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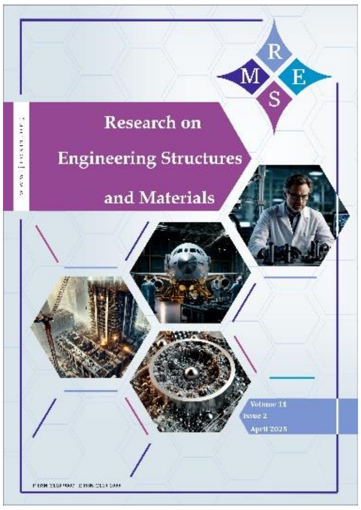

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Research Article

Effect of PVA and basalt fibers on enhancing the structural and thermal behavior of cement panels

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Abstract

This study investigates the influence of basalt fibers (BF) and polyvinyl alcohol fibers (PVA) on the mechanical and thermal performance of cement panels incorporating silica fume as a supplementary binder. A series of mortar mixes were prepared with varying fiber dosages and tested under controlled curing conditions. The experimental program included compressive strength, flexural strength, splitting tensile strength, water absorption, surface hardness, ultrasonic pulse velocity (UPV), thermal conductivity, and microstructural characterization using scanning electron microscopy (SEM).The results demonstrated that basalt fibers provided superior reinforcement, with the 3% BF mix achieving the highest compressive strength (45.28 MPa), flexural strength (11.23 MPa), and enhanced thermal insulation (thermal conductivity reduced to 0.644 W/m•K). In contrast, PVA fibers showed optimal performance at 2% content, yielding a compressive strength of 43.43 MPa and moderate improvements in flexural and tensile behavior. However, both fiber types increased water absorption relative to the reference mix, indicating a trade-off between mechanical enhancement and durability. SEM analyses confirmed the role of fibers in bridging microcracks and improving matrix integrity. Overall, the findings highlight that incorporating 3% basalt fibers and 2% PVA fibers optimizes the structural and thermal behavior of cement panels, suggesting their potential as effective reinforcement strategies in advanced construction materials.

1. Introduction

Cement, sand, and water are the components of ordinary Portland cement (OPC). Invented by Joseph Aspdin in 1794, it gained popularity in the 19th century due to its speed and ease of installation [1]. However, it is considered unsuitable for the restoration of lime mortar structures, which require flexibility and breathability [2, 3]. Due to their exceptional durability, fire resistance, and ease of installation, cement boards, including fiber cement boards (FCBs), are widely used in modern buildings. The primary binding material in these boards is cement, to which sand, reinforcing fibers, and other additives are added to improve performance. They are typically used for floors, walls, ceilings, and facades of residential and commercial buildings. FCBs can be painted, impregnated with protective coatings, or left uncoated. FCBs have proven their reliability through widespread use in construction for over a century, particularly in non-pressurized pipes and corrugated roofing sheets. However, when used in facade systems, they are often exposed to a wide range of weather conditions. Wind-borne debris, freeze-thaw cycles, prolonged exposure to ultraviolet radiation, and thermal stresses resulting from temperature changes are some of the factors that affect their long-term performance and durability [4, 5]. Cement boards are widely used in architectural and construction applications due to their favorable mechanical and thermal

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properties. However, they are still subject to various challenges that can affect their long-term performance and durability. The primary physical problems include cracking and buckling, often caused by fluctuations in temperature and humidity levels, as well as thermal expansion and contraction, which can lead to internal stresses and compromise mechanical stability. From an environmental perspective, prolonged exposure to ultraviolet radiation and freeze-thaw cycles can lead to surface deterioration and internal degradation. Additionally, the high moisture absorption capacity of inadequately treated boards can lead to swelling, discoloration, and biological growth such as mold and fungi. These problems are exacerbated by improper installation, including the use of incompatible fasteners or neglect of expansion joints [6, 7]. Fiber-reinforced mortars offer a compelling solution, enhancing the mechanical properties, crack resistance, and overall structural durability [8]. Glass fibers are widely used in composite mixes, while carbon fibers are among the most common reinforcing fibers used in the manufacture of composite materials under high load conditions. Despite their excellent properties, they are expensive [9, 10]. Therefore, basalt fibers are used due to their low cost, enabled by modern industrial production technologies. Consequently, basalt fibers and the materials made from them are characterized by high quality and cost-effectiveness. Basalt has excellent mechanical and thermal properties, is non-toxic to air or water, non-flammable, and biologically stable, making it suitable for a variety of building applications [9]. Polyvinyl alcohol (PVA) fibers are also part of the reinforcing fiber group. PVA fibers are characterized by their exceptional mechanical properties and compatibility with the cement matrix. Due to their stiffness compared to the concrete matrix, their ability to form a strong interfacial bond with the cement matrix, and their good dispersibility, they positively influence mechanical properties, particularly flexural and compressive strengths, and splitting tensile strength [11]. PVA fibers play an important role in tensile strength, as they withstand the first crack stress and resist pullout forces [12]. In addition, silica fume is commonly added to cement mixtures to improve porosity and durability. Silica fume is an industrial by-product of metallurgical processes and consists mainly of nanosized, spherical silicon dioxide. particles. These particles have a surface area and reactivity significantly higher than cement, being approximately 100 times smaller. Silica fume exhibits strong pozzolanic activity, reacting with calcium hydroxide produced during cement hydration to form calcium silicate hydrate (C–S–H) gel. This gel fills the pores within the cement structure, reducing moisture absorption and improving durability [13]. Although numerous studies have addressed the role of silica fume in cementitious matrixes in improving density and reducing porosity, its effect with basalt fibers and PVA remains limited, as each material was studied separately. Furthermore, most studies used the traditional method of measuring porosity without combining it with SEM at the fiber-cement matrix interface. Therefore, there is still a need to combine experimental and microscopic analysis to elucidate the mechanisms that lead to increased water absorption upon fiber incorporation, despite the fact that silica fume improves density and reduces porosity. The novelty of this study is in evaluating the effect of incorporating basalt fibers (BF) and polyvinyl alcohol (PVA) fibers on the mechanical and thermal performance of cementitious panels containing silica fume. In addition, microscopic analysis using a scanning electron microscope (SEM) was combined with physical tests to explain the interaction between SF and fibers and to understand the mechanisms that lead to increased water absorption when fibers are incorporated into a matrix containing SF despite the improvement of mechanical and thermal properties at specific ratios, an aspect that has not been clearly addressed in previous studies.

2. Experimental Work and Materials

2.1. Materials

There are many materials which are used to prepare specimens, these materials consist cement, fine aggregate, water and silica fume and basalt fiber

2.1.1 Cement

The Ordinary Portland cement (Type I) manufactured in Iraq with trademark of (Tasluga-Bazian) was used in this study. Its physical and chemical properties conformed to ASTM C150-04 [14] and

Iraqi Standard Specifications IQS No. 5/1984 [15] . the chemical and physical requirements of cement represents in Table 1 and 2.

Table 1. Chemical requirements of cement

Chemical Composition	Weight%	ASTM C 150-04	IQS5/1984
CaO	63.19	***	***
SiO2	21.60	20.0min	***
AL2O3	4.10	6.0 max	***
Fe2O3	4.48	6.0 max	***
MgO	2.28	6.0 max	5 max
SO3	1.98	3* max	2.5** max
L.O.I.	2.45	3 max	4 max
I.R.	0.47	0.75 max	1.5 max
L.S.F.	0.905		0.66-1.02

Table 2. Physical requirements of cement

Physical Properties	Test result	ASTM C 150-04	IQS5/1984
Fineness using Blaine air permeability apparatus (m2/kg)	330	280 min	230 min
Setting time (Vicat Apparatus), Initial setting (min) Final setting (min)	175 225	45min 375 max	45 min 600 max
Compressive strength, MPa for cement paste cube mold (50mm) at: 3 days 7 days 28 days	25.13 34.6 40.5	12 min 19 min ***	15 min 23 min ***
Soundness (Autoclave Method), %	0.19	0.8 max	0.8 max

2.1.2 Fine Aggregate

Sand passing through sieve 1.18 mm, has been used in this research. It was conformed Fine aggregate was Ottawa sand, complying with ASTM C778 [16]. The specification of fine aggregate represents in Table 3.

Table 3. The fine aggregate sieving analysis

Sieve size	Percent passing (%)	Specification limits (%)
10	100	100
4.75	92.7	90_100
2.36	79.65	75_100
1.18mm	68.6	55_90
600 µm	52.6	35_59
300 µm	27.4	8_30
150	2.65	0-10

2.1.3 Silica Fume

Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolan when used in Cementous materials. Its physical and chemical properties conformed to ASTM C1240-05 [17]. The chemical composition and Physical requirements illustrate in Table 4 and 5.

Table 4. Silica fume specifications

Oxides	Content %	ASTM C1240-05 limitations
SiO_2	90.51	≥ 85
Al2O3	0.60	_
Fe_2O_3	2.32	_
CaO	0.58	_
MgO	0.3	_
TiO2	0.01	_
Na_2O	0.15	_
K_2O	1.26	_
P2O5	0.11	_
SO_3	0.36	≤ 4
L.O. I	3.82	≤ 6

** Test was carried out by testing laboratory in the College of Engineering, Kufa University.*

Table 5. Physical requirements of silica fumes

Physical properties	SF	ASTM C1240-05 limits
Specific surface area, min, (m2/g)	20	≥15
Strength activity index with Portland cement at 7 days, min percent of control.	122	≥105
Percent retained on 45m (No. 325), max%	9	≤10

**Tests were carried out by testing laboratory in the College of Engineering. University of Kufa.*

2.1.4 Basalt Fiber

Basalt fiber is produced by melting basalt rock at temperatures 1500°C and extruding it into fine fibers, similar in process to producing glass fibers but with higher energy efficiency. [18] Basalt fiber it was obtained from the Iraqi Sika Company as a reinforcing element in cement mortar are shows in Figure (1). the basalt fibers properties illustrate in the Table 6.

Table 6. The basalt fiber properties

Property	Continuous Basalt fiber
Breaking Strength (MPa)	3,000 – 4,840
Modulus of Elasticity (GPa)	3,100– 3,800
Breaking Extension (%)	3.1
Fiber Diameter (μm)	6 - 21
Linear Density (tex)	60-4,200
Temperature Withstand (°C)	-260….+700

2.1.5 Superplasticizer

Polycarboxylate (VISCO CRETE-180 GS) is a highly effective water-reducing, setting-slowing, shrinkage-preserving, and super plasticizing additive for mortars and concrete. meeting the requirements of ASTM C494/494M-19 [19]. 1.5 % of the total weight of cementitious materials is used .the properties of Polycarboxylate super plasticizer showing in the Table 7.

Table 7. The properties of Polycarboxylate super plasticizer

Composition	Aqueous solution of modified polycarboxylates
Packaging	Bulk Deliveries 1000 LTRs IBC 20 kg Pail
Appearance / Color	Light brownish liquid
Storage conditions	In dry conditions at temperatures between +5°C and +35°C. Protect from direct sunlight. It requires recirculation when held in storage for extended periods.
Specific gravity	1.070 ± (0.005) g/cm³
pH-Value	4 - 6
Total chloride ion content	Nil

2.1.6 polyvinyl Alcohol

PVA Fibers (polyvinyl alcohol) are high-performance reinforcement fibres for concrete and mortar, obtained from LAKHANI FABRICS COMPANY, INDIA. That show in Figure 1. PVA fibres are well-suited for a wide variety of applications because of their superior crack-fighting properties, high modulus of elasticity, excellent tensile and molecular bond strength, and high resistance to alkali, UV, chemicals, fatigue and abrasion. PVA fibres are unique in their ability to create a molecular bond with mortar and concrete that is 300% greater than other fibres. 6 mm fibers are used in the mixtures. The polyvinyl alcohol fiber Technical Parameter showing in the Table 8.

Table 8. The polyvinyl alcohol fiber technical Parameters

Technical Parameter	100% PVA
Fibre Type	Bunchy Monofilaments
Density	1.29
Formula	$(CH_2CHOH)n$
Titer	1.80-2.40 Dtex
Dry breaking tenacity	≥11.50 cN/dtex ≥
Dry breaking elongation	4.0-9.0 % (L/L)
Initial modulus	280 cN/dtex ≥
Specification	6MM, 12MM
Hot water resistance	2.0 % ≤
Oli agent content	0.2 % ≤
Elongation at fracture (%)	6.5
Young's modulus (GPa)	42
Flexural strength (MPa)	1560

2.2. Mixture Design

For this research seven mixes were prepared with the same mix proportion (cement: sand) equal to (1:2.75) by weight, and water /binder equal to (0.42). The total binder amounts for all the produced mixtures, as shown in Table (7). The reference mix (Ref.) was prepared using super plasticizer (1.5%) by weight of cement to obtain (100±5) percent of flow with low water/binder ratio (0.42). While The other Six mixes (BF1, BF2, BF3, PVA1, PVA2 and PVA3) were prepared from the reference mix with a partial replacement of cement by (10%) of SF. Using (SF) reduces significantly the workability of fresh mortar and increases the dosage of super plasticizer. Therefore, the optimum SF ratio is 10% [20, 21]. The flow values of all mixtures were kept in the range of (100±5) percent of flow with regulates the dosage of super plasticizer. Three samples were prepared from each mixture for all treatment periods. The resulting samples were treated with water in a standard treatment tank for 7, 14, and 28 days. The material quantities used in mixes production are presented in Table 9.

Table 9. Mix proportions of cement mortar (g)

Mixture Name	Cement (g)	Sand (g)	Water (g)	SF (g)	BF%	PVA%
Ref	1000	2750	420	0	0	0
BF 1	900	2750	420	100	1	0
BF 2	900	2750	420	100	2	0
BF 3	900	2750	420	100	3	0
P 1	900	2750	420	100	0	1
P 2	900	2750	420	100	0	2
P 3	900	2750	420	100	0	3

The experimental program involved evaluating various mechanical and physical properties of cement mortar samples using standardized procedures. Tests were conducted on (5 × 5 × 5 cm) cubic specimens to assess compressive strength, water absorption and surface hardness. Compression and flexural strength tests were conducted using a Tecnotest Universal Testing Machine (UTM), manufactured by Tecnotest S.r.l., Italy. The machine has a maximum loading capacity of 2000 kN for compression tests and 300 kN for flexural tests. It is equipped with an automatic data acquisition system and a digital load control unit, ensuring precise control of the loading rate in accordance with ASTM C109/C109M [22] and ASTM C348 standards [23]. Compressive strength was measured in accordance with ASTM C109/C109M [22]. Specimens were demolded after 24 hours and cured in water at a constant temperature for 7, 14, and 28 days before testing.

(a) (b)

Fig. 1. (a) PVA fiber 6mm and (b)basalt fiber 12 mm

Surface hardness is a non-destructive test used to determine a material's surface resistance to deformation. The hardness test was conducted using the Shore D, an electronic instrument with decimal accuracy produced by the German company QUALITEST INC. in accordance with ASTM D 2240-03 [24].

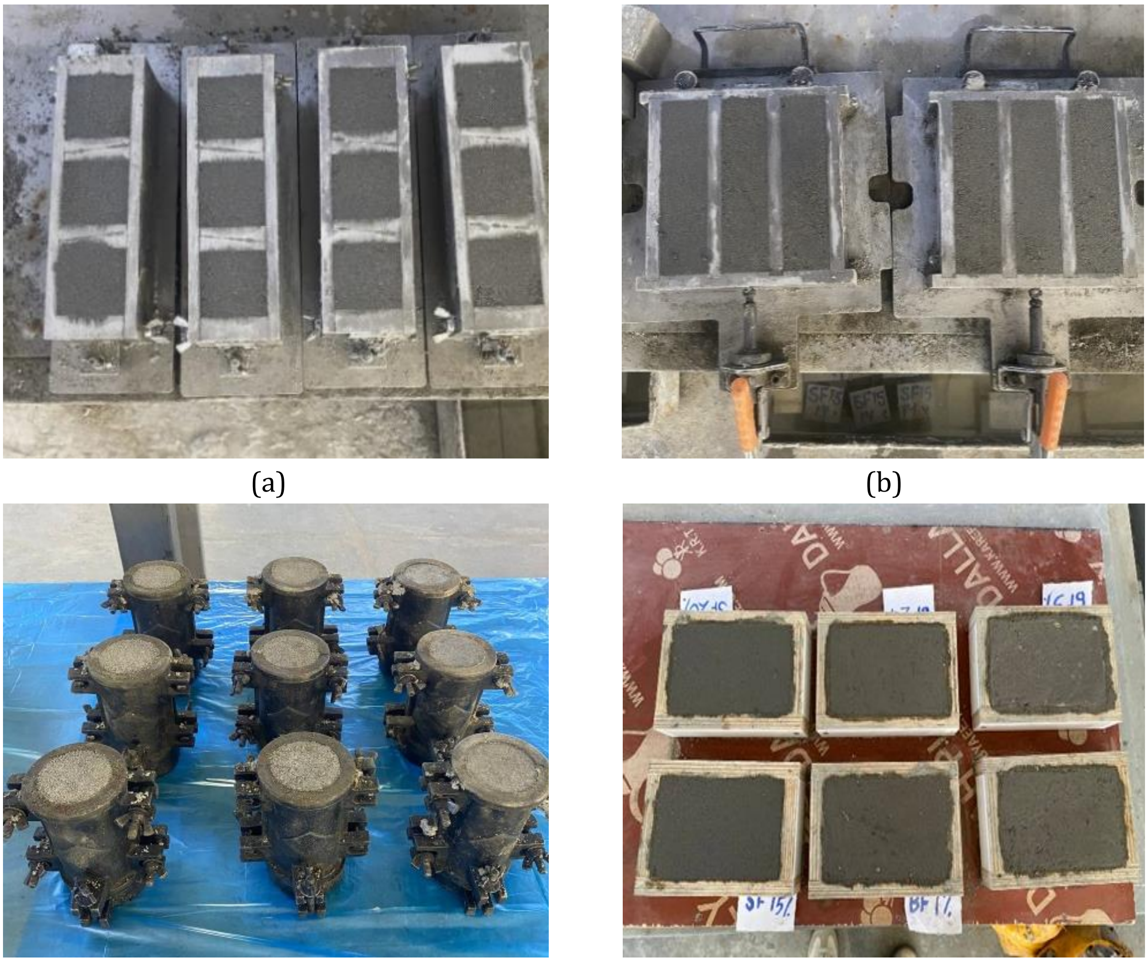
Splitting tensile strength, the splitting tensile strength test is the easiest way to evaluate the tensile strength of concrete. Since it is difficult to apply a direct tensile force to this material, it is usually subjected to a radial compression force, which produces an indirect tensile force in the vertical direction, leading to failure. The mold is a cylinder with a diameter of 5 cm and a height of 10 cm. The mortar is poured into the mold in three batches, and each batch is compacted 25 times using a cylindrical rod. The surface of the mold is then polished, according to ASTM C 496/C496M-04 [25].

Ultrasonic pulse velocity (UPV) was tested using the direct transmission method, following ASTM C597-22 [26]. The pulse velocity was calculated by dividing the specimen length by the transit time of the ultrasonic wave.

Water absorption was measured based on ASTM C642, applying the procedure involving dry and saturated mass comparisons [27].

The flexural strength test was conducted on prismatic specimens (16 × 4 × 4 cm) following ASTM C348, using a three-point bending setup where a load is applied at the center of the span until failure occurs [23].

The thermal conductivity coefficient (k-value) of all samples was measured (15 x 10 x 5 cm) were prepared and using the ASTM C1113/C1113M-09(2013) method based on the hot wire technique [28]. The test method involves inserting a thin resistance wire into the refractory material sample and passing an electric current through the wire, which generates heat. The temperature is monitored using thermometers to measure the temperature rise of the sample at different times as heat dissipates through the material Thermal conductivity k-values can be determined from room temperature to 1500°C [2732°F], or to the temperature at which the refractory is no longer dielectric.



(a) (b) (c) (d)

Fig. 2. The mold using to cast sample (a) for cubic sample 5x5x5 cm, (b) for prism sample 4x4x16 cm (c) For cylinder sample 5x10 cm and (d) Sample 15x10x5 cm

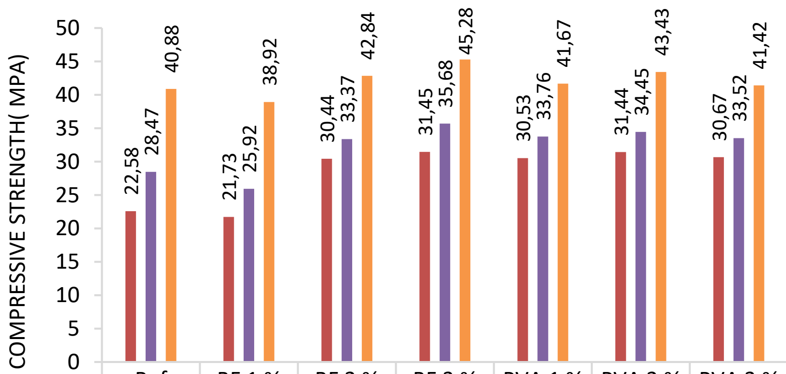
It is an advanced analytical technique used to examine the structure of materials at very high resolution. It is of great importance in understanding the microscopic properties that directly affect the strength, durability, and quality of mortar. An Axia ChemiSEM is used, a new generation of scanning electron microscope (SEM). The process of imaging mortar using a scanning electron microscope involves several steps. First, the sample is prepared and oven-dried at 40–60°C to prevent rapid evaporation of water inside the scanning electron microscope chamber, which could damage the sample. The sample is then fractured or cut to reveal a fresh surface. The surface of the material is coated with a conductive material such as gold using spray painting. Second, the sample is carefully mounted on a holder inside the microscope to prevent vibration. The electron beam is generated so that the device emits a focused beam of electrons directed at the sample surface.

All specimens were prepared and cured under identical conditions to ensure consistency and enable accurate comparative analysis across different mix designs. Figure (2) shows the shapes of the molds used to prepare the appropriate samples for each test.

3. Results and Discussion

3.1. Compressive Strength Results

The results in the Figure 3 illustrate how basalt fiber (BF) and polyvinyl alcohol (PVA) fibers affect the compressive strength of cement slabs at different curing ages. The results demonstrate a clear link between fiber type and quantity and mechanical performance. The bar graph shows the compressive strength test results of several cement mortar mixtures cured for 7, 14, and 28 days. There is a reference sample (REF), three samples with basalt fiber (BF) at 1%, 2%, and 3%, and three samples with polyvinyl alcohol fiber (PVA) at 1%, 2%, and 3%. The results demonstrate how basalt fiber (BF) and polyvinyl alcohol (PVA) fibers affect the compressive strength of concrete at different curing stages. The research identifies an optimal percentage for each fiber type. The compressive strength of basalt fiber increased with increasing fiber content compared to the reference mix. We notice a gradual increase in compressive strength with increasing curing period in water, where it recorded 21.73, 30.44 and 31.45 at BF1%, BF2% and BF3% respectively at 7 days and at 14 days the increase rate reached 19.3%, 9.6% and 13.5%, while at 28 days it achieved the highest compressive strength, where we notice the increase rate was 50.2%, 28.4% and 26.9%.



	Ref	BF 1 %	BF 2 %	BF 3 %	PVA 1 %	PVA 2 %	PVA 3 %
7- day CS (MPa)	22,58	21,73	30,44	31,45	30,53	31,44	30,67
14- day CS (MPa)	28,47	25,92	33,37	35,68	33,76	34,45	33,52
28- day CS (MPa)	40,88	38,92	42,84	45,28	41,67	43,43	41,42

Fig. 3. Compressive strength behavior of different mixing ratio

The results show that the highest increase in strength is at 1%, because the low fiber percentage improves hydration and allows the matrix to grow without difficulty in integration or increased porosity [29]. While at 2 and 3%, the increase rate was low because the concrete was approaching its early mechanical maturity, and the fiber density hinders concrete growth due to barriers. However, the 3% BF mixture showed the highest strength (45.28 MPa) among all samples. This is because the fibers form a network within the matrix, acting as a barrier that prevents crack propagation. This means that this concentration was the best for increasing strength, but with a lower internal density, as the pores around the fibers increased [30]. Despite the presence of 10% silica fume in all mixes, the presence of fibers hinders its homogeneous diffusion within the matrix and the filling of gaps around the fibers [31]. This can be observed in the UPV test and the water absorption test. This means that increasing the fiber density by 3% was sufficient to significantly improve mechanical properties, but at the expense of density [18]. When adding PVA fibers, we notice a slight gradual increase in compressive strength with an increase in the curing period in water. Compressive strength was recorded at 7 days for PVA1%, PVA2%, and PVA3% (30.53, 31.44, and 30.67, respectively). At 14 days, the increase rate reached 10.6%, 9.6%, and 9.3%. We note that the increase is low, indicating that PVA fibers accelerate the strength gain at an early stage due to the enhancement of internal cohesion by forming chemical and molecular bonds at the contact surface between the fibers and the matrix. This is because the surface of the polar PVA fibers contains an OH- (hydroxyl) group, which allows for a partial chemical reaction with C-S-H when the cement is hydrated, thus reducing microcracks. [32, 33] This makes the increase between 7 and 14 days small because the matrix developed its strength early. At 28 days, the highest strength was achieved, with the increase rate being 23.4%, 26.1%, and 23.6%, respectively. We note the highest increase at PVA2%, indicating that this percentage represents the best balance between the workability and fiber distribution gave a peak strength of 43.43 MPa [34, 35]. Adding more PVA (3%) resulted in a slight decrease in strength (41.42 MPa). This type of behavior is prevalent in fiber-reinforced composites and can be explained by several factors.

(a) (b)

Fig. 4. (a) Compression cubic before failureand (b) the cubic after failure

The strengthening effect is not as strong at low percentages. The benefits of crack management are greatest when the percentage is at its optimum level. However, exceeding this ideal condition can weaken the cement board matrix, as it is difficult to distribute the fibers evenly, which can cause weaknesses or gaps in the matrix and reduce its durability. Overall, the results also show that both basalt fiber and PVA fiber can significantly improve the compressive strength of cement boards. This study indicated that the optimum concentrations are 3% basalt fiber and 2% PVA fiber. Basalt fiber performs better than the others, especially at 3%. This suggests that it may be a good method for strengthening cement boards. The Figure 4 shows the sample before and after failure.

3.2. Absorption Test

This test is used to evaluate the durability and quality of cement mortar by measuring its susceptibility to water seepage and moisture damage, according to ASTM C642-13 [36] . We performed this test on mortar samples containing varying amounts of basalt fiber (BF) and polyvinyl alcohol fiber (PVA) and compared them to a reference mix (Ref) as shown in Figure (5). The reference mix had the lowest water absorption rate (1.8%), meaning it had a relatively dense matrix with low porosity.

Table 10. Water absorption results of cement mortar containing different additives

Mix	Dry Mass (g)	Saturated Mass (g)	Water Absorbed (g)	Water Absorption (%)
Ref	277	282	5	1.8 %
BF 1	259	269	10	3.71 %
BF 2	259	270	11	3.83 %
BF 3	255	266	11	4.31%
PVA 1	241	252	11	4.56%
PVA 2	242	254	12	4.95 %
PVA 3	242	253	12	4.97 %

Water absorption was observed to gradually increase when basalt fiber was added to the reference mix at a fixed replacement ratio of 10% silica fume. The absorption rate increased with increasing fiber content, with BF 1% showing 3.71%, BF 2% recording 3.83%, and BF 3% reaching 4.31%. This trend suggests that basalt fibers may improve mechanical properties, but they may also make the material more internally porous by creating microchannels and insufficient fiber dispersion [37], as shown in SEM. Although silica fume reduces porosity by filling gaps via C-S-H gel formation due to the reaction of silica fume with calcium hydroxide resulting from cement hydration [38, 39], these effects may outweigh the porosity-reducing benefit of silica fume. PVA fiber blends absorbed more water than the reference blend. When the PVA fiber concentration was 1%, 2%, and 3%, the results were 4.56%, 4.95%, and 4.97%, respectively. [30] This is shown in Table 10. These results indicate that the incorporation of PVA fibers affects the cohesion of the matrix, most likely due to the hydrophilicity, fiber dimensions, and inhomogeneous distribution of fibers, which hinders the distribution of silica fume in the cement matrix and fills some micropores in places around the fibers, thus weakening the effectiveness of silica fume, leading to increased water absorption [31, 40]. Overall, BF and PVA fibers made the mortar absorb more water than the standard blend. It was shown that the addition of fibers increases water absorption because more surface area and weak areas at the interface leave water channels and create pores. This indicates that fiber content and dispersion need to be optimized to find a balance between strength and durability.[41] Figure (6) show the sample during curing.

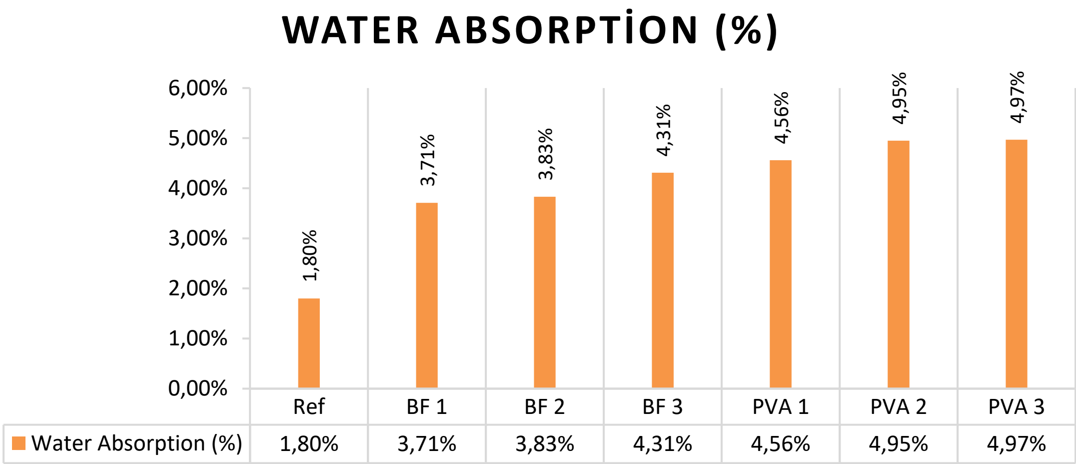


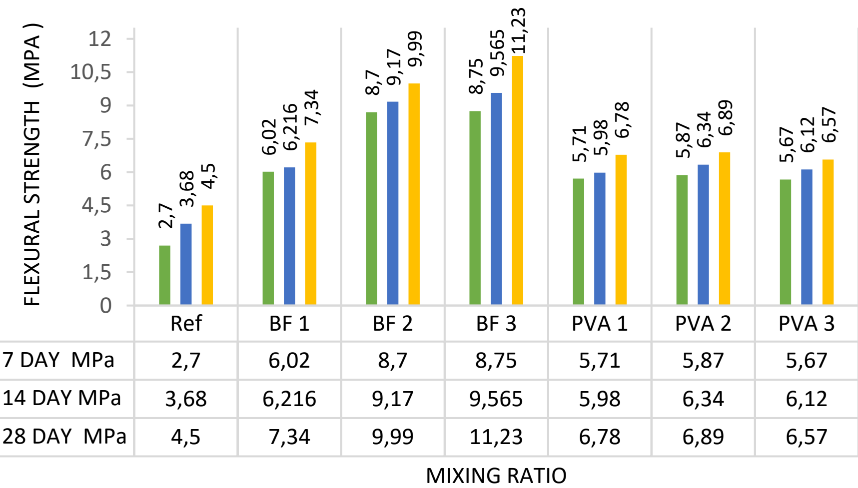
Fig. 5. Water Absorption behavior of different mixing ratio

(a) (b)

Fig. 6. (a) The samples during curing in water and (b) the sample is weighed

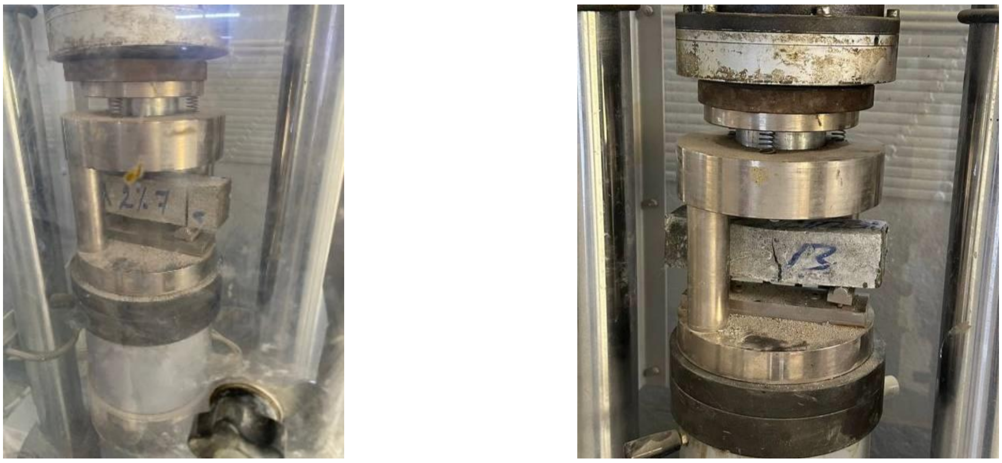
3.3. Flexural Strength

Flexural strength results indicated a significant improvement as a result of fiber addition. The reference mixture achieved only 4.5 MPa after 28 days. In contrast, basalt fiber blends showed a significant increase, with BF3 achieving the highest value (11.23 MPa), followed by BF2 (9.99 MPa) and BF1 (7.34 MPa).[42] PVA fiber blends also improved flexural performance compared to the reference, with PVA2 reaching its peak (6.89 MPa). These results demonstrate that basalt fibers provide superior flexural strengthening, while PVA fibers offer moderate improvement. [2]



	Ref	BF 1	BF 2	BF 3	PVA 1	PVA 2	PVA 3
7 DAY MPa	2,7	6,02	8,7	8,75	5,71	5,87	5,67
14 DAY MPa	3,68	6,216	9,17	9,565	5,98	6,34	6,12
28 DAY MPa	4,5	7,34	9,99	11,23	6,78	6,89	6,57

Fig. 7 . The flexural strength behavior of different mixing ratio



(a) (b)

Fig. 8. A. The prism befor failure B. prism after failure

3.4. Thermal Conductivity

The Effect of Basalt Fibers and Polyvinyl Alcohol (PVA) Fibers on the Thermal Properties of Cement Boards. This study sought to incorporate basalt fibers (BF) and polyvinyl alcohol (PVA) fibers in varying quantities into cement boards with a fixed silica replacement ratio of 10%, and to evaluate their effect on the thermal conductivity coefficient (k value). Tests were conducted according to the American standard ASTM C1113/C1113M-09 [28], which evaluated the k value at varying fiber ratios. A gradual decrease in thermal conductivity values was observed as the basalt fiber ratio increased from 1% to 3%. On the other hand, PVA fibers showed a slight improvement at 1%, then values gradually increased with increasing ratios [34].

- Case (1): Basalt fiber additive (BF): Thermal properties improved significantly when basalt fiber was added to the cement mixture. As the basalt content increased, the thermal conductivity decreased, reaching 0.83 W/m.K at 1% and 0.644 W/m.K at 3%. This is attributed to the fact that the basalt fibers increased porosity and created additional interfaces within the cement matrix, reducing heat transfer through the material. Thus, basalt fibers have been shown to improve thermal insulation.[43]

- Case (2): PVA fiber additive: The PVA samples recorded a value of 0.905 W/m.k at 1%, which is lower than the reference value, indicating a slight improvement in insulation. However, when the percentage was increased to 2%, the value increased to 0.963 W/m.k, and at 3%, it reached 1.049 W/m.k, indicating that the fibers act as a thermal bridge within the cement paste. At high ratios, the fibers clump together, losing their role in improving porosity and gaps, leading to a gradual increase in thermal conductivity, but still providing better thermal insulation than the reference mixture. This has been demonstrated by numerous studies conducted on PVA fibers in cement mixtures [44].

Fig. 9. The simple during test in Thermometers

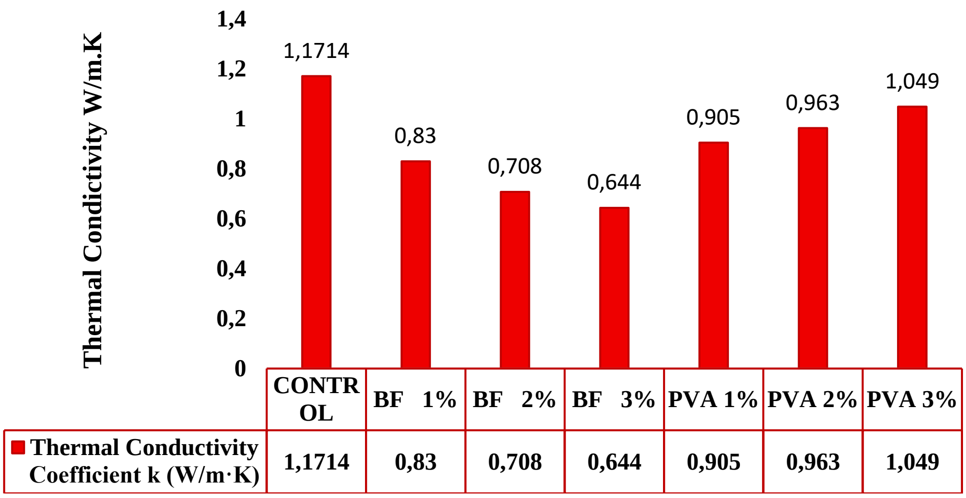


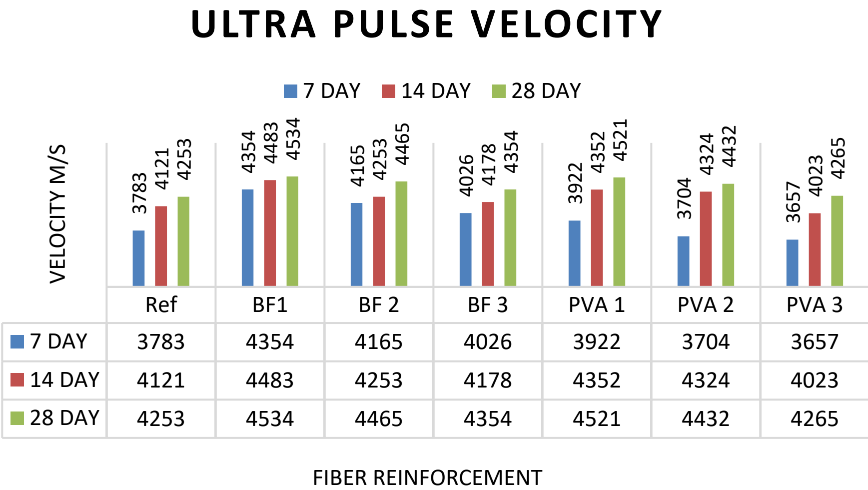
Fig. 10. The thermal conductivity behavior of different mixing ratio

3.5. Ultra-Pulse Velocity

The UPV test is used to determine the internal density and cohesion of concrete with or without the addition of fibers. The reference mix showed 4253 m^3/s after 28 days. Mixes containing basalt fibers (1% BF) showed higher UPV values (4534 m^3/s) compared to the reference mix and slightly decreased at (2% BF, 3% BF (4465 m^3/s, 4354 m^3/s, respectively) but still higher than the reference mix. We note that UPV increases with increasing concrete age because the hydraulic reaction completes and improves the cohesion of the internal matrix over time and reduces porosity and tightens the bonds between the gaps, indicating improved internal density [45] While we note that UPV gradually decreases with increasing PVA content, the highest UPV value (4521

m^3/s) was found at 1% PVA, while it decreased slightly at 2% PVA (4432 m^3/s) and the decrease increases to (4265 m^3/s) at 3% PVA compared to 1% PVA. [43, 46] These results indicate a decrease in UPV with increasing fiber content compared to lower fiber contents, due to lower workability leading to increased fiber clumping and difficulty in homogeneous distribution. However, it has the ability to resist the bridge stress transmitted through the PVAF, BF crack, leading to high compressive strength up to a certain fiber content [47]. This has been shown in Figure 11.

Fig. 11. The sample during test in UPV devise

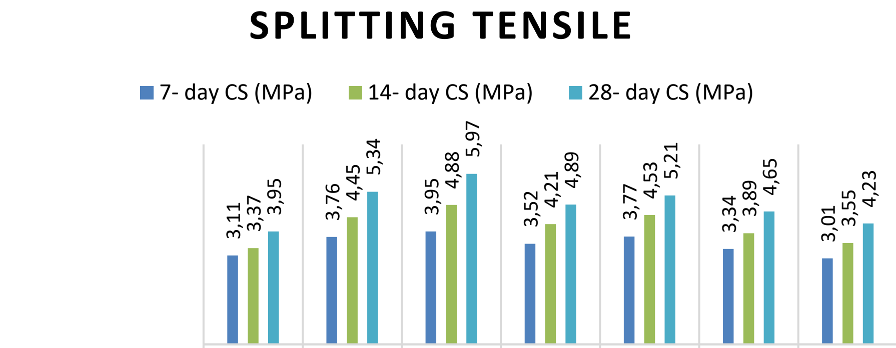


	Ref	BF1	BF 2	BF 3	PVA 1	PVA 2	PVA 3
7 DAY	3783	4354	4165	4026	3922	3704	3657
14 DAY	4121	4483	4253	4178	4352	4324	4023
28 DAY	4253	4534	4465	4354	4521	4432	4265

Fig. 12. The Ultra pulse velocity of different mixing ratio

3.6. Splitting Tensile

Figure (13) shows the split tensile strengths of both plain and fiber-reinforced concrete for all curing periods in water. We note that the tensile strength improves up to a certain percentage and then decreases when using 1-3% PVA in a mortar containing a fixed replacement ratio of SF. This indicates that these fibers have reached a percentage where the fibers are distributed homogeneously within the matrix and reduce the spread of cracks. When the dosage is increased, difficulty occurs in distributing the fibers and clumps occur within the matrix, causing an increase in gaps. The split tensile strength of 1% PVA, 2% PVA, and 3% PVA increased by 20.9%, 27.01%, and 13.18%, respectively, compared to the reference mixture of 3.11 MPa at 7 days. At 14 days, the increase rate reached 32.05%, 44.81% and 24.93% respectively, while at 28 days it achieved an increase of 35.19%, 51.14% and 23.80%. We notice a gradual increase in the tensile strength with the increase in the curing period from 7 to 28 days, indicating the continued growth of C-S-H hydration products that improve the bond between the fibers and the cement matrix, where 2% PVA achieved the highest improvement in tensile strength at all curing periods, the increase rate reached 51.14% (5.97MPa) at 28 days compared to the reference mixture. [48] As for BF fibers, the same ratios (1, 2, and 3%) were used with the reference mix, where we observed a gradual increase in strength with increasing percentages of added fibers, reaching 10.9%, 13.67%, and 31.90% compared to the reference mix, which achieved the highest tensile strength at 3% (5.21 MPa) [49]. This can be explained by the fact that fibers increase the strength of concrete and hinder the propagation of cracks. Although the fiber density may cause an increase in gaps and pores around the fibers because it hinders the homogeneous distribution of pozzolanic particles to fill the pores, these fibers increase the cohesion of the matrix and increase its tensile capacity. Concrete reinforced with polyvinyl alcohol (PVA) fibers exhibits the highest splitting tensile strength, followed by concrete reinforced with basalt fibers. This indicates that the basalt fiber interface exhibited the highest Ca/Si ratio (1.59), followed by the PVA fiber-mortar interface (1.33 This indicates that PVA fibers are hydrophilic, leading to hydrophilic interactions between the PVA fibers and the mortar matrix and increased C-S-H formation. Basalt fibers also possess stronger chemical bond strength with the mortar matrix due to their similar chemical compositions [50, 51]. This improvement is attributed to the effect of basalt and PVA fibers in slowing crack propagation and enhancing matrix ductility. Figure (14) show the cylinder before and after failure.



	Ref	PVA 1 %	PVA 2 %	PVA 3 %	H 1 %	H 2 %	H 3 %
7- day CS (MPa)	3,11	3,76	3,95	3,52	3,77	3,34	3,01
14- day CS (MPa)	3,37	4,45	4,88	4,21	4,53	3,89	3,55
28- day CS (MPa)	3,95	5,34	5,97	4,89	5,21	4,65	4,23

Fig. 13. The splitting tensile of different mixing ratio

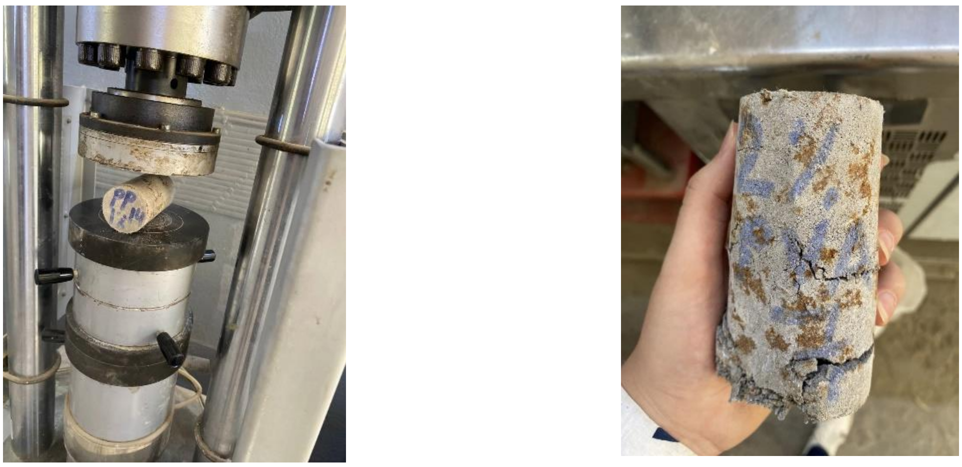


Fig. 14. The cylinder before and after failure

3.7. Scanning Electron Microscope (SEM)

Figure (15) shows the internal structure of the reference mixture. The microstructure of the reference sample exhibited numerous microcracks and pores. The lack of fibers resulted in a weaker interface between the cement matrix and the concrete, resulting in lower tensile and flexural strengths.

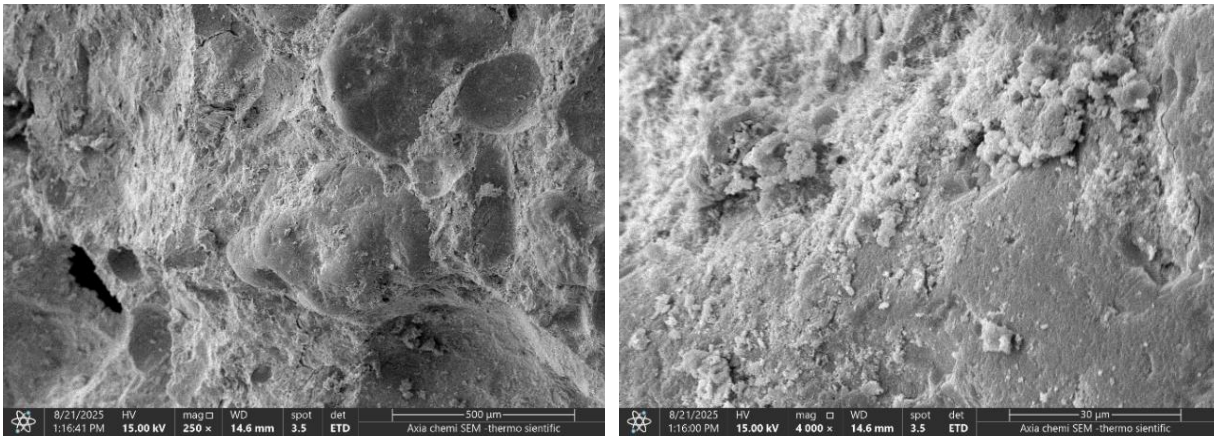


Fig. 15. The SEM of microstructure surface of control sample

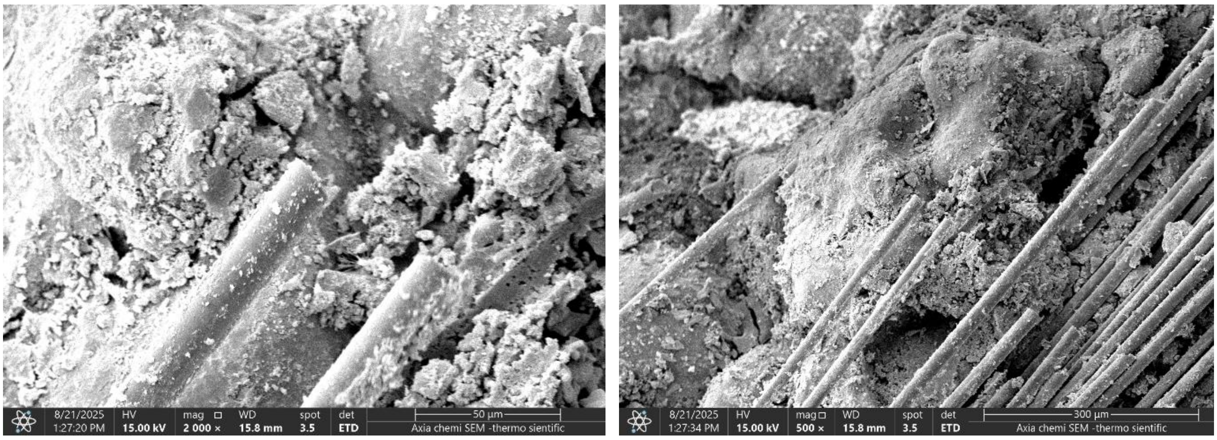


Fig. 16. The SEM of microstructure surface of 3% addition of BF sample

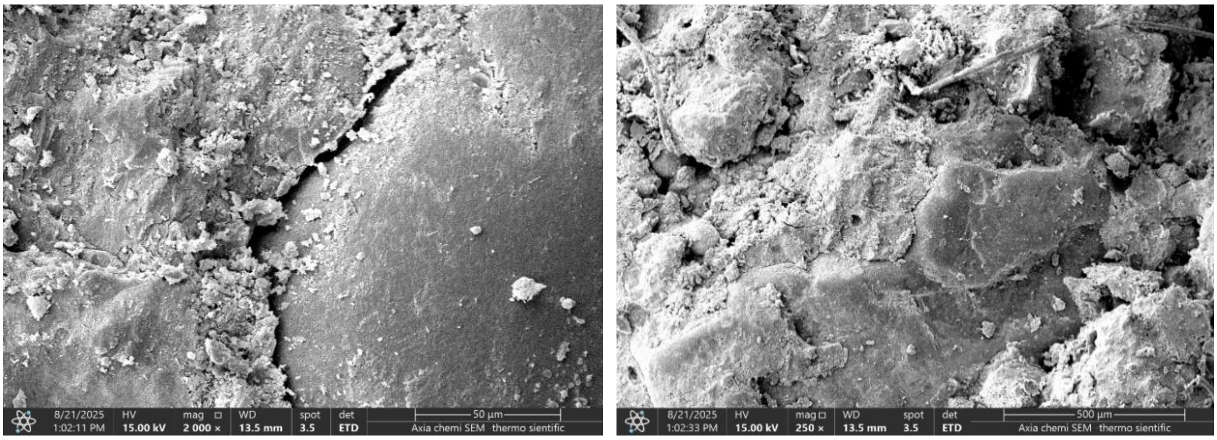


Fig. 17. The SEM of microstructure surface of 2% addition of PVA sample [27]

The absence of fibers or nanoparticles resulted in increased porosity and a relative decrease in structural integrity when compared to reinforced samples. The scanning electron microscope image shown in Figure (16) shows that basalt fibers are dispersed throughout the cement matrix. These fibers act as microscopic bridges between particles, making it difficult for microcracks to pass through and propagate through the cement matrix. This makes the cement stronger in both tensile and flexural strength. The fibers are connected to the cement paste, showing good bonding between the fibers and the matrix. This makes the material stronger and more flexible. However, some lumps and pores can be seen in small places due to the silica not being allowed to diffuse within the matrix, making the structure less regular.[52] A scanning electron microscope image of a 2% PVA sample shows that the fibers are not very evenly distributed within the cement matrix, and that there are pores and pozzolanic agglomerates. Despite the presence of some pores, the mechanical properties are high, but at the expense of a slight increase in water absorption. Therefore, the presence of fibers improves compressive and flexural properties, making the material stiffer and stronger than the reference sample [40, 51, 52].

4. Conclusions

Based on the experimental studies and analytical results obtained in this study, several key findings can be highlighted regarding the effect of basalt fiber (BF) and polyvinyl alcohol (PVA) fibers on the mechanical and thermal performance of cement boards. The following points summarize the most important findings:

- The combination of basalt fiber (BF) and polyvinyl alcohol (PVA) fibers significantly improved the mechanical and thermal performance of cement boards.
- Basalt fibers at a concentration of 3% achieved the greatest improvement, achieving superior compressive strength (45.28 MPa), flexural strength (11.23 MPa), and the lowest thermal conductivity (0.644 W/m°C).
- PVA fibers demonstrated optimal performance at a concentration of 2%, achieving a compressive strength of 43.43 MPa and a moderate improvement in flexural strength.
- Both fiber types increased water absorption compared to the standard mix, indicating a balance between mechanical improvement and strength.
- Scanning electron microscope (SEM) analysis confirmed that the fibers act as microbridges, reduce crack propagation, and improve the cohesion of the cement matrix.
- The combined use of fibers and silica fume demonstrated synergistic effects, resulting in improved strength, strength, and structural integrity.
- The 2% PVA and 3% BF fibers exhibited the highest surface harnesses (99.97 and 99.92 MPa) compared to the reference mix.
- The 1% BF and 1% PVA fibers achieved the highest internal density/integrity in the UPV test, 6.61% and 6.3%, respectively, compared to the reference mix.
- Finally, the splitting tensile strengths of concrete reinforced with PVA fibers and basalt fibers were tested. The results showed that concrete reinforced with 2% PVA fibers had the highest splitting tensile strength, followed by 3% basalt fibers. This indicates that the interface bond properties obtained depend to some extent on the behavior of the fiber and mortar surfaces in the concrete materials. The increase was 51.14% and 31.90%, respectively, compared to the reference mix.

Overall, the study recommends using 3% (BF) and 2% (PVA) as the most effective reinforcement ratios for producing durable, high-performance, and thermally efficient cementitious panels.

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