IMPROVEMENT OF THE CEMENT MORTAR CHARACTERISTICS REINFORCED WITH BASALT FIBERS

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Abstract: *Fibers derived from basalt rocks exhibit high strength and stability in aggressive environments and are environmentally benign. Consequently, in this study, basalt fiber (BF) was selected as a material to reinforce the mortar. The influence of BF content on the mechanical properties of cement mortars was investigated, and the optimal fiber concentration was determined to be 3.3 kg per 1 m^3 of the mixture. The research was conducted on the filler-cement-fiber-water system, and the following results were obtained through analysis of experimental research: flexural strengths increased by 3.7-16.2% for mixtures prepared with river sand and 9.1-16.8% for those prepared with lithoidal sand. Additionally, compressive strengths increased by 3.1-13.7% when river sand was utilized as filler and 5.9-12.4% when lithoidal sand was employed. Developing cement mortar compositions incorporating basalt fibers up to 12 mm in length and lithoidal light and river sands, abundant in our republic, represents a scientific innovation that results in enhanced compressive and bending strengths.*

Keywords: *basalt fiber, cement mortar, flexural strength, compressive strength..*

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Introduction

Concrete science improvements at the end of the 20th century allowed for producing high-quality, high-strength concretes with compressive strengths of not less than 100 MPa. High-rise skyscrapers, oil platforms, and other remarkable structures in the seas and oceans are all constructed using these concretes [1,2]. However, with a significant increase in the compressive strength of concrete, the flexural strength of high-strength concrete increases only slightly, reducing its efficiency. Reducing costs and technological complexity, using materials and energy resources efficiently, and implementing new, cutting-edge materials and technologies are all aspects of modern construction that directly address the issue of improving the efficiency of construction product production. This type of material is known as distributed reinforced concrete, and it is being utilized extensively in many industries [3-5]. Increases in tensile and flexural strength, crack resistance, impact strength, durability, frost resistance, stability, water permeability, wear resistance, and shrinkage reduction are required for new architectural forms, thin-walled panels with complex relief, airport takeoff and landing zones, roads, and industrial building floor panels. Non-metallic composite reinforcement made of glass, basalt, and carbon fibers impregnated and reinforced with a polymer binder, fibrous reinforcement for dispersed reinforcement of concrete made of the same fibers (for fiber-reinforced concrete or, in other words, fiber-reinforced concrete) are used to improve the listed properties. Woven tapes and preparations for reinforcing the web and gutters are also widely used from the same fibers [6-9]. A common reinforcing material is dispersed reinforcement made of different fibers, such as steel, polypropylene, and basalt [10]. The fibers in the concrete mixture are evenly distributed throughout the material field to accomplish dispersed reinforcing. The latter can be considered a revolution in building materials for the twentieth century.

Today, all sectors worldwide are trying to use or develop environmentally friendly materials and processes due to the economic use of ecosystems and natural resources. Therefore, the construction industry should also contribute to producing and using sustainable materials with low CO_2 emissions. Basalt fibers, which have a high modulus of elasticity and tensile strength, were considered in this work [11-13]. Because of their high strength and varying sizes, these fibers greatly enhance the mechanical and physical properties of the final product under stress influences and during abrupt temperature changes. According to [14], 0.5-3.5% BF by weight of cement was added to the concrete mixture. At BF 2%, the strength increased by 10%, and a further increase in BF to 2.5 and 3% led to a decrease in strength by 12 and 21%, respectively. The reduction in compressive strength due to the addition of basalt fiber is explained by the formation of weak interfacial areas between the fibers and the cement mixture [15].

Another study [16] reported a maximum compressive strength increase of 10 % when 0.3% BF with a length of 22 mm was used. The effect of the fiber length on the compressive strength was studied. Four distinct fibers with lengths of 3, 6, 12, and 24 mm were employed at dosages of 0.1, 0.3, and 0.5% by volume of concrete [15]. The test results showed a significant improvement in compressive strength: composites with 12 mm fibers showed the highest compressive strength compared to other composites at all fiber dosages. In addition, a fiber content of 0.1% was considered the optimum content for fibers of any length. According to many studies, the optimum fiber content for compressive strength is approximately 0.3%. However, it is known [17-19] that using basalt fibers increases the tensile and bending strengths of concrete and mortar. In particular, the flexural strength increased by approximately 75% when 0.3% basalt fiber was used in the mixture. The optimum length was 3-12 mm fiber [20,21] owing to the creation of a concrete bridge effect, which contributes to a higher tensile strength and, consequently, an increase in flexural strength. This study explored how the type of filler material, lithoid-pumice sand and river sand, and the quantity of locally produced basalt fiber affected the primary mechanical and physical properties of processed cement mortars.

Materials and Methods

Raw Materials

M400 (Class B42.5) Portland cement manufactured by the Ararat cement plant was used as the binding material in the processed compositions. Laboratory studies of the main physical and mechanical characteristics were carried out according to the GOST EN 196-3-2002 standard[1] and are presented in Table 1. In addition to the characteristics defined by the aforementioned standards, the bulk density of the cement was also determined for practical use.

Table 1. Physical and mechanical properties of cement

N	Characteristics	Unit	Results obtained
1.	The residue on the 0.08 sieve according the fineness of grinding	% by mass	3.6
2.	Specific gravity	g/cm^3	2.89
3.	Bulk density	kg/m^3	1135
4.	Standard consistency	%	26.3
5.	Setting time	min	Initial - 75 Final - 216
6.	Compressive strength	MPa	42.23
7.	Flexural strength	MPa	6.12

This study aimed to develop and research cement mortars reinforced with basalt fibers. Therefore, large aggregates were not considered, and only small aggregates with a grain size of 0-2.5 mm were considered. River and lithoidal pumice sands, currently the most used sands in the construction industry in the Republic, are used as fine aggregates for fiber concretes. Moreover, pre-washed river sand was obtained from the Araksavan deposit and lithoidal-pumice from the Jraber deposit. The physico-mechanical characteristics of the

[1] GOST EN 196-3-2002. Methods of Testing Cement. Part 3. Determination of Setting Time and Soundness. GOST: Moscow, Russia, 2002. Available at: https://www.armstandard.am/en/standart/5558 (accessed on July 31, 2023).

selected sand samples were determined using the current GOST 8735-88[2] standard method. For the sand, the average bulk density, fine particles, and water absorption indicators were also determined, as shown in Table 2. The grain-size composition data determined by standard sieve analysis and the bulk modulus (Ms) are presented in Table 3.

Table 2. Grain size composition of sands

Name of rocks	Balance type	Whole residues on the sieves, %					
		2.5	**1.25**	**0.63**	**0.315**	**0.16**	**< 0.16**
River sand	Partial	9.96	14.9	32.65	31.2	9.24	1.99
	Total	9.96	24.86	57.51	88.71	97.92	99.91
Lithoidal pumice sand	Partial	12.10	21.45	17.51	17.04	21.25	8.24
	Total	12.10	33.55	51.06	68.10	59.35	97.59

Moreover, according to the values of size modules Ms = 2.54 and 2.79, according to GOST 8736-2014, they belong to the group of course (Ms = 2.5-3.0) sands.

Table 3. Main characteristics of sands

Name of rocks	Bulk density, kg/m^3	Dust content, % by mass	Water absorption, % by mass	Size Modulus, Ms
River sand	1630	1.76	16.3	2.54
Lithoidal pumice sand	1020	5.63	30	2.79

In contemporary practice, lightweight concretes and construction mortars are in high demand and widespread use due to their numerous advantages. Consequently, this study considers not only river sand but also lithoid-pumice aggregate, which is currently extensively utilized in the construction industry. In contrast to river sand, lithoid-pumice aggregate exhibits high chemical reactivity and, through interaction with calcium hydroxide — a product of cement hydration — mitigates the alkaline environment that poses a threat to fibers. This interaction contributes significantly to enhancing the durability of the resultant products.

It is known that the fibers obtained from basalt rocks have high strength and resistance to many aggressive environments, including cement and calcareous alkaline environments, as well as the thermal effects of fires and other valuable features [22,23]. In addition, it is obtained from natural raw materials and is environmentally safe. Basalt fiber manufactured by "ArmBasalt" Continuous Basalt Fiber Manufacturing Plant CJSC was chosen as the dispersed reinforcement for this work.

Short-length fiber segments are often utilized for dispersed reinforcement, and the waste material generated during the production of basalt fiber roving is also appropriate for this purpose. In the compositions developed, fibers measuring between 10 to 12 mm in length were employed, and their effects on the key physicochemical and mechanical properties of the mortar were examined. Figure 1 presents an example of basalt fibers, while Table 4 summarizes their key characteristics.

Fig. 1. *Dispersed basalt fibers for cement mortar reinforcement*

[2] GOST 8735-88. Sand for Construction Work. Test Methods. GOST: Moscow, Russia, 2021. Available at: https://meganorm.ru/Index2/1/4294853/4294853080.htm (accessed on January 1, 2021).

Table 4. Main characteristics of basalt fibers

Basalt fiber	Characteristics					
	Raw material	**Density, kg/m^3**	**Diameter, μm**	**Melting temperature, ^{O}C**	**Alkali and corrosion resistance**	**Tensile strength, MPa**
	Basalt stone	2800	17	1450	high	450-600

Compositions and Specimen Preparation

To ensure a fair comparison between mortars made with lithoidal pumice sand and basalt fibers and those made with river sand and basalt fibers, we standardized the cost of cement in both cases. However, considering the differences in the average density of these two types of sand, we mixed them in the mortars using the same volumetric proportions rather than by weight. Taking as a basis that the bulk density with river sand is 1630 kg/m^3, and with lithoidal pumice, it is 1020 kg/m^3. Basalt fiber (BF) dosages were chosen according to the amount of content in 1 m^3 of the mortar, with a measurement unit of kg/m^3. BF = 0; 0.5; 1.2; 2.1; 3.3; 4.5; and 6.1 kg/m^3. Laboratory research was conducted using three identical size 40 × 40 × 160 mm test samples. The mortar was prepared in the proportion of cement — filler — water of 1:3:0.5, and the average density ρ_{average} was determined by vibration in a standard 1 liter container. Ten different mortars were developed, as presented in Table 5.

Table 5. Quantites of starting materials for 10 different components

N	River sand, g	Lithoid pumice sand, g	Cement, g	Water, ml	Basalt fiber, g	The volume of the prepared mixture, cm^3	Fresh mix density, ρ_{av}, g/cm^3
1.	1650	-	550	275	-	1.124	2.201
2.	-	1030	550	395	-	1.1	1.794
3.	1650	-	550	275	0.562	1.124	2.248
4.	1650	-	550	275	1.349	1.124	2.232
5.	1650	-	550	275	2.36	1.124	2.187
6.	1650	-	550	275	3.709	1.124	2.151
7.	1650	-	550	275	5.058	1.124	2.201
8.	1650	-	550	275	6.744	1.124	2.172
9.	-	1030	550	395	2.31	1.1	1.774
10.	-	1030	550	395	3.63	1.1	1.789

The mixtures were prepared in a standard mixer for cement mortar (Fig. 2a), with basalt fiber pre-mixed with sand. The resulting mixture with basalt fiber is illustrated in (Fig.2b).

The test specimens were molded using a vibrating platform. After being cured in a normal curing chamber alongside the molds for one day, they were demolded and immersed in water for an additional two days. Subsequently, the specimens underwent heat treatment in a heat bath chamber (Fig.3a).

Fig. 2. *Electric mixer (a) for mortar and the resulting fiber mixture (b)*

The hydrothermal processing was conducted as follows:

- The temperature was slowly raised to 800°C over 1 hour.
- An isothermal treatment was maintained at 800°C for 3 hours.
- After the treatment, the thermo-humidity cell was disconnected, and the samples were allowed to cool until the following day.

Once removed from the heat sink, the test samples were oven-dried (Fig.3b) until they reached a constant mass.

(a) *(b)*

Fig. 3. *Humidity test chamber (a), drying oven (b), and the specimen*

After using the mentioned technology and applying accelerated strengthening through heat treatment, all prism-shaped test samples, measuring 40 × 40 × 160 mm and containing doses of 0.5-6.0 kg/m³ of both non-fiber and basalt fiber, were tested according to standard methods after drying (Fig.3a). Their halves were then also subjected to testing (Fig.3b).

Methods

Flexural Strength

The flexural strength of the specimens was tested using the Unitronic Compression/Tensile 50 kN testing equipment, which had a 50 kN maximum capacity and specimen sizes of 40 mm × 40 mm × 160 mm. A three-point flexural test on a poured prism formed the basis of the experiment using the standard EN 196-1[3].

Compressive Strength

In accordance with the Concrete Compression Machine 2000 kN automatic, Servo-Plus Progress, the compressive strength was determined by the average value of six test specimens, using the standard EN 196-1[4], and the specimen size was 40 × 40 mm. At a loading rate of 2.4 kN/s, compressive tests were performed on an automatic pressure machine.

Results and Discussion

Mechanical Properties

For each component, the final value of the flexural strength was determined by calculating the mean of three identical test samples, while the compressive strength was derived from the average of six halves obtained from the flexural test. The results are presented in Table 6.

[3] GOST EN 196-1-2002. Methods of Testing Cement. Part 1. Determination of Strength. Available at: https://www.armstandard.am/en/standart/5556 (accessed on July 31, 2023).

[4] Ibid.

Table 6. The main physical-mechanical characteristics of cement mortars without basalt fiber and dispersed-reinforced with basalt fiber

N (Filler, BF consumption)	Average density, ρ_{av}, g/cm^3	Flexural strength, MPa	Compressive strength, MPa
N1 (with river sand, without fiber)	2.18	7.03	37.33
N2 (with lithoid pumice sand, without fiber)	1.7	4.7	29.64
N3 (with river sand, 0.5kg basalt fiber)	2.24	7.29	38.13
N4 (with river sand, 1.2kg basalt fiber)	2.21	7.58	38.80
N5 (with river sand, 2.1kg basalt fiber)	2.18	7.87	39.75
N6 (with river sand, 3.3kg basalt fiber)	2.19	8.17	42.43
N7 (with river sand, 4.5kg basalt fiber)	2.21	7.89	39.51
N8 (with river sand, 6.1kg basalt fiber)	2.17	7.59	38.50
N9 (with lithoid pumice sand, 2.1kg basalt fiber)	1.69	5.13	31.40
N10 (with lithoid pumice sand, 3.3kg basalt fiber)	1.66	5.49	33.32

Flexural strength

According to the data presented in Table 6, the analysis of flexural strength in test samples composed of river sand and varying concentrations of basalt fibers revealed that, in comparison to the flexural strength of the reference test sample N1 (7.03 MPa), the values increased by 3.7% (BF = 0.5 kg, N3 = 7.29 MPa), 7.8% (BF = 1.2 kg, N4 = 7.58 MPa), 11.9% (BF = 2.1 kg, N5 = 7.87 MPa), 16.2% (BF = 3.3 kg, N6 = 8.17 MPa), 12.2% (BF = 4.5 kg, N7 = 7.89 MPa), and 8% (BF = 6.1 kg, N8 = 7.59 MPa). For test samples prepared with lithoidal sand filler, the following data were obtained: the flexural strength of the reference sample was N2 = 4.7 MPa, while the flexural strength of samples made with composition N9, where BF = 2.1 kg was used, was N9 = 5.13 MPa. For composition N10, where BF = 3.3 kg was used, the flexural strength was N10 = 5.49 MPa, representing a 16.8% increase. Figure 4 shows a comparison of the flexural strength tests of reference samples (with a dashed line) and samples prepared with different concentrations of BF.

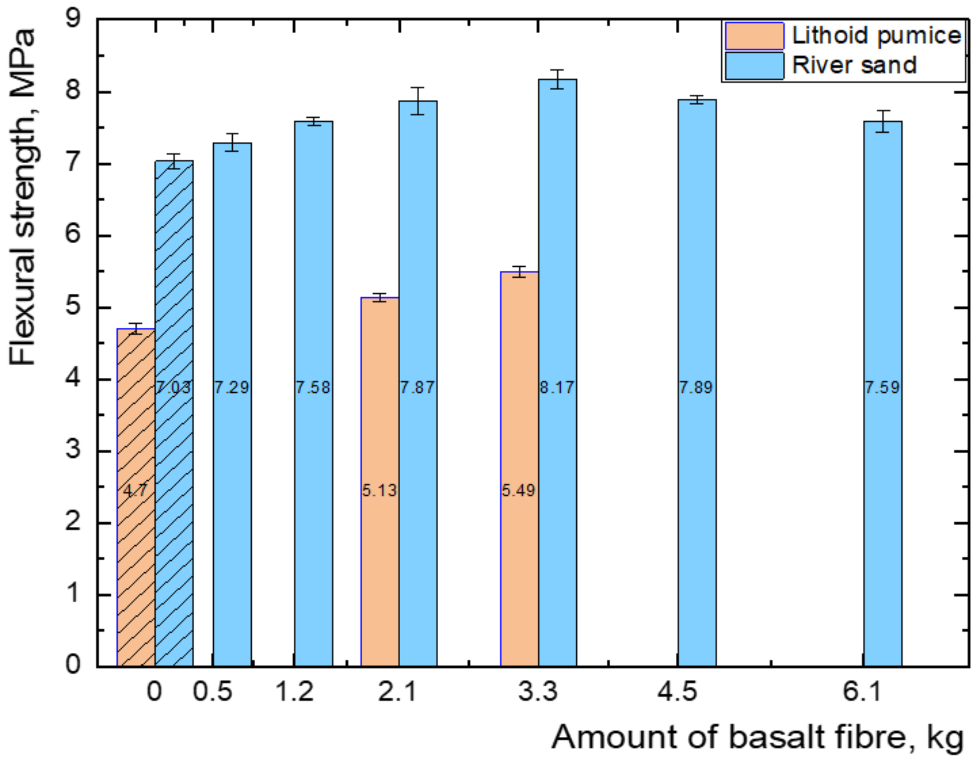

Fig. 4. *Effect of basalt fiber content on the flexural strength of cement mortar*

Compressive strength

The compressive strength testing of the samples yielded the following results (Table 6): For the reference sample utilizing river sand as a filler, the strength was N1 = 37.33 MPa. The compressive strength of the N3 composite post-heat treatment increased by 2.1% relative to the reference sample, reaching 38.13 MPa (BF = 0.5 kg). Sample N4 exhibited a 3.9% increase, attaining 38.80 MPa (BF = 1.2 kg), while N5 demonstrated a 6.5% increase, achieving a compressive strength of 39.75 MPa (BF = 2.1 kg). The N6 composition samples showed a 13.7% increase, reaching 42.43 MPa (BF = 3.3 kg). For compositions N7 and N8, although the strengths began to decrease, they remained elevated compared to the reference sample, with increases of 5.8% (39.51 MPa, BF = 4.5 kg) and 3.1% (38.50 MPa, BF = 6.1 kg), respectively. The compressive strength of the reference sample composed of lithoidal sand was N2 = 29.64 MPa. For N9, the results indicated a 5.9% increase to 31.40 MPa (BF = 2.1 kg), while composition N10 demonstrated a 12.4% increase, with a strength of 33.32 MPa (BF = 3.3 kg).

Figure 5 presents representative graphs illustrating the flexural and compressive strength of the tested samples, while Figure 6 depicts the relationship between the compressive strength values of samples derived from river and lithoid-pemza sands and various concentrations of BF.

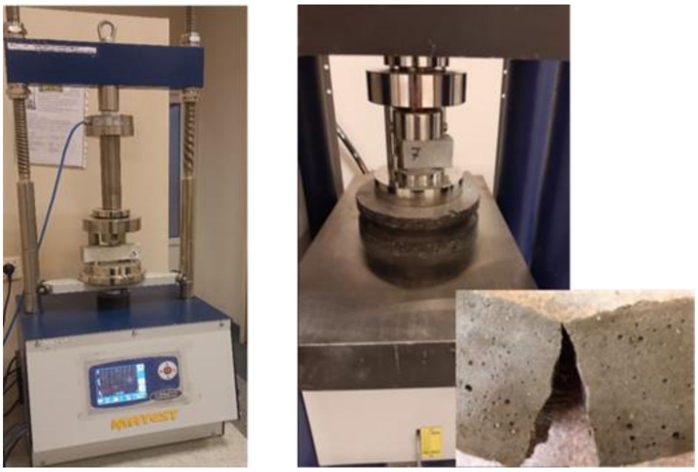

Fig. 5. *Flexural and compressive strength tests*

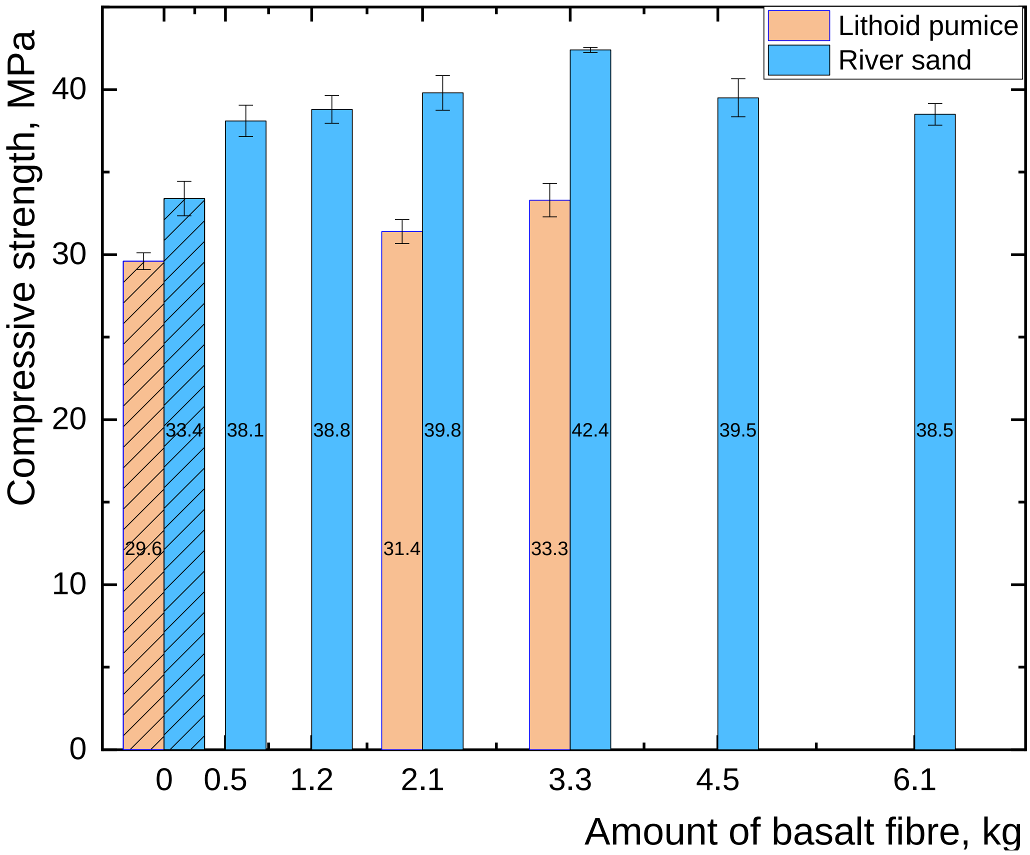

Fig. 6. *Effect of basalt fiber content on the compressive strength of cement mortar*

Basalt fiber can significantly enhance the mechanical properties of concrete due to its unique characteristics. Basalt fibers are known for their high tensile strength. When added to concrete, they enhance its ability to resist tensile forces, reducing the likelihood of cracking and improving its overall durability. By distributing the stress more evenly throughout the concrete matrix, basalt fibers increase the flexural strength of concrete. This is particularly beneficial in applications requiring high load-bearing capacity and resistance to deformation. Basalt fibers minimize shrinkage-induced cracking by acting as reinforcement at the micro level. They also have excellent thermal stability, reducing the risk of cracking due to temperature fluctuations [24,25].

Conclusion

The following conclusion can be made after examining the experimental measurement results from this study:

- Analysis of the obtained results indicates that the flexural strength of the fiber-reinforced mortar, within the range of 0-6.1 kg of fiber consumption per 1 m^3 of mortar mix reinforced with river sand filler and 10-12 mm long dispersed basalt fiber, demonstrates a notable increase. Specifically, at a consumption of 3.3 kg compared to the same mix without fiber, the flexural strength gradually increases from 7.03 MPa to a maximum value of 8.17 MPa, representing an enhancement of 16.2%. Subsequent increases in fiber dosage result in a diminished fiber effect, halting further improvements in bending strength. The flexural strength then begins to decrease gradually, reaching 7.59 MPa at the consumption of 6.1 kg, corresponding to only an 8% increase compared to the fiber-free product.
- The analysis of the obtained results indicates that an initial increase in compressive strength is observed within the range of 0-6.1 kg of fiber consumption per 1 m3 of mortar mixtures reinforced with river sand filler and dispersed 10-12 mm long basalt fiber. Specifically, up to a consumption of 3.3 kg, the compressive strength of the fiber-reinforced mortar compared to the non-fiber mixture gradually increases from 37.33 MPa to 42.43 MPa, reaching a maximum enhancement of 12.4%. However, further increase in the fiber dosage results in a diminishing effect, halting the increase in compressive strength and subsequently leading to a gradual decrease.
- The results presented in the aforementioned points demonstrate that for 1m^3 of dispersed cement mortars reinforced with basalt fiber 10-12 mm in length, the optimal quantity of fiber is 3.3kg. Concurrently, the experimental results obtained for flexural and compressive strength indicate that they vary according to a similar pattern; however, the influence of fiber on flexural strength is marginally greater than on compressive strength.

Basalt fiber mortars are utilized for strengthening and retrofitting existing structures (both concrete and masonry). This process may be implemented through basalt-based fiber-reinforced polymers and cementitious matrices. In plastering and rendering applications, basalt fiber mortars enhance crack resistance and impact strength. These materials are employed for structural and non-structural repairs, particularly in historical buildings.

Conflict of Interest

The author declares no conflicts of interest.

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