and 24 mm, the fibre diameter was 18±2 μm and the moisture content 1%. The technical data of the fibres is presented in Tables 2-3 and illustrated in Figs 2-6.

Table 2

Technical data of the metallic fibres (*source: ArcelorMittal*)

Parameter	HE 75/50	Tabix 90/35
Diameter of the fibre (d)	0,75 mm	0,90 mm
Length of the fibre (L)	50,0 mm	35,0 mm
Amount of fibres per kg	5700	5500
Total length of fibres per 10 kg	2885 m	1925 m
Tensile strength of the fibre	1100 MPa	1200 MPa

Table 3

Technical data of the polymer fibres
(*source: Elasto Plastic Concrete Ltd; Betotrade OÜ*)

Parameter	Barchip 48	Eurofiber Ref 512
Material	Modified olefin	Polypropylene
Length of the fibre (L)	48 mm	12 mm
Diameter of the fibre (d)	0,72 mm	20 μm
Density	0,90-0,92 kg/m^3	0,91 kg/m^3
Tensile strength of the fibre	640 N/mm^2	170-240 N/mm^2
Modulus of elasticity	10 GPa	0,57 GPa

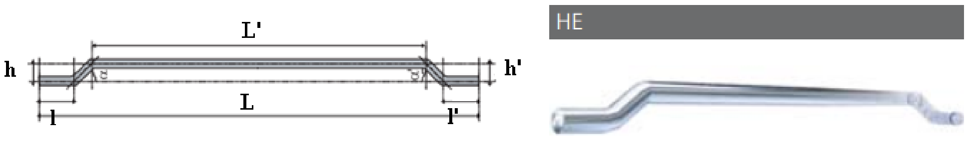


Fig. 2. HE 75/50 (*source: ArcelorMittal*)

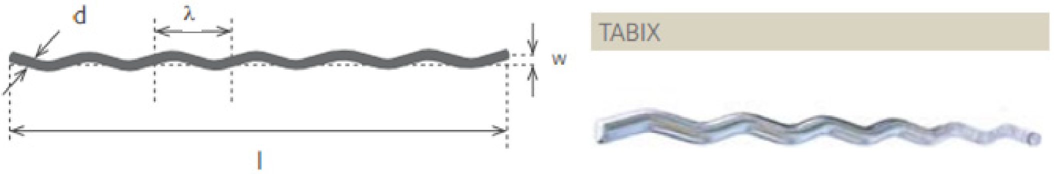


Fig. 3. Tabix 90/35 (*source: ArcelorMittal*)

Fig. 4. Barchip 48 fibres (*source: Elasto Plastic Concrete Ltd*)

Fig. 5. Eurofiber Ref 512 (*source: Betotrade OÜ*)

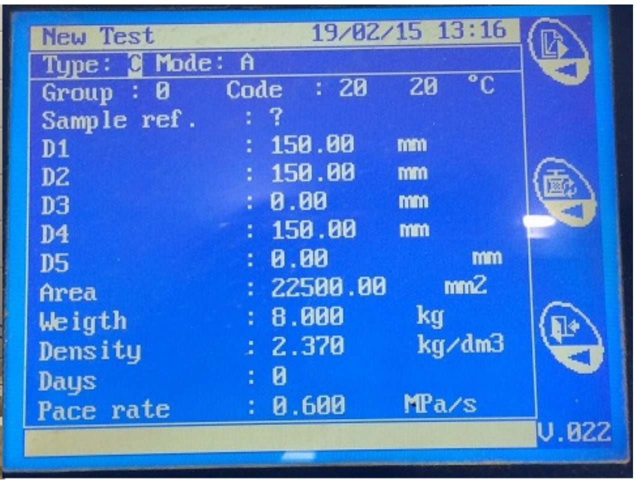
Fig. 6. Basalt fibre (*source: Technobasalt-Invest LLC*)

3.2. Test methods

The necessary tests were conducted in the mechanical testing laboratory of the faculty of construction of TTK University of Applied Sciences, the test laboratory of Rudus AS Lagedi factory and the science and testing laboratory of building materials in Tallinn University of Technology (Figs 7-11). The tests were based on the following standards:

- EN 12390-2:2009 Testing hardened concrete - Part 2: Making and curing specimens for strength tests;
- EN 12390-3:2009+AC:2011 Testing hardened concrete - Part 3: Compressive strength of test specimens;
- EN 12350-2:2009 Testing fresh concrete - Part 2: Slump test;
- EVS-EN 12350-7:2009 Testing fresh concrete - Part 7: Air content - Pressure methods;

- EN 14651:2005+A1:2007 Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual);
- EN 14845-1:2007 Test methods for fibres in concrete - Part 1: Reference concretes;
- EN 14845-2:2006 Test methods for fibres in concrete - Part 2: Effect on concrete;
- EN 772-14:2001 Methods of test for masonry units - Part 14: Determination of moisture movement of aggregate concrete and manufactured stone masonry units.



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New Test                    19/02/15 13:16
Type: C Mode: A
Group : 0     Code  : 20    20   °C
Sample ref.   : ?
D1            : 150.00    mm
D2            : 150.00    mm
D3            : 0.00      mm
D4            : 150.00    mm
D5            : 0.00            mm
Area          : 22500.00     mm2
Weigth        : 8.000      kg
Density       : 2.370      kg/dm3
Days          : 0
Pace rate     : 0.600     MPa/s
                                  V.022
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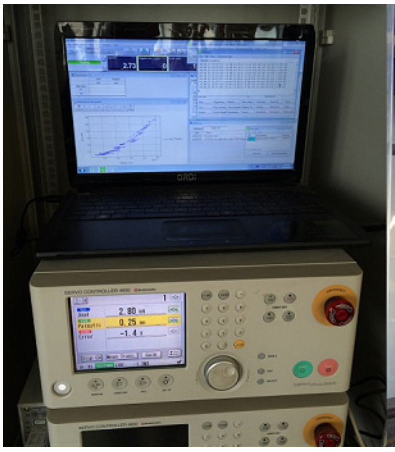
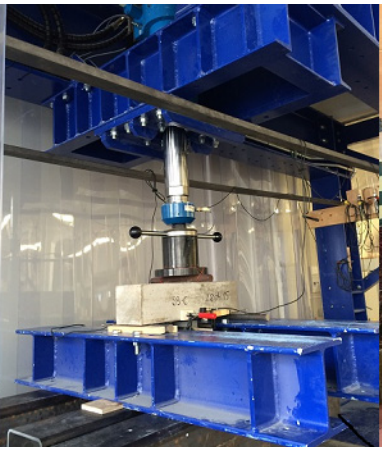
Figs 7-8. Tests in the laboratory of Rudus AS Lagedi factory





Figs 9-11. Tests in the mechanical testing laboratory of the faculty of construction of TTK University of Applied Sciences

3.3. Test results

Conclusions of the test results:

1) Effect of the fibres to the concrete mix (Fig. 12)

The content of fibres affects the consistency of concrete. The effect of metallic fibres on lowering the consistency is considerable in case of bigger dosages. In case of comparable amounts, the shape of metallic fibres (hooked end or undulated) does not pay an important role for the consistency. Similarly to metallic fibres, the dose of macro polymer fibres has an effect on the consistency, but is smaller than in the case of a comparable amount of metallic fibres. Micro polymer fibres, due to their specifics, lower the consistency substantially. The effect of basalt fibres on the consistency, when the dose is similar to the micro polymer fibres, is minimal. Using metallic and micro polymer fibres together is not a suitable option, because of the big loss in consistency. Surprisingly, when using metallic and basalt fibres, the consistency did not change (when compared to metallic fibres). For the same recipe (recipe 1) it can be said, that both lengths of basalt fibres lower the consistency according to the dose and with that raise the need of plasticisers. It can also be said, that in case of the most suitable recipe for basalt fibres (recipe 3), the consistency decreases with the increase of the amount of fibres. In addition, longer fibres have a smaller effect on consistency.

2) Effect of the fibres to the air content (Fig. 13)

The rise in air content due to the addition of fibres was not observed at this point. The specifics in the addition of plasticisers and the mixing time play an important role in this. Thus, the effect of air content on fresh concrete needs additional research.

3) Effect of the fibres to the compressive strength (Figs 14-15)

The effect of fibres on the compressive strength is relatively small. Metallic and macro polymer fibres did not affect the compressive strength. When the amount of fibres increases, a fall in compressive strength can be observed. The micro polymer fibre seems to slow the growth of compressive strength, but does not affect the end result. The basalt fibre, when dosed similarly to the micro polymer fibre, also does not affect the compressive strength. The mixing of metallic and basalt fibres also does not affect the compressive strength considerably. For the same recipe (recipe 1) and both lengths of basalt fibres it can be said, that the biggest increase in compressive strength was for the average dose of basalt fibres (3 kg/m^3). When the extraction of cement paste is not an issue, then the best results for the most suitable recipe for basalt fibres (recipe 3) is provided by the average dose (3 kg/m^3) for the shorter fibres and the largest dose (4 kg/m^3) for the longer fibres. In addition, for both recipes, the longer fibres have a significantly bigger effect on the increase of strength properties.

4) Effect of the fibres to the flexural tensile strength (Figs 16-28, Table 4)

Based on this study, a generalized conclusion can be made of the residual flexural tensile strength. The bigger the effect of fibres is on the residual flexural tensile strength (a.k.a. toughness), the smaller is the concrete strength and vice versa – the bigger the increase in concrete strength, the smaller is the effect on the residual flexural tensile strength (or it lacks completely). The metallic fibres were divided into two – the hooked end metallic fibre gave a better residual flexural tensile strength and the undulated fibre gave a better flexural tensile strength. With the increase in content, macro polymer fibres increase the residual flexural tensile strength, but when having comparable amounts of macro polymer and metallic fibres, the strength properties of concrete were lower. In addition, it was observed that comparing to other fibres with residual flexural tensile strength, macro polymer fibres showed a growth in the residual flexural tensile strength during crack mouth opening. The micro polymer fibre did not affect the strength and the same amount of basalt fibres to the contrary lowered them. The mix of metallic and basalt fibres gave similar results to purely metallic fibres so the effect of basalt fibres was not seen. For the mix of metallic and micro polymer fibres, an increase in the residual flexural tensile strength could be seen. When comparing the same recipes (recipe 1), then the best results of flexural tensile strength came from the same concrete mixes, that gave the best results for compressive strength (for both lengths of fibre). The same correlation applies to basalt fibre when using the most suitable recipe for basalt (recipe 3). For basalt fibres, a correlation can be seen where the concrete mix with the biggest compressive strength also gives the best flexural tensile strength and it is so for both fibre lengths and recipes.

5) Effect of the fibres to the drying shrinkage (Fig. 29, Table 5)

The hooked end fibres affect the shrinkage only at high fibre contents, whereas undulated fibres affect it also at low fibre contents. Conclusions on the effect of macro polymer fibres to the shrinkage cannot be done based on this experimental investigation. Also the surprisingly poor results of the micro polymer fibres need additional research. Since the basalt fibre (with the same dosage as the micro polymer fibre) individually did not have an effect, then it is also unknown for the concrete mixes with mixed fibres. The micro polymer and metallic fibre mix gave an increase in the drying shrinkage only when compared to concrete reinforced with only metallic fibres. For both used recipes it can be generalized, that with the increase in fibre content the drying shrinkage decreases. The effect of basalt fibre on the drying shrinkage needs additional research.

6) The effect of basalt fibres compared to other used fibres (recipe 1)

a) Consistency – the fibre content affects the consistency and with that increases the need for plasticisers.

b) Air content – basalt fibre did not affect the air content.

c) Compressive strength – the biggest compressive strength for both lengths of fibres is achieved with a fibre content of 3 kg/m^3. The longer fibres (24 mm) have a bigger effect on the increase of compressive strength.

d) Flexural tensile strength – the biggest flexural tensile strength of concrete for both lengths of fibres is achieved with a fibre content of 3 kg/m^3. The longer fibres (24 mm) have a bigger effect on the increase of flexural tensile strength. Both lengths of fibres did not have a residual flexural tensile strength.

e) Shrinkage – the shrinkage of concrete decreases with the increase in fibre content.

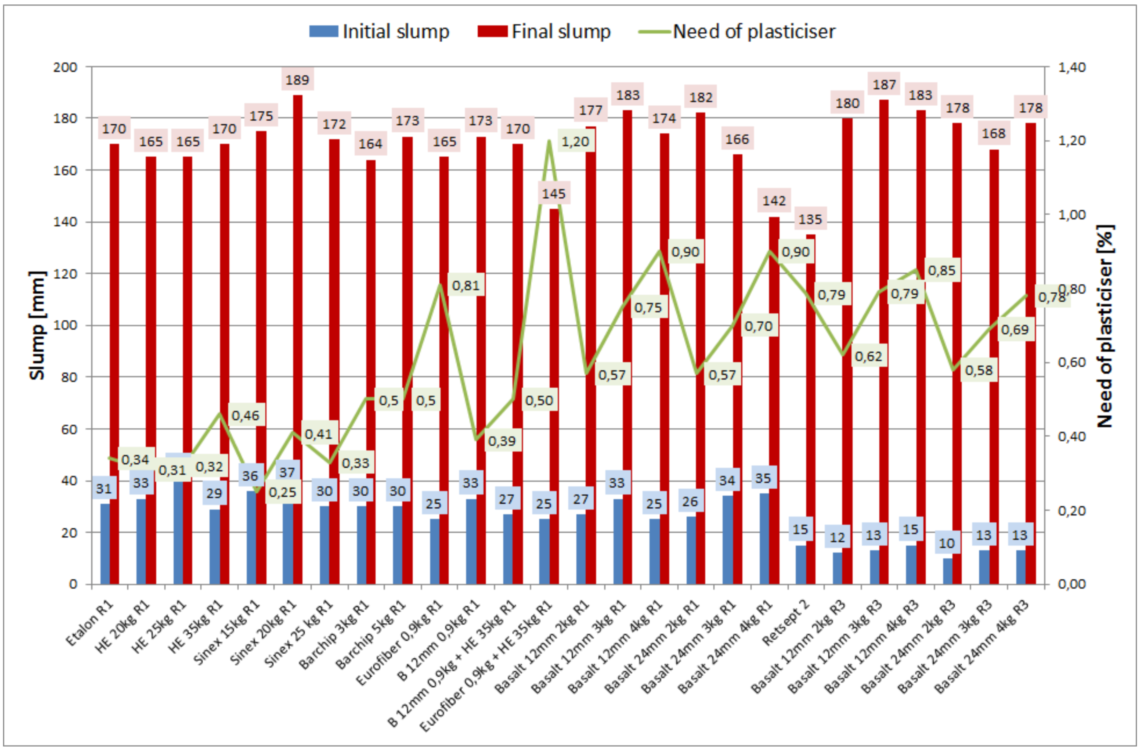


Fig. 12. Initial and final slumps and the need of plasticisers of fresh concrete

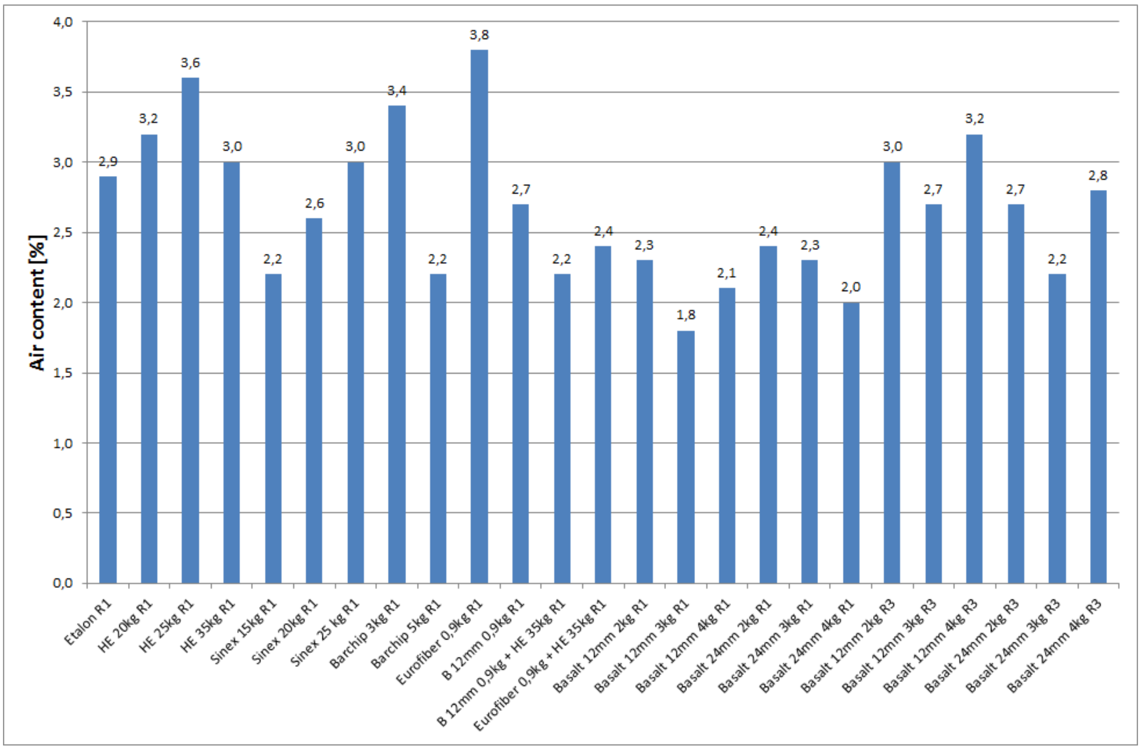


Fig. 13. Air content of compacted fresh concrete

Fig. 14. The failure modes of compressive strength test specimens

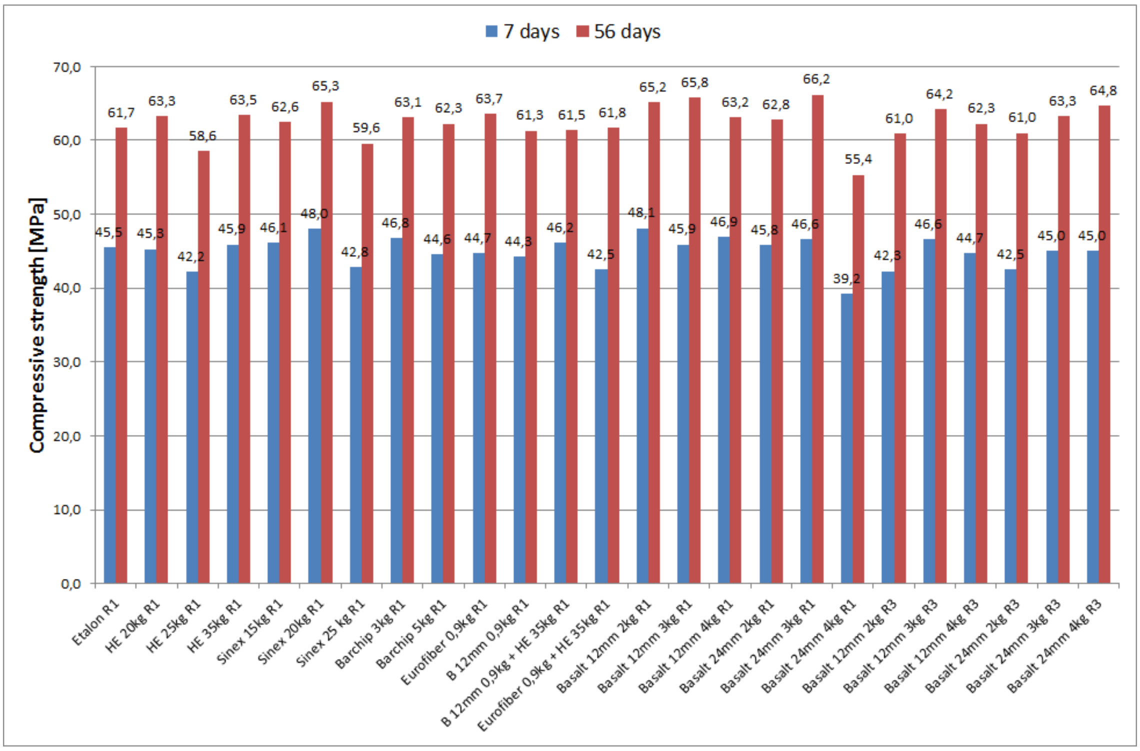


Fig. 15. Compressive strengths

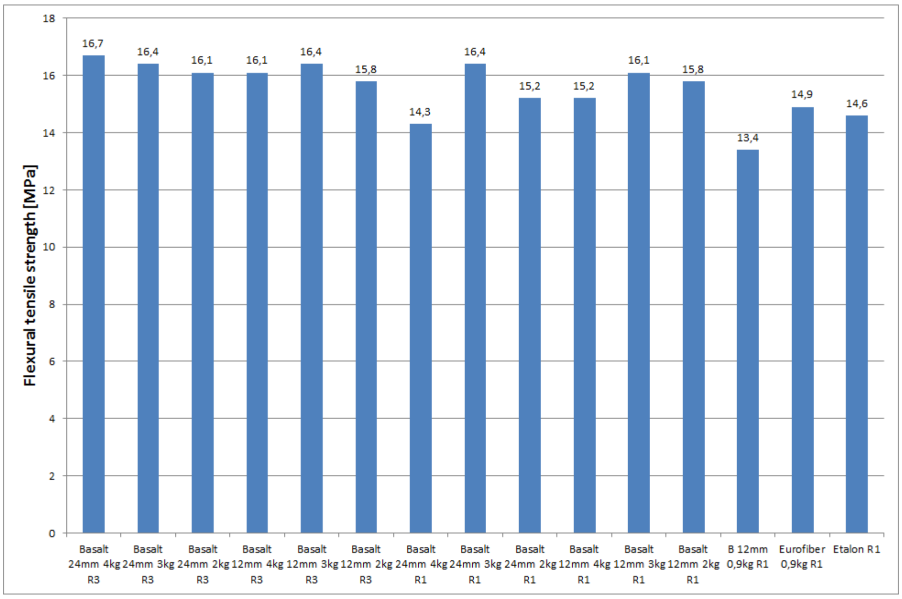
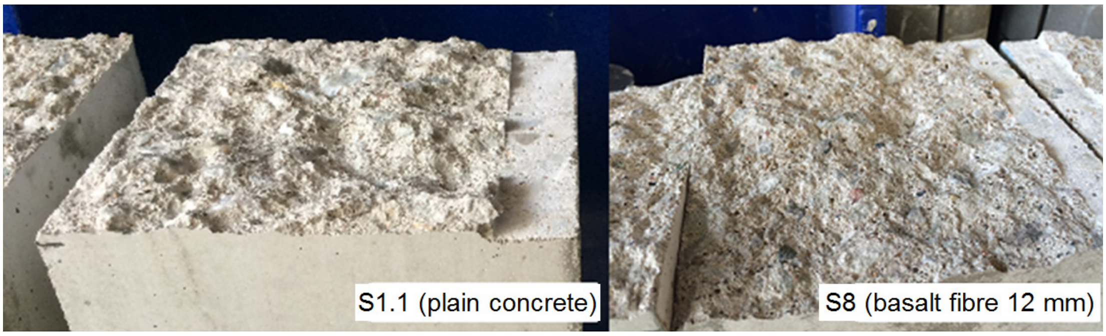


Fig. 16. Flexural tensile strengths of concrete mixes without residual flexural tensile strength



Figs 17-18. Failure modes for plain concrete and concrete reinforced with basalt fibres

Figs 19-27. Failure modes of concretes reinforced with different fibres

Table 4

Flexural tensile strengths of all concrete mixes

		Residual flexural tensile strength [MPa]				Flexural tensile strength of concrete (MPa)	Re_3 value (%)	Average amount of fibres per cross-section (pc)	
		Width of crack (mm)							
		0,5	1,5	2,5	3,5			left	right
S1.1	Etalon R1					4,7			
Concrete reinforced with metallic fibres									
S2.1	HE 20kg R1	2	1,5	1,2	1,1	4,4	39,8	29	26
S3.1	HE 25kg R1	1,9	1,6	1,1	0,9	4,5	37,9	34	24
S4.1	HE 35kg R1	2,8	2,2	1,5	1,2	4,8	47,3	46	37
S5.1	Sinex 15kg R1	0,5	0,7	0,7	0,6	5,1	19,9	14	15
S6.1	Sinex 20kg R1	1,4	1,4	1,1	1,0	5,2	30,5	24	28
S7	Sinex 25 kg R1	1,6	1,6	1,2	1,0	4,2	39,4	20	26
*Width of the first crack resulting from the flexural tensile strength:							0,72	0,57	
Concrete reinforced with polymer fibres									
S14	Barchip 3kg R1	0,9	0,9	0,9	0,8	4,2	26,8	46	47
S15	Barchip 5kg R1	1,7	2,0	2,2	2,2	4,1	53,8	92	90
S16	Eurofiber 0,9kg R1	No residual flexural tensile strength				4,8			
S17	B 12mm 0,9kg R1					4,3			
*Width of the first crack resulting from the flexural tensile strength:							0,58		
Concrete reinforced with mixed fibres									
S18	B 12mm 0,9kg + HE 35kg R1	3,1	2,1	1,7	1,4	5,4	44,3	47	46
S19	Eurofiber 0,9kg + HE 35kg R1	3,5	2,5	1,5	1,1	4,8	51,7	40	41
Concrete reinforced with basalt fibres, recipe 1									
S8	Basalt 12mm 2kg R1	No residual flexural tensile strength				5,1			
S9	Basalt 12mm 3kg R1					5,2			
S10	Basalt 12mm 4kg R1					4,9			
S11	Basalt 24mm 2kg R1					4,9			
S12	Basalt 24mm 3kg R1					5,3			
S13	Basalt 24mm 4kg R1					4,6			
Concrete reinforced with basalt fibres, recipe 3									
S8.2	Basalt 12mm 2kg R3	No residual flexural tensile strength				5,1			
S9.2	Basalt 12mm 3kg R3					5,3			
S10.2	Basalt 12mm 4kg R3					5,2			
S11.2	Basalt 24mm 2kg R3					5,2			
S12.2	Basalt 24mm 3kg R3					5,3			
S13.2	Basalt 24mm 4kg R3					5,4			

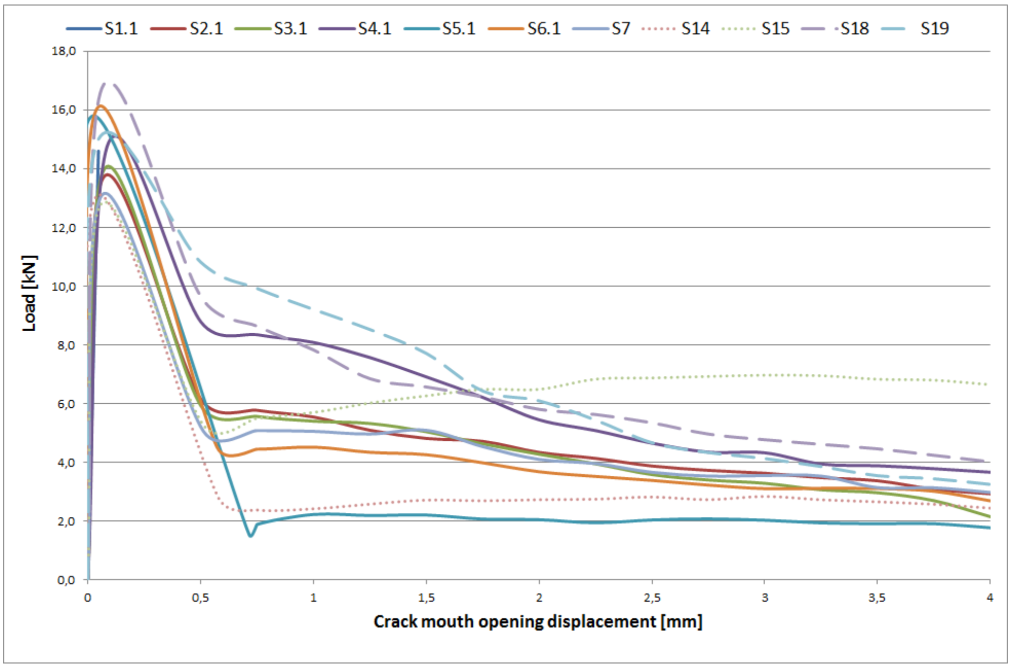


Fig. 28. Flexural tensile strengths of concrete mixes with residual flexural tensile strength

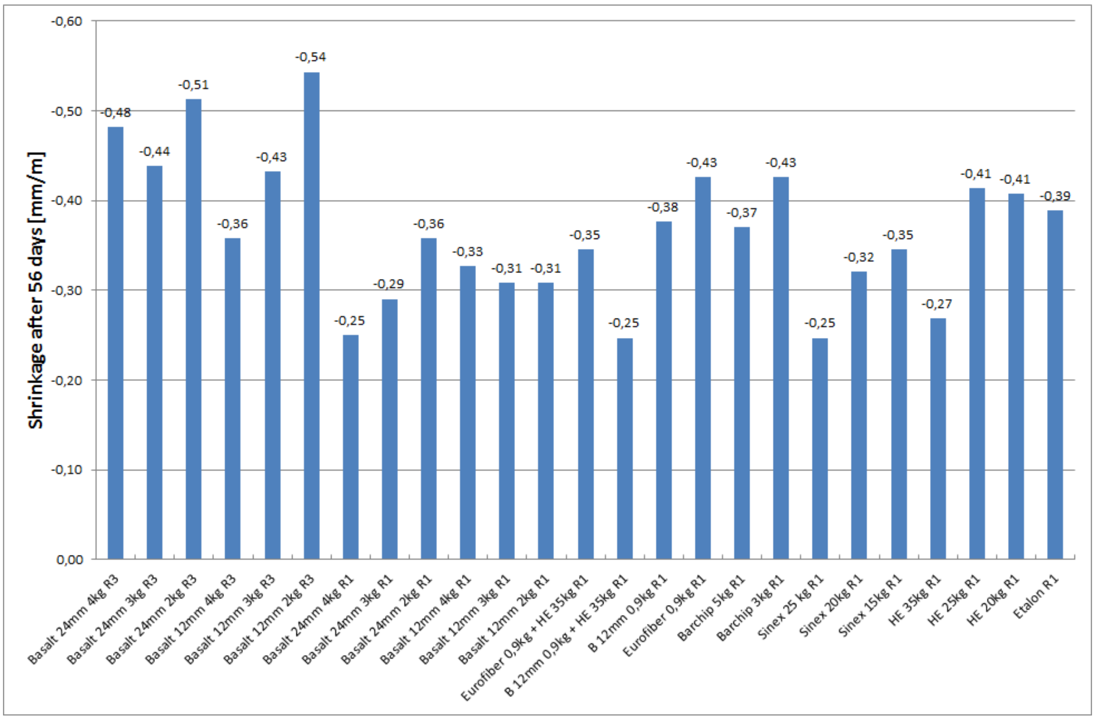


Fig. 29. Concrete shrinkages

Table 5

Concrete shrinkages

		Shrinkage [mm/m]			
		Time [days]			
		7d	14d	28d	56d
S1.1	Etalon R1	-0,09	-0,28	-0,35	-0,39
Concrete reinforced with metallic fibres					
S2.1	HE 20kg R1	-0,12	-0,30	-0,38	-0,41
S3.1	HE 25kg R1	-0,12	-0,28	-0,39	-0,41
S4.1	HE 35kg R1	-0,02	-0,14	-0,26	-0,27
S5	Sinex 15kg R1	-0,06	-0,15	-0,29	-0,35
S6	Sinex 20kg R1	-0,05	-0,17	-0,28	-0,32
S7	Sinex 25 kg R1	0,00	-0,12	-0,22	-0,25
Concrete reinforced with polymer fibres					
S14	Barchip 3kg R1	-0,07	-0,27	-0,39	-0,43
S15	Barchip 5kg R1	-0,09	-0,24	-0,35	-0,37
S16	Eurofiber 0,9kg R1	-0,07	-0,27	-0,37	-0,43
S17	B 12mm 0,9kg R1	-0,12	-0,28	-0,35	-0,38
Concrete reinforced with mixed fibres					
S18	B 12mm 0,9kg + HE 35kg R1	0,00	-0,14	-0,23	-0,25
S19	Eurofiber 0,9kg + HE 35kg R1	-0,02	-0,23	-0,33	-0,35
Concrete reinforced with basalt fibres, recipe 1					
S8	Basalt 12mm 2kg R1	-0,04	-0,22	-0,27	-0,31
S9	Basalt 12mm 3kg R1	-0,04	-0,22	-0,25	-0,31
S10	Basalt 12mm 4kg R1	-0,04	-0,20	-0,28	-0,33
S11	Basalt 24mm 2kg R1	-0,06	-0,23	-0,30	-0,36
S12	Basalt 24mm 3kg R1	-0,03	-0,14	-0,25	-0,29
S13	Basalt 24mm 4kg R1	-0,04	-0,12	-0,25	-0,25
Concrete reinforced with basalt fibres, recipe 3					
S8.2	Basalt 12mm 2kg R3	-0,07	-0,25	-0,40	-0,54
S9.2	Basalt 12mm 3kg R3	-0,07	-0,24	-0,37	-0,43
S10.2	Basalt 12mm 4kg R3	-0,02	-0,20	-0,31	-0,36
S11.2	Basalt 24mm 2kg R3	-0,07	-0,26	-0,40	-0,51
S12.2	Basalt 24mm 3kg R3	-0,03	-0,20	-0,34	-0,44
S13.2	Basalt 24mm 4kg R3	-0,04	-0,21	-0,36	-0,48

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