

Effect of Fiber Type and Content on the Compressive Strength and Flexural Performance of Cement Mortar

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ABSTRACT

Cement mortar has a high compressive strength, but has a weak resistance to cracking. Therefore, Fibers have been used in enhancing resistance against cracks and toughness. The effect of Fiber content and type on compressive and flexural strengths of cement mortar was investigated. The standard cement mortar mix was modified by the inclusion of three types of Fibers at different volume fractions, which are steel, polypropylene, and basalt Fibers at 0.5% 1.0% and 1.5%. After 28 days of curing, the mechanical tests, compressive strength, and four-point bending tests were done. According to the findings, content and Fiber type significantly affected the performance of mortar. The compressive strength increased up to 24.2 MPa due to the addition of 0.5% steel Fiber, and up to 24.9 MPa due to the addition of 1.0% basalt Fiber. The flexural strength saw the highest improvement through steel Fibers, with a moderate improvement in compressive strength. Polypropylene Fibers did not significantly affect the compressive strength and flexural capacity. The presence of Basalt Fiber at low contents showed increased flexural strength and improved crack control, while with an increase in contents, performance is reduced due to agglomeration of the Fiber. The results proved that the selective type and contents of each Fiber may greatly help in achieving desired mechanical properties. Therefore, it shall contribute to the design of high-performance cement-based material for structural and repair applications.

Keywords: Steel Fiber; polypropylene Fiber; basalt Fiber; cement mortar; compressive strength' flexural performance.

1. Introduction

The low tensile strength and brittleness are some drawbacks of the conventional cement mortar and concrete; therefore, different fiber types have been added to the cement matrix to treat these issues [1]. Numerous studies have shown that the addition of Fiber enhances flexural and tensile strengths and shifts the behavior of concrete from brittle to ductile [2-5]. The benefits acquired from using Fiber are highly dependent on many factors, like Fiber length, diameter, aspect ratio, and its content [6,7]. For instance, Xia et al. [8] examined the effect of macro and micro basalt fibers on the toughening mechanism and fracture mode of concrete reinforced with hybrid Fibers for concrete structures. They observed that the addition of basalt Fiber enhanced the ductility of concrete and increased the flexural strength by more than 300 %. Wang et al. [9] studied the effect of Fiber content and type on the failure mechanisms and mechanical properties of Fiber-reinforced concrete. They used three types of Fibers, basalt Fibers (BF), carbon Fibers (CF), and steel Fibers (SF). They detected that the failure method changes from brittle to plastic when increasing the Fiber content.

The addition of Fibers into the concrete mix enhances their properties like toughness, flexural, and tensile strengths [7,10]. But the presence of Fiber, especially in high concentrations, might lead to reducing the workability of the concrete [11]. The optimal Fiber content in concrete varies based on several factors, including the shape, size, and type of the Fibers [12]. Furthermore, Wang et al. [13] reported that the addition of PP Fiber up to 0.3% increases the flexural strength of concrete, and they detected that the addition of 0.2 - 0.3 is the optimum volume of PP Fiber to achieve the highest flexural strength. Yoo et al. [6] examined the possibility of decreasing Fiber content in cement composites. They used three various aspect ratios and types of steel Fiber. They detected that the flexural strength of cement composite reached the highest value with the addition of a low Fiber volume (1.0%). Mínguez et al. [14] studied the effect of Fiber geometries, like volume fraction and Fiber orientation, on the remaining flexural strength of high-strength concrete. They detected a practical association between the Fiber geometries and residual post-cracking flexural strength. Silva et al. [15] reported that the good distribution/orientation Fiber demonstrated a significant development in the flexural strength.

Despite these studies, most research has investigated specific Fiber types, often under different experimental conditions [16, 17]. A notable gap in the literature exists regarding the systematic evaluation of different Fiber geometries and volume fractions under identical mixing and testing conditions. While individual studies have investigated steel [18, 19], basalt [17, 20], or

polypropylene Fibers [21, 22]. Comparative valuations involving these materials at multiple contents in cement mortar are still scarce. Even though many studies have explored Fiber-reinforced mortars [23-25]. There is still limited research comparing a wide range of Fiber geometries and volume fractions under the same conditions. In particular, the combined effect of Fiber shape and content on the flexural performance of cement mortar remains an area that needs further investigation. This study aims to evaluate the effect of Fiber type and content on the flexural performance of cement mortar under controlled conditions. In order to compare, three Fiber types (steel, basalt, and polypropylene) at volume contents of 0.5%, 1.0% and 1.5% were incorporated with a control mixture. Ten mortar mix varieties were prepared and tested to determine the effect of these parameters on flexural strength. The results of this study are expected to provide useful guidance for the efficient use of Fiber reinforcement in the development of more efficient, durable, and sustainable cement-based materials for the construction industry.

2. Materials and Methods

2.1. Raw Materials

This study used ordinary Portland cement (OPC) as the main binder, and the chemical and physical properties of cement are shown in Tables 1 and 2, respectively. It conforms to the Iraqi specification IQS 5/2019 [26]. Clean tap water was used for mixing and curing, and clean river sand (conformed to the Iraqi specification IQS No. 45 [27]) was used as the fine aggregate. The particle size of river sand is shown in Table 3.

Table 1. Chemical composition of cement.

Oxide Composition	Contents (%)	ASTM C114
CaO	59.68	
AL ₂ O ₃	7.6	
SiO ₂	21.7	
Fe ₂ O ₃	1.6	
MgO	3.4	6 % Max
SO ₃	2.4	2.5 %Max
L.O.I	2.3	3% Max
Insoluble Materials	1.3	1.5% Max

Table 2. Physical properties of cement.

Tests	Results
Initial setting time	56 min.
Final setting time	455 min.
Compressive strength 3days	21.8 MPa
Compressive strength 7days	26.9 MPa

Table 3. Sieve analysis of sand used SO₃=0.14%, Specific gravity=2.64

Sieve size (mm)	Percentage of passing (%)	Specification zone No. 3 Iraqi
10	100	100
4.75	99	90-100
2.36	85	85-100
1.18	77	75-100
0.6	74	60-79
0.3	38	12-40
0.15	9	0-10
0.075	2	0-5

Three different types of Fibers were selected and used to reinforce the mortar. These Fibers are;

- Synthetic polypropylene (PP) Fibers, selected for their lightweight properties and crack control benefits.
- Basalt Fibers, which are known for their high temperature resistance and durability, and
- Steel Fibers, chosen for their high tensile strength and ability to resist cracking.

Each Fiber type had different physical and mechanical properties, such as length, diameter, and tensile strength, and these properties as shown in Figure 1 and Table 4.

Figure 1. The types of Fibers.



Table 4. Specifications and volume of Fibers used in this study.

Material Type	Symbol	Volume fraction of fibre (%)				Dimensions (mm)	Stress (MPa)
		0.0%	0.5%	1.0%	1.5%		
Control Beam	C	C	--	--	--		
PP Fiber	F	-	FA	FB	FC	12mm×32μm	300
Basalt Fiber	B	-	BA	BB	BC	12mm×20 μm	2800
Steel Fiber	S	-	SA	SB	SC	35mm×0.5 mm	1000

2.2 Mix Proportions and Sample Preparation

All mortar mixtures were prepared with a constant mix ratio of cement to sand to water by weight, equal to 1:2.5:0.5. This ratio ensured workability while maintaining adequate strength. Fibers were added at three different volume fractions: 0.5%, 1.0%, and 1.5%, with an additional control mix (0.0%) that contained no Fibers. This setup allowed for comparison between Fiber-reinforced and plain mortar. In total, 10 different mixtures were prepared. Table 5 shows the mix proportions of materials used in this study. The mix proportion (1.0: 2.5: 0.5) is a ratio of cement, sand, and water, respectively.

Table 5. Mix proportions of materials.

Mix	Steel Fiber	Basalt Fiber	Polypropylene Fiber	Compressive at 28 days
Control	0	0	0	20.2
St-0.5	0.5	0	0	24.6
St-1.0	1.0	0	0	24.2
St-1.5	1.5	0	0	23.6
Ba-0.5	0	0.5	0	22.4
Ba-1	0	1	0	24.9
Ba-1.5	0	1.5	0	22.1
pp-0.5	0	0	0.5	23.9
pp-1.0	0	0	1	22.5
pp-1.5	0	0	1.5	22.2

2.3. Casting and Curing Procedure

The mortar was mixed with a machine for uniformity. So first the dry materials, cement and sand, and Fibers, were properly mixed, and followed by adding water slowly to obtain a paste which is smooth. The new blend was placed in rectangular molds (400 × 100 × 20) mm and cubes (50 × 50 × 50) mm as shown in Figure 2 and compacted in a vibrating table to remove air. The samples stayed damp with wet burlap and plastic for a day and were subjected to a controlled room at 20 °C, 95 %RH. The period of 28 days curing was employed to attain full strength of the mortar samples. The mortar's mechanical properties improved because of proper hydration to cure it.



Figure 2. Casting cubes and beams.

The study examined the effect of three types of Fibers, namely steel Fiber, basalt Fiber, and PP Fiber, at three volume fractions (0.5%, 1.0%, and 1.5%) for each, along with a control mix without Fibers. A total of 10 mortar mixtures were produced, with each mix cast into uniform cubes ($50 \times 50 \times 50$ mm) for testing. The mix design was prepared based on several series of trial-and-error in the concrete lab and results obtained from the previous studies. The ratio of cement: water: sand was kept at 1:0.5:2.5 to maintain consistency. The different Fiber types were added as a percentage of the total dry weight.

All concrete samples were prepared and compacted to achieve acceptable density and avoid defects that could influence the compressive strength. The compressive strength was tested after curing, using a universal testing machine. Flexural strength was measured with a four-point bending setup, as shown in Figure 3. The maximum load at failure was recorded for each specimen, and flexural stress was calculated using a standard formula.



Figure 3. Testing of flexural strength using LVDT.

3. Results

3.1 Effect of Fiber Type on Compressive Strength

The compressive strength of cement mortar is affected by the addition of fiber, as shown in Figure 4. Each Fiber type has a different effect on the compressive strength of cement mortar. The addition of Fiber improves compressive strength up to an optimal point, which differs depending on the Fiber type [15]. After this point, the strength decreases due to the uneven distribution of Fibers [28]. The cement mortar reinforced with steel Fibers showed the highest compressive strength, reaching up to 24.5 MPa with a volume fraction of 0.5%, which is higher than any of the other Fibers. However, the cement mortar with 1.0% basalt fiber into cement mortar recorded the highest strength, about 25 MPa, reflecting their good physical properties, such as high tensile strength and thermal stability. While the addition of polypropylene Fibers into cement mortar showed a moderate

improvement, with strength peaking at 0.5% before gradually declining. This reflects their more effective role in controlling micro-cracks rather than enhancing compressive strength [29].

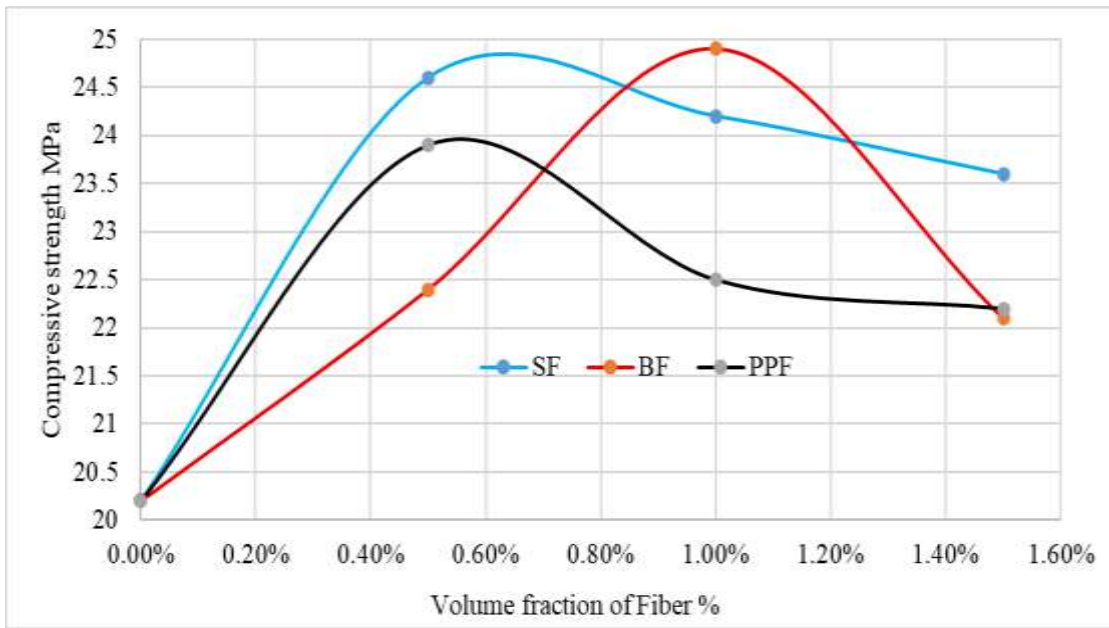


Figure 4. Compressive strength of cement mortar using various Fiber types and volumes.

As shown in Figure 4, all Fiber types recorded significant compressive strength based on their content. Instead, all these Fibers enhance sustainability, such as basalt, which is taken out from abundant natural resources, and polypropylene Fibers, which can be obtained from recycled plastic waste, contribute to reducing reliance on raw materials with a high environmental impact [30]. Improving mortar durability with Fibers also reduces the need for maintenance of concrete structures [31]. Therefore, the addition of Fibers into cement mortar not only improves the properties of concrete but also contributes to improving the entire life cycle efficiency of construction materials [32]. For instance, Chottemada et al. [33] reported that the addition of Fibers into mortar and concrete mixes enhances life cycle assessment (LCA) by lowering embodied energy and extending service life. They observed that the addition of 1–2% Fibers can reduce crack propagation by up to 40% and increase flexural strength by 15–25%. This performance improvement translates into a reduction of overall environmental impact indicators [34]. Bzeni [35] used several PP volumes, between 0.45 and 2.27% to enhance the flexural strength of concrete. They observed that the addition of 1.81% PP Fiber reduced the compressive strength of concrete by about 15%. On the other hand, irrespective of the content and length of the PP Fiber, the compressive strength does not change [36].

3.2 Effect of Fiber type on the deflection of beams

3.2.1 Effect of Steel Fiber

The relationship between applied load and deflection for four cement mortar samples with different Fiber volumes is shown in Figure 5. These samples are a control sample and three samples containing different steel Fiber volumes (S6F0.5, S6F1.0, and S6F1.5). The results obtained from this study indicate that the control sample (CON) shows brittle behavior, reaching its maximum load at a slight bend to about 1.4 mm, followed by sudden failure, indicating poor toughness, the ability to absorb energy before and after fracture. The addition of 0.5% Fiber to S6F0.5 significantly increased the maximum load compared to the control sample. But the post-peak behavior remained brittle, with a rapid decrease in load. This indicates that the overall toughness of the sample remained limited despite the improved ultimate strength [37]. When the Fiber content was increased to 1.0% and 1.5% in the samples of (S6F1.0 and S6F1.5), the performance of the samples improved significantly. These samples exhibited a gradual slope and greater energy absorption under bending, reflecting a significant increase in overall toughness [38, 39].

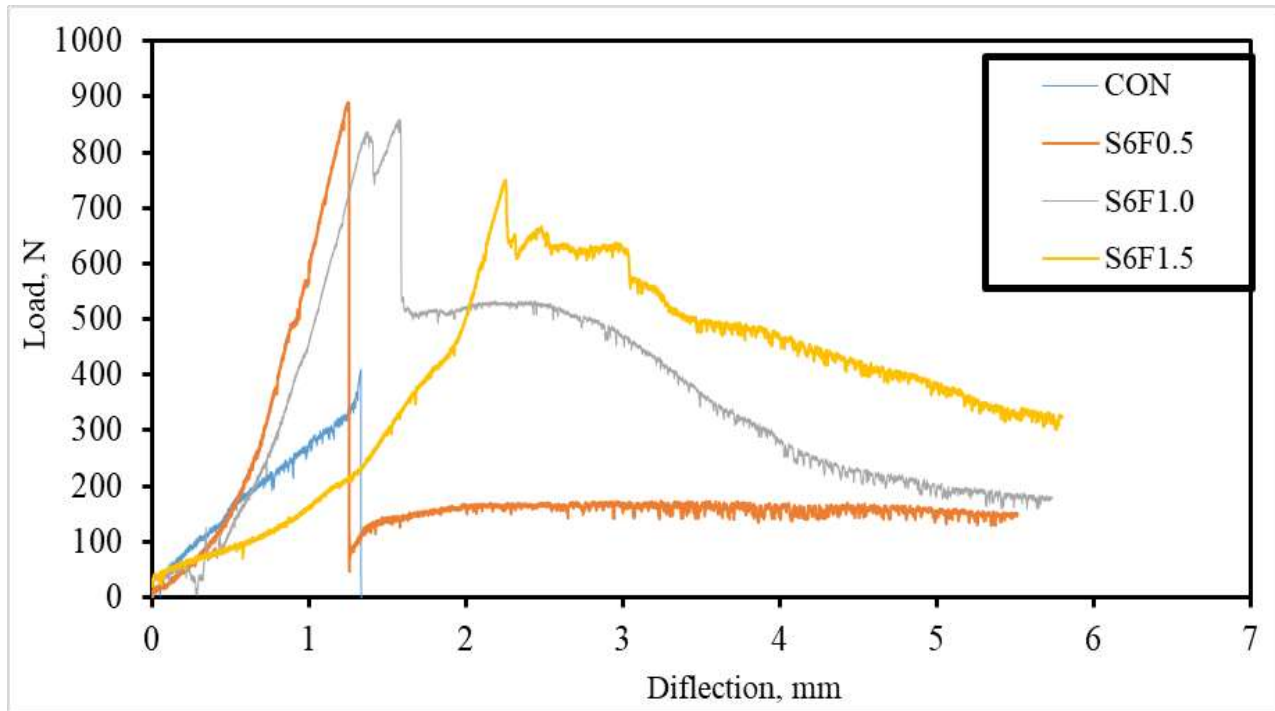


Figure 5. Load vs deflection due to the addition of steel Fiber on the concrete beam.

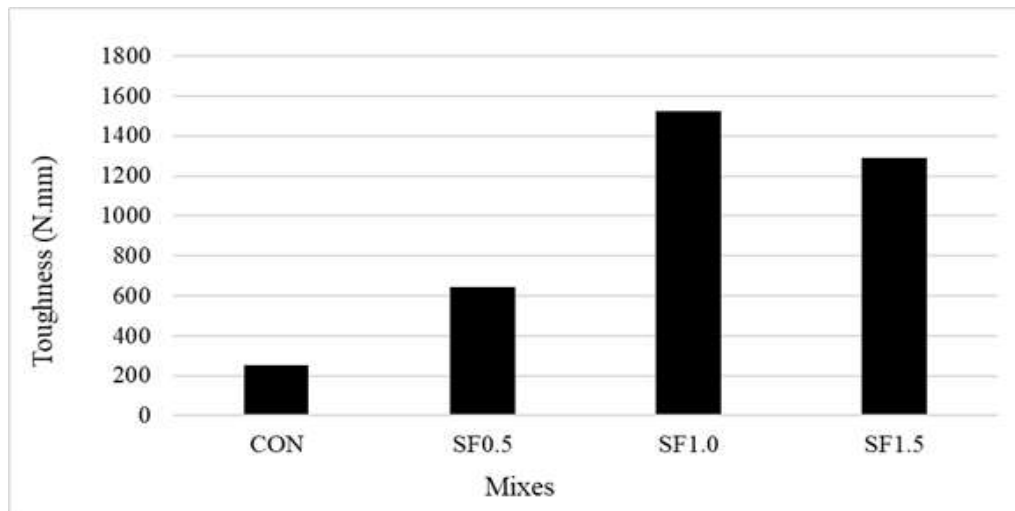


Figure 6. Toughness of mixtures with and without steel Fiber.

The deflection increases as the steel Fiber reinforced cement mortar increases, as shown in Figure 6. This study agrees with the results obtained by Yoo et al. [6], who reported that the increase in steel Fiber content leads to improved post-cracking flexural performance, which comprises toughness, deflection capacity, and strength. Steel Fibers have a main role in enhancing the toughness and ductility of cement mortar, thus supporting concrete structures to absorb more energy and resist cracking under load [40]. Therefore, it's recommended to be used in the important elements that require high flexural strength, like industrial floors, pavements, and structural beams [41].

3.2.2. Effect of Basalt Fiber

The relationship between load and deflection for the cement mortars reinforced by different basalt fiber contents is shown in Figure 7. Four cement mortar samples were tested, namely the control sample (CON), and three samples containing basalt Fibers at different volume fractions, namely 0.5% (BF0.5), 1.0% (BF1.0), and 1.5% (BF1.5). The results show that the control sample (CON) showed brittle behavior for conventional cement mortars without fiber, reaching maximum load at a quite small deflection of 1.3 mm, followed by sudden collapse, indicating very low stiffness, limited energy absorption capacity [42]. When basalt Fiber

is added at a rate of 0.5% (BF0.5), the maximum load increased significantly up to about 700 N, indicating an improvement in mortar strength. However, the post-peak behavior was still somewhat brittle, with a rapid decrease in load, indicating a slight improvement in stiffness.

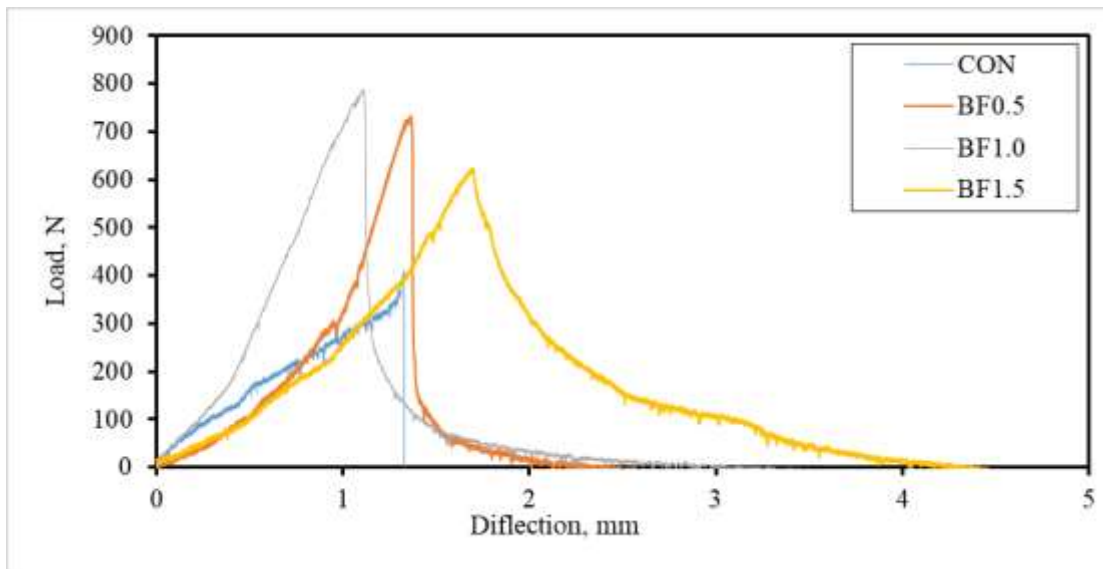


Figure 7. Load vs deflection due to the addition of basalt Fiber on the concrete beam.

The increased BF content up to 1.0% (BF1.0), further enhancements were observed in both the ultimate load and post-fracture behavior [43]. The sample containing 1.5% basalt Fibers (BF1.5) demonstrated the best performance among all samples. Not only increase the maximum load, but it also demonstrated a pronounced ductile behavior, with a high capacity to deform without sudden loss of load, and continued to withstand loads even at bends of approximately 4 mm.

These improvements in toughness are attributed to the effective role of basalt Fibers in strengthening the internal structure of the mortar by resisting the propagation of micro-cracks and providing bridges to connect cracked sections after cracking has begun, delaying specimen failure and increasing the amount of energy absorbed during loading (see figure 8). The Fibers also contribute to a more uniform stress distribution within the specimen, giving it a better ability to resist sudden collapse.

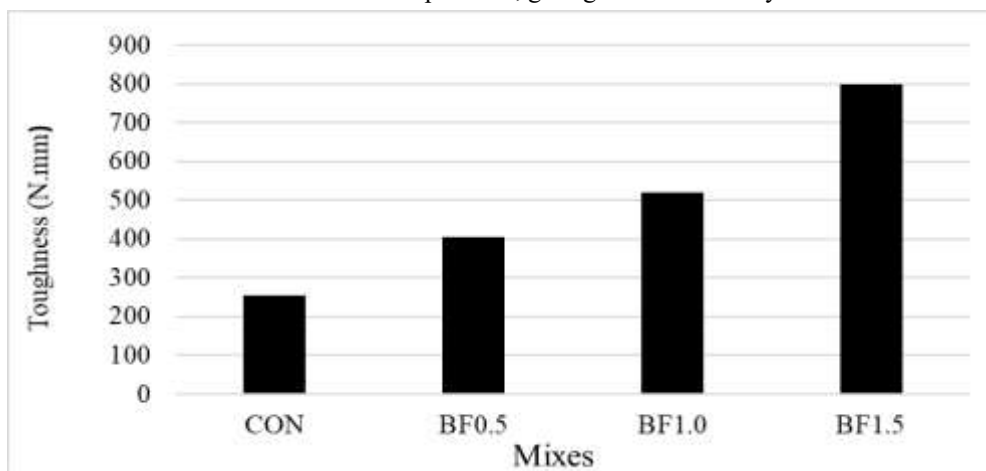


Figure 8. Toughness of mixtures with and without basalt Fiber.

Basalt Fibers improve the toughness and crack resistance of cement mortar, making it more durable and reliable under load. This enhancement is essential for structural elements exposed to dynamic or high-stress conditions, like bridges and pavements, which require high ductility [44]. In general, the addition of basalt Fibers significantly enhanced the load-bearing capacity and toughness of cement mortar.

3.2.3 Effect of Polypropylene Fiber

The relationship between applied load and deflection for cement mortars reinforced with PPF at different volume fractions (0.5%, 1.0%, and 1.5%), is shown in Figure 9. The samples containing PP Fibers showed more ductile behavior and deformation tolerance, particularly at 1.0%, achieving the optimum balance between maximum load and deflection [45]. Figure 10 shows the

highest toughness value, of the ability of the material to resist cracks. Although the 1.5% sample exhibited greater ductility, the decrease in maximum load may indicate a negative effect of Fiber agglomeration at higher volume fractions [46].

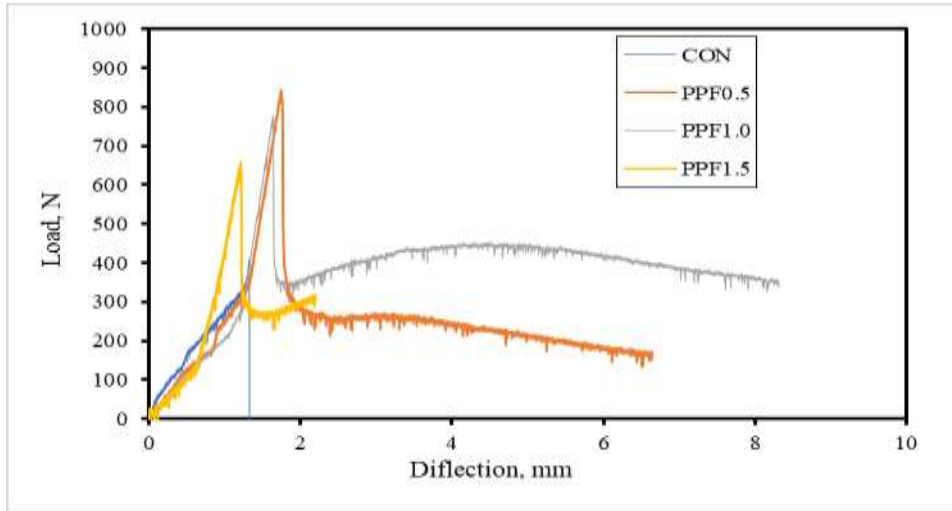


Figure 9. Load vs deflection due to the addition of polypropylene Fiber on the concrete beam.

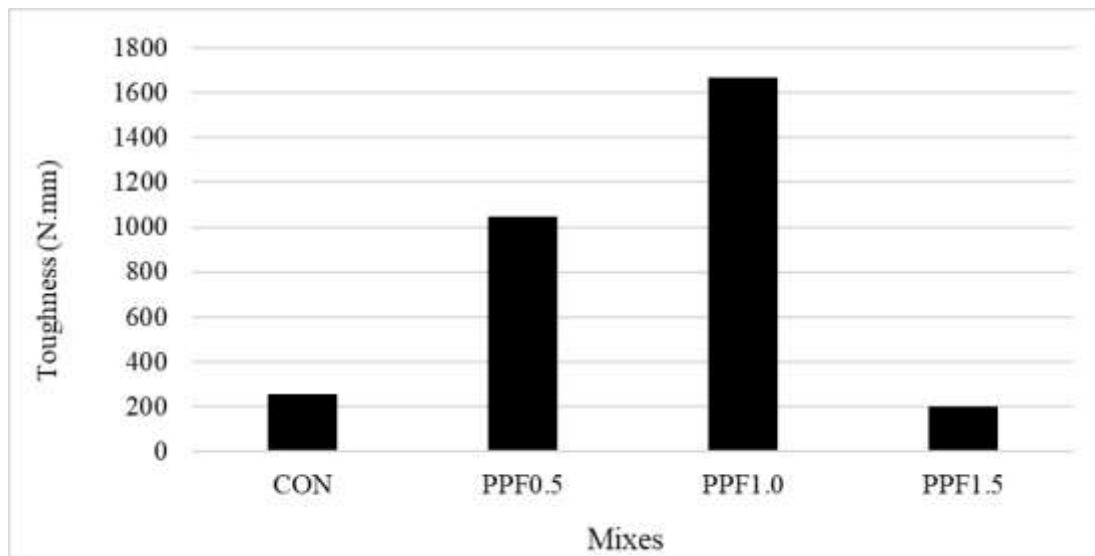


Figure 10. Toughness of mixtures with and without polypropylene Fiber.

Chen et al. [21] studied the relationships between the loading speed of polypropylene Fiber and flexural strength at different curing times. They observed that the addition of PPF enhanced the compressive and flexural strengths of cement mortar, and this enhancement can be attributed to the interaction between the PPF and cement mortar. Bzeni [35] used PPF in different volume fractions ranging between 0.45 and 2.27% to enhance the flexural strength of concrete. They observed that incorporation of macro-polypropylene at 0.8% and above led to an increase in the deflection hardening, which was qualified to the higher interfacial bond strength between Fibers. Burgos Cotrina et al. [47] investigated the effect of PPF with glass Fiber on the mechanical properties of cement mortar. They used 0.1%, 0.3%, and 0.5% PPF with 1%, 3%, and 5% glass Fiber of cement weight. They detected that the use of 0.1% PPF and 1.0% glass Fiber was the optimum proportion in enhancing the mechanical strength of cement mortar. To sum up, the addition of PP Fibers significantly improved the flexural strength and toughness of cement mortars compared to the unreinforced sample. The addition of 1.0% PP Fiber volume fraction showed the best balance between strength and ductility, while higher Fiber content led to minor performance reductions due to agglomeration.

4. Discuss the results

The results of the current study showed that the addition of SF, BF, and PP Fibers had a clear effect on the mechanical strength of cement mortar. Steel and basalt Fibers recorded the highest improvement in compressive and flexural strengths [48]. In the case of SF and BF, the compressive strength increased from 20.2 MPa for the control mix to 24.6 MPa due to the addition of 0.5% SF and 24.9 MPa due to the addition of 1.0% BF, indicating the strong reinforcing capability of these Fibers. However, the compressive strength reduced due to an increase in the SF and BF content, and this reduction in strength is owing to Fiber accumulation and its

poor dispersion, which created weak zones in the matrix [49]. PPF with low content showed moderate improvement in compressive strength, but the general improvement was less important compared to SF and BF.

In terms of flexural behavior, the results showed that the addition of Fibers significantly increased the mortar's ability to resist cracking and deformation under load [28]. SF provided the greatest improvement in toughness and load-bearing capacity, producing a more ductile response and delaying sudden failure [50]. BF also improved energy absorption and crack resistance, especially at 1.0–1.5% content, by effectively bridging cracks and maintaining structural integrity after initial cracking [51]. PPF enhanced deflection capacity and crack control at lower contents but showed diminished performance at higher levels due to Fiber clumping [52]. Overall, the experimental results confirm that an optimum Fiber type and content can significantly enhance the mechanical properties of cement mortar.

5. Conclusions and recommendations

This study, as an experimental work, aims to investigate the effect of Fiber type and content on the properties of cement mortars. Three Fiber types are used in this study, namely, steel Fiber, basalt Fiber, and Polypropylene fiber. These fibers are used in different volume fractions to enhance the performance of cement mortars, and the results obtained as shown in the following conclusions:

1. The addition of 0.5% SF into cement mortar has recorded the best compressive strength of 24.6 MPa, followed by 1.0% BF, which recorded 24.9 MPa, and then PPF, which performed 23.9 MPa with the addition of 0.5% PPF.
2. Toughness of cement mortar with 1.0% SF recorded the highest value of 1520 N.mm, while 1.5% BF recorded the maximum toughness of 800 N.mm, and the toughness of 1650 N.mm for cement mortar with 1.0% PPF.
3. Flexural test results showed that reinforcing cement mortar with PPF, especially at a volume fraction of 1.0%, significantly improved flexural strength and increased the energy absorbed after fracture (toughness).

From these conclusions, some suggestions can be recommended to future studies.

1. Future studies should explore the combined use of different Fiber types (such as steel-basalt or basalt-polypropylene) to determine possible synergistic effects on the strength, toughness, and durability of cement mortars.
2. It is recommended to perform microstructural and interfacial analyses, using techniques such as SEM or XRD, to better understand the bonding mechanisms between Fibers and the cement matrix and how these influence mechanical performance.

Author Contributions

All authors contributed in preparing this article: “Conceptualization, Haider T. Abed and Harith Ali; methodology, Hussein M. Hamada; resources, Harith Ali; data curation, Harith Ali; writing—original draft preparation, Hussein M. Hamada and Van Mohammed; writing—review and editing, Hussein M. Hamada and Van Mohammed; visualization, Yousif A. Ibrahim; supervision, Hussein M. Hamada; project administration, Ali Majdi. All authors have read and agreed to the published version of the manuscript.

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The data will be available when requested.

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Conflicts of Interest

The authors declare no conflict of interest.

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