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Mechanical and thermal behaviors comparison of basalt and glass fibers reinforced concrete with two different fiber length distributions

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ABSTRACT

This paper deals with the mechanical and thermal behavior of glass and basalt fiber reinforced concrete. Two different composites were studied containing either basalt or glass fibers. Fiber ratios were selected as 1%, 1.25% and 1.5% for glass fiber; 0.3%, 0.4% and 0.5% for basalt fibers. Fiber length was preferred as 12 mm and 24 mm. The addition of basalt fiber had very limited effect on the compressive, flexure and thermal conductivity properties compared to the glass fiber reinforced composite. The results also showed that composites having fibers with the length of 12 mm had better mechanical properties. Heat transfer simulation of the composites were also conducted. It was obtained that both fibers with the length of 12 mm had very close results on the heat transfer studies.

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1. Introduction

Many researches have been extensively conducted on the mechanical behavior of fiber reinforced concrete due to their wide usage in the construction industry. With the addition of very small amount of fibers, tensile strength and ductility properties of the composites can be enhanced (Alberti et al., 2017; Banthia and Grupta, 2006). There are many fiber types such as glass, basalt, polypropylene and carbon used for this aim (Ivorra et al., 2010).

Among the fiber used for concrete reinforcement, the most common are glass fiber in decorative concrete production. Concrete mixes reinforced with the glass fiber are generally classified as glass fiber reinforced concrete (GFRC). These types of mix designs are widely used in façade, flooring, and sculpturing works (Yıldızel and Ozturk, 2016). Glass fibers enhance the mechanical behavior of the concrete and many academics have been focused on these improvement studies in the last decade (Lv et al., 2012; De Luca et al., 2010; Wei et al., 2010).

Basalt fiber usage in concrete industry has gained popularity due to its mechanical enhancement abilities (Branston et al., 2016). Basalt fiber tensile strength values are higher compared to the glass fibers'. Researches regarding basalt fiber reinforced concrete (BFRC) were mainly focused on mechanical properties of the reinforcing composite materials. Basalt fibers are generally added with the maximum ratio of 0.5 % by volume in the literature studies (Borhan, 2013; Iyer, 2015). However, optimum fiber ratio can be changed for different studies (Ayub et al., 2015). Basalt fibers also enhance the flexural toughness of the concrete (Lipatov et al., 2015).

Basalt fiber production costs are low, these types of fibers can be manufactured under more environment friendly conditions compared to the glass fiber. This paper aims to discuss the potential use of basalt fiber in replacement of glass fiber for decorative concrete production industry.

2. Materials and Experimental Method

Twelve different mixes were designed and prepared within the scope of this study. CEM I 52.5 R Portland type cement was used. The chemical and physical properties of the cement are given in Table 1. Alkali resistant glass fibers and basalt fiber were selected as aggregates. The fiber properties are presented in Table 2.

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Table 1. The chemical and physical properties of the cement.

Chemical properties (%)		Physical and mechanical properties	
SiO2	21.60	Specific Weight	3.06
Al2O3	4.05	Specific Surface (cm²/gr)	4600
Fe2O3	0.26	Whiteness (%)	85.5
CaO	65.70	Initial Setting (min.)	100
MgO	1.30	Final Setting (min.)	130
Na2O	0.30	Water Used for Consistency (%)	30
K2O	0.35	Volume Constancy (mm)	1.0
SO3	3.30	Remnants Obtained Using 0.045 Sieve (%)	1.0
Free CaO	1.60	Remnants Obtained Using 0.090 Sieve (%)	0.1
Chloride (Cl)	0.01	Compressive Strength for 2 days (MPa)	37.0
Insoluble	0.18	Compressive Strength for 7 days (MPa)	50.0
Loss on Ignition	3.20	Compressive Strength for 28 days (MPa)	60.0

Table 2. Basalt and glass fiber properties.

Alkali resistant glass fiber (GF)		Basalt fiber (BF)	
Ultimate strength, bending (MOR, MPa)	20-28	Breaking strength (MPa)	3,200-4,800
Elastic limit (LOP, MPa)	7-11	Modulus of elasticity (GPa)	79 - 92
Compressive strength (MPa)	50-80	Thermal conductivity (W/mK)	0.031-0.038
Modulus of elasticity (GPa)	10-20	Density (kg/m^3)	2650
Thermal conductivity (W/mK)	0.034 – 0.04	Alkali resistant	excellent
Density (kg/m^3)	1870 - 2100		
Alkali resistant	excellent		

Fiber were added into the mixes with the length of 12 mm and 24 mm. Glass fiber were used with the ratio of 1%, 1.25% and 1.5%. Basalt fibers were added as 0.3%, 0.4% and 0.5% in parallel with the similar literature research (Lipatov et al., 2015). Silica sand with the AFS value of 80 to 100 was preferred as the aggregate ingredient in this study. Properties of the sand are given in Table 3.

Table 3. Silica sand properties.

Sieve size	1mm	710 μm	500 μm	355 μm	250 μm	180 μm	125 μm	90 μm	63 μm
Production range (%)	0	0	0	0.2	0.3	20.1	60.4	16.1	1.8
Mean grain size (μm)					140-170				
Clay content (%)					0.6 -0.8				
Specific weight					2.68				
AFS values					84.6				

The third generation polycarboxylate based plasticizer were used as the chemical agent. Water / cement ratio was kept constant at 0.42.

Mix designs and experimental sets are given in Table 4. All prepared specimens were kept at the molds for 24 hours at the room temperature, and potable water was used for the mixes.

5 cm x 5 cm x 5 cm cubic samples for compressive tests, and 27.5 cm x 5 cm x 1.2 cm rectangular samples for flexural tests were prepared according to the TS EN 12467 standard. Compressive and flexural strength of the samples were measured for 1, 7 and 28 days according to the TS EN 1170-4,5 standards. Water absorption and density measurement results were also recorded as per the regulations of TS EN 12467 standard.

Heat transfer simulation of the mixture were analyzed with the aid of the simulation program Energy2D to make further selection of the more compatible composite due to the limited time and material constraints. Simulation results were compared with the similar research test results.

Table 4. The mixture designs.

Mixture Code	Cement (kg)	Sand (kg)	GF (%)	BF (%)	Fiber Length (mm)	W / C
GFM-1	50	50	1.00	-	12 mm	0.42
GFM-2	50	50	1.25	-	12 mm	0.42
GFM-3	50	50	1.50	-	12 mm	0.42
GFM-4	50	50	1.00	-	24 mm	0.42
GFM-5	50	50	1.25	-	24 mm	0.42
GFM-6	50	50	1.50	-	24 mm	0.42
BFM-1	50	50	-	0.30	12 mm	0.42
BFM-2	50	50	-	0.40	12 mm	0.42
BFM-3	50	50	-	0.50	12 mm	0.42
BFM-4	50	50	-	0.30	24 mm	0.42
BFM-5	50	50	-	0.40	24 mm	0.42
BFM-6	50	50	-	0.50	24 mm	0.42

3. Results and Discussions

Mechanical properties of the composites were presented in this section. The compressive and flexural test results of the specimens are given in Figs. 1 and 2, respectively.

Compressive test results showed that compressive strength values increase with the increasing fiber ratios. Mixture design GFM-3 had the highest compressive strength value as 36.43 MPa for 28 days. BFM-3 with the basalt fiber ratio of 0.5 % had close compressive strength value compared to the glass fiber reinforced composites. Fiber length factor also effected the compressive strength values. Mix design with the fiber length of 12-mm showed better performances compared to the 24-mm fiber added composites, as seen in Fig. 1.

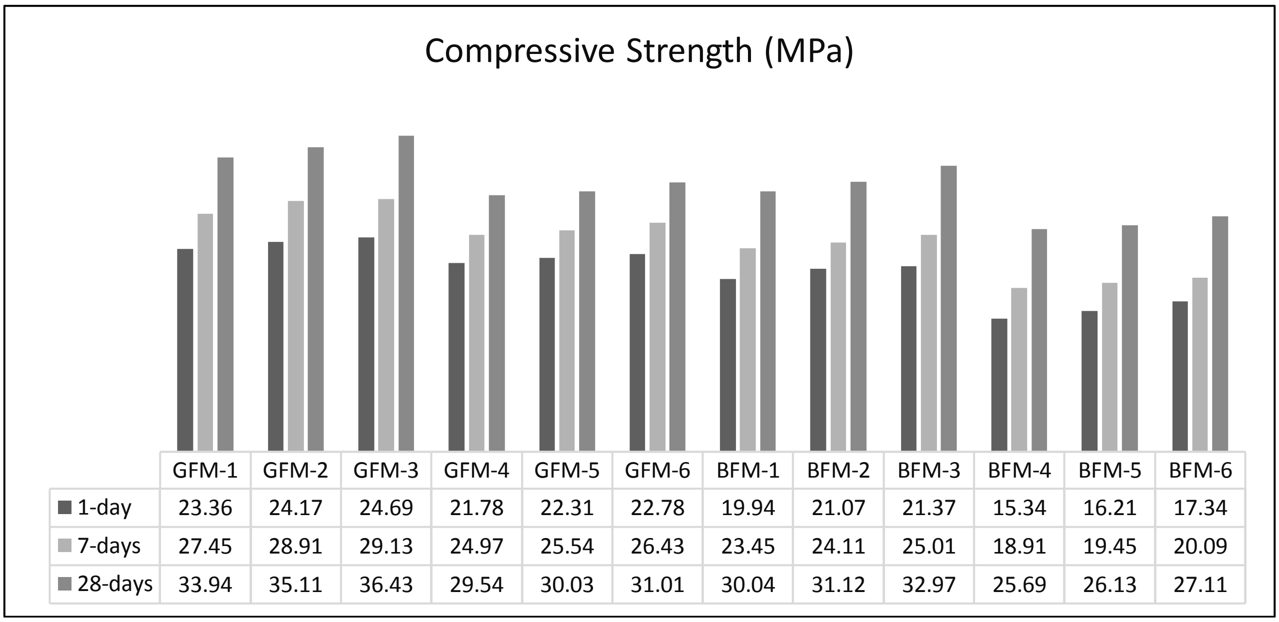
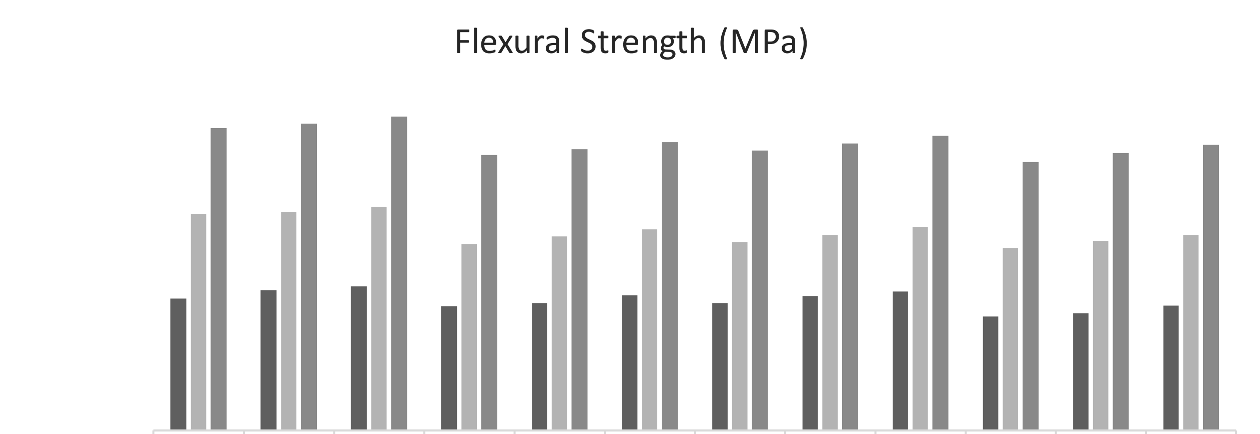


Fig. 1. Compressive strength test results.

Flexural strength values increased with the increase in fiber ratios. The mix GFM-3 had the highest strength value as seen in Fig. 2. As expected, the flexural strength values are increased with the increasing fiber ratio 12-mm length fiber added composite showed better performance for both fiber types. The mix BFM-3 had similar mechanical performance compared to the glass fiber reinforced concrete test results.

Water absorption (%) and density measurement results are given in Fig. 3. Water absorption values increases with the increasing pore ratio of the samples. In other words, water absorption percentages decrease with the increase in density values.



	GFM-1	GFM-2	GFM-3	GFM-4	GFM-5	GFM-6	BFM-1	BFM-2	BFM-3	BFM-4	BFM-5	BFM-6
1-day	5.52	5.87	6.02	5.19	5.34	5.65	5.32	5.62	5.81	4.78	4.91	5.23
7-days	9.05	9.14	9.37	7.79	8.12	8.43	7.87	8.19	8.52	7.63	7.94	8.17
28-days	12.67	12.85	13.14	11.52	11.76	12.08	11.71	12.01	12.34	11.23	11.61	11.97

Fig. 2. Flexural strength test results.

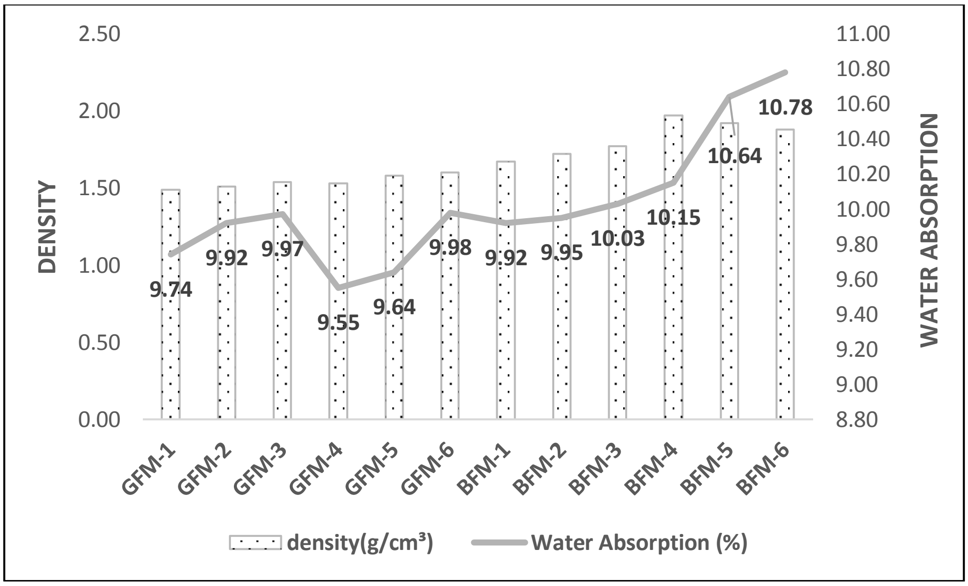


Fig. 3. Water absorption (%) vs density (g/cm^3).

Thermal behavior of the fiber added composites were analyzed via Energy2D software. The heat transfer properties of the GFM-3 and BFM-3 composites were simulated due to their superior mechanical behaviour compared to the other mixes. Heat transfer rate of the composites were simulated at the temperature value of –30°C and +60°C. Material thermal bridge method was used. The simulation results were given in Figs. 4-7 respectively.

Simulation result showed that GFM-3 and BFM-3 showed very similar performance on heat transmission values. Results are the same as 0.17 W/m^2 for both mixes at the temperature of –30°C. Additionally, simulation results vary from 0.34 W/m^2 to 0.3 W/m^2 at 60°C.

4. Conclusions

Glass and basalt fiber reinforced composites were analyzed and compared for the mechanical and heat transfer rate properties. The main findings can be summarized as follows:

- The increase in fiber ratio for glass fibers up to 1.5% and for basalt fibers up to 0.5% in composites designs increases the compressive and flexural test results of the mixes.
- Glass fiber added composites showed better performances when analyzing flexural and compressive strength test results with the fiber ratio of 1.5%. However, basalt fiber reinforced concrete had very similar results with fiber ratio of 0.5%.

- Fiber length of 12-mm showed better test results for all types of fibers compared to the 24mm fiber added mixes.
- Heat transfer simulation results of the both fiber types were very close as 0.34 W/m^2 to 0.3 W/m^2 at 60°C.
- Addition of 1.5% glass fiber presents the best mechanical results for the fiber reinforced composites.
- Water absorption values decreased with the increase in the density values of the composites. Basalt fiber reinforced mixes can be strengthened with a filler material to obtain more impermeable composite material.

In the light of abovementioned results, basalt fibers can be used as replacement of glass fiber due to their low cost and very similar performances in concrete composite applications.

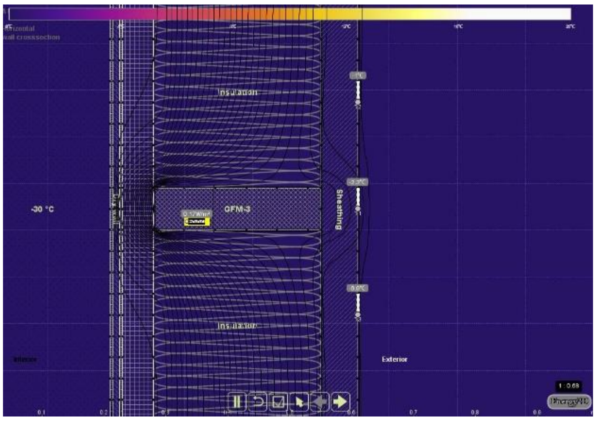


Fig. 4. GFM-3 (Sim:1@-30°C).

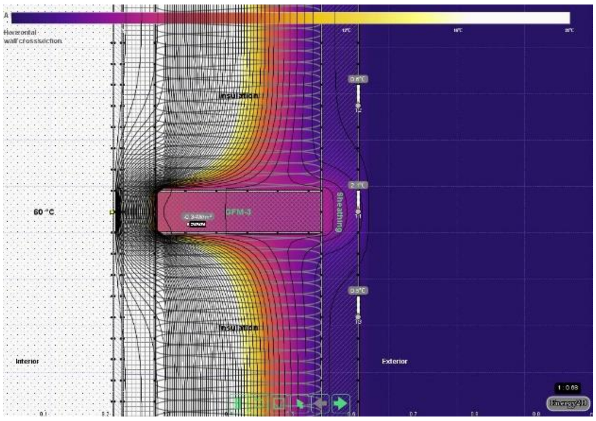


Fig. 5. GFM-3 (Sim:2@60°C).

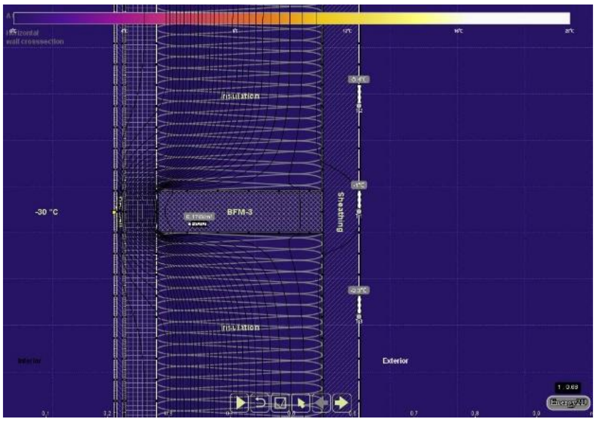


Fig. 6. BFM-3 (Sim:3@-30°C).

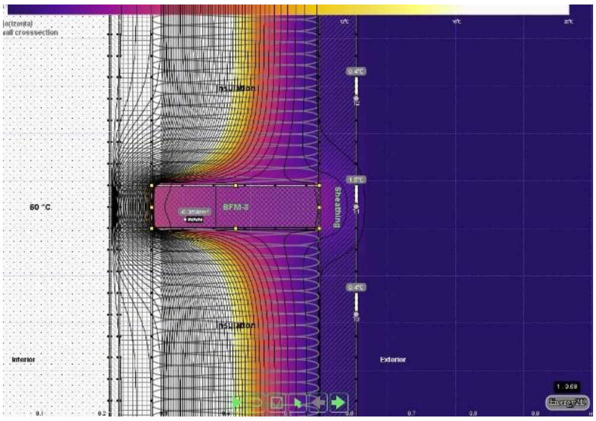


Fig. 7. BFM-3 (Sim:4@60°C).

References

Alberti MG, Enfedaque A, Gálvez JC (2017). Fibre reinforced concrete with a combination of polyolefin and steel-hooked fibres. *Composite Structures*, 171, 317-325.

Ayub T, Shafiq N, Nuruddin MF (2014). Mechanical properties of high-performance concrete reinforced with basalt fibers. *Procedia Engineering*, 77, 131-139.

Banthia N, Gupta R (2006). Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete. *Cement and Concrete Research*, 36(7), 1263-1267.

Borhan TM (2013). Thermal and mechanical properties of basalt fibre reinforced concrete. *In Proceedings of World Academy of Science, Engineering and Technology (WASET)*, 76, 313.

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

De Luca A, Matta F, Nanni A (2010). Behavior of full-scale glass fiber-reinforced polymer reinforced concrete columns under axial load. *ACI Structural Journal*, 107(5), 589.

Ivorra S, Garcés P, Catalá G, Andión LG, Zornoza E (2010). Effect of silica fume particle size on mechanical properties of short carbon fiber reinforced concrete. *Materials & Design*, 31(3), 1553-1558.

Iyer P, Kenno SY, Das S (2015). Mechanical properties of fiber-reinforced concrete made with basalt filament fibers. *Journal of Materials in Civil Engineering*, 27(11), 04015015.

Lipatov YV, Gutnikov SI, Manylov MS, Zhukovskaya ES, Lazoryak BI (2015). High alkali-resistant basalt fiber for reinforcing concrete. *Materials & Design*, 73, 60-66.

Lv Y, Cheng HM, Ma ZG (2012). Fatigue performances of glass fiber reinforced concrete in flexure. *Procedia Engineering*, 31, 550-556.

Wei B, Cao H, Song S (2010). Tensile behavior contrast of basalt and glass fibers after chemical treatment. *Materials & Design*, 31(9), 4244-4250.

Yıldızel SA, Öztürk AU (2016). A study on the estimation of prefabricated glass fiber reinforced concrete panel strength values with an artificial neural network model. *CMC: Computers, Materials & Continua*, 52(1), 42-51.