

Mechanical Properties of Basalt Fiber Reinforced Perlite Aggregate Cement Mortars

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Abstract – In this study, the mechanical properties of basalt fiber reinforced perlite aggregate cement mortars were investigated. The aim of the research was to determine the effect of basalt fiber on the strength properties of cement mortar and to identify the optimal fiber content. Specimens with different proportions of basalt fiber were prepared, and their compressive and flexural strengths were measured at 7 days and 28 days. A control specimen with no fiber reinforcement (B0) was used for comparison.

The results showed that basalt fiber generally enhanced the strength of the cement mortar. The specimens with basalt fiber reinforcement exhibited higher compressive and flexural strengths compared to the control specimen (B0). Particularly, a more significant increase in strength values was observed in the specimens with basalt fiber at the 28-day testing period. However, the effect of basalt fiber content and distribution varied among the specimens. In some specimens (B1.5, B2, B3), a slight decrease in strength was observed at certain testing periods.

This study highlights the significance of basalt fiber reinforced perlite aggregate cement mortars as a research area, considering the increasing demand for their use in construction applications.

Keywords – Basalt Fiber, Raw Perlite Aggregate Cement Mortars, Mechanical Properties

I. INTRODUCTION

Sustainable and lightweight building materials are playing an increasingly important role in the construction industry due to their many benefits and advantages [1], [2]. Here are some key reasons why these materials are so important: Sustainable and lightweight building materials can significantly reduce the environmental impact of construction projects. [3]. They can increase the energy efficiency of buildings by reducing heat loss, regulating temperature, and minimizing the need for heating and cooling systems [4]. The transportation and installation of lightweight materials can be easier, which can reduce the risk of accidents and injuries on construction sites. Sustainable materials can also reduce the risk of toxic exposure to workers and building occupants [5]. Sustainable and lightweight building materials can be designed to be durable and long-lasting, which can reduce the need for maintenance and repairs over time. This can lead

to lower life cycle costs and a smaller environmental impact [2], [6]. Contribution of sustainable and lightweight building materials can increasingly play an important role in green building certifications in the construction industry [7]. In using these materials, builders can demonstrate their commitment to sustainable and environmentally responsible building practices.

The use of basalt fiber cement mortars and perlite aggregates can improve the strength, durability, fire resistance, thermal insulation, and workability of building materials. Additionally, their lightweight and sustainable properties make them an excellent choice for environmentally friendly and energy-efficient construction projects.

In his 2021 study, Bheel [8] examines the properties of Basalt Fiber Reinforced Concrete (BFRC) in terms of its fresh and mechanical properties. The research focuses on how the dosage and length of basalt fibers can affect the properties

of BFRC. In terms of fresh properties, the study notes that the addition of basalt fibers to concrete can reduce workability by impeding the movement of the concrete mixture. However, the use of superplasticizers and other chemical additives can help mitigate this effect. The article notes that, in terms of mechanical properties, the addition of basalt fibers to concrete can improve its tensile and flexural strength, as well as its toughness and ductility. The dosage and length of the fibers are important factors that can affect these properties

Zongwen Li et al. 2018 [9] found that the combination of basalt fiber and substrate can improve material properties, making basalt fiber an attractive option for use in composites with other materials. For example, basalt fiber composites can be used to create high-temperature and low-temperature protective clothing, as well as sound insulation materials for use in sound absorption and thermal insulation applications.

Adding perlite aggregates to cement-based mortars increases the fluidity of the mortars, which makes mixing, pumping, and application of the mixture easier. Perlite particles have a spherical shape and smooth surface, which allows them to move more freely in the mixture, reducing friction and increasing fluidity. This results in a smoother and more consistent mixture that can be easily applied to different surfaces. Additionally, perlite aggregates are lightweight, which can reduce the overall weight of the mortar. This is particularly important in construction applications where weight is a critical factor, such as in the production of lightweight concrete or installation of insulation layers. In summary, using perlite aggregates in cement mortars can improve the workability of the mixture, making mixing, pumping, and application easier. This can lead to more efficient construction processes and higher-quality finished products.

Nili and Afroughsabet 2010, the study investigated the effects of adding polypropylene fibers and silica fume to concrete mixtures with water-cement ratios of 0.36 and 0.46. Polypropylene fibers with different volume fractions were used, and silica fume was used as a cement replacement material. Results showed that incorporating polypropylene fibers improved the mechanical properties of the concrete, while silica fume facilitated their dispersion, resulting in improved impact resistance and strength performance [10].

The study conducted by Wade et al. (2022) focused on the development and characterization of prototype cementitious mortars that incorporated lightweight aggregates impregnated with phase change material (LWA-PCM). Efficient methods were developed to impregnate phase change materials into lightweight aggregates like gas concrete particles (ACG) and perlite. These impregnated aggregates were then used in cementitious mortar mixtures at various substitution rates. The aim was to assess how the inclusion of PCM-impregnated particles affected the mechanical and thermal properties of the mortars. The results indicated that increasing the amount of PCM-loaded particles resulted in a decrease in flexural and compressive strengths, with reductions of up to 38% and 49% respectively. However, the volumetric heat capacity of the materials exhibited an increase of approximately 60%. [11].

One of the most significant benefits of using perlite in construction is its sustainability. Perlite is a naturally occurring material that is mined from the earth, so it does not require the use of non-renewable resources or harmful production processes. Additionally, perlite is recyclable and can be reused, which reduces waste and preserves resources. Perlite also has a low thermal conductivity, making it an energy-efficient material that can help reduce heat loss and energy consumption in buildings. This makes it an ideal material for insulation applications. Furthermore, perlite is non-toxic and does not release any harmful substances into the environment. It is also fire-resistant, making it a safe choice for building construction. Overall, perlite is a sustainable and environmentally friendly material with many applications in the construction industry. Its lightweight, insulating, and fire-resistant properties make it an attractive option for building insulation, lightweight concrete, and other construction applications.

The article "Experimental Investigation on Wheat Straw and Perlite-Based Environmentally Sustainable Cement Composites" by Petrella et al. (2022) [12], focuses on the development of sustainable cementitious composites using wheat straw and perlite as aggregates. The study conducted various tests to evaluate the properties of these composites, including rheological, thermal, acoustic, mechanical, optical, and microstructure tests.

The results of the study indicate that mortars incorporating wheat straw and perlite aggregates exhibit favorable thermal insulation and acoustic absorption properties. The best outcomes were achieved with a combination of inorganic and organic aggregates. The addition of expanded perlite to the mixture enhanced the mechanical strength of the composites without significantly affecting their thermal properties.

In this study, Wang et al. (2021) [13] investigate the use of expanded perlite (EP) powder and sand as replacements for cement and quartz sand, respectively, in ultra-high performance concrete (UHPC). The rheological properties, workability, mechanical properties, and durability of UHPC containing EP powder and sand are examined. The results show that the addition of EP powder significantly reduces the viscosity of UHPC, shortens the V-funnel time, and increases the slump flow. The addition of EP powder also results in a durability comparable to up to 60% cement replacement with slightly lower strength. EP also exhibits pozzolanic activity and supports early hydration. The replacement of quartz sand with EP aggregate results in a relatively larger strength loss, but has no significant impact on workability. The authors also calculate CO₂ emissions and cement efficiency values, demonstrating the potential use of UHPC containing EP powder and sand as a sustainable building material.

De Oliveira Neto et al. 2022 [14], In this study, the use of powdered and coarse perlite waste (PP and CP) was investigated to develop sustainable mortar compositions. The waste was characterized using X-ray diffraction and particle size distribution. Compression strength and water/binder ratio were measured for 21 different mortar compositions containing different proportions of cement, lime, and perlite waste. Experimental design was then used to select four mortar compositions for evaluation of their resistance to sulfate attack. These four compositions were immersed in a sodium sulfate solution for 42 days and evaluated for linear expansion, X-ray diffraction, differential thermal analysis, thermal gravimetry, and compression strength. The results showed that the emergence of ettringite phase led to greater linear expansion and mechanical strength loss. However, the new sustainable mortar compositions still had compression strength greater than 2 MPa (according

to ASTM C452), which made them suitable for use as alternative coating mortars in civil construction.

Literature reviews have explored mechanical and physical properties of lightweight concrete produced using various types and origins of lightweight aggregates. However, there is a lack of research on the effects of different granulometry ratios. Since Turkey has approximately 4.5 billion tons of perlite reserves, effectively increasing the use of perlite as a concrete aggregate in the construction industry is of great importance. The aim of this study is to investigate the changes in flexural and compressive strength of lightweight concretes made with natural perlite aggregate and a water/cement ratio of 0.55, as well as granulometric mixtures.

II. MATERIALS AND METHOD

As seen in Figure 1, basalt (BZ) fibers of 12 mm length were used as fiber in the study. The density of basalt fiber typically ranges from 2.6 to 2.8 g/cm³. Basalt fibers have high tensile strength, which is one of their key properties. The exact tensile strength can vary depending on the manufacturing process and specific type of basalt fiber, but generally, it can range from 2.6 to 4.8 GPa (gigapascals). For comparison, steel has a tensile strength of about 0.5 to 2.0 GPa. This high tensile strength makes basalt fibers a desirable reinforcement material in composites, as they can resist tension and prevent cracking or breaking of the composite material.



Figure 1. Digital camera image of basalt fiber

Raw perlite aggregate was taken from Ankara/Çubuk region. Raw perlite was obtained by breaking at intervals of 0–5 mm. As seen in Figure 2, perlite aggregate with particle sizes of 0–0.5 mm, 1–2 mm and 2–4 mm was used and the mixing water was supplied from the city network.

Perlite aggregate is a lightweight, naturally occurring volcanic glass that is formed by the rapid cooling of lava when it comes into contact with water. It is widely used in construction applications as an aggregate in lightweight concrete, plaster, and insulation materials due to its low density, high porosity, and thermal insulation properties. In this study, raw perlite was used as aggregate and CEM I 42.5 R type cement was used as binder for the production of fiber-added composite concrete.

Table 1. The physical and chemical characteristics of the materials used

Oxides (%)	CEM I 42.5 R	Perlite
Chemical Properties		
SiO ₂	21.01	72.35
Al ₂ O ₃	5.39	12.24
Fe ₂ O ₃	3.23	1.51
CaO	62.11	1.12
MgO	1.97	0.65
SO ₃	3.10	1.24
Na ₂ O	0.39	3.15
K ₂ O	0.82	3.85
Physical Properties		
Blaine fineness (cm ² /g)	3.355	-
Loss on ignition (%)	2.36	3.15
Specific gravity (g/cm ³)	3.12	2.35

Table 2. The material mix of natural perlite aggregate

Aggregate Mix	PC (kg/m ³)	S/C	D1 (2-4 mm)	D2 (1-2 mm)	D5 (0-0.5mm)	Basalt Fiber (%)
B0	600	0.55	33.05	21.43	45.52	0.00
B0,5	600	0.55	33.05	21.43	45.52	3
B1	600	0.55	33.05	21.43	45.52	6
B1,5	600	0.55	33.05	21.43	45.52	9
B2	600	0.55	33.05	21.43	45.52	12
B3	600	0.55	33.05	21.43	45.52	15

This information shows the properties of various aggregate mixtures. Each mix is defined by a certain amount of cement (PC), water-cement ratio (S/C), percentages of different aggregate sizes (D1, D2, D5), and basalt fiber ratio (Basalt Fiber). The samples in Figure 2 are Basalt Fiber Reinforced Raw Perlite Aggregate Cement Mortar samples



Figure 2. Basalt fiber reinforced raw perlite aggregate cement mortar samples

III. EXPERIMENT RESULTS

The conducted study and the provided data represent the compressive strength and flexural strength of raw perlite aggregate and basalt fiber reinforced cement mortar samples. The inclusion of basalt fiber generally improves the strength properties of the mortar compared to the fiber-free sample (B0). Samples with higher amounts of basalt fiber (B1, B1.5, B2) tend to exhibit higher compressive and flexural strengths, particularly during the 28-day testing period.

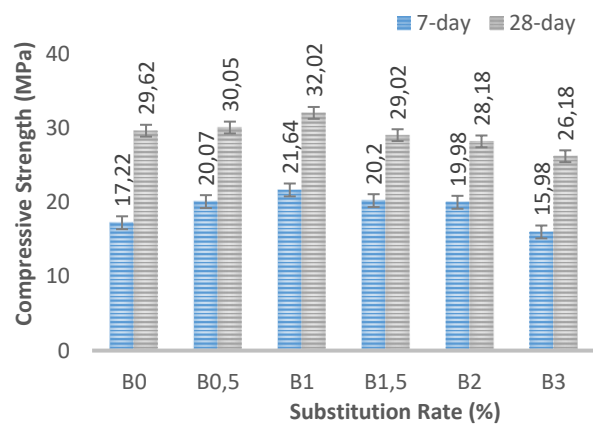


Figure 3. Compressive strength graph of basalt fiber reinforced raw perlite aggregate cement mortar

The samples with basalt fiber reinforcement generally exhibit higher compressive strength at 7 days and 28 days compared to the B0 sample. Among the samples, B1 shows the highest compressive strength at both 7 days and 28 days, while B3 exhibits the lowest compressive strength. Some decrease in strength is observed among the samples with basalt fiber reinforcement at the 28-day testing period (B1.5, B2, B3).

These results indicate that basalt fiber reinforcement can generally enhance the strength of

cement mortar, but the strength can vary depending on the amount of basalt fiber and other factors.

According to the data, we observe that samples with basalt fiber reinforcement generally increase the compressive strength of the cement mortar. The magnitudes of increase vary among the samples. For example, the B1 sample shows a 12.1% increase in flexural strength at 7 days compared to the B0 sample, while the B3 sample exhibits a decrease of 3.4%. Similarly, at 28 days, the B1 sample shows a 24.4% increase in flexural strength compared to the B0 sample, while the B3 sample shows a decrease of 5.3%.

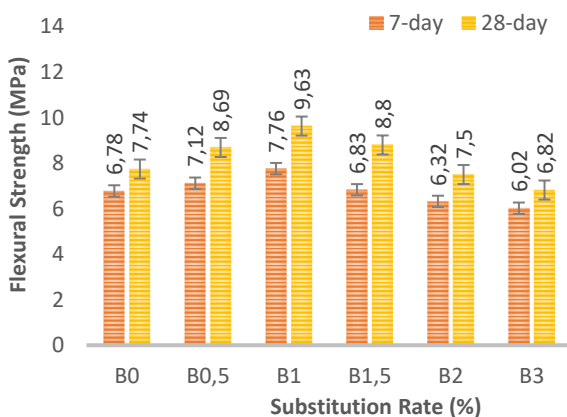


Figure 4. Flexural strength graph of basalt fiber reinforced raw perlite aggregate cement mortar

Based on the comparison between the basalt fiber reinforced cement mortar samples and the B0 reference sample, the flexural strength results indicate the following trends:

- B0.5 sample demonstrates a 4.8% increase in 7-day flexural strength and a 12.4% increase in 28-day flexural strength.
- B1 sample exhibits a significant improvement with a 14.1% increase in 7-day flexural strength and a substantial 24.7% increase in 28-day flexural strength.
- B1.5 sample shows a slight increase of 0.6% in 7-day flexural strength and a moderate 13.8% increase in 28-day flexural strength.
- B2 sample displays a decrease of 6.8% in 7-day flexural strength and a smaller reduction of 2.8% in 28-day flexural strength.
- B3 sample exhibits the most notable decrease, with an 11.1% reduction in 7-day flexural strength and an 11.8% decrease in 28-day flexural strength.

These results indicate that the inclusion of basalt fiber reinforcement generally leads to

improvements in flexural strength compared to the B0 reference sample. The magnitude of enhancement varies depending on the specific sample, with B1 sample demonstrating the highest increases. However, it is important to note that certain samples (B2, B3) show decreases in flexural strength. These findings highlight the significance of carefully considering the amount and distribution of basalt fiber to achieve the desired strength properties in cement mortar applications. Based on these results, it can be observed that the inclusion of basalt fiber generally leads to increased flexural strength in the cement mortar samples. Notably, the B1 sample exhibits the highest increase in both 7-day and 28-day flexural strengths. However, it should be noted that the effects of basalt fiber content and distribution vary among the samples. In some cases (B2, B3), a decrease in flexural strength is observed.

These findings highlight the potential of basalt fiber reinforcement in improving the flexural strength of cement mortar, with the optimal fiber content and distribution needing careful consideration to achieve desired strength properties.

IV. CONCLUSION

As a result of the study, the following conclusions were drawn regarding the basalt fiber reinforced raw perlite aggregate cement mortar.

Basalt fiber reinforcement generally enhances the compressive strength of the cement mortar at both 7 days and 28 days when compared to the reference sample (B0). Notably, the B1 sample demonstrates the highest compressive strength, while B3 exhibits the lowest.

Some samples with higher amounts of basalt fiber (B1.5, B2, B3) show a decrease in compressive strength at the 28-day testing period. This suggests that the optimal content and distribution of basalt fiber need to be carefully determined to achieve desired strength properties.

The flexural strength of the basalt fiber reinforced cement mortar samples generally increases compared to the reference sample (B0). The magnitude of increase varies among the samples, with the B1 sample demonstrating the highest increase in both 7-day and 28-day flexural strengths.

However, it is important to note that the effects of basalt fiber content and distribution on flexural strength also vary among the samples. In some cases (B2, B3), a decrease in flexural strength is observed. This highlights the need for careful consideration of basalt fiber content and distribution to achieve the desired strength enhancement.

In conclusion, the findings emphasize the potential of basalt fiber reinforcement in improving the mechanical properties, particularly compressive and flexural strengths, of cement mortar. However, the specific parameters, such as fiber content and distribution, should be optimized to ensure consistent and desirable results. Further research and experimentation can provide valuable insights for the effective utilization of basalt fiber reinforcement in construction applications.

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