

Mechanical Behaviour of Concrete Reinforced with Plasticized PVC and Galvanized Steel Fibers

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Abstract In order to improve its mechanical performance, the incorporation of fibers into concrete is one of the most widely used methods in the construction industry. Depending on the type and proportion of fibers added, the performance of the resulting concrete varies. This article presents an experimental study whose main objective is to propose types of polymer clay fibers based on plasticized PVC. The study compared the mechanical behavior under compression and bending of standard concrete with that of concrete reinforced with plasticized PVC and galvanized steel fibers. Using two mixtures containing 14% and 18% fibers, the compressive and flexural strengths were evaluated at 28 days. The results show that the addition of fibers, particularly plasticized PVC fibers, significantly improves the compressive strength, flexural strength, and ductility of the material. In terms of compressive strength, concrete reinforced with plasticized PVC fibers shows an average increase of 3.7% to 8.7%, depending on the dosage. In terms of flexural strength, the performance is even more remarkable: the time to failure increases by up to 115%, the maximum deflection by 114% to 135%, and the time to the first crack is delayed by more than 100%. These results confirm the positive mechanical contribution of adding plasticized PVC fibers, which represent an effective, economical, and innovative solution for improving the mechanical properties of concrete.

Keywords Fiber-Reinforced Concrete, Plasticized

PVC, Polymer Clay, Compression, Flexure, Ductility, Reinforcement

1. Introduction

Although concrete has limited tensile and flexural strength, it remains one of the most widely used materials in the construction industry due to its high compressive strength. To improve its overall mechanical performance, several strategies have been developed, including the use of metal reinforcement [1], geometric optimization of structures to increase their ductility [2], and the incorporation of materials into the cement matrix. This latter approach, considered innovative, significantly improves the mechanical properties of concrete, particularly its flexural strength and, to a lesser extent, its compressive strength. Among the most common solutions, adding fibers to concrete has proven particularly effective. Numerous studies have shown that incorporating fibers increases the mechanical strength of concrete and limits the spread of cracks, provided that a suitable type of fiber is chosen and the optimal dosage is used [3]. The addition of fibers (steel, basalt, carbon, polypropylene, etc.) improves compressive strength (up to 50 MPa), flexural strength (up to 10 MPa), and impact resistance, while increasing ductility [4]. Natural fibers, such as hemp, jute, or coconut

fiber, are valued for their low cost, light weight, and biodegradability. Their compatibility with the cement matrix can be improved through alkaline treatment. Synthetic fibers, on the other hand, help to strengthen mechanical resistance, reduce plastic shrinkage, and improve post-cracking behavior. An optimal dosage of around 1% by volume is generally recommended to maximize mechanical performance [5]. However, excessive dosage can impair the workability of the mixture and lead to a decrease in mechanical performance [4].

Steel fibers can increase flexural strength by up to 80%, while glass and polyethylene fibers also reinforce this property. Certain natural fibers, such as jute or basalt, are more effective in compression [5]. Fibers play an essential role in bridging cracks, which improves the toughness of the material as well as its resistance to freeze-thaw cycles. In addition, steel fibers reduce water absorption, while basalt fibers can increase it. Fiber-reinforced lightweight concrete (FRLWC) also performs better in fire conditions, particularly due to polypropylene fibers, which limit explosive spalling at high temperatures [4]. However, poor selection or overuse of certain fibers, such as coconut fiber, can lead to reduced performance, particularly in bending [5].

Among the first fibers to be used in concrete, steel fibers are now widely used due to their mechanical performance. According to H. Suiffi et al. [6], their incorporation improves tensile strength by more than 50%. Q. Zhang et al. [7] also showed that an appropriate dosage of metal fibers can increase compressive strength by approximately 30.6%. However, M.A. Abed et al. [8] observed that, in the case of self-compacting concrete, the addition of steel fibers has no significant effect on compressive strength, although it significantly improves other properties, with gains of up to 46% in tensile strength, 21% in flexural strength, and 16% in shear strength. Similarly, P.R. Tadepalle et al. [9] pointed out that, even when varying the shapes of the fibers, the impact on compression remains limited compared to that observed in tension and bending. Furthermore, these fibers improve the concrete's resistance to propagation and the appearance of the first crack [10]. However, their dosage must be strictly controlled, as excess can lead to a decrease in overall mechanical performance and a significant reduction in the workability of the mixture [11]. It should also be noted that steel fibers present a high risk of corrosion; even after treatment, this problem persists and constitutes a major limitation to their durability [12].

To overcome this corrosion problem, synthetic fibers have been proposed as an alternative solution. This type of fiber has also demonstrated a significant improvement in the mechanical performance of concrete. Using different PVA fiber contents, P. Zhang et al. [13] showed an increase of more than 67% in tensile strength at a rate of 0.6%, while compressive strength reached its maximum value at 0.3% fiber content. Synthetic fibers are also valued for their light weight. According to [14], they provide an

average improvement of 26% in compression and 30% in flexural strength compared to ordinary concrete. Although their mechanical effects are generally inferior to those of metal fibers, polypropylene fibers are distinguished by their effectiveness in limiting early cracking [6] and by their better resistance to crack propagation compared to metal fibers [11]. Another interesting approach involves the use of recycled synthetic fibers. S. Spadea et al. [15] studied the incorporation of recycled nylon fibers, which improved crack resistance by more than 35% while recycling plastic waste. These fibers also showed good resistance in alkaline environments. However, excessive amounts of synthetic fibers can reduce the mechanical properties of concrete [16]. In addition, polypropylene fibers have been found to increase the water absorption of concrete compared to other types of fibers [17]. Finally, the sensitivity of polymers to temperature is another important limitation. In general, synthetic fibers become more fragile at high temperatures [18]. According to Y. Wang et al. [19], polypropylene fibers tested at 25 °C resulted in a more than 34% increase in tensile strength. However, above 165 °C, these fibers melt, which increases the porosity of the concrete and leads to a decrease in its mechanical performance.

Despite their advantages, each type of fiber has specific limitations. Hybrid approaches combining two types of fibers have therefore been developed to take advantage of synergies between materials, thereby optimizing several mechanical properties of concrete simultaneously [20].

In a study conducted by X. Boa [21], it was demonstrated that adding steel fibers of varying lengths significantly improves the ultimate flexural strength of concrete, with an average gain of more than 22%. Each type of fiber has a different effect on the microstructure of the material; however, this improvement is accompanied by a decrease in the workability of the mixture. Furthermore, H. El-Din et al. [22] showed that by combining two types of fibers (steel and polypropylene), flexural and tensile strengths can be increased by an average of more than 60%. However, this combination carries an increased risk of segregation and overdosing. In general, mixing different types of fibers significantly improves the mechanical performance of concrete, depending on the type of fibers used and their respective proportions. M.H. Wei et al. [23] observed that hybrid concrete using steel fibers and polymer fibers offers better performance, although it is more expensive. The steel-polypropylene combination thus appears to be an attractive compromise, offering a good balance between performance and cost. These findings also apply to natural fibers. In the study conducted by M. Adamu et al. [24], the incorporation of natural date palm fibers increased tensile strength by more than 14% and flexural strength by more than 9%, provided that the optimal dosage was used. Such a combination helps to optimize the mechanical properties of concrete. However, overdosing of fibers, regardless of

their nature, can lead to a decrease in workability and an increase in the water absorption of concrete [25].

In this context, this study is part of the search for innovative solutions to improve the mechanical performance of concrete while limiting its usage constraints. The experimental study aims to evaluate the effect of incorporating plasticized PVC-based polymer clay fibers, compared to galvanized steel fibers, on compressive and flexural strength. Two dosages were studied, with tests carried out at 28 days. The relatively high fiber percentages selected in this work were chosen based on preliminary trials showing that lower dosages did not produce sufficient mechanical contribution, particularly in terms of crack bridging and post-cracking behavior. Given the low density and flexibility of plasticized PVC fibers, higher volume fractions are required to ensure adequate fiber interlocking and effective stress transfer within the matrix. The results obtained show that the addition of fibers, particularly plasticized PVC fibers, contributes to a significant improvement in compressive and flexural strength, while delaying the appearance of the first cracks and increasing the ductility of the material. These observations confirm that the use of plasticized PVC fibers is an effective, economical, and innovative approach to optimizing the overall mechanical properties of concrete. The structure of the article is as follows: an in-depth presentation of the fibers used, including their nature and their physical and mechanical properties; a description of the formulations studied; a presentation of the experimental protocols implemented; an analysis and discussion of the results; and finally, a conclusion with prospects for further research.

2. Experimental Procedure

2.1. Types of Fibers

The title of the work should clearly define what the article is about. It must be written in Roman script.

The addition of fibers significantly improves the mechanical performance of concrete, increasing its tensile strength, toughness, and ductility. Steel fibers, for example, significantly reinforce the overall strength and capacity of concrete to absorb dynamic loads [26]. Polymer fibers, such as polypropylene, reduce plastic shrinkage cracking and increase the ductility of the material [27]. Carbon fibers offer the highest tensile strength and modulus of elasticity among fibers, making them ideal for applications requiring maximum durability [28].

In this study, two different types of fiber are used: galvanized steel fibers and polymer paste fibers consisting mainly of polyvinyl chloride (PVC) mixed with

plasticizers. Figure 1 shows the two types of fibers used.

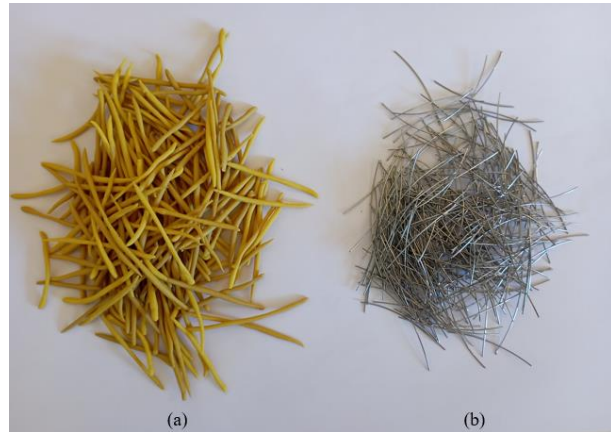


Figure 1. (a) Plasticized polyvinyl chloride (PVC) fibers, (b) Galvanized steel fibers

The fibers used in this study are divided into two types: metallic and polymeric. The metallic fibers are made of galvanized steel, with an average length of 2 cm and a diameter of approximately 0.7 mm. Galvanization involves coating the steel with a thin layer of zinc, usually by immersion in a bath of molten zinc. This treatment forms a protective barrier that prevents oxygen and moisture from penetrating the steel, thereby significantly reducing the risk of corrosion [29]. In the event of partial deterioration of this layer, protection remains assured due to a phenomenon known as cathodic protection: zinc, being more electrochemically reactive, corrodes instead of steel, thus preserving the latter [29].

The polymer fibers used are made from plasticized PVC, a thermosetting polymer derived from polyvinyl chloride resin. After polymerization, this material has a rigid but lightweight structure, perfectly suited for homogeneous dispersion in a cement matrix. The fibers have an average length of 2 cm and a diameter of approximately 1 mm. They offer several advantages: good tensile strength, low density, excellent dimensional stability after curing, and chemical inertness in the alkaline environments of concrete. Additionally, their absorption capacity enables a better fiber-matrix interaction, while the absence of phthalates in their composition further reinforces their suitability for sustainable applications. The mechanical characteristics measured on three plasticized PVC test specimens confirm these qualities. On average, the elasticity resistance is 8.72 MPa, the maximum tensile strength reaches 20.75 MPa, the Young's modulus is 23.89 MPa, and the elongation at break is 10.74%. These performance characteristics suggest that plasticized PVC fibers contribute to enhancing the ductility, toughness, and durability of concrete while maintaining a low specific weight and good long-term stability.

2.2. Description of Mixtures and Preparation of Test Specimens

In this study, two distinct concrete formulations were designed, each incorporating a specific fiber content. The mix designs were defined according to the method proposed by G. Dreux et al. [30]. The first formulation contains 18% fibers, while the second contains 14%. The remaining proportions are divided between gravel and sand, taking into account the particle size requirements and the cohesion of the mixture.

Three types of concrete were prepared: a reference concrete without added fibers, a concrete reinforced with galvanized steel fibers, and another containing plasticized PVC fibers (Figure 2). All mixtures are composed of aggregates (gravel with a maximum diameter of 15 mm and fine sand up to 4 mm), CPJ 55 cement (Portland Composite Cement conforming to Moroccan standard NM 10.1.004, with a nominal strength class of 55 MPa), and water. The two fiber-enriched formulations differ in the type of fibers used: galvanized metal fibers for one, and polymeric fibers (plasticized PVC) for the other.

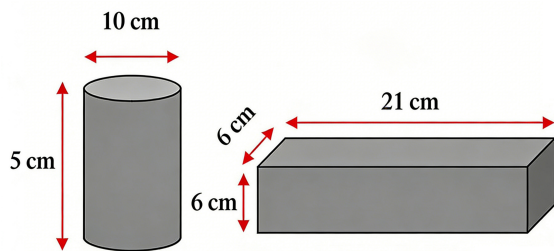


Figure 2. Dimensions of test specimens used

Table 1 shows the detailed composition of each mixture.

Table 1. Composition of each mixture

Component	Gravel	Sand	Fibers	Cement	Water	
Quantity (Kg/m ³)	Mixture 1	531,5	271,43	17	330	211,85
	Mixture 2	561,6	280,8	13	330	211,85

For this study, a total of 30 test specimens were prepared for mechanical testing. These included 18 cylindrical specimens measuring 5 cm in diameter and 10 cm in height, intended for compression testing, and 12 prismatic specimens measuring 6 × 6 × 21 cm, used for flexural testing. After demolding, all of these test specimens were immersed in water for 28 days, in accordance with the curing requirements specified in the standards for the hardening of cementitious materials. This curing period allows the concrete to reach optimal strength before being subjected to testing. Figure 2 shows the dimensions of each mold used.

2.3. Test Description

2.3.1. Compression Test

Compression tests are performed using a manual

hydraulic press (Figure 3) with a capacity of 30 tons. The test specimens are positioned in the center of the press, under the upper plate, which descends to exert increasing force on them until they break. This force is measured accurately using a pressure gauge.



Figure 3. Compression and flexural tests performed with a hydraulic press

2.3.2. Flexural Test

Flexural tests are performed using the same 30-ton manual hydraulic press. The prismatic specimens are positioned in the center of the press, as shown in Figure 3. To ensure accurate force distribution, metal cylinders have been added to the press device. These cylinders concentrate the compressive force at the center of the specimens, improving test accuracy and reducing the risk of unwanted lateral bending. The upper plate of the press is lowered, applying increasing force to the specimens. The applied force is measured accurately using a pressure gauge. Because the device is manual and not equipped with a displacement sensor or data acquisition system, it does not allow continuous recording of load–deflection curves or displacement measurements. Therefore, the flexural performance was assessed using observable indicators such as time to failure and visible cracking behavior.

3. Results and Discussion

3.1. Compressive Strength

After 28 days of curing, compression tests were performed on the various concrete specimens. Table 2 shows the results obtained for these tests. In Table 2, SF refers to plain concrete without fibers, FP refers to concrete reinforced with plasticized PVC fibers, and FF refers to concrete reinforced with galvanized steel fibers.

It was observed that, on average, for mixture 1, fiber-free concrete has a compressive strength of 13.50 MPa, while the strengths reach 14.00 MPa and 14.17 MPa for concrete reinforced with plasticized PVC fibers and

galvanized steel fibers, respectively. For mixture 2, the average compressive strengths of concrete without fibers, with plasticized PVC fibers, and with galvanized steel fibers are 9.05 MPa, 10.33 MPa, and 12.83 MPa, respectively.

Furthermore, the results for the first mixture show that adding 18% fibers does not significantly alter the compressive strength. Conversely, for the second mixture, adding 14% fibers increases the strength, making the differences between the measured values more significant.

During compression testing, it was observed that the specimens made from mixture 1 resisted cracking longer than those made from mixture 2. This result indicates that adding a larger quantity of fibers significantly strengthens the mechanical resistance of the specimens. In other words, the increased presence of fibers in mixture 1 helps to delay the appearance of cracks and improve the material's ability to withstand high compressive forces. Figures 4 and 5 illustrate, respectively, the different failure modes of the specimens from mixtures 1 and 2, showing distinct failure behaviors between these two compositions.

In addition, test specimens containing fibers, whether made of plasticized PVC or galvanized steel, demonstrated improved resilience to applied compressive forces. This performance can be attributed to the structural reinforcement effect exerted by the fibers, which act by absorbing part of the compressive forces. This absorption allows for better distribution of stresses within the concrete and reduces the propagation of internal cracks, giving the material greater ability to withstand intense pressures. This behavior is particularly evident in specimens reinforced with galvanized steel fibers, which show a notable improvement in strength, likely due to the additional stiffness provided by these metal fibers compared to PVC fibers.

Finally, analysis of the test specimens after crushing revealed the appearance of an hourglass-shaped fracture, a fracture pattern that complies with the criteria defined in standards NM 10.1.051 [31] and NF EN 12390-3 [32]. Figure 6 shows the condition of the test specimens after compression testing for both mixtures, clearly illustrating these characteristic failure modes.

Table 2. Compression test results

	Mixture 1 (18%)			Mixture 2 (14%)			
	SF	FP	FF	SF	FP	FF	
Compressive strength (MPa)	Specimen 1	14	12,5	14	9	10	13
	Specimen 2	12	15	14,5	10	11	12,5
	Specimen 3	14,5	14,5	14	9,5	10	13
Average	13,50	14,00	14,17	9,50	10,33	12,83	

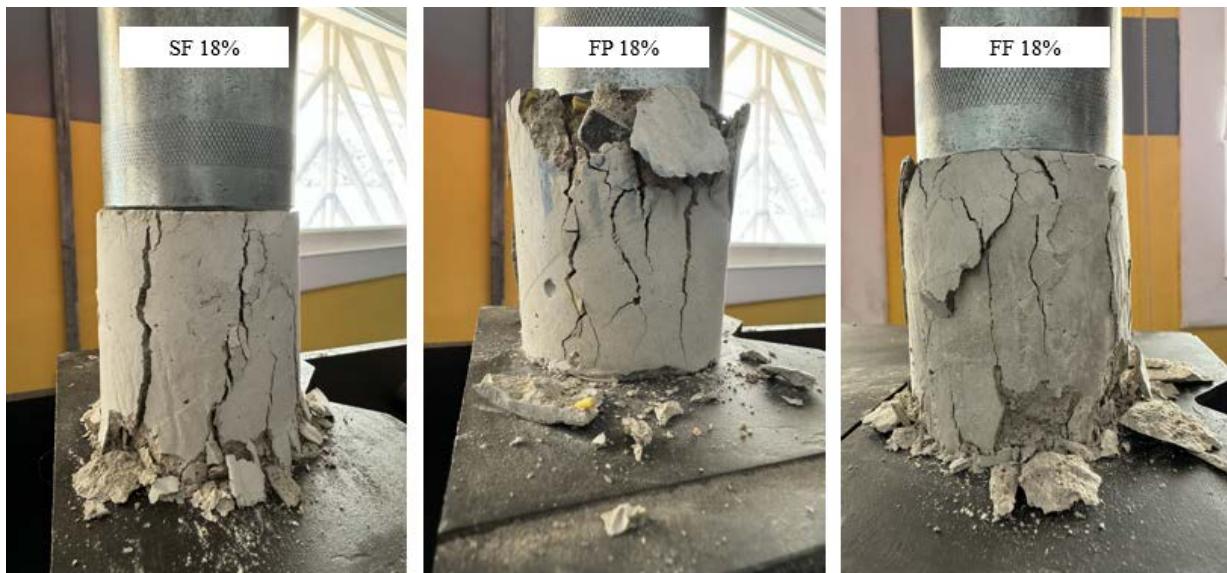


Figure 4. Failure modes comparison of concrete with 18% fiber content

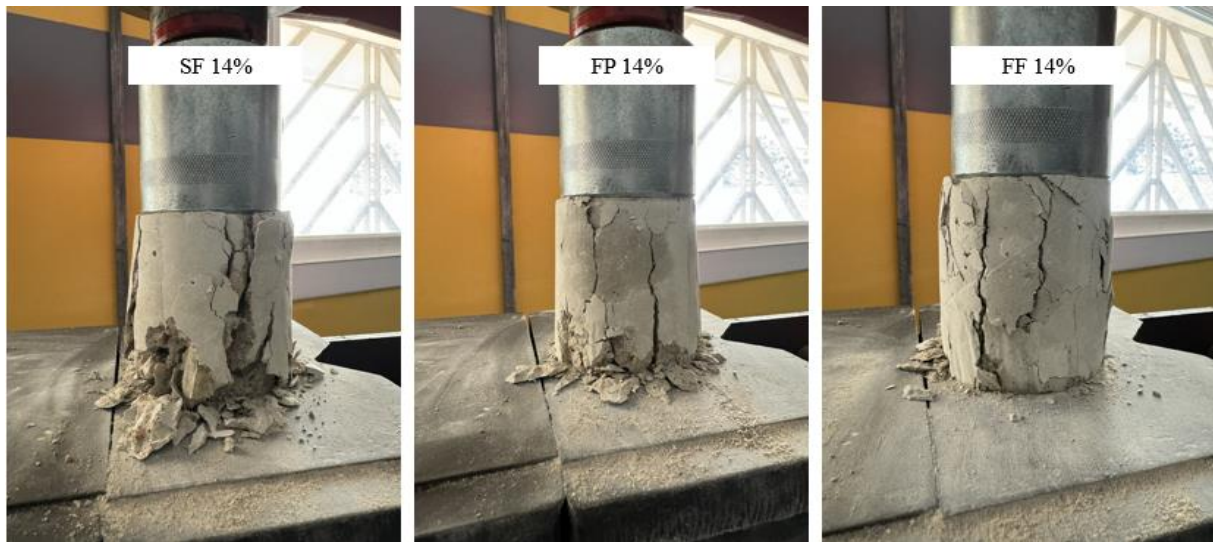


Figure 5. Failure modes comparison of concrete with 14% fiber content

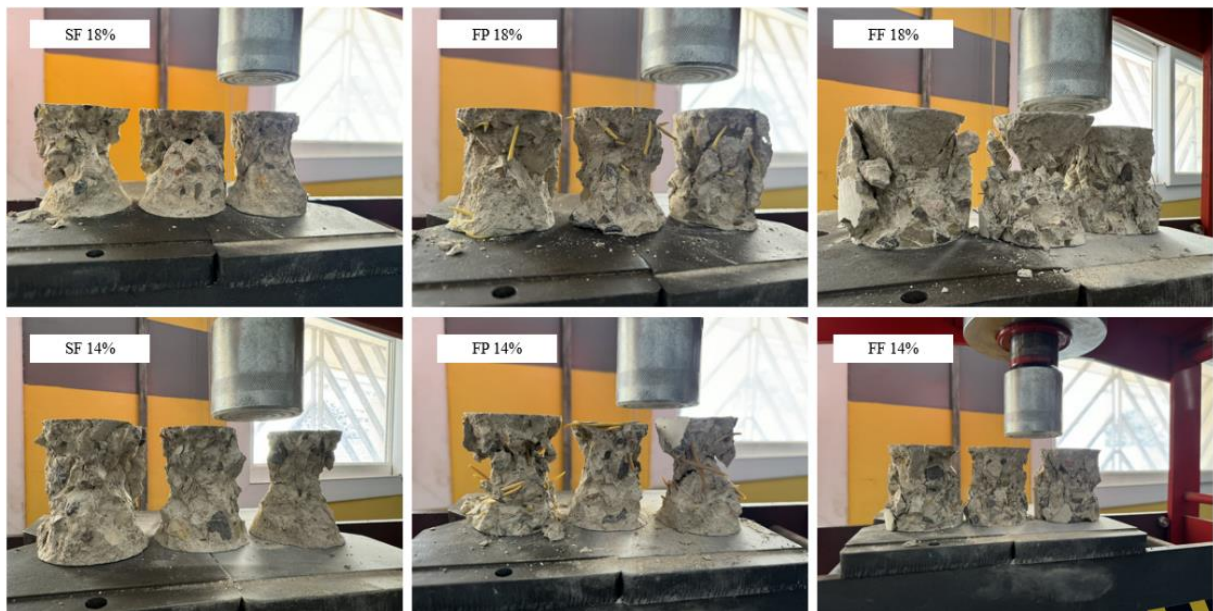


Figure 6. Post-compression test condition of test specimens for mixtures 1 and 2

3.2. Flexural Strength

After curing, the prismatic specimens were subjected to flexural testing. The analysis was based on the time elapsed from the first crack appearing to final failure. The maximum deflection was also measured for each specimen of each mixture composition. Figure 7 shows the time taken by each specimen of each composition before the first crack appeared.

As the results indicate, the appearance of the first crack varies from one mixture to another. On average, the first crack in the fiber-free concrete of mixture 1 is only visible after 13.5 seconds, while for mixture 2, the fiber-free concrete cracks after 9.5 seconds. Similarly, the concrete reinforced with plasticized PVC and galvanized steel fibers in mixture 1 cracks after 25 seconds and 32.5 seconds,

respectively. In contrast, for mixture 2, the two reinforced concretes have average cracking times of 19.5 seconds and 20.5 seconds, respectively.

These observations are also confirmed concerning the overall failure time of the specimens. Figure 8 shows a comparison of the total times of the specimens until final failure.

It has been observed that fiber-reinforced concrete specimens have a longer rupture time compared to concrete specimens without fibers. On average, for a fiber content of 18%, concrete reinforced with plasticized PVC fibers and concrete reinforced with galvanized steel fibers show improvements of 37 seconds and 61.5 seconds, respectively, compared to concrete without fibers. However, adding fibers at a proportion of 14% results in an improvement of 30.5 seconds for concrete reinforced with

plasticized PVC fibers and 37.5 seconds for concrete reinforced with galvanized steel fibers, compared to concrete without fibers. In addition, the test specimens of mixture 1 show greater strength than those of mixture 2.

Before the final failure of the specimens, measurements of the maximum deflections were also taken. Figure 9 summarizes the results of the maximum deflections obtained.

The effect of fibers observed when measuring crack initiation and failure times is also confirmed in maximum deflection measurements. The deflection value increases with the percentage of fibers in the mixture. On average, an improvement of 0.65×10^{-1} mm, 1.35×10^{-1} mm, and 2.15×10^{-1} mm was obtained for concrete mixtures without fibers, concrete reinforced with plasticized PVC fibers, and concrete reinforced with galvanized steel fibers, respectively, by increasing the fiber content from 14% to 18%.

It was also noted that fiber reinforcement improves the

flexural strength of concrete, allowing for a higher maximum deflection compared to an ordinary concrete mix.

Figure 10 illustrates the impact of adding fibers on the flexural behavior of concrete specimens for fiber proportions of 14% and 18%. The results show that the incorporation of fibers improves the ductility and strength of the concrete. Indeed, the specimens reinforced with galvanized steel fibers exhibit a central fracture, with the steel fibers maintaining a certain cohesion of the concrete despite the fracture, which demonstrates good ductility (Figure 11, right). For specimens reinforced with plasticized PVC fibers, the crack also formed in the center, but cohesion was slightly less well maintained than with steel fibers. PVC fibers provide moderate flexibility, but with weaker cohesion (Figure 11, left). Finally, the specimens without fibers, which also break in the center, show greater fragility and lower deformation capacity under load.

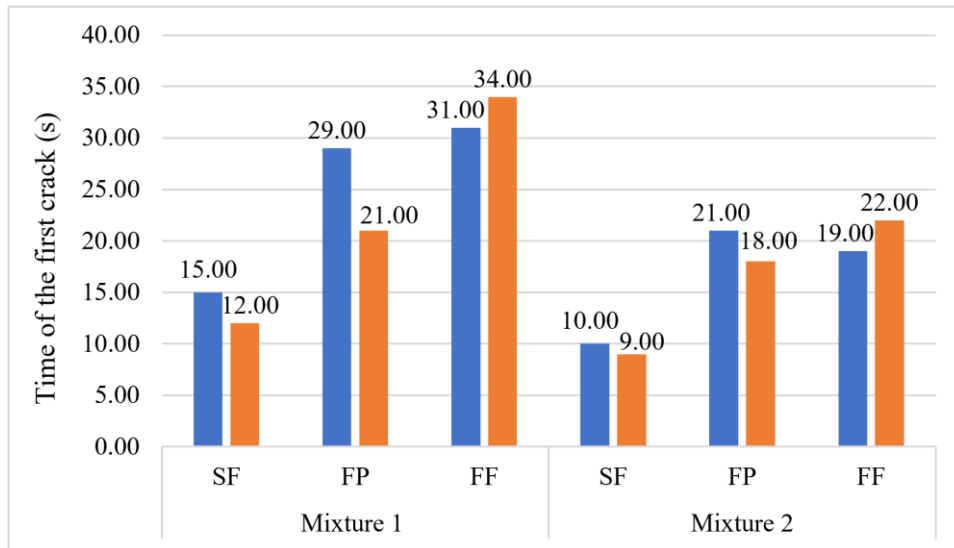


Figure 7. Time required for the first crack to appear in the test specimens

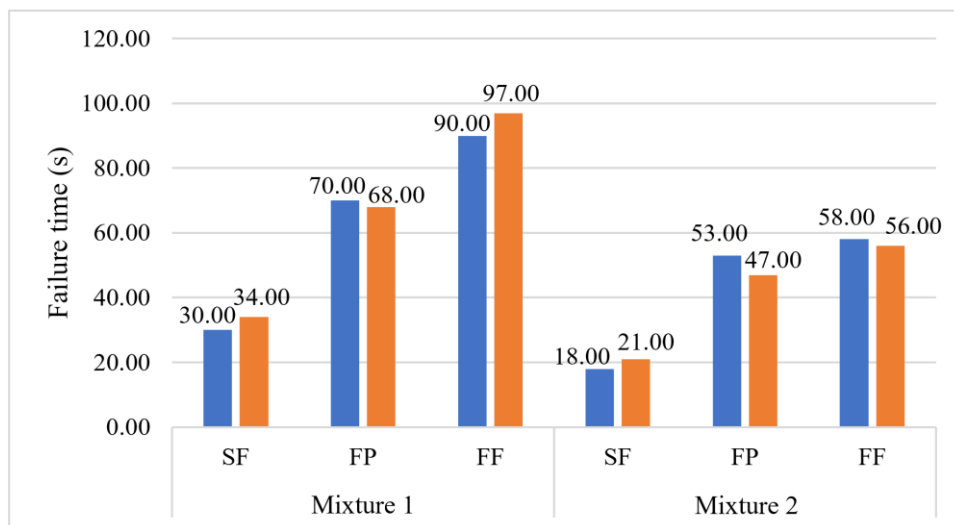


Figure 8. Comparative analysis of the rupture time of the test specimens for each mixture

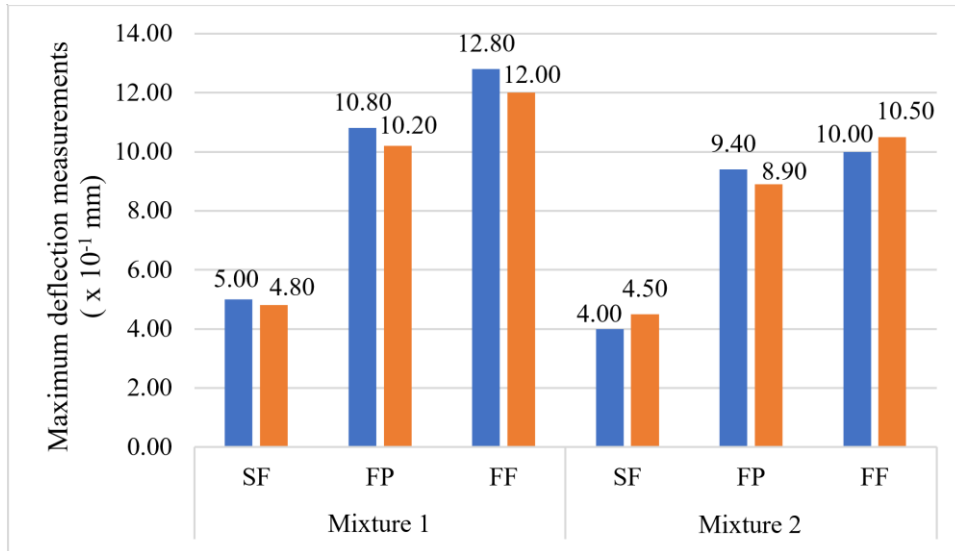


Figure 9. Maximum deflection measurements

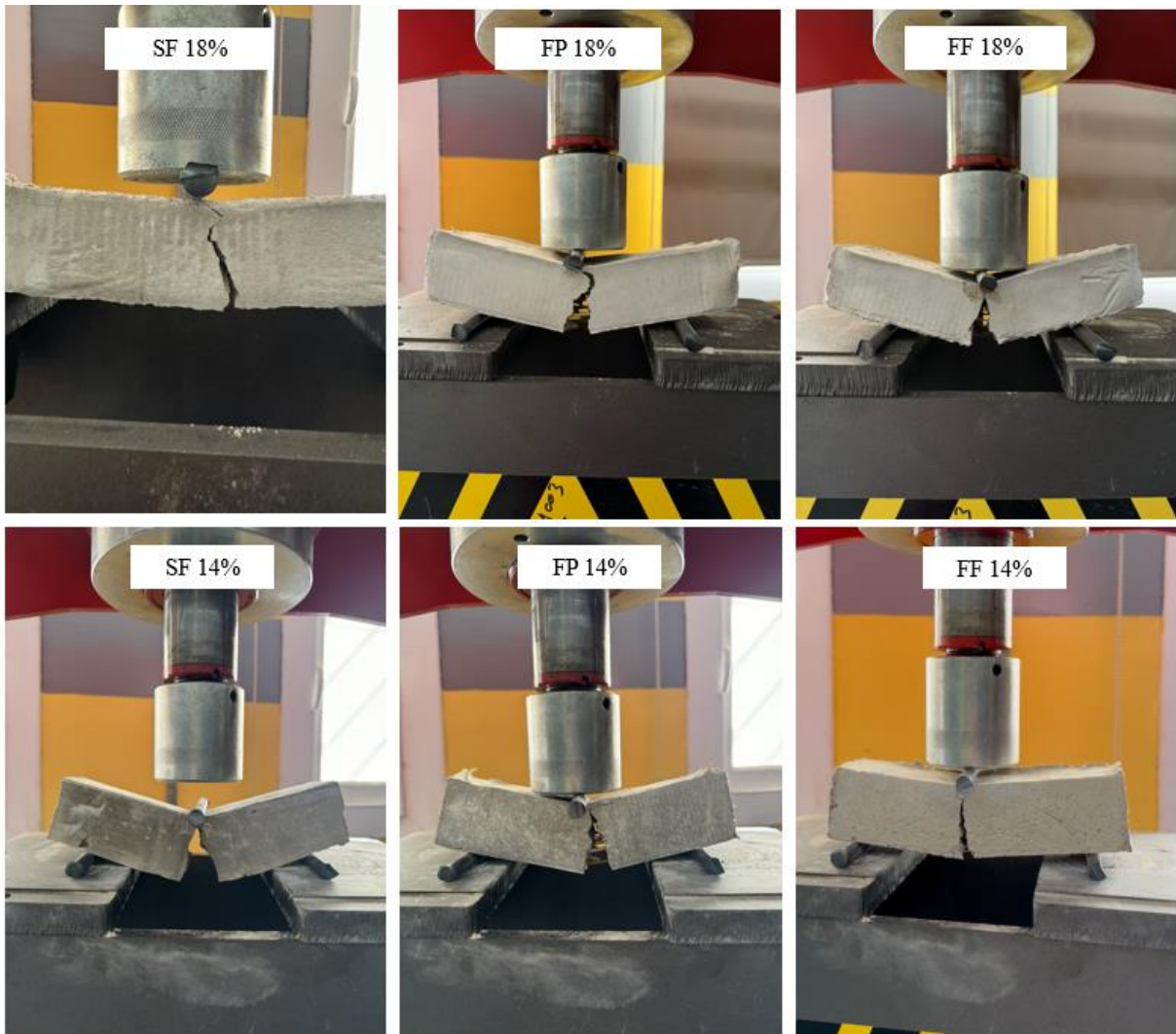


Figure 10. Impact of fibers on the flexural behavior of concrete specimens with 18% and 14% reinforcement

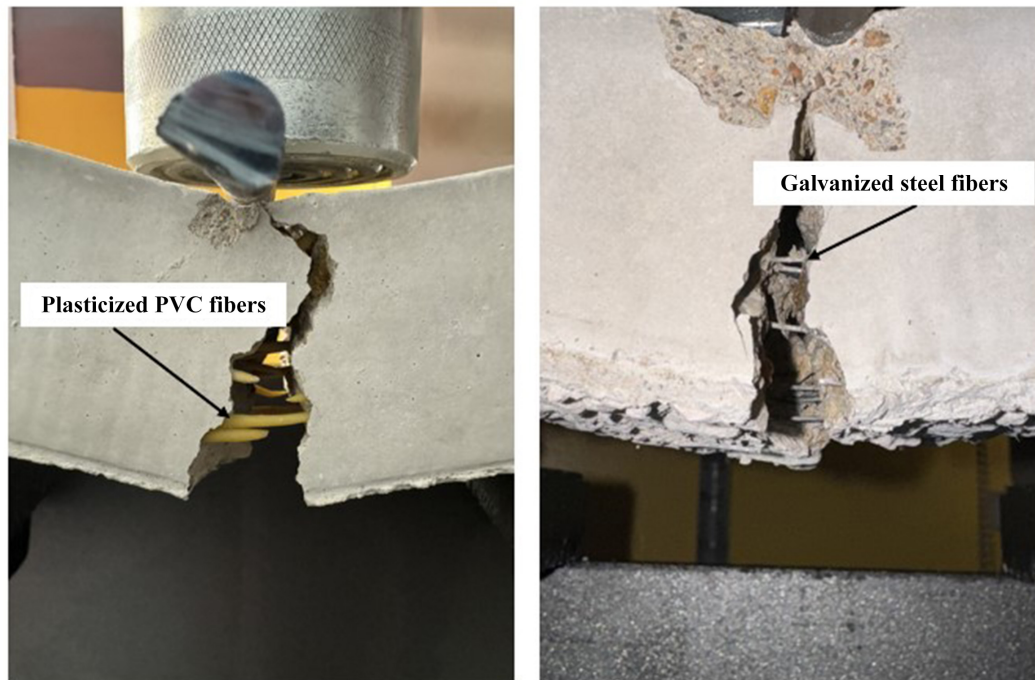


Figure 11. Comparison of post-cracking cohesion of concrete specimens reinforced with galvanized steel fibers and plasticized PVC fibers

3.3. Discussion and Interpretation

The experimental results obtained show that the addition of fibers, whether galvanized steel or plasticized PVC, significantly improves the mechanical properties of concrete, with a particularly marked effect on flexural behavior. This observation is consistent with the work of Q. Zhang et al. [7] and P.R. Tadepalle et al. [9], who report that the influence of fibers is often more significant in tension and bending than in compression.

In compression, the gains recorded vary from 3.7% to 8.7%, depending on the dosage and type of fiber, which are still lower than the increases of around 30% reported by Q. Zhang et al. [7] for metal fibers under certain optimal conditions. This difference could be related to the formulation, the compactness of the matrix, and the nature of the fibers used. Galvanized steel fibers perform slightly better than plasticized PVC fibers, probably due to their higher modulus of elasticity. However, the difference remains limited, confirming that synthetic fibers can be an effective alternative, as highlighted by P. Zhang et al. [13] for PVA, with a positive effect on compression at low dosages.

It is also important to note that the reference concrete used in this study exhibits a relatively low compressive strength (9.5-13.5 MPa), corresponding to a moderate-performance mix representative of non-structural or lightweight applications. This choice was made to better isolate the effect of fiber addition on mechanical behavior. Nevertheless, the relative percentage gains observed suggest that similar or even greater improvements could be expected in higher-strength

concretes, where enhanced matrix compactness and improved fiber–matrix adhesion would likely amplify the reinforcing effect.

In the case of flexure, the beneficial effect of fibers is much more pronounced. The increase in the time to first crack appearance (up to +115%), the time to failure, and the maximum deflection confirms the observations of H. El-Din et al. [22] and M. Adamu et al. [24], according to which fibers improve ductility and post-cracking toughness. Galvanized steel fibers provide better cohesion after rupture, as observed by M.A. Abed et al. [8], while plasticized PVC fibers, although less rigid, provide increased flexibility, reducing the fragility of ruptures. This flexibility, combined with the chemical inertness of PVC, could offer an advantage in aggressive conditions, where corrosion of steel fibers is a major limitation [12].

The effect of dosage is also notable: at 14%, the improvement in compression is more visible, while at 18%, the benefit in flexural strength is enhanced, but the fiber density can reduce compactness and thus limit the gain in compression. This observation is consistent with the remarks in [5] on the need for optimal dosage, as excess can adversely affect certain properties.

Moreover, the use of such high fiber contents (14-18 %) raises practical challenges in terms of workability and mixture homogeneity. At these levels, the concrete tends to become more viscous and difficult to cast, increasing the risk of fiber clustering and air entrapment. In practice, these issues could be mitigated by optimizing the mixing sequence, adjusting the water-to-cement ratio, or incorporating superplasticizers. Addressing these aspects is essential for transferring the experimental results to

large-scale applications, where workability and uniform fiber dispersion play a critical role in achieving consistent performance.

Finally, comparison with the results of M.H. Wei et al. [23] on hybrid concretes suggests that a combination of plasticized PVC and steel could combine rigidity and durability while limiting the negative effects associated with corrosion and overdosing of metal fibers.

4. Conclusions

This study showed that adding plasticized PVC and galvanized steel fibers improves the mechanical properties of concrete, with a bigger impact on flexural strength than on compressive strength. Galvanized steel fibers are distinguished by their ability to maintain good post-cracking cohesion due to their rigidity, while plasticized PVC fibers offer increased ductility, better chemical resistance, and reduced weight, making them an attractive alternative in aggressive environments. The gains observed in compression (3.7% to 8.7%) and the significant improvements in flexural strength (delayed cracking > 100%, notable increase in maximum deflection, and time to failure) confirm the key role of fibers in optimizing concrete performance.

To reinforce the applicability of this approach, it would be useful to assess its long-term durability under severe conditions, optimize the fiber dosage, and explore hybrid PVC–steel formulations to combine mechanical rigidity and chemical resistance. Thus, plasticized PVC appears not only as a technically viable alternative to metal fibers, but also as a promising path toward more durable, lighter, and potentially more environmentally friendly concretes.

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