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Research Article

Effect of basalt, polypropylene and macro-synthetic fibres on workability and mechanical properties of self-compacting concrete

Zinnur Çelik [a,*], Ahmet Ferhat Bingöl [b]

[a] Department of Civil Engineering, Pasinler Vocational School, Atatürk University, 25300 Erzurum, Turkey
[b] Department of Civil Engineering, Atatürk University, 25240 Erzurum, Turkey

ABSTRACT

In this study, the effects of different fibre types on the workability and mechanical properties of self-compacting concrete were investigated. Fresh and hardened properties of self-compacting concrete, different fibre content 0.90, 1.35 and 1.80 kg/m^3 were evaluated using basalt, polypropylene and macro synthetic fibres with different fibre lengths of 24, 19 and 40 mm, respectively. The properties of fresh concrete were evaluated in terms of slump flowing, viscosity and flowability. In addition, compressive, flexural and splitting tensile strength were obtained from hardened concrete properties. To characterize mechanical properties 90 specimens were experimentally tested. The results show that the use of fibre reduces the workability of self-compacting concrete. On the other hand, tensile and flexural strength of the self-compacting fibre reinforced concrete increased with increasing fibre content, but it was determined that the fibre addition had no significant effect on the compressive strength.

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1. Introduction

Self-compacting concrete (SCC) is a type of concrete that can be processed under its own weight without the need for vibration (Sahmaran et al., 2006; Uysal and Yılmaz, 2011; Bingol and Tohumcu, 2013). High range water- reducing superplasticizer chemical additives, powder material and/or viscosity regulators are used in the production of SCC. The main fresh concrete properties of SCC can be specified as filling ability, passing ability and segregation resistance (Liu, 2010; El-Dieb and Taha, 2012). Since its development in Japan in the mid-1980s, research has been conducted on SCC.

Fibre reinforced concrete is a composite material based on cement based matrix using short or long fibres. The use of fibre-reinforced concrete has recently increased due to the significant improvement of the properties of the fibres such as flexural strength, tensile strength, impact resistance and toughness of the concrete. It is also known that adding fibre to the concrete has little or no effect on the compressive strength and the modulus of elasticity (ACI Committee 544, 1988; Mazaheripour, 2011). The mechanical properties of fibre reinforced concrete are dependent on many factors including the aspect ratio (fibre length / equivalent diameter) of the fibres, volume percentage, physical and mechanical properties of the fibres (CNR-DT 204, 2007; Smarzewski, 2019). The addition of fibre in SCC improves the mechanical properties of hardened concrete, but also has a negative effect on the fresh properties of the SCC, such as the slump flow diameter, passing and filling ability. The most commonly used fibre types are steel, polypropylene, glass, carbon, basalt, aramid and polyethylene.

In the study conducted by Jiang et al. (2014), the behaviour of concrete produced with basalt fibre was investigated using the fibre amounts ranging from 0.05% to 0.3%. It was stated that the addition of fibre into concrete increases the compressive strength by 3.66% to 2.62%, respectively. The effect of the addition of basalt fibre on the mechanical properties of concrete was investigated by Arslan (2016). The compressive strength of normal concrete tend to increase by an average of 7.25% in the presence of 3 kg/m^3 content of basalt fibre.

* *Corresponding author*. Tel.: +90-442-661-3982 ; Fax: +90-442-661-3713 ; E-mail address: zinnur.celik@atauni.edu.tr (Z. Çelik)
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Dias and Thaumaturgo (2005) reported that the addition of basalt fibre at 0.5% volume fraction caused a 3.9% reduction on the compressive strength at 28 days. For polypropylene FRC, some studies (Mazaheripour et al., 2011; Komlos et al., 1995), reported that polypropylene fibres have no significant effect on the compressive strength of concrete.

Algin and Ozen (2018) investigated influence of basalt fibre on splitting tensile and flexural strength of SCC. It was stated that the addition of basalt fibre into SCC increases the splitting tensile and flexural strength by 15% and 19%, respectively. Jiang et al. (2014) reports that the incorporation of basalt and polypropylene fibres at a rate of 0.05–0.3% induces the increase in the flexural strength by the ranges of 6.30% to 9.58% and 3.94% to 6.96%. Branston et al. (2016) stated that the flexural strength of the 36 mm diameters of 4, 8 and 12 kg/m^3 basalt fibre reinforced concrete improved by 8.40%, 16.05% and 21.72%, respectively. The effect of basalt fibre on high strength concrete was investigated by Zhang et al. (2018), it was stated that the highest flexural strength value is obtained in the case of using 0.1% by volume of fibre, and there is no significant change in strength in 0.2% and 0.3%.

2. Experimental Program

2.1. Materials

In this study, two different aggregates were used as aggregate size: fine aggregate (0-5 mm) and coarse aggregate (5-12). The specific gravity of the fine and coarse aggregate was 2.62 and 2.67 g/cm^3, respectively. CEM 1 42.5 R Portland cement was used to obtain concrete mixtures. To provide the workability properties of the self-compacting concrete, the cement was replaced with fly ash by 20% of its weight. The chemical, physical and mechanical properties of cement and fly ash used in concrete mixtures are shown in Table 1.

Table 1. Properties of cement and fly ash.

Chemical composition	CEM 1 42.5 R	Fly ash
SiO_2 (%)	18.10	60.61
Al_2O_3 (%)	4.48	20.81
Fe_2O_3 (%)	3.09	7.36
CaO (%)	63.65	2.44
MgO (%)	2.58	1.64
SO_3 (%)	2.84	0.51
Na_2O (%)	3.90	0.56
K_2O (%)	0.21	1.91
CI (%)	0.015	0.0067
Loss on ignition (%)	3.90	2.71
Insoluble Residue (%)	0.55	89.19
Physical and mechanical characteristics	**CEM 1 42.5 R**	**Fly ash**
Specific gravity (g/cm^3)	3.12	2.33
Specific surface (cm^2/g)	3698	2475
Compressive strength (MPa)		
2nd day	27.90	
28th day	58.00	

Detailed properties provided by manufacturer and basalt, macro-synthetic and polypropylene fibres are presented in Table 2 and Fig. 1. In addition, high range water reducing admixture was used by weight of cement for concrete mixtures in order to obtain self-compactability concretes.

Table 2. Properties of fibres.

Fibre type	Length (mm)	Diameter (μm)	Modulus of elasticity (GPa)	Tensile strength (MPa)	Density (g/cm^3)
Basalt	24	13-20	88	4000-4500	2.80
Polypropylene	19	18-20	3.0-3.5	350	0.91
Macro-synthetic	40	440	9.5	620	0.92

Fig. 1. Polypropylene, basalt and macro-synthetic fibre.

2.2. Concrete mix design

In this study, the ratio of coarse aggregate and fine aggregate content (50–50% of total aggregate by volume). The W/B ratio was kept constant at 0.42. The mixture design included 2% superplasticizer by weight of total cement. Table 3 shows the details of mix proportions of ten different concrete mixtures prepared in this research.

2.3. Testing methods

To determine the flow properties of self-compacting concrete, slump flow test, V-funnel and L-box test was performed instantly after mixing the concrete. The workability tests were conducted before casting according to the EFNARC suggestions. According to EFNARC, SCC classes and conformity criteria are presented in Table 4.

Table 3. Concrete mixture proportions.

Concrete	Cement (kg/m^3)	Fly ash (kg/m^3)	W/B	Coarse aggregate (5-12 mm.) (kg/m^3)	Fine aggregate (0-5 mm.) (kg/m^3)	Superplasticizer (%)	Fibre (kg/m^3)
Control	425	75	0,42	816	802	2	------
BF 0.90	425	75	0,42	816	802	2	0,90
BF 1.35	425	75	0,42	816	802	2	1,35
BF 1.80	425	75	0,42	816	802	2	1,80
PPF 0.90	425	75	0,42	816	802	2	0,90
PPF 1.35	425	75	0,42	816	802	2	1,35
PPF 1.80	425	75	0,42	816	802	2	1,80
MSF 0.90	425	75	0,42	816	802	2	0,90
MSF 1.35	425	75	0,42	816	802	2	1,35
MSF 1.80	425	75	0,42	816	802	2	1,80

Table 4. Conformity criteria for the properties of SCC.

Slump-Flow classes	Slump flow in mm
SF1	550 to 650
SF2	660 to 750
SF3	760 to 850
Viscosity classes	V-funnel time in s
VF1	≤ 8
VF2	9 - 25
Passing ability classes (L-box)	Passing ability
PA1	≥ 0,80 with 2 rebars
PA2	≥ 0,80 with 3 rebars

The compressive strength of the self-compacting concrete batches was obtained by three 150x150x150 mm cube samples according to ASTM C39. Splitting tensile testing was completed following the guidelines of ASTM C496. The splitting tensile strength was determined on the cylindrical samples measuring 100 mm diameter and 200 mm height. The flexural strength was completed according to ASTM C78. Concrete prisms 400 mm in length and 100 mm by 100 mm in cross-section were subjected to third point loading using a compression testing machine with a 3000 kN capacity. The compressive, splitting tensile and flexural strength is computed by averaging the results from three samples.

3. Results and Discussion

3.1. Workability properties

In order to determine the workability properties of fresh self-compacting concrete samples, slump flow test, L-box test and V-funnel test were carried out on the samples and the results are presented in Table 5.

As a result of the investigation of the fresh concrete properties of the SCC, it is seen that the use of fibre negatively effects the workability properties of fresh concrete. The flow spread for all groups of concrete mixes that was measured to be in between 570 and 720 mm. The test results demonstrated that control, BF 0.90, BF 1.35 and MSF 0.90 group falls in SF2 class which is suitable for many normal applications (e.g. walls, columns). Use of fibre decreased workability of the fresh concrete and BF 1.80, MSF 1.35, MSF 1.80 and all polypropylene fibre groups determined to be in SF1 class which is appropriate for unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point, casting by a pump injection system or sections that are small enough to prevent long horizontal flow.

When the V-funnel flow times of the mixture samples are evaluated, the control, BF 0.90 and BF 1.35 series falls in VF-1 class specified in the standard and the other mixture samples are in the VF-2 class. The slump flow diameter and the V-Funnel flow time of the mixtures are shown in Fig.2. According to EFNARC, passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. The L-box tests are used to evaluate the passing ability of SCC. According to the results of the L-box test, were obtained the results below the target value of 0.80. Control, BF 0.90, BF 1.35, PPF 0.90 and MSF 0.90 group falls in PA1 class which has good filling ability even with congested reinforcement, capable of self-levelling and generally has the best surface finish.

Table 5. Concrete mixture proportions.

Concrete	Slump-flow diameter (mm)	V funnel time (s)	L- box blocking ratio (H_2/H_1)
Control	720	5,50	0,88
BF 0.90	680	7,03	0,85
BF 1.35	650	7,30	0,81
BF 1.80	630	8,16	0,76
PPF 0.90	640	8,10	0,83
PPF 1.35	600	8,80	0,79
PPF 1.80	570	9,73	0,74
MSF 0.90	660	10,30	0,82
MSF 1.35	630	10,90	0,76
MSF 1.80	590	11,50	0,71

3.2. Results of the mechanical test

3.2.1. Compressive strength

Compressive strength testing was performed at 28 days and the results are shown in Fig. 3 for all SCC series. In this study the compressive strength of polypropylene, basalt and macro-synthetic FRSCC shows no obvious improvement. Compared with the control concrete, the compressive strength of the samples reinforced with basalt fibre with the fibre content of 0.90, 1.35 and 1.80 kg/m3 increase by 2.43%, 3,58% and 4.20%, respectively. When adding PPF and MSF with the content of 0.90, 1.35 and 1.80 kg/m3, the compressive strength improvement of PPF reinforced concrete ranges from 1.90% to 3.63% and the compressive strength improvement of MSF reinforced concrete ranges from 0.73% to 1.97%. For the concrete mixtures containing the macro - synthetic fibre content of 1.80 kg/m3, the compressive strength is lower than the mixture containing the content of 0.90 kg/m3 and 1.35 kg/m3, but the results are higher than the control sample.

Basalt, macro-synthetic and polypropylene fibres, have a tendency to reduce the workability of fresh concrete and resulting in the risk of reduction in the concrete compressive strength. In addition, the fibres create void regions in FRSCC and failure may occur due to them. In this study, low fibre content had a positive effect on compressive strength. The increase in compressive strength of FRC reported by some experimental studies may have been the effect of the reduction in water/cement ratio for cement hydration, which resulted in a higher compressive strength of the hydrated cement paste and not by the beneficial fibres effect (Smarzewski, 2019).

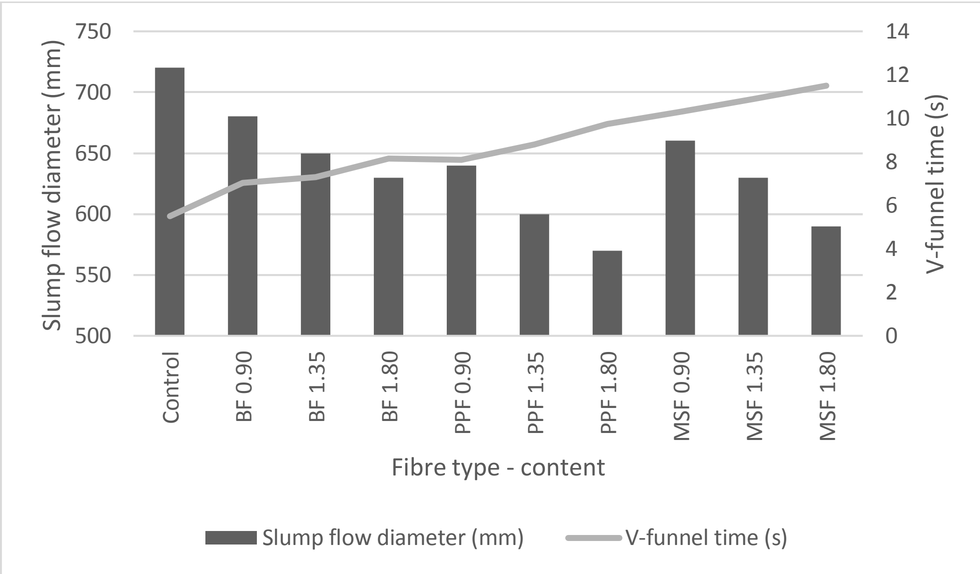

Fig. 2. Slump flow and V-funnel test results of FRSCC.

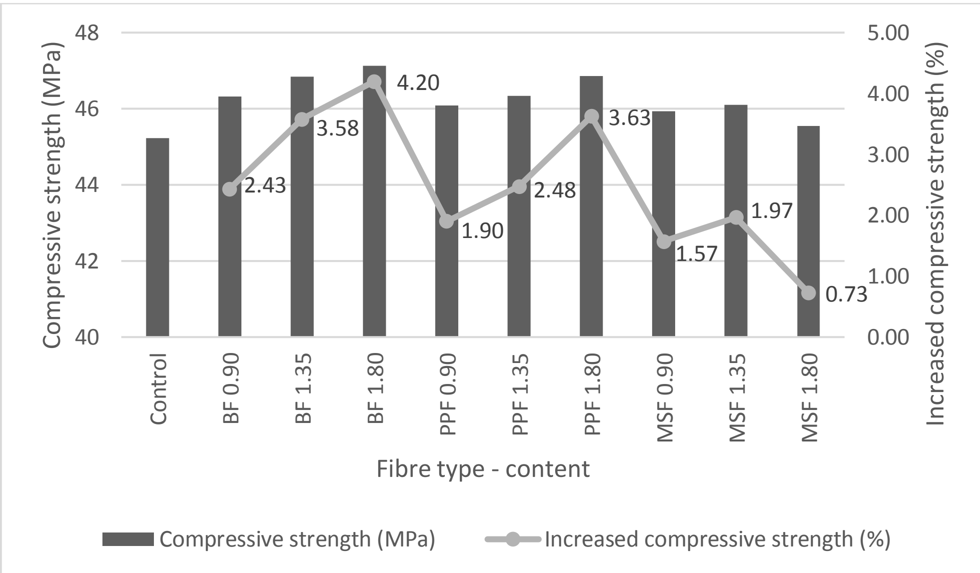

Fig. 3. Compressive strength test results of FRSCC.

3.2.2. Splitting tensile strength

The strength–effectiveness of the splitting tensile strength of the fibre concrete at 28 days shows Fig.4.

Compared with control concrete, the use of fibre significantly increased the splitting tensile strength of FRSCC and the highest splitting tensile strength was obtained in the MSF 1.80 series. The splitting tensile strength of the samples reinforced with macro synthetic fibre with the fibre content of 0.90, 1.35 and 1.80 kg/m^3 increase by 9.68%, 14.84% and 17.42% compared with the control concrete, respectively. Longer fibres show more obvious bridging effect and stronger pulling out resistance, which would contribute to strength development (Jiang et al., 2014). The splitting tensile strength improve of BF and PPF reinforced concrete ranges from 7.10% to 16.77% and 5.81% to 14.19% respectively at 28 days. Previous studies have stated that the adding fibre to concrete induced a significant increase on the splitting tensile strength. Jiang et al. (2014) reported that the splitting tensile strengths of the basalt and polypropylene fibre at 0.05% volume fraction, compared with control concrete were 6.30% and 3.94% higher, respectively. Arslan (2016) reported a 10.1% increase in the splitting tensile strength of concrete containing 2 kg/m^3 basalt fibre.

3.2.3. Flexural strength

Flexural strength testing was performed at 28 days and the results are shown in Fig. 5 for all SCC series. The maximum increase of flexural strength was recorded 8.61% in series BF 1.80 compared to the control concrete. Also, when added basalt fibres with fibre content of 0.90 kg/m^3 and 1.35 kg/m^3, the flexural strength increased 4.65% and 6.34%, respectively.

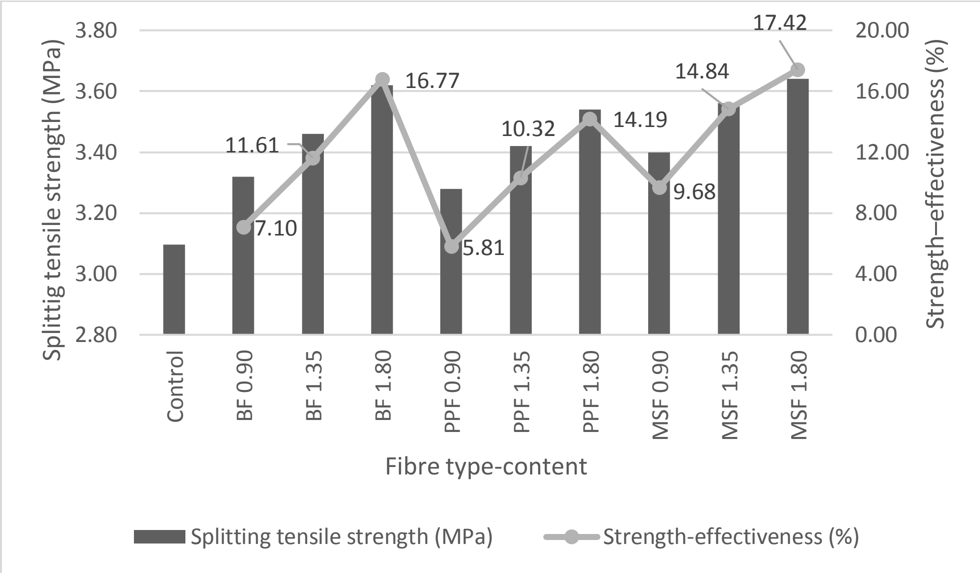

Fig. 4. Splitting tensile strength test results of FRSCC.

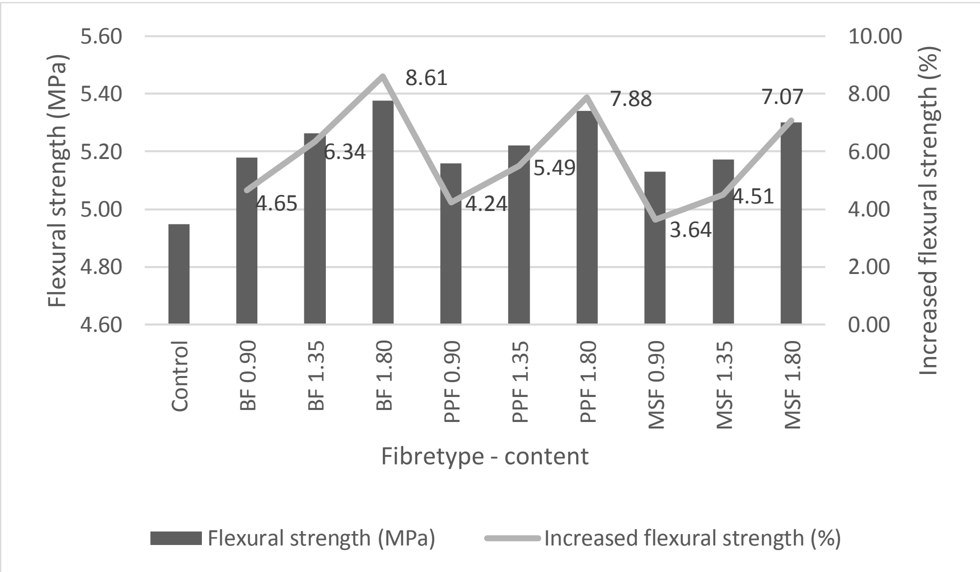

Fig. 5. Flexural strength test results of FRSCC.

The flexural strength results of PPF and MSF series with the fibre content of 0.90, 1.35 and 1.80 kg/m^3 cause the increase by ranges from 4.24% to 7.88% and 3.64% to %7.07%, compared to the control concrete. In the examination of the fracture patterns of the specimens during the flexural strength test, a more ductile behavior was observed in polypropylene and macro synthetic fibre mixtures, whereas the basalt fibre mixtures showed a more brittle behavior. Mazaheripour et al. (2011) stated that the flexural strength of the polypropylene reinforced concrete increased by 4.45% at a fibre content 1.82 kg/m^3. Effect of the content of basalt fibre on the flexural strength was investigated by Kabay (2014), 2 kg/m^3 content of basalt fibre increased the flexural strength of concrete 6.35%. Arslan (2016) reported that 2 kg/m^3 content of polypropylene fibre increased the flexural strength of the concrete 25.3%, compared with plain concrete. Mechanical properties values obtained from are given in Table 6.

4. Conclusions

In the study, workability and mechanical properties of FRSCC mixtures were determined. The results obtained in the scope of this study are indicated below.

As a result obtained indicate that addition of BF, PPF and MSF to the self-compacting concrete leads to significantly reduce in the workability of concrete. Compared with the control concrete, the slump flow diameter of the mixtures reinforced with BF, PPF and MSF with the fibre content of 1.80 kg/m^3 decrease by 12.50%, 20.83% and 18.05%, respectively. When the V funnel results are examined, the control, BF 0.90 and BF 1.35 series fall into the VF-1 class specified in the standard and the other mix samples are in the VF-2 class.

Although the use of fibre in SCC series has no significant effect on compressive strength, the highest compressive strength results were obtained in the BF series. Furthermore, during the compressive strength test, the fibres restricted the lateral expansion of the concrete and delayed the fracture.

Compared with control group, the results of flexural strength of the SCC series, adding 0.90, 1.35 and 1.80 kg/m^3 basalt, polypropylene and macro synthetic fibre, the flexural strength increase of concrete ranges from 4.65% - 8.61%, 4.24% - 7.88% and 3.64% - 7.07%, respectively. The PF and MSF series showed a ductile post peak behavior, whereas the BF series brittle failure after reaching the peak load.

Adding BF, PPF and MSF notably increased splitting tensile strengths of FRSCC with according to control mixture. The highest splitting tensile strength values were obtained from MSF 1.80 specimens.

Table 6. Mechanical results of FRSCC.

Concrete	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)
Control	45.22	3.10	4.95
BF 0.90	46.32	3.32	5.18
BF 1.35	46.84	3.46	5.26
BF 1.80	47.12	3.62	5.38
PPF 0.90	46.08	3.28	5.16
PPF 1.35	46.34	3.42	5.22
PPF 1.80	46.86	3.54	5.34
MSF 0.90	45.93	3.40	5.13
MSF 1.35	46.11	3.56	5.17
MSF 1.80	45.55	3.64	5.30

REFERENCES

ACI Committee 544 (1988). Measurements of properties of fibre reinforced concrete. *ACI Materials Journal*, 85(6), 583–593.

Algın Z, Ozen M (2018). The properties of chopped basalt fibre reinforced self-compacting concrete. *Construction and Building Materials*, 186, 678-685.

Arslan ME (2016). Effects of basalt and glass chopped fibres addition on fracture energy and mechanical properties of ordinary concrete: CMOD measurement. *Construction and Building Materials*, 114, 383-391.

ASTM C39 (1994). Standard test method for compressive strength of cylindrical concrete specimens, West Conshohocken, PA.

ASTM C496 (1994). Standard test method for split tensile strength of cylindrical concrete specimens, West Conshohocken, PA.

ASTM C78 (2016). Standard test method for flexural strength of concrete (using simple beam with third-point loading). *Annual Book of ASTM Standards*. American Society for Testing and Materials, West Conshohocken, PA.

Bingol AF, Tohumcu I (2013). Effects of different curing regimes on the compressive strength properties of self-compacting concrete incorporating fly ash and silica fume. *Materials and Design*, 51, 12-18.

Branston J, Das S, Kenno SY, Taylor C (2016). Mechanical behaviour of basalt fibre reinforced concrete. *Construction and Building Materials*, 124, 878-886.

CNR-DT 204 (2006, 2007). Guide for the design and construction of fibre-reinforced concrete structure. *CNR*.

Dias DP, Thaumaturgo C (2005). Fracture toughness of geopolymeric concretes reinforced with basalt fibres. *Cement and Concrete Composites*, 27(1), 49-54.

EFNARC (2005). The European Guidelines for Self Compacting Concrete-Specification, Production and use, *The European Federation of Specialist Construction Chemicals and Concrete Systems*.

El-Dieb AS, Taha MMR (2012). Flow characteristics and acceptance criteria of fibre-reinforced self-compacted concrete (FR–SCC). *Construction and Building Materials*, 27, 585-596.

Jiang C, Fan K, Wu F, Chen D (2014). Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete. *Materials and Design*, 58, 187-193.

Kabay N (2014). Abrasion resistance and fracture energy of concretes with basalt fibre. *Construction and Building Materials*, 50, 95-101.

Komlos K, Babal B, Nurnbergerova T (1995). Hybrid fibre reinforced concrete under repeated loading. *Nuclear Engineering Design*, 156, 195–200.

Liu M (2010). Self-compacting concrete with different levels of pulverized fuel ash. *Construction and Building Materials*, 24, 1245-1252.

Mazaheripour H, Ghanbarpour S, Mirmoradi SH, Hosseinpour I (2011). The effect of polypropylene fibres on the properties of fresh and hardened lightweight self-compacting concrete. *Construction and Building Materials*, 25, 351-358.

Sahmaran M, Christianto HA, Yaman İO (2006). The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars. *Cement and Concrete Composites*, 28, 432-440.

Smarzewski P (2019). Influence of basalt-polypropylene fibres on fracture properties of high performance concrete. *Composite Structures*, 209, 23-33.

Uysal M, Yılmaz K (2011). Effect of mineral admixtures on properties of self-compacting concrete. *Cement and Concrete Composites*, 33, 771-776.

Zhang J, Zhao Y, Li H (2018). Effect of basalt fibres on mechanical properties of high-performance concrete containing supplementary cementitious materials. *RILEM Bookseries*, 15, 181-187.