THE MECHANICAL PROPERTIES OF FIBER REINFORCED MORTARS CONTAINING AIR ENTRAINING ADMIXTURES

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ABSTRACT
This study investigates the effects of steel, carbon, basalt, and polypropylene fibers on the workability and mechanical properties of mortar mixtures containing an air-entraining admixture. Five mortar mixtures were prepared using CEM I 42.5R cement, standard sand, water-reducing admixture, and air-entraining chemical admixture, along with four different fibers (steel, basalt, carbon, and polypropylene). All mixtures contained 0.1% by weight of cement as an air-entraining admixture. The control mixture was prepared without fibers, while the other mixtures were added 0.5% by volume of fibers. The water/cement ratio, sand/binder ratio, and spreading values of all mortar mixtures were kept constant at 0.485, 2.75, and 190±20 mm, respectively. As part of the fresh properties, the amount of water-reducing chemical admixture required to achieve the target spreading value was determined. Compressive strength, flexural strength, and water absorption tests were carried out on the mortar mixtures at 28 days. The results showed that the workability of mixtures containing basalt, carbon, and polypropylene fibers was negatively affected, leading to an increased need for water-reducing admixture to reach the target spread. The mixtures with basalt and carbon fibers exhibited the lowest water absorption rates, while the control, steel, and polypropylene fiber mixtures showed similar, but higher, water absorption rates compared to the others. Mixtures containing basalt and carbon fiber had the highest compressive and flexural strengths. The control mixture had the lowest strength, while mixtures containing steel and polypropylene fibers exhibited slightly higher strength performance than the control mixture.

Keywords: Fiber, basalt fiber, steel fiber, carbon fiber, polypropylene fiber, air-entraining admixture, water absorption, mechanical properties

INTRODUCTION
Concrete is one of the most widely utilized building materials today, primarily due to its affordability, strength, and versatility in achieving the desired shapes and characteristics. The hydration reactions between cement and water confer concrete its strength; however, concrete inherently possesses low tensile strength and a limited capacity for deformation. These properties lead to a fragile structure, even though it is resistant to external influences.
To enhance the durability of concrete and reduce the likelihood of cracking, fiber-reinforced concrete has gained significant popularity. Fibers are incorporated into concrete to control crack formation and improve overall structural properties. By increasing the tensile strength, various types of fibers can inhibit crack propagation (Afroughsabet & Ozbakkaloglu, 2015; Boulekbache

et al., 2016; Chandramouli et al., 2010). The primary purpose of incorporating fibers is to enhance mechanical characteristics, including tensile strength, ductility, and crack resistance.

Fibers can be classified into two main categories: synthetic and natural, both of which contribute to the improvement of the mechanical and physical properties of concrete. Various types of fibers, such as steel, basalt, carbon, and polypropylene, can enhance concrete's performance. The primary function of these fibers is to provide ductility and toughness by bridging the cracks that develop in the concrete matrix.

The use of steel fibers in concrete and mortar mixtures stands out as a method that significantly increases structural performance. Research shows that steel fibers improve properties such as density, flexural strength, compressive strength, and toughness, especially in high-strength mortars. Steel fibers used in optimum amounts reduce the number of microcracks by preventing crack expansion and also increase wear resistance. In addition, steel fibers can double the load-carrying capacity with the correct orientation. However, steel fibers used in high volumes can negatively affect the workability of fresh concrete and limit fluidity. For this reason, the volume fraction of steel fibers is generally kept between 0.8 and 2.5%. Proper distribution of fibers in concrete mixes is critical because this distribution cannot be changed after mixing. Proper distribution ensures that the fibers do not rotate or clump in certain areas during placement of the concrete. Problems such as clumping or alignment in one direction are particularly common in concrete mixes reinforced with steel fibers (Bing, 2006; Gueciouer et al., 2022; Hannant & Spring, 1974; Kwon & Lee, 2009; Ramli & Dawood, 2011; Wang et al., 2021).

Research shows that basalt fiber reinforcement significantly improves the mechanical and durability properties of cement mortars. While the large surface area of basalt fibers can slightly reduce workability by increasing water absorption, these fibers enhance the cohesion of the composites (Hanafi et al., 2020). Basalt fibers, derived from natural resources, offer important structural properties such as high tensile strength, high temperature resistance, and chemical durability(Gao et al., 2021). In the 21st century, basalt fibers have emerged as an eco-friendly material, providing not only a high elastic modulus and fracture elongation but also excellent insulation, durability, and fire resistance(Yang, Xie, Zhang, et al., 2021). When used in appropriate amounts, basalt fibers can delay early cracking in concrete, leading to the transformation of long surface cracks into smaller micro-cracks. With these properties, basalt fibers present a sustainable and environmentally friendly alternative to traditional reinforcement materials in construction applications (Yang, Xie, Fang, et al., 2021; Yang, Xie, Zhang, et al., 2021).

Carbon fibers are gaining increasing popularity in cement-based materials due to their high strength, high elastic modulus, low weight, and excellent wear resistance (Chung, 1999). However, it is important to note that as fiber content increases, porosity and water absorption also rise; thus, the fiber ratio should be maintained at an optimal level. Carbon fibers present an attractive option for cement composites because of their superior chemical stability at ambient temperatures. These fibers are inert, medically safe, as strong as steel fibers, and chemically stable in alkaline environments. Additionally, carbon fibers are lightweight and possess a higher strength-to-density ratio than other fibers. The incorporation of carbon fibers in mortar offers several advantages, including lower unit costs, reduced shrinkage, and improved rheological behavior, along with excellent mechanical properties (Safiuddin et al., 2018).

Room temperature polypropylene fibers are low-density, low-elastic-modulus solid materials (Mazzucco et al., 2015). Compared to other synthetic fibers, they are less expensive, have a lower weight, have a lower thermal conductivity, and are more resistant to acid and alkali attacks. The cement paste does not wet the hydrophobic surfaces of the polypropylene fibers used in cement-based concretes. These fibers act as bridges to hold different particles in close proximity, thereby improving mechanical properties such as compressive and tensile strength under shear (Raif Boğa et al., 2022). The addition of polypropylene fibers to concrete can improve its post-cracking ductility because of its crack-bridging properties. These fibers have the potential to melt at

temperatures above 170 °C, releasing internal pressure and preventing spalling on concrete surfaces (Yin et al., 2015).
Furthermore, both polypropylene and steel fibers enhance concrete's resistance to high temperatures (Bošnjak et al., 2019). Studies suggest that steel fibers outperform polyester or polypropylene in crack bridging due to their superior stiffness (Sivakumar & Santhanam, 2007).
While some properties of concrete are improved by the use of fibers, some fresh and hardened properties are adversely affected. At this point, superplasticizers, together with chemical and mineral additives such as air-entraining agents, play an important role in achieving the desired performance properties of concrete.
This study aims to investigate the effects of steel, carbon, basalt, and polypropylene fibers on the workability and mechanical properties of mortar mixtures containing an air-entraining admixture, ultimately contributing to the development of more durable and efficient construction materials.

MATERIAL AND METHODS

Materials

For preparing the mortar mixtures, portland cement, fine aggregate (sand), steel fiber, basalt fiber, carbon fiber, polypropylene fiber, air-entraining admixture, and superplasticizer were used.

Cement

Portland Cement (CEM I 42.5R), complying with TS EN 197-1 standard(2002), with a specific gravity of 3.15 g/cm³ and a specific surface area of 3530 cm²/g, was used in the study. The physical, chemical and mechanical properties of cement are provided in Table 1.

Table 1. Physical, chemical and mechanical properties of cement

Oxide (%)	Cement	Physical Properties		
SiO_2	18.86	Specific Gravity		3.15
Al_2O_3	5.71	**Fineness**		
Fe_2O_3	3.09	Specific surface (Blaine, cm²/g)		3530
CaO	62.70	Residue on 0.045 mm sieve (%)		7.6
MgO	1.16	**Mechanical Properties**		
SO_3	2.39	Compressive Strength (MPa)	1-day	14.7
Na_2O+0,658 K_2O	0.92		2-days	26.80
Cl’	0.01		7-days	49.80
Insoluble residue	0.32		28 days	58.5
Loss on ignition	3.20			
Free CaO	1.26			

Fine Aggregate

According to TS EN 196-1, CEN(2009) standard sand was used for the preparation of mortar specimens. Standard sand is characterized by its uniform particle size distribution, which is essential for ensuring consistent properties in mortar mixtures. In Figure 1, fine aggregate granulometry curve is provided.

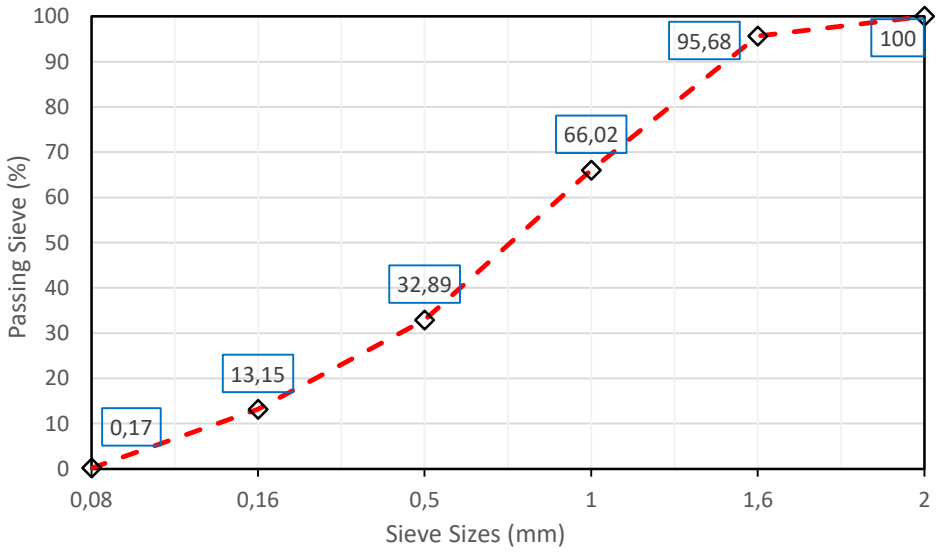


Figure 1. Fine aggregate granulometry curve

Fibers

In this study, various types of fibers were incorporated into the mortar, specifically steel fibers measuring 6 mm in length, basalt fibers measuring 8 mm, carbon fibers measuring 6 mm, and polypropylene fibers measuring 12 mm. The properties of the fibers used in the mortar are provided below at Table 2.

Table 2. Properties of fibers

Fiber	Steel	Basalt	Carbon	Polypropylene
Length	6 mm	8 mm	6 mm	12 mm

Air-Entraining Admixture

Air-entraining admixtures are surface-active agents that increase the resistance of concrete to freeze-thaw cycles by introducing small, stable air bubbles into the mix. The properties of the air-entraining admixture to be used in the mixtures are provided in Table 3.

Table 3. Properties of the air-entraining admixture

Product Information	Value
Appearance	Yellowish or colorless clear liquid
Chemical Composition	Liquid composed of special surfactants
Density	0,99-1,03 kg/l
pH value	3-7
Freezing Point	0 ºC
Alkali Content	Maximum 3%

Water Reducing Admixtures

Within the scope of the study, water reducing admixture was used in the mortar mixtures to achieve the target spreading values.

The physical and chemical properties of the water reducing admixture used in the study are presented in Table 4.

Table 4. Physical and chemical properties of water reducing admixture

Properties	Values
Recommended dosage range (%)	0.8-1.5*
Density (g/cm³)	1.073
Solid content (%)	28.76
Chloride content (% by weight)	0.0618
Alkali content (% by weight)	≤4
pH Value (10% solution)	4.89

*As a percentage of the cement weight

Production of Mortar Mixtures

In the production process, mortar mixtures were prepared by 0.1% air-entraining admixture, and 0.5% steel fiber, carbon fiber, basalt fiber, or polypropylene fiber. A total of 5 mortar mixtures were produced, and the flow-spread values of these mixtures were determined. Table 5 provides the codes and material ratios of the mortar mixtures.

Table 5. Materials used in the produced mortar mixtures

Code	Cement (g)	AEA (g)	WRA (g)	Fine aggregate (g)	Water (g)	Steel fiber (g)	Basalt fiber (g)	Carbon fiber (g)	PP fiber (g)
C	500	0,5	0,4	1375	242,5	-	-	-	-
C-ST	500	0,5	0	1375	242,5	35,36	-	-	-
C-BS	500	0,5	1,5	1375	242,5	-	12,02	-	-
C-CR	500	0,5	3,3	1375	242,5	-	-	8,21	-
C-PP	500	0,5	1	1375	242,5	-	-	-	4,11

*AEA: Air-Entraining admixture
*WRA: Water reducing admixture

The mortar mixtures were prepared according to the ASTM C109(2009). The water/binder ratio and sand/binder ratio of the prepared mortar mixtures were kept constant at 0.485 and 2.75, respectively.

The prepared mortar mixtures were placed into prismatic flexural molds (40x40x160 mm) in two layers and compacted. The molds were then placed on a shaking table to ensure proper settling. The molded samples were kept for 24 hours in an environment with a temperature of 20±2°C and at least 90% relative humidity, covered with a plastic plate. After 24 hours, the samples were demolded and stored in saturated limewater at 20±2°C until the test day, which was 28 days later.

Determination of Fresh State Properties

The flow of the produced mixtures was determined according to the ASTM C1437(2020). The target flow value was set at 190±20 mm. The water reducing admixture requirement to achieve the target flow value in the mortar mixtures was determined.



Figure 2. Flow table test

The mortar was transferred from the mixing container to the mold on the flow table, filling half of the mold. After applying 25 blows with a tamper, the remaining portion of the mold was filled, followed by another 25 blows (Figure 2). After leveling the top surface of the mold with a trowel, the mold was carefully lifted, and the fresh mortar was dropped 25 times at a rate of once per second. The flow diameter was measured in two different directions using a ruler, and the average of these two measurements was taken.

Water Absorption

The water absorption rates of the concrete samples were calculated according to TS EN 12390-7, (2002), using the following equation:

$$\text{Water Absorption by Weight} = \left(\frac{W_1 - W_2}{W_2}\right) \times 100$$

where:

- W_1: Saturated surface dry sample weight (g)
- W_2: Dry sample weight (g)

Flexural and Compressive Strength Test

The flexural strength of the mortar mixtures was determined according to the TS EN 196-1 standard. Fifteen minutes before the test, the 40×40×160 mm samples were removed from the curing pool, dried with a cloth, and placed in the flexural testing machine. The flexural test was conducted on at least three prismatic samples, with the load applied at the midpoint of each sample.

The two prism halves obtained from the flexural test were subjected to a compressive strength test, using a 40×40×40 mm metal breaking head to simulate a cube effect. The compressive strength of the mortar mixtures was determined on 40×40×40 mm prismatic samples according to the TS EN 196-1 standard. Flexural and compressive tests are shown in Figure 3.



Figure 3. Flexural and compressive strength test

RESULTS AND DISCUSSIONS

Fresh Properties

Figure 4 shows the amount of water-reducing admixture required to achieve the target spread, along with the corresponding spread diameter.

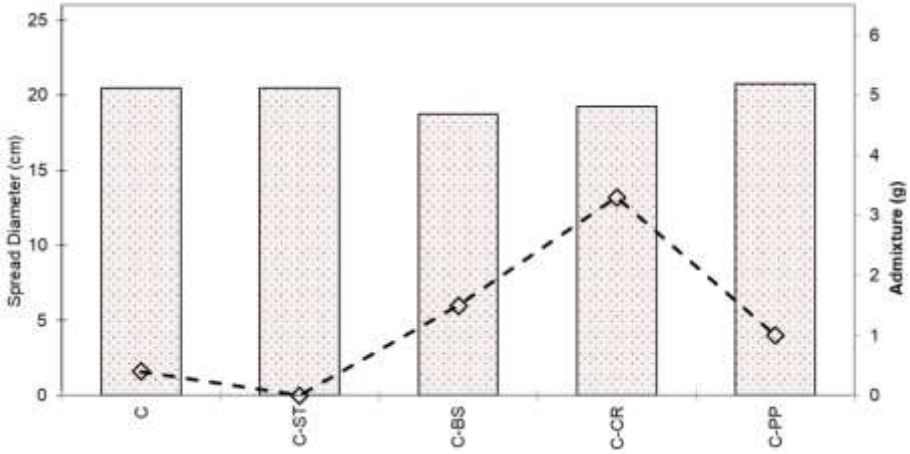


Figure 4. Admixture-spread diameter results

As seen from the results in Figure 4, the amount of water-reducing admixture required to achieve the target spreading increased with the addition of fiber (excluding steel fibers) to the mortar mixtures. The carbon fiber mixture utilized the highest amount of water-reducing admixture, which was 3.3 grams. In contrast, the control mixture required only 0.4 grams of admixture, while the steel fiber mixture met the targeted workability without needing any admixture.

Previous studies have reported that the addition of fibers to cementitious mixtures decreases workability (Köksal et al., 2012). Kızılılgın (2009) stated that as the volume of microfibers increased, the spread performance of the mortars decreased. In steel fiber-reinforced mortars, an increase in fiber content led to a reduction in spread values. A similar trend was noted in the carbon fiber series, although the performance loss was more pronounced in this case. Specifically, as the carbon fiber ratio increased, the decrease in the spread performance of the mortar became more evident (Kızılılgın, 2009). This decrease is attributed to the large surface area of the carbon fibers, which restricts the mobility of the fresh mortar and causes the fibers to interlock (Safiuddin et al., 2018).

Hardened Properties

Figure 5 displays the water absorption ratios for the different mortar mixtures. The polypropylene fiber mortar mixture exhibited the highest water absorption rate, recorded at 10.24%. Water absorption rates of C and C-ST mixtures were close to C-PP mixture.

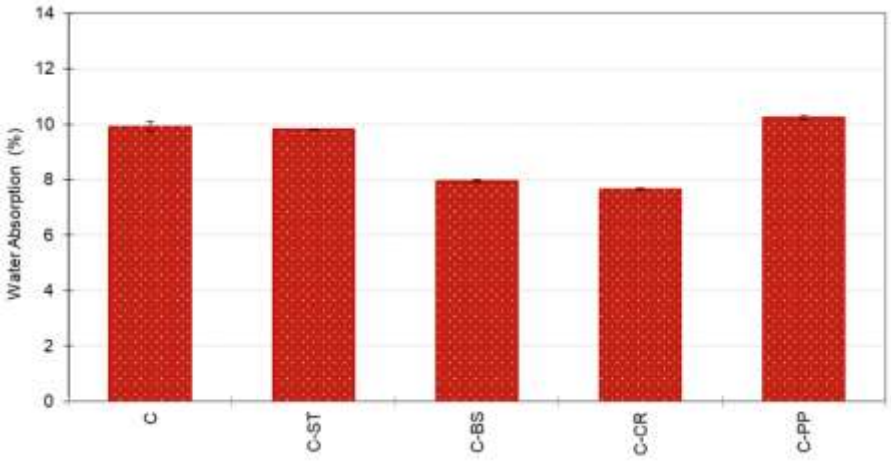


Figure 5. Water absorption percentage results

The lowest water absorption percentage was measured in the carbon fiber-reinforced mixture. The mixture containing polypropylene fibers showed a value quite close to the control and C-ST mixture. It was found that the water absorption values of the samples increased or decreased depending on the type of fiber. Compared to the control mixture, the water absorption value increased by 3.23% with the addition of polypropylene fibers, while it decreased with the addition of steel, basalt, and carbon fibers. The water absorption value was observed to decrease by 22.88% in the carbon fiber mixture compared to the control.

It is known that adding fibers to cementitious systems has a significant effect on the water absorption. Previous studies have shown that the water absorption rate increased when polypropylene fibers were added. However, this increase was greater when longer fibers were used compared to shorter fibers. It can be concluded that the increase in water absorption is related to the entrapment of air during the mixing process, resulting in the formation of voids in the concrete. The interlocking phenomenon of long fibers causes the emergence of voids that are suitable for water diffusion (Bayasi & Zeng, 1993; Richardson, 2006). An increase in the fiber ratio leads to a significant increase in water absorption levels for both fiber lengths (at a 0.95 confidence interval) (Bagherzadeh et al., 2012) .

The results illustrated in Figure 6 below present the compressive strength test outcomes, highlighting that the mortar incorporating basalt fibers achieved the highest compressive strength, reaching 31.06 MPa.

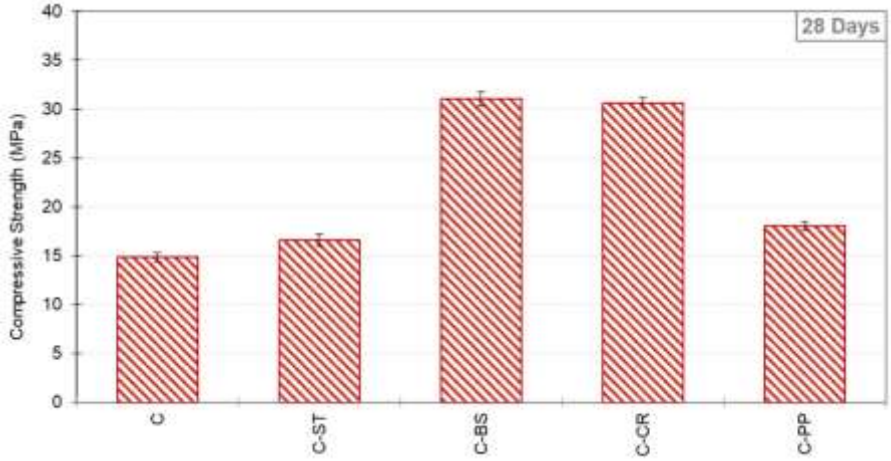


Figure 6. Compressive strength test results

The carbon fibre reinforced mixture followed closely behind, providing the second-best result at 30.57 MPa. Compared to the control mixture, all fibre types contributed positively to the compressive strength. The closest result to the control was measured at 16.59 MPa in the steel

fibre reinforced mixture. It is anticipated that factors such as fibre aggregation and alignment may have caused the strength reduction.
In a study conducted by El-Gelani et al. (2018), the inclusion of basalt fibers in the mixture led to an increase in compressive strength of up to 10% on both the 3rd and 7th days of curing. This improvement can be attributed to the ability of basalt fibers to facilitate early strength development within the concrete matrix. By increasing the bonding capacity and strengthening the internal structure, these fibers effectively prevent crack propagation. As a result, this mechanism contributes to higher compressive strength and allows greater energy absorption under load.

The results of the flexural strength test, as illustrated in the graph below (Figure 7), demonstrate that the basalt fiber mortar mixture achieved the highest flexural strength at 5.01 MPa.

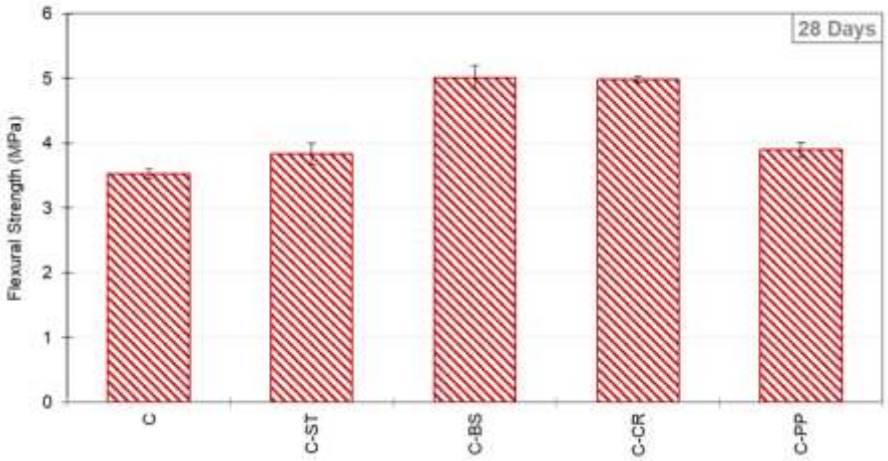


Figure 7. Flexural strength test results

The basalt fiber mortar mixture exhibited the highest flexural strength, measuring 5.01 MPa, closely followed by the carbon fiber mixture with a value of 4.98 MPa. These results were similar to those observed for compressive strength.
Based on these findings, it can be concluded that the addition of basalt and carbon fibers yields better mechanical properties than the addition of steel or polypropylene fibers to mortar mixture. Compared to the control mixture, the basalt fiber-reinforced mortar showed a remarkable increase of 56.09% in flexural strength. In contrast, the mixtures containing steel and polypropylene fibers did not demonstrate any significant increase in flexural strength.
Joshi et al (2014), reported that additions of basalt fibers resulted in significant improvements in both compressive and flexural strengths. Basalt fibers promote early strength development within the concrete matrix, enhancing its binding capacity and reinforcing the internal structure. Furthermore, the presence of basalt fibers impedes crack propagation, thereby facilitating higher compressive strength and allowing for greater energy absorption under load. The microstructural effects of the fibers contribute to an increased resistance to deformation and cracking, ultimately improving the overall durability of the concrete. Consequently, the incorporation of basalt fibers emerges as a significant strategy for enhancing the mechanical performance of concrete mixtures. This study underscores the potential of basalt fibers in achieving desired strength characteristics and improving the overall performance of concrete.

CONCLUSION

- The highest proportion of water reducing additives required to achieve the target spread was found in the carbon fiber mixture.

- The control, steel fiber, and polypropylene fiber mortar mixtures exhibit the highest water absorption rate, while the basalt and carbon fiber mixtures demonstrate the lowest water absorption rate.
- In terms of compressive strength and flexural strength, the mixtures containing basalt and carbon fiber showed the highest strength performance. The control mix has the lowest compressive and flexural strength.

REFERENCES

Afroughsabet, V., & Ozbakkaloglu, T. (2015). Mechanical and Durability Properties of High-Strength Concrete Containing Steel and Polypropylene Fibers. *Construction and Building Materials*, *94*, 73–82. https://doi.org/10.1016/J.CONBUILDMAT.2015.06.051

Bagherzadeh, R., Pakravan, H. R., Sadeghi, A. H., Latifi, M., & Merati, A. A. (2012). An investigation on adding polypropylene fibers to reinforce lightweight cement composites (LWC). *Journal of Engineered Fibers and Fabrics*, *7*(4), 13–21. https://doi.org/10.1177/155892501200700410

Bayasi, Z., & Zeng, J. (1993). PROPERTIES OF POLYPROPYLENE FIBER REINFORCED CONCRETE. *ACI Materials Journal*, *90*(6).

Bing, S. (2006). Properties and Applıcation of Steel-Fiber Reinforced Magnesia Phosphate Cement Mortar. *Architecture Technology*.

Bošnjak, J., Sharma, A., & Grauf, K. (2019). Mechanical Properties of Concrete with Steel and Polypropylene Fibres at Elevated Temperatures. *Fibers 2019, Vol. 7, Page 9*, *7*(2), 9. https://doi.org/10.3390/FIB7020009

Boulekbache, B., Hamrat, M., Chemrouk, M., & Amziane, S. (2016). Flexural Behaviour of Steel Fibre-Reinforced Concrete Under Cyclic Loading. *Construction and Building Materials*, *126*, 253–262. https://doi.org/10.1016/J.CONBUILDMAT.2016.09.035

C109/C109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). (2009).

C1437 Standard Test Method for Flow of Hydraulic Cement Mortar (2020). https://www.astm.org/c1437-20.html

Chandramouli, K. & R., P Srinivasa Rao & Narayanan, & Pannirselvam & Tirumala. (2010). *Long Term Durability Studies on Glass Fibre Reinforced Concrete Using Rapid Chloride Permeability Test*.

Chung, D. D. L. (1999). Carbon Fiber Cement-Matrix Composites. *Carbon*, *1999*(190), 300–312. https://doi.org/10.7209/TANSO.1999.300

El-Gelani, A. M., High, C. M., Rizkalla, S. H., & Abdalla, E. A. (2018). Effects of Basalt Fibres on Mechanical Properties of Concrete. *MATEC Web of Conferences*, *149*, 01028. https://doi.org/10.1051/MATECCONF/201814901028

Gao, L., Adesina, A., & Das, S. (2021). Properties of eco-friendly basalt fibre reinforced concrete designed by Taguchi method. *Construction and Building Materials*, *302*, 124161. https://doi.org/10.1016/J.CONBUILDMAT.2021.124161

Gueciouer, D., Youcef, G., & Tarek, N. (2022). Rheological and mechanical optimization of a steel fiber reinforced self-compacting concrete using the design of experiments method. *European Journal of Environmental and Civil Engineering*, *26*(3), 1097–1117. https://doi.org/10.1080/19648189.2019.1697758

Hanafi, M., Aydin, E., & Ekinci, A. (2020). Engineering Properties of Basalt Fiber-Reinforced Bottom Ash Cement Paste Composites. *Materials 2020, Vol. 13, Page 1952*, *13*(8), 1952. https://doi.org/10.3390/MA13081952

Hannant, D. J., & Spring, N. (1974). Steel-fibre-reinforced mortar: a Technique for Producing Composites with Uniaxial Fibre Alignment. *Magazine of Concrete Research*, *26*(86), 47–48. https://doi.org/10.1680/MACR.1974.26.86.47

Joshi, A., Student, P. G., Patil, D., & Students, P. (2014). *The use of Basalt Fibers to Improve the Flexural Strength of Concrete Beam*.

Kızılılgın, B. (2009). *Çelik ve karbon lifli harçların sülfat etkilerine dayanıklılığının incelenmesi*. http://acikerisim.deu.edu.tr:8080/xmlui/handle/20.500.12397/8249

Köksal, F., Gencel, O., Unal, B., & Durgun, M. Y. (2012). Durability properties of concrete reinforced with steel-polypropylene hybrid fibers. *Science and Engineering of Composite Materials*, *19*(1), 19–27. https://doi.org/10.1515/SECM.2011.0064

Kwon, S., & Lee, H. K. (2009). A Computational Approach to Investigate Electromagnetic Shielding Effectiveness of Steel Fiber-Reinforced Mortar. *Cmc-Computers Materials & Continua*. https://doi.org/10.3970/CMC.2009.012.197

Mazzucco, G., Majorana, C. E., & Salomoni, V. A. (2015). Numerical simulation of polypropylene fibres in concrete materials under fire conditions. *Computers & Structures*, *154*, 17–28. https://doi.org/10.1016/J.COMPSTRUC.2015.03.012

Raif Boğa, A., Karakurt, C., & Ferdi Şenol, A. (2022). The effect of elevated temperature on the properties of SCC's produced with different types of fibers. *Construction and Building Materials*, *340*. https://doi.org/10.1016/J.CONBUILDMAT.2022.127803

Ramli, M., & Dawood, E. (2011). High-strength Flowable Mortar Reinforced by Steel Fiber. *Slovak Journal of Civil Engineering*, *19*(3), 10–16. https://doi.org/10.2478/V10189-011-0013-0

Richardson, A. E. (2006). Compressive strength of concrete with polypropylene fibre additions. *Structural Survey*, *24*(2), 138–153. https://doi.org/10.1108/02630800610666673

Safiuddin, M., Abdel-Sayed, G., & Hearn, N. (2018). Effects of Pitch-Based Short Carbon Fibers on the Workability, Unit Weight, and Air Content of Mortar Composite. *Fibers*, *6*(3). https://doi.org/10.3390/FIB6030063

Sivakumar, A., & Santhanam, M. (2007). Mechanical Properties of High Strength Concrete Reinforced with Metallic and non-metallic Fibres. *Cement and Concrete Composites*, *29*(8), 603–608. https://doi.org/10.1016/J.CEMCONCOMP.2007.03.006

TS EN 196-1 Methods of testing cement - Part 1: Determination of strength. (2009).

TS EN 197-1 Cement- Part 1: Compositions and conformity criteria for common cements. (2002).

TS EN 12390-7 Testing Hardened Concrete - Part 7: Density of Hardened Concrete (2002).

Wang, W., Shen, A., Lyu, Z., He, Z., & Nguyen, K. T. Q. (2021). Fresh and rheological characteristics of fiber reinforced concrete——A review. *Construction and Building Materials*, *296*, 1–39. https://doi.org/10.1016/J.CONBUILDMAT.2021.123734

Yang, L., Xie, H., Fang, S., Huang, C., Yang, A., & Chao, Y. J. (2021). Experimental study on mechanical properties and damage mechanism of basalt fiber reinforced concrete under uniaxial compression. *Structures*, *31*, 330–340. https://doi.org/10.1016/J.ISTRUC.2021.01.071

Yang, L., Xie, H., Zhang, D., Zhang, F., Lin, C., & Fang, S. (2021). Acoustic emission characteristics and crack resistance of basalt fiber reinforced concrete under tensile load. *Construction and Building Materials*, *312*. https://doi.org/10.1016/J.CONBUILDMAT.2021.125442

Yin, S., Tuladhar, R., Shanks, R. A., Collister, T., Combe, M., Jacob, M., Tian, M., & Sivakugan, N. (2015). Fiber Preparation and Mechanical Properties of Recycled Polypropylene for Reinforcing Concrete. *Journal of Applied Polymer Science*, *132*(16). https://doi.org/10.1002/APP.41866