

Investigation of the Effect of Textile Shredding Process Waste Fibers on the Physical and Mechanical Properties of Concrete

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Abstract

In this study, the effects of incorporating textile shredding process waste fibers into fiber reinforced concretes were experimentally investigated. A total of six concrete mixtures with varying fiber contents (0 to 3.6 kg/m³) were produced and examined in terms of physical and mechanical properties. The results showed that the addition of up to 1.2 kg/m³ fibers improved the hardened density of the mortars due to enhanced compactness and void filling. However, further increases in fiber content led to reductions in density and workability, as indicated by decreased slump values. Despite this, compressive and flexural strength values increased with fiber addition up to certain thresholds, particularly at early curing ages (7 and 28 days). The highest increase in compressive strength at 28 days was recorded as 13.79% compared to the reference sample. A slight decrease in long-term compressive strength (150 days) was observed at higher fiber contents, likely due to fiber degradation in prolonged water exposure. These findings suggest that waste fibers can enhance the early-age mechanical performance of lightweight mortars, offering a sustainable and effective approach to fiber reinforcement in cement composites. However, optimal dosage and curing strategies must be considered to ensure long-term durability.

Keywords: Waste fiber, fiber reinforced concrete, fiber addition, mechanical analysis

Introduction

The construction industry is one of the leading consumers of raw materials, making the adoption of more efficient and sustainable alternatives increasingly important. Recycling and reusing materials have emerged as effective strategies to promote sustainability within the sector. Among these, textile waste fibers represent a promising resource (Kalkan et al., 2023). Global fiber production reached an all-time high of 124 million tons in 2023 (Textile Exchange, 2024), a considerable amount of waste is generated through industrial processes and discarded textile products. In Europe alone, the textile industry produces approximately 12.6 million tons of waste each year (European Parliament, 2024). Although some of this waste is recycled into yarn, fine fibers are inevitably produced as byproducts during the process. These residual fibers are often incinerated or disposed of in landfills, posing environmental risks due to their non-biodegradable nature (Reis, 2009; Ryu et al., 2007). Nevertheless, the extensive accumulation of textile waste fibers presents a valuable opportunity for their application in construction materials. In Turkey, the textile and apparel industry play a vital role in the national economy, ranking third in textile exports among European countries and sixth globally in garment exports. Given this substantial production capacity, the volume and type of waste generated vary depending on the specific manufacturing activities. While a portion of this waste is recycled within the industry, the quantity of residual fibers resulting from these processes remains significant.

In recent years, the use of waste materials in construction has gained increased attention, particularly due to their potential benefits, including improved thermal insulation, acoustic performance, structural reinforcement, and the development of lightweight composites when incorporated into cement-based materials. Textile waste fibers are among these valuable waste products (Kalkan et al., 2023). Thus, it is essential to investigate their integration into cementitious composites further, considering both environmental sustainability and economic viability. The incorporation of fibers into concrete began in the early 1960s in developed countries, and since then, the use of fiber-reinforced concrete has expanded considerably (Aghaee & Foroughi, 2013). The literature indicates that a wide range of fibres have been utilized as reinforcement in cementitious composites. Numerous studies have examined the effectiveness of various fibres, including steel (Grabois et al., 2016; Pogorelov & Semenyak, 2016), polypropylene (Yin et al., 2016; Zhang et al., 2016), glass (Marikunte et al., 1997; Shah et al., 1988), and natural fibres such as sisal (Savastano Jr et al., 2003, 2006), coconut and oil palm (Lertwattanaruk & Suntijitto, 2015), and banana (Mostafa & Uddin, 2016). While significant research has been

conducted on textile-reinforced cementitious composites, particularly for strengthening masonry walls and concrete structures (Elsanadedy et al., 2013; Garmendia et al., 2014; Papanicolaou et al., 2008; Triantafillou & Papanicolaou, 2006), the exploration of waste textile fibers as reinforcement in cementitious materials remains limited. Among the few studies available, waste carpet fibers have been more commonly investigated (Aspiras & Manalo, 1995; Ucar & Wang, 2011; Wang et al., 1994), whereas other types of waste textile fibers—such as cotton, polypropylene (Murathan et al., 2014), and acrylic (Briga-Sa et al., 2013; Pinto et al., 2013)—have received comparatively less attention.

Research on the incorporation of fine textile shredding waste fibers—generated during producing yarn from waste textiles—into cementitious materials is highly limited. Kalkan and Gündüz (2016) reported that adding 1.7% denim waste fibers by weight enhanced the mechanical performance of lightweight mortars. Similarly, Özcan and Gündüz (2021) found that denim waste fibers contributed positively to the strength characteristics of aerated concrete. Kalkan et al. (2023) concluded that the consistency of the mortars decreased with increasing fine fiber content. Nevertheless, the incorporation of fibers at any dosage resulted in improved mechanical properties of the lightweight mortars. Although scarce, the existing studies suggest that this type of waste material holds significant potential for reinforcing lightweight cementitious composites. Enhancing the physical and mechanical properties of cementitious lightweight products—whose importance in the construction industry has grown in recent years—has become a key area of research. This study investigates the influence of varying amounts of textile shredding process waste fiber on the properties of concrete through a series of experimental analyses. Six different concrete mixes, both with and without fiber additives, were prepared, and their physical and mechanical properties were comparatively evaluated. The resulting data are discussed in detail, and insights are provided that may guide future R&D efforts concerning the application of this type of waste fibers in the development of fiber reinforced concretes.

Materials and Methods

CEM II B-M(L-W) 42.5R ordinary Portland cement, according to TS EN 197-1 cement, was used in the formulation of six concrete mixtures. The specific gravity of the cement was determined to be 3.15. The mixing process for concrete mixtures was done with local tap water. 0/4 mm sand, 0/4 mm sand, 4/8 mm aggregate and 8/16 mm aggregate were used in the mixtures. The specific gravity of the aggregates was determined as 2.66, 2.64 and 2.64, respectively. Polycarboxylate-based superplasticizer was used to improve the workability of fresh concrete samples. The fibers used in this study contain both cotton and synthetic components, as they are derived from the recycling of different types of products woven from a blend of cotton and synthetic fibers. The fibers have an average diameter of 40 μm and an average length of 3.5 mm. The materials used in concrete production are shown in Figure 1.



Figure 1. Ingredients of concrete mixture; (a) cement; (b) sand; (c) fine gravel; (d) coarse gravel; (e) superplasticizer; (f) waste fibers

In this experimental study, six different concrete mixtures were designed to investigate the effect of waste textile fibers on physical and mechanical properties of concrete samples. In addition, a separate

mixture without waste fiber was designed as a reference concrete mixture to accurately study the effects that may arise from the use of the fibers. The concrete mixture design is presented in Table 1.

Table 1. Mix design

Mixture	Cement (kg/m ³)	0/4 mm Sand	4/11 mm Aggregate (kg/m ³)	11/22 mm Aggregate (kg/m ³)	Water (kg/m ³)	Superplasticizer (kg/m ³)	Waste Fiber (kg/m ³)
TL0	380	860	300	550	220	3.04	0
TL0.4	380	860	300	550	220	3.04	0.4
TL1.2	380	860	300	550	220	3.04	1.2
TL2.0	380	860	300	550	220	3.04	2
TL2.8	380	860	300	550	220	3.04	2.8
TL3.6	380	860	300	550	220	3.04	3.6

As can be easily seen from Table 1, in order to determine the effect of textile waste fibers on the physical and mechanical properties of concrete, sixteen different concrete mixtures were produced using waste fibers at the rates of 0, 0.4, 1.2, 2.0, 2.8 and 3.6 kg/m³. In order to make a suitable comparison in all mix designs, the cement, sand, aggregate and superplasticizer ratios were kept constant. In addition, the water/cement ratio was fixed as 0.58 in order to ensure sufficient workability for all six mixes. In the mixing stage, first all solid form components were put into the mixer and mixed for 2 minutes to obtain a homogeneous dry mixture. In order to produce fresh concrete mixtures, the appropriate amount of water was added to the mixer and the mixture was mixed for another 2 minutes. The water was normal tap water and its temperature was determined as $20 \pm 2^\circ$ C. After the samples were mixed homogeneously, they were poured into 15×15×15 cm cubes and 15×15×60 cm beam molds. The samples were removed from the mold after 24 hours and cured in the curing pools at $21 \pm 2^\circ$ C until the test day.

Determination of hardened concrete densities was carried out on hardened concrete samples in accordance with TS EN 12390-7 standard. Slump tests were carried out in accordance with TS EN 12350-2 standard. Flexural and compressive strengths of concretes were determined in accordance with TS EN 12390-5 and TS EN 12390-3 standards, respectively.

Results and Discussion

Fresh and hardened density findings of concrete samples prepared in different mix designs are given in Table 2.

Table 2. Hardened densities of concrete samples

Added fiber amount (kg/m ³)	Hardened Density (kg/m ³)
0	2305
0.4	2364
1.2	2319
2.0	2302
2.8	2290
3.6	2273

When Table 2 is examined, the density of concrete samples increased compared to the hardened density of the reference sample up to the use of 1.2 kg/m³ waste fiber. It can be said that the mortar gained a more compact structure in the use of fibers up to this usage rate, and the very fine fibers were well distributed and filled the voids in the fresh concrete. However, as the amount of fiber increased, the density started to decrease. From this point on, it can be thought that the fibers created more voids in the mixture or that the fiber-aggregations disrupted the homogeneity. At the highest fiber content (3.6 kg/m³), the density decreased to the lowest level with 2273 kg/m³. This shows that the increase in the amount of fiber negatively affects the compactness of the mixture and increases porosity.

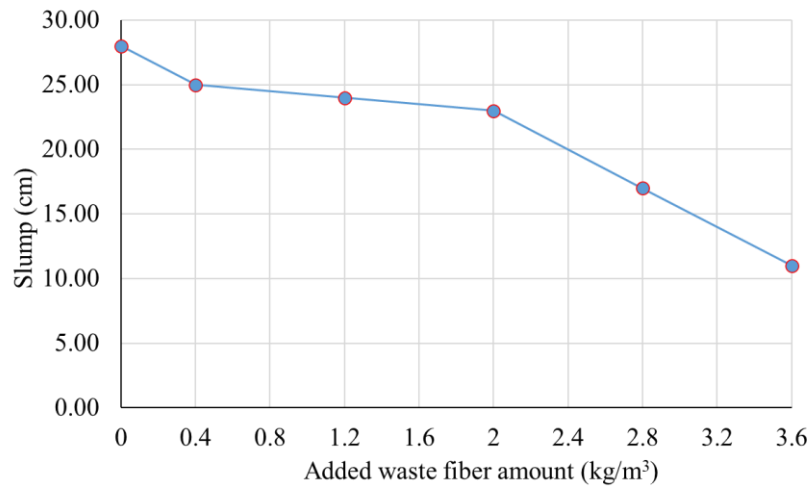


Figure 2. Slump of test concretes

Figure 2 shows the changes in the slump values of the concrete samples depending on the increase in the amount of waste fiber. The slump value represents the workability and fluidity of the fresh concrete. According to the figure, at 0 kg/m³ fiber content, the slump value is at the highest level. This shows that the mortar without fibers has high workability. With 0.4 kg/m³ fiber, the slump value slightly decreases. This shows that the fibers start to limit the fluidity of the fresh concrete. In the range of 1.2–2.0 kg/m³, the slump value continues to decrease gradually. At 2.8 and 3.6 kg/m³ levels, the slump values reach the lowest level. This suggests that high fiber content causes serious workability loss in the mixture and that the fibers harden the consistency by retaining water or creating an irregular structure in the mixture. Moreover, it can be predicted that such slump loss may create large amounts of voids in the fresh concrete and these voids may limit the mechanical properties of the concrete.

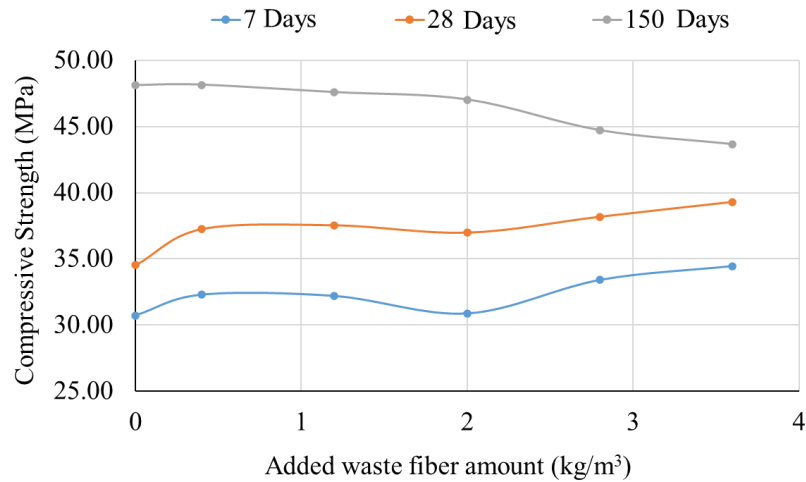


Figure 3. Compressive strength analysis of test specimens

Figure 3 shows the compressive strength analysis of concrete test specimens. The compressive strength values of all concrete test samples on the 7-, 28- and 150-days increased with the curing time. The compressive strengths of the reference concrete coded TL0 on the 7- and 28-days are 30.72 and 34.53 MPa, respectively. In the mixture sample TL3.6 where the waste fiber usage level is 3.6 kg/m³, the compressive strength values on the 7- and 28-days are 34.45 and 39.29 MPa. The increase in compressive strength in 7- and 28-day samples was 12.15% and 13.79%, respectively, compared to the reference sample. An increase in the compressive strength of the concrete was observed as the amount of waste fiber added to the concrete increased, especially in the 7- and 28-day curing periods. It has also been determined in other studies in the literature that the compressive strength of the material increases with the increase in the amount of fiber in cement-bound materials (Kalkan et al., 2023; Uğurer et al., 2023). The compressive strength of concrete is a variable that depends mostly on the density of the concrete. In Table 2, it is observed that as the amount of fiber added to the concrete samples increases, the hardened density of the concrete samples decreases slightly. This may indicate that some loss of compressive strength may occur in the concrete. However, as shown in Figure 3, an increase in the 28-

day compressive strength of the concrete was observed in proportion to the increase in the amount of fiber, although there was a slight decrease in the densities. This can be considered as one of the positive properties that this fiber adds to the concrete. On the other hand, the increase in the amount of fiber added to the concrete caused a slight decrease in the compressive strength of the concrete test samples subjected to 150 days of water curing. It was observed that the strength loss of concrete samples exposed to water curing for 150 days, especially with the use of higher amounts of waste fiber (use rates of 2.8 and 3.6 kg/m³), was undeniable. It was determined that there was a relative decrease in the compressive strength of the samples that were cured in water for 150 days. It was thought that the fibers of the samples that remained in water for a long time may have deteriorated. For this reason, the mechanical properties of samples containing waste powder fibers after being kept in different types of curing environments should also be examined and compared.

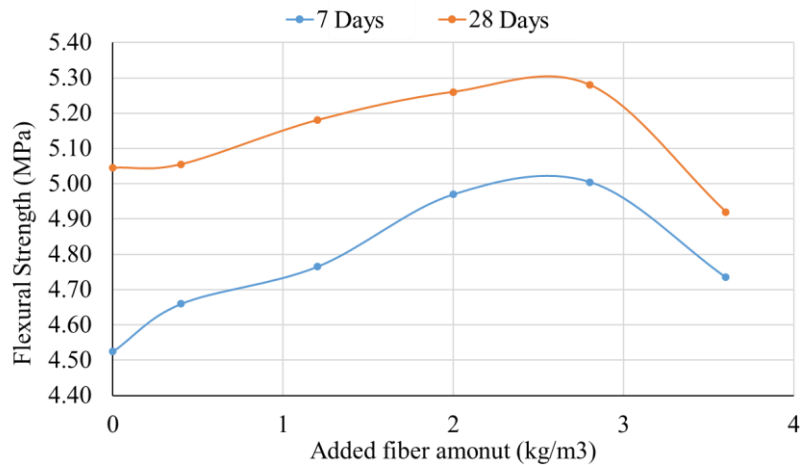


Figure 4. Flexural strength analysis of test specimens

Figure 4 shows the flexural strength analysis of concrete test specimens. When the figure is examined, it is observed that the mechanical behavior of the concrete samples in flexural strength and compressive strength are similar up to 2.8 kg/m³ fiber usage rate. This means that since the fibers prevent the development of microcracks, the flexural strength increased as the amount of fibers increased. However, with the use of high amounts of fibers, the flexural strength tended to decrease again as the high amount of air entrained into the concrete and the clumped fibers created weak areas. The flexural strengths of the reference concrete coded TL0 on the 7- and 28-days are 4.53 and 5.05 MPa, respectively. In the mixture sample TL3.6 where the waste fiber usage level is 2.8 kg/m³, the compressive strength values on the 7- and 28-days are 5.01 and 5.28 MPa. The increase in compressive strength in 7- and 28-day samples was 10.60% and 4.55%, respectively, compared to the reference sample.

Conclusions

This study evaluated the effects of incorporating very fine recycled textile waste fibers into fiber reinforced concrete through a set of experimental investigations. Based on the findings, the following conclusions can be drawn:

1. The slump test results showed a continuous decline in the workability of the mortars with increasing fiber content. This indicates that waste fibers limit the flowability of fresh concrete mixtures, likely due to their water absorption capacity and tendency to form a fibrous network structure.
2. The addition of up to 1.2 kg/m³ of fibers increased the density slightly, suggesting improved compactness and better void filling due to uniform fiber distribution. However, beyond this dosage, density decreased steadily, indicating the formation of voids and poor homogeneity caused by fiber agglomeration at higher contents.
3. Compressive strength values improved consistently with increased fiber addition up to 3.6 kg/m³ at both 7 and 28 days. Compared to the reference mortar, the highest strength improvement at 28 days was 13.79%, suggesting that fibers enhanced the internal structure by bridging microcracks and contributing to better stress distribution.
4. A slight reduction in compressive strength was observed at 150 days in mixes with higher fiber content. This is likely due to degradation or weakening of the fiber matrix interface during

prolonged water curing, highlighting the need to investigate alternative curing regimes for long-term durability.

5. Flexural strength results showed a similar trend to compressive strength, with improvements observed up to 2.8 kg/m³ fiber addition. Beyond this level, a slight reduction was recorded, likely due to fiber agglomeration and increased porosity. Nonetheless, up to the optimal dosage, fibers contributed positively by controlling crack propagation.

Despite a reduction in workability and density at higher fiber contents, the addition of waste fibres positively influenced the mechanical properties of concrete samples, particularly at early curing ages. However, durability under extended curing conditions remains a concern and requires further investigation.

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