THE EFFECT OF PLASTIC FIBERS ON THE MECHANICAL PROPERTIES, DUCTILITY AND ENVIRONMENTAL PERFORMANCE OF CONCRETE – A REVIEW

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Abstract- Concrete is a common building material due to its strength and durability, but it is essentially brittle, which can lead to cracking and reduced ductility under tensile loads. To enhance the ductility of concrete, different studies have done on various fiber, including plastic fibers. This paper explores the impact of plastic fibers on the mechanical properties, ductility and environmental performance of concrete. This review paper includes different studies on plastic fiber reinforced concrete under compressive, split tensile and flexure, focusing on the effect of plastic fibers on the ductility and environmental effect of it. Different studies show that plastic fibers significantly improve the compressive, split tensile, flexure, ductility and it will also help in reducing the plastic waste. These findings have important implications for the design of concrete buildings and their construction., particularly in earthquake-prone regions, where improved ductility capacity can amplify the seismic performance of structures additionally decrease the risk of catastrophic failure. Furthermore, the use of plastic fibers as reinforcement provides a sustainable solution for managing plastic waste. Plastic fibers have low cost, high availability, and favorable mechanical properties, making them an attractive alternative to traditional fiber reinforcement materials. The use of plastic fibers into concrete can reduce the environmental impact of plastic waste. The results of this study demonstrate the potential of plastic fiber reinforced concrete to improve the ductility and concrete structure's capacity to absorb energy while providing a sustainable solution for managing plastic waste.

Keywords- Plastic Fiber Concrete, Mechanical Properties, Ductility of Plastic Fiber, Environmental Effect, Plastic Reinforced Concrete.

1 Introduction

Concrete is frequently used in building because of its high compressive strength and durability, but it is essentially brittle, which can lead to cracking and reduced ductility under tensile loads. To address this issue, different studies have explored various fiber reinforcements to improve the mechanical properties and ductility of concrete. Plastic shrinkage is a well-known phenomenon in concrete, characterized by the quick evaporation of water from the freshly laid concrete's surface. This can lead to significant shrinkage, resulting in cracking, internal warping, and external deflection, which can weaken the concrete structure [1]. According to studies on concrete, to increase the resistance to cracking, various modifications are made to the composition of mixtures. These include the use of highly absorbent polymers, particle size distribution optimization, and fiber addition. [2]. Plastic fibers have emerged as a potential alternative to traditional fiber reinforcement materials due to their high availability, low cost and favorable mechanical properties.

Plastic fibers are synthetic fibers made from different types of polymers, including polypropylene, polyester, and nylon. This paper reviews the effects of different types of fibers (steel[3], carbon[4], basalt[5], glass[6], polypropylene[7], polyvinyl alcohol[8], and plant fibers[9]) on the dynamic mechanical properties of concrete under impact loads. It also summarizes the dynamic constitutive models and numerical simulation methods for fiber-reinforced concrete[10]. They are commonly used for a variety of purposes, including textiles, packaging, and construction. Plastic waste disposal is a major environmental problem worldwide due of the health dangers and challenges involved in land filling [11]. Steel fibers have the ability to absorb energy and control cracks, which leads to improvements in both tensile strength and flexural strength of concrete [12]. the incorporation of glass fibers in concrete provides excellent strengthening effects. However, it is important to note that glass fibers exhibit poor alkali resistance [13]. Wood, sisal, coconut, sugarcane bagasse, palm, and vegetable fibers are examples of natural fibers which are cost-effective and readily accessible. However, it is worth noting that these natural fibers tend to have poor durability [14]. Compared to traditional fiber reinforcement materials such as steel and glass, plastic fibers are lightweight, non-corrosive, and easy to handle. Additionally, they have a high tensile strength and elastic modulus., which makes them ideal for use as reinforcement in concrete.

This study investigates how plastic fibers affect the ductility and strength of concrete. Different studies include testing of plain and plastic fiber reinforced concrete under tensile, compressive and flexure loading, focusing on the impact of plastic fibers on the ductility and concrete's potential to absorb energy. This study investigated the addition of Polyethylene terephthalate fiber (PET) to concrete to improve its tensile strength and ductile properties. Various fiber volumes were tested, showing reduced slump and compaction factor at higher percentages. Workability remained satisfactory up to 1.5% to 2.0% fiber addition. Higher fiber content also increased bond strength[15]. As a result, Concrete has been acknowledged as one of the possible options for developing alternative methods of utilizing the plastic waste for other purposes [16]. The results show that plastic fibers significantly improve the ductility and energy absorption capacity of concrete. This study examined waste plastic fiber reinforced concrete by varying the percentage of plastic reinforcement (0%, 0.5%, 1%, 1.5%, 2%). Mechanical properties and ductility factors were evaluated, revealing improved concrete performance with the addition of plastic [17]. This is consistent with fundamental ecological practices including preventing waste, recycling trash, avoiding landfills, extracting energy from garbage, and preserving raw materials[18]. The findings have important implications for the design and construction of concrete structures, particularly in earthquake-prone regions, where improved ductility and energy absorption capacity can enhance the seismic performance of structures and reduce the risk of catastrophic failure. On the other hand, concrete has limited properties, such as weak tensile strength, impact energy absorption, and ductility[19]. [20] They conducted research on reinforced concrete utilizing waste metalized plastic waste fibers. They discovered that the strength and IR development of concrete composites might be significantly affected by the addition of these waste fibers. Furthermore, the use of plastic fibers as reinforcement provides a sustainable solution for managing plastic waste. Several studies have shown that incorporating plastic waste from various sources (PET bottles, plastic bags, and fishing nets) as fibers in concrete beams can effectively reduce plastic waste in landfills[21]. The findings of this research demonstrate the potential of plastic fiber reinforced concrete to improve the ductility and energy absorption capacity of concrete structures while providing a sustainable solution for managing plastic waste.

2 Mechanical Properties of Plastic Fiber in Concrete

The mechanical properties of plastic fiber in concrete refer to the characteristics and behavior of concrete when reinforced with plastic fibers. These properties include the strength, ductility, energy absorption capacity, and other relevant mechanical behaviors exhibited by the composite material. Table 1 presents the findings regarding the improved mechanical properties of 28-day cured concrete incorporating plastic fiber. The results demonstrate the positive effects of plastic fiber reinforcement on the performance of the concrete. The addition of 1.5% polyethylene terephthalate (PET) fibers with an aspect ratio of 17 (AR-17) resulted in a significant increase of up to 26.3% in the compressive strength of the concrete. This enhancement indicates that the inclusion of PET fibers contributed to the concrete's ability to withstand compressive forces. Similarly, the tensile strength of the concrete increased by up to 14.48% when 1.5% PET fibers with AR-17 were incorporated. This improvement in tensile strength highlights the reinforcing effect of the fibers on the concrete's resistance to tension. The table also reveals that by adding 0.15% volume fraction (Vf) of plastic fibers confined in the tension zone, the flexural strength of the concrete increased by up to 5.26 N/mm2. This increase in flexural strength suggests that the plastic fibers enhanced the concrete's ability to resist bending stresses. Moreover, the inclusion of plastic fibers improved the concrete bond strength and reduced cracks, thereby enhancing its overall durability. Additionally, the table mentions that the typical compressive strength specified for concrete ranges from 4,000 to 5,000 psi, and it emphasizes that concrete products must undergo a curing period of 28 days before installation or use. Lastly, the table highlights that the inclusion of pozzolans and supplementary cementitious materials (SCMs) increased the strength of the concrete by 25% to 40%, further enhancing its long-term strength and durability. Overall, these findings demonstrate the positive impact of incorporating plastic fibers on the mechanical properties of 28-day cured concrete, indicating their potential to improve the overall performance and durability of concrete structures.

Table 1 Improved Mechanical Properties of 28-Day Cured Concrete Incorporating Plastic Fiber [22], [23]

Compressive Strength	**Tensile Strength**	**Flexural Strength**	**Key Findings**
Increased up to 26.3% using 1.5% PET with AR-17	Increased up to 14.48% using 1.5% PET with AR-17	-	Plastic fibers improved the concrete bond strength and reduced the cracks
Increased up to 8.4% using 0.15% Vf of plastic fibers	-	Increased up to 5.26 N/mm2 using 0.15% Vf of plastic fibers confined in the tension zone	Plastic fibers increased the post-crack toughness and residual strength of concrete
4,000 to 5,000 psi for typical concrete specification	-	-	Concrete products cannot be installed or used until 28 days after the date of manufacture
Increased by 25% to 40% with the inclusion of pozzolans and SCMs	-	-	Pozzolans and SCMs enhanced the long-term strength and durability of concrete

2.1 Influence of Plastic Fibers on Compressive Strength

Concrete's compressive strength may be considerably increased by adding plastic fibers. The addition of plastic fibers can increase the ability of concrete to resist compressive stresses, resulting in stronger concrete. The results demonstrate that incorporating waste plastic fibers in concrete causes a slight reduction in compressive strength, with negligible differences between M (0%) and M (5%) following 7, 14, and 28 days of curing [24]. The increase in strength is mainly due to the fiber's ability to bridge cracks that can form in the concrete. According to a study, the addition of 1.5% PET fibers and 6% Alccofine in concrete resulted in the highest compressive strength, with a decrease in strength observed beyond these percentages [25]. As a result, the fibers improve the concrete's capacity to sustain itself and increase its resistance to deformation and cracking. Additionally, plastic fibers can also improve the durability of concrete structures, as they can prevent water from penetrating the surface and reduce the potential for freeze-thaw damage.

Table 1 provides details on the various Polyethylene terephthalate fiber fiber reinforcing options for concrete's compressive strength. The properties analyzed include elastic modulus and compressive strength. The elastic modulus (Ec) is a measure of a material's stiffness or rigidity. The elastic modulus values range from 24.2 GPa to 25.9 GPa, with C2 having the lowest value and C7 having the highest. The compressive strength values are given for two different types of specimens: cubes (F(cube)) and cylinders (F(cylinder)). The age of the specimens is given as 28 days and 90 days, representing the time at which the concrete samples were tested. For the plain concrete (C1), without any fiber reinforcement, the compressive strengths are 28 MPa at 28 days and 90 MPa at 90 days, for both the cube and cylinder specimens. When fiber reinforcement is applied, the kind and length of the fibers utilized affect the compressive strengths. Two types of fibers are considered: 0.25mm fiber and 0.40mm fiber. or the 0.25mm fiber reinforcement, the compressive strengths range from 31.0 MPa to 38.7 MPa at 28 days for cube specimens. For 90-day cube specimens, the compressive strengths vary from 37.2 MPa to 40.1 MPa. The corresponding compressive strengths for 28-day cylinder specimens range from 23.3 MPa to 26.6 MPa. For the 0.40mm fiber reinforcement, the compressive strengths at 28 days for cube specimens range from 30.5 MPa to 38.7 MPa. At 90 days, the compressive strengths range from 37.7 MPa to 38.4 MPa. The compressive strengths for 28-day cylinder specimens range from 23.4 MPa to 26.2 MPa. Overall, the table demonstrates the impact of fiber reinforcement on the mechanical properties of concrete. The addition of fibers generally leads to higher compressive strengths compared to plain concrete. The specific combination of fiber type and length influences the resulting strengths. Additionally, there are slight variations in the elastic modulus values among the different concrete properties analyzed.

Table 2 Compressive Strength of Three Concrete Mixtures (Average of Three Specimens) [26]

Concrete Property	**Unit**	**Age**	**Plain**	**0:25mm PET Fiber**			**0:40mm PET Fiber**		
			C1	C2	C3	C4	C5	C6	C7
Elastic modulus E_c	GPa	28	24.2	24.5	24.9	25.2	24.2	25.9	25.5
Compressive strengths F(cube)	MPa	28	33.2	34.3	31.1	32.3	31.0	31.0	30.5
F(cube)	MPa	90	38.1	40.1	38.4	37.7	37.2	37.7	38.7
F(cylinder)	MPa	28	23.3	26.2	24.1	23.4	24.1	26.6	23.5

2.2 Influence of Plastic Fibers on Tensile Strength.

A material's tensile strength is determined by its capacity to withstand breaking or fracture under tensile forces. Concrete has relatively low tensile strength, and the addition of plastic fibers can improve its ability to resist tensile stresses. The study shows that the use of 30% waste plastic fiber in mortar increases the strength significantly, with the mortar strength at 90 days being more than double that of the 7 days strength [27]. The study shows that FRC with ring-shaped Polyethylene terephthalate fiber (PET) showed stronger splitting tensile strength compared to those with irregularly shaped PET and waste wire fibers because of the interlocking tensile strength of the fibers in the fiber-bridging zone. Among the ring-shaped fibers, R-10 fibers with a width of 10 mm showed the highest maximum loads, while synthetic macro-fibers had the highest splitting tensile strength. [28]. By bridging the fractures that develop as a result of tensile stresses, plastic fibers can enhance the tensile strength of concrete. By bridging these cracks, the fibers can prevent them from propagating and reduce the potential for failure. The improved tensile strength can lead to more durable concrete structures that can resist deformation and cracking.

This table 2, explains the mechanical characteristics of concrete with various fiber reinforcing choices., specifically focusing on tensile strength. The properties analyzed include elastic modulus and tensile strength. The elastic modulus (Ec) represents the stiffness or rigidity of a material. In this table, the values of elastic modulus for different concrete properties are given. The values range from 24.2 GPa to 25.9 GPa, with C2 having the lowest value and C7 having the highest. Tensile strength is a crucial property of concrete, indicating its ability to resist tension forces. It is typically measured in megapascals (MPa). The table provides tensile strength values for concrete samples at different ages and with various fiber reinforcement options. The tensile strength values are given for two types of specimens: cubes (F(cube)) and cylinders (F(cylinder)). The age of the specimens is given as 28 days and 90 days, representing the time at which the concrete samples were tested. For plain concrete (C1), without any fiber reinforcement, the tensile strengths are 28 MPa at 28 days and 90 MPa at 90 days for both cube and cylinder specimens. When 0.25mm fiber reinforcement is introduced, the tensile strengths vary depending on the concrete property. At 28 days for cube specimens, the tensile strengths range from 2.79 MPa to 3.08 MPa. At 90 days, the tensile strengths range from 3.32 MPa to 3.49 MPa. The tensile strengths for 28-day cylinder specimens range from 3.84 MPa to 4.35 MPa. For 0.40mm fiber reinforcement, the tensile strengths at 28 days for cube specimens range from 2.88 MPa to 3.03 MPa. At 90 days, the tensile strengths range from 3.40 MPa to 3.53 MPa. The tensile strengths for 28-day cylinder specimens range from 3.96 MPa to 4.37 MPa. Overall, the table illustrates how fiber reinforcement affects concrete's tensile strength. The addition of fibers generally leads to higher tensile strengths compared to plain concrete. The resultant strengths are influenced by the particular fiber type and length combination. The values in the table highlight the improvement in tensile strength achieved by incorporating fiber reinforcement in concrete samples, providing valuable information for construction and structural design applications.

Table 3 Compressive Strength of Three Concrete Mixtures (Average of Three Specimens except f(ctm), which is based on one load-tested prism) [26]

Concrete Property	**Unit**	**Age**	**Plain**	**0:25mm PET Fiber**			**0:40mm PET Fiber**		
			C1	C2	C3	C4	C5	C6	C7
Elastic modulus E_c	GPa	28	24.2	24.5	24.9	25.2	24.2	25.9	25.5
Tensile strengths F(cube)	MPa	28	2.79	3.08	2.95	2.96	3.03	2.93	2.88
F(cube)	MPa	90	3.32	3.47	3.49	3.43	3.40	3.47	3.53
F(ctm)	MPa	28	3.84	4.35	4.14	4.37	4.01	4.05	3.96

2.3 Influence of Plastic Fibers on Flexure Strength

The capacity of a material to resist bending or breaking under bending forces is referred to as flexure strength or bending strength. Plastic fibers may significantly enhance the flexural strength of concrete. According to a study by [25], Flexural strength rises with increasing PET fiber content and Alccofine %. With 1.5% fiber and 9% Alccofine, the maximum flexural strength is achieved. By boosting the material's tensile strength, the fibers can make concrete more flexibly strong., and by bridging the cracks that can form under bending stresses. The bridging of these cracks can prevent the formation of larger cracks and can reduce the potential for failure. As a result, the addition of plastic fibers can lead to more durable concrete structures that can resist deformation and cracking under bending stresses.

The ductility and flexural strength of 500 mm long prisms subjected to four-point bending are shown to be impacted by recycled HDPE (high-density polyethylene) fibers in Figure 6.A displacement-controlled power ram was used to load the material at a speed of 1 mm per minute. The load-deflection plots reveal that all prisms reached similar peak flexural loads, approximately Fcr (15.0-16.0 kN), at deflections around 0.45-0.50 mm over the 300 mm spans. However, prisms reinforced with Ø1 = 0.25 mm fibers demonstrated slightly higher loads compared to those reinforced with Ø1 = 0.40 mm fibers. Upon cracking, the prisms exhibited residual load levels, RL. The Ø1 = 0.25 mm fiber-reinforced prisms achieved RL values ranging from 25% to 45% of Fcr, indicating an improved residual load capacity compared to the Ø1 = 0.40 mm fiber-reinforced prisms, which had RL values between 13% and 32% of Fcr. As expected, a higher volume of added fibers led to a higher RL/Fcr ratio. This figure provides valuable insights into the behavior of recycled plain HDPE fiber-reinforced prisms under flexural loading. It highlights the effect of fiber diameter and volume on both peak load capacity and residual load levels, demonstrating the potential for enhancing the flexural performance and ductility of concrete structures.

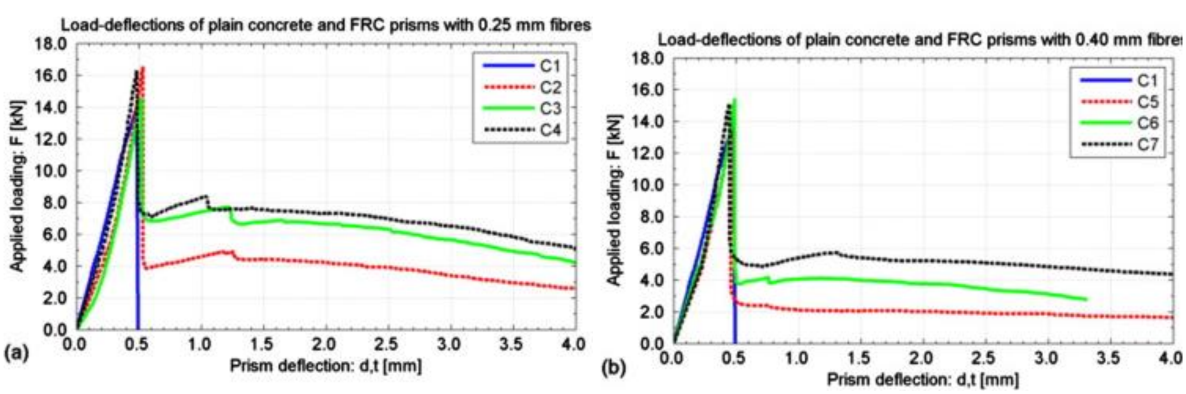

Figure 1 Flexural Strength Comparison of Plain Concrete (C1) and FRC with a) Ø 0.25 mm PET Fibers (C2-C4) and b) Ø 0.40 mm PET Fibers (C5-C7) [26]

3 The Effect of Plastic Fibers on Ductility

Ductility is an important mechanical property of construction materials such as concrete, which refers to the material's ability to undergo plastic deformation before failure. In other words, ductility measures how much a material can bend or stretch under stress without breaking. It is a crucial property for structures subjected to various types of loads and dynamic forces. plastic macro-fibers decreased the workability of fresh concrete and increased cracking caused by plastic shrinkage. By enhancing its ductility, toughness, and flexural and tensile strength, fibers added to concrete increase the material's total strength [29]. The ductility of concrete has been discovered to be improved by the inclusion of plastic fibers. To increase the mechanical qualities of concrete, plastic fibers, which are commonly formed of materials like polypropylene, polyester, or nylon, are employed as a reinforcing material. These fibers can enhance the ductility of concrete in several ways.

Firstly, concrete's brittleness can be lessened with plastic fibers, making it less susceptible to unexpected breakdown while under stress. This is because the fibers act as tiny shock absorbers, absorbing the energy from the impact and distributing it evenly throughout the concrete matrix. As a result, the concrete becomes more resistant to cracks and fractures, and is able to undergo greater plastic deformation before failure. Secondly, the presence of plastic fibers in concrete can improve the material's post-cracking behavior. This research was done to look at the behavior of ductility, energy absorption, and impact resistance of fiber-reinforced concrete [29]. When concrete cracks under stress, the fibers help to hold the cracked surfaces together, preventing further propagation of the cracks. The impact of this is an increase in the residual strength of the material, which means that the concrete can still carry load even after cracking. This is crucial for buildings that are vulnerable to dynamic loads like earthquakes, as it allows the material to undergo a certain level of deformation without failing completely.

Finally, Plastic fibers can be added to concrete to increase its overall toughness. Concrete tends to deteriorate over time when subjected to adverse weather conditions like freeze-thaw cycles or chemical assault, decreasing its mechanical qualities. A study investigated the use of waste plastic fibers from flour sacks to enhance the performance of mortar by partially replacing sand with varying rates. According to [30], plastic shrinkage cracks in newly laid concrete can be avoided, and the post-cracking behavior of concrete can be enhanced by using synthetic fibers comprised of polyolefin, acrylic, aramid, and carbon. However, the use of plastic fibers can help to mitigate this degradation, as they act as a barrier against moisture and chemicals, preventing them from penetrating deep into the concrete matrix. The inclusion of plastic fibers to concrete has a significant impact on the material's ductility, improving its ability to undergo plastic deformation before failure. This is due to the fibers' ability to reduce brittleness, improve post-cracking behavior, and enhance overall durability. As a result, the use of plastic fibers in concrete can lead to more resilient and sustainable structures, capable of withstanding a wide range of loads and environmental conditions.

4 Environmental and Sustainability Considerations

There are a number of sustainability and environmental issues related to the usage of plastic fibers as reinforcement in concrete. First, using plastic fibers in concrete offers a long-term method of disposing of plastic waste. Less than 9% of the 335 Mt of plastic generated year worldwide, according to the report, is recycled. The majority of plastic waste ends up in landfills, leading to significant environmental concerns. The study highlights the environmental advantages of using recycled industrial plastic waste as microplastic fibers for concrete reinforcement [31]. Plastic waste is a significant environmental problem worldwide, with large amounts of plastic ending up in landfills or oceans. By using plastic fibers as reinforcement in concrete, the environmental impact of plastic waste can be reduced while providing a valuable resource for construction.

Additionally, using plastic fibers as concrete reinforcement can help cut down on carbon emissions. The production of concrete with traditional steel reinforcement requires a lot of energy and emits a lot of carbon dioxide. When used in large-scale concrete manufacturing, the strategy of partially substituting Portland cement with recovered waste plastic has the potential to minimize carbon emissions [32]. The study examined the environmental effects of utilizing recycled PET as fine aggregate in concrete and found that doing so greatly lessens both the carbon footprint and the human toxicity impact of concrete manufacturing [33]. In contrast, plastic fibers have a low carbon footprint and require less energy to produce, making them a more sustainable alternative. Finally, the use of plastic fibers in concrete can contribute to the development of a circular economy. By incorporating plastic waste into construction materials, the value of waste materials is increased, and the need for virgin materials is reduced. This approach can help to create a more sustainable and resource-efficient construction industry.

The different stages involved in the production of plastic fiber for use in concrete. The first stage is plastic bottles being collected from landfills, indicating that these bottles are being diverted from traditional waste disposal methods. The second step is that the bottles being cleaned, which is an important step in ensuring that the material is free from contaminants that could affect the quality of the final product. Finally, the third step is the plastic bottles being converted into fibers, which are then used as a reinforcement material in concrete. The potential of recycling plastic waste into valuable products, which not only reduces the amount of plastic waste in landfills but also helps to conserve natural resources. An example of a sustainable material solution that may help in reducing the negative effects of construction activities on the environment is the use of plastic fibers in concrete. By using recycled plastic, the production of new materials can be reduced, and the environmental footprint of the construction industry can be minimized.

5 Conclusions

The research presented in this paper explores the effect of plastic fibers on the mechanical properties, ductility, and environmental performance of concrete. The findings have significant implications for sustainable construction practices and the management of plastic waste. The key conclusions from different studies are summarized as follows:

1. The inclusion of waste plastic fibers in concrete results in the higher compressive strengths achieved compared to plain concrete.
2. Concrete's split tensile strength is greatly increased by the addition of plastic fibers, indicating improved resistance to tensile stresses.
3. Plastic fibers contribute to the enhancement of flexural strength in concrete.
4. The inclusion of plastic fibers improves the ductility of concrete, making it less brittle and more resistant to cracking.
5. By utilizing recycled plastic waste as reinforcement, the environmental impact of plastic disposal in landfills or oceans can be reduced.

The study's findings show that adding plastic fibers to concrete enhances its mechanical qualities, such as ductility, flexure strength, split tensile strength, and compressive strength. Furthermore, incorporating plastic fibers offers environmental benefits by reducing plastic waste and lowering carbon emissions. These results encourage the use of environmentally friendly building techniques, where plastic fibers may be successfully used as a reinforcing material in concrete buildings.

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