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Mechanical Performance and Sustainability Potential of Concrete Incorporating Waste Polytetrafluoroethylene Fibers

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Abstract

This study investigates the feasibility of utilizing waste polytetrafluoroethylene (PTFE) fibers as a recycled additive in concrete to support plastic waste valorization and sustainable construction material development. Waste PTFE fibers obtained from industrial seal production were mechanically processed into irregular fiber-like particles with sizes of approximately 4–6 mm and incorporated into concrete mixtures at 0.2%, 0.4%, 0.6%, and 0.8% by weight of concrete. The effects of PTFE fiber addition on workability, splitting tensile strength, and flexural strength were evaluated using cylindrical and beam specimens tested according to SNI and ASTM standards. The results show that increasing PTFE fiber content reduced concrete workability, as indicated by a decrease in slump from 125 mm for the control mixture to 75 mm for the mixture containing 0.8% PTFE fibers. The incorporation of untreated PTFE fibers also decreased mechanical strength. Compared with the control concrete, splitting tensile strength decreased by 6.924%–18.474%, while flexural strength decreased by 15.409%–32.060%. This reduction is attributed to the smooth, hydrophobic, chemically inert, and low-friction surface characteristics of PTFE, which weaken adhesion between the fibers and the cementitious matrix and reduce load-transfer efficiency. Although untreated waste PTFE fibers did not improve the tensile-related mechanical performance of concrete, their use may contribute to plastic waste utilization in construction materials. Further surface treatment, fiber modification, and mix design optimization are required before waste PTFE fibers can be effectively applied as reinforcing materials in sustainable concrete.

Keywords: waste PTFE fiber; plastic waste valorization; sustainable concrete; fiber-reinforced concrete; splitting tensile strength; flexural strength

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INTRODUCTION

Plastic use has become an inseparable part of modern life. Plastic waste has become a critical environmental issue due to its increasing volume and poor degradability. Among engineering plastics, polytetrafluoroethylene (PTFE), commercially known as Teflon, is widely used in metallurgy, electrical insulation, and anti-sticking coatings because of its excellent thermal stability and chemical resistance (Almohana et al., 2022). Consequently, waste PTFE is increasingly generated from manufacturing and end-of-life products, posing disposal challenges (Dhanumalayan & Joshi, 2018).

Recent studies have increasingly examined recycled plastic fibers and plastic aggregates as alternative materials in concrete. Recycled PET fibers and plastic bottle-derived fibers have been reported to influence the mechanical behavior, crack resistance, and sustainability potential of concrete materials (Foti, 2011; Adajar & Ubay-Anongphouth, 2022; Abdulateef et al., 2024). Other studies have also investigated different types of waste fibers and polymer-based materials for improving or modifying cementitious composites (Çelik et al., 2022; Su et al., 2022). In addition, recent reviews have emphasized the need to evaluate not only mechanical performance but also the sustainability and life-cycle implications of fiber-reinforced concrete incorporating waste materials (Manso-Morato et al., 2024).

PTFE differs fundamentally from PET and PP fibers due to its fluoropolymer chemistry and strong carbon–fluorine bonds. These chemical characteristics give PTFE very low surface energy, hydrophobic behavior, chemical inertness, and a low coefficient of friction, which may reduce adhesion between PTFE fibers and the cementitious matrix (Dhanumalayan & Joshi, 2018; Mazur et al., 2021; Wang et al., 2023). The hydrophobic, chemically inert, and low-surface-energy characteristics of PTFE may contribute to poor adhesion between PTFE fibers and the cement paste, resulting in a weak fiber–matrix interfacial zone and reduced load-transfer efficiency (Dhanumalayan & Joshi, 2018; Mazur et al., 2021; Wang et al., 2023). Unlike PET, which contains polar functional groups capable of forming weak interactions with cement hydration products, PTFE has a chemically inert and low-surface-energy structure that limits fiber–matrix bonding (Saikia & de Brito, 2014; Dhanumalayan & Joshi, 2018). This mechanism helps explain the reduction in splitting tensile and flexural strength observed in this study and is consistent with previous studies reporting that weak bonding between plastic-based fibers or particles and the cementitious matrix can reduce the mechanical performance of concrete (Saikia & de Brito, 2014; Mercante et al., 2020; Dhanumalayan & Joshi, 2018; Wang et al., 2023; Marinelli et al., 2023).

Although numerous studies have investigated the use of recycled PET, HDPE, and other plastic fibers in concrete (Ochi et al., 2007; Kim et al., 2010; Fraternali et al., 2011; Faraj et al., 2020), research on waste PTFE fibers remains very limited. Unlike PET and other commonly used polymer fibers, PTFE possesses very low surface energy, a low coefficient of friction, high chemical resistance, and hydrophobic characteristics (Mazur et al., 2021). These unique properties may significantly affect the interfacial bond between the fiber and the cementitious matrix, resulting in mechanical behavior that differs from that of concrete containing recycled plastic fibers. Therefore, this study aims to evaluate the effect of waste PTFE fiber content on the workability, splitting tensile strength, and flexural strength of concrete (Çelik et al., 2022).

Concrete is a brittle material with relatively low tensile strength. Reinforcement is commonly used to improve the low tensile strength of concrete. Generally, steel bars are used as reinforcement in concrete structures. Lately, many researchers look for micro reinforcement, namely fiber, as alternatives. Metallic, mineral, natural, or synthetic organic, such as Polytetrafluoroethylene (PTFE) and Polyethylene terephthalate (PET), can be classified as fibers. PTFE and PET are classified as thermoplastic polymers (Abdulateef et al., 2024; Adajar & Ubay-Anongphouth., 2022).

Industrialization, urbanization and population growth are leading factors for enhancing plastic production (Nyika et al., 2022). Regardless of the low biodegradability of plastics, only small number is being reprocessed and the rest turns out to be a waste in dumping ground. This study deals with prospects for sustainable disposal of PTFE by its integration in the construction engineering as a concrete filler material. Moreover, the mechanical properties, particularly splitting tensile strength and flexural strength, can be evaluated.

METHOD

Materials

Ordinary Portland Cement (Type I) was used as the binder in all concrete mixtures. Natural river sand was used as fine aggregate, while crushed stone with a maximum size of 20 mm was used as coarse aggregate. Waste PTFE fibers were obtained from a company manufacturing PTFE seals and gaskets. The PTFE waste was processed through a mechanical crushing method to produce irregular fibers with lengths ranging from 4–6 mm. The general properties of the PTFE fibers are shown in **Table 1**.

Table 1. Specification of PTFE fiber (Dhanumalayan & Joshi, 2018; Mazur et al., 2021)

Specifications of waste PTFE fiber	
Particle sizes and thickness	0.54-6.00 mm
Colors	White
Melting point	≥ 279 – 326°C
Thermal conductivity	0.25 W/(m·K)
Standard relative density	2.15 - 2.17 kg/l
Scale of restraining water	≤ 0.04%
Water Absorption, 24 hours (%)	< 0.01
Tensile Strength (MPa)	14 to 38
Compressive Strength (MPa)	24

Preparation of Waste PTFE Fibers

Waste PTFE scraps generated from seal manufacturing were collected and mechanically crushed using a plastic crusher machine. The resulting particles exhibited irregular fiber-like shapes with dimensions ranging from 4–6 mm. No chemical treatment or surface modification was applied prior to mixing. The fibers were used in their as-received condition to evaluate the feasibility of direct waste utilization in concrete production **(Figure 1)**.

Figure 1. Production process of waste PTFE fibers

Concrete Mix Design

Five concrete mixtures were prepared in this study, consisting of one control mixture without PTFE fibers and four mixtures containing waste PTFE fibers. The PTFE fiber contents were 0.2%, 0.4%, 0.6%, and 0.8%, calculated based on the total weight of concrete. The mixture identification and PTFE fiber contents are presented in **Table 2.**

Table 2. Concrete Mixture Identification and PTFE Fiber Content

Mix ID	**PTFE Fiber Content (% by Weight of Concrete)**
PTFE-0	0.0
PTFE-0.2	0.2
PTFE-0.4	0.4
PTFE-0.6	0.6
PTFE-0.8	0.8

The concrete mixtures were designed to achieve a target compressive strength of 25 MPa in accordance with SNI 03-2834-2000 (Standar Nasional Indonesia, 2000). Ordinary Portland Cement

(Type I), natural river sand, crushed stone, and water were used as the constituent materials. The control mixture was prepared without PTFE fibers, while the modified mixtures incorporated waste PTFE fibers at different proportions. The mix proportions were kept constant for all mixtures, except for the PTFE fiber content. Details of the concrete mix proportions are presented in **Table 3**.

Table 3. Details of raw concrete

Mix Number	Value
Cement (kg/m^3)	427
W/C (minimum)	0.48
W/C (maximum)	0.60
Maximum aggregate size (mm)	20
Fine aggregate (river sand) (kg/m3)	729
% Fine aggregate	41
Total aggregate (kg/m3)	1778
Coarse aggregate (split stone) (kg/m3)	1049
Gradation area of fine aggregate	Zone II
Net mix water (kg/m3)	205
Density of wet concrete (kg/m3)	2410
Slump (mm)	75 -125
Required Compressive Strength for Mix Design (MPa)	25
Target Compressive Strength for Mix Design (MPa)	33.5

Specimen Preparation and Testing

A total of 30 concrete specimens were prepared and tested in this study. The specimens consisted of 15 cylindrical specimens (150 mm diameter × 300 mm height) for splitting tensile strength testing and 15 beam specimens (150 mm × 150 mm × 600 mm) for flexural strength testing. Five concrete mixtures were investigated, namely the control mixture (0% PTFE fiber) and mixtures containing 0.2%, 0.4%, 0.6%, and 0.8% waste PTFE fibers. For each mixture, three cylindrical specimens and three beam specimens were produced and tested. The specimen matrix is presented in **Table 4**.

Table 4. Specimen Matrix

Mix ID	PTFE (%)	Cylinder	Beam	Total
PTFE-0	0.0	3	3	6
PTFE-0.2	0.2	3	3	6
PTFE-0.4	0.4	3	3	6
PTFE-0.6	0.6	3	3	6
PTFE-0.8	0.8	3	3	6
Total	-	15	15	30

After casting, all specimens were demolded after 24 hours and cured in water under laboratory conditions for 28 days. Splitting tensile strength tests were conducted on cylindrical specimens in accordance with ASTM C496/C496M (ASTM International, 2008), while flexural strength tests were performed following ASTM C78 (ASTM International, 2002).

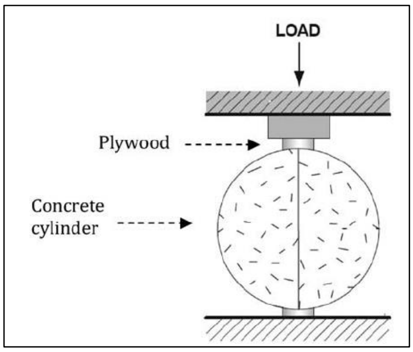

Figure 2. Splitting tensile strength cylinder test

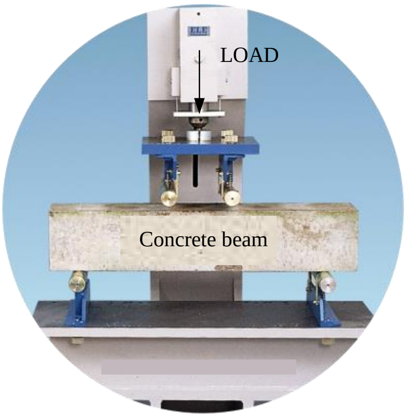

Figure 3. Flexural strength beam test

RESULTS AND DISCUSSION

After completing the experimental program, the workability and mechanical properties of all concrete mixtures were evaluated. No significant fiber segregation or settlement was observed during casting and testing. The PTFE fibers were generally well distributed throughout the concrete specimens, as shown in **Figures 4** and **5**.

The slump test results indicate that the incorporation of waste PTFE fibers reduced the workability of the concrete mixture. The control mixture without PTFE fibers showed the highest slump value of 125 mm, while the mixture containing 0.8% PTFE fibers showed the lowest slump value of 75 mm, as presented in **Table 5**. This decrease in slump may be attributed to the irregular fiber-like shape of the waste PTFE particles, which increased internal friction and reduced the flowability of the fresh concrete. Although PTFE has very low water absorption, the physical shape and random distribution of the PTFE fibers may obstruct particle movement within the mixture, resulting in lower workability at higher PTFE contents.

Table 5. Slump Value of Concrete Mixtures

Mix ID	PTFE Content (%)	Slump (mm)
PTFE-0	0.0	125
PTFE-0.2	0.2	100
PTFE-0.4	0.4	90
PTFE-0.6	0.6	80
PTFE-0.8	0.8	75

Figure 4. Fiber distribution in cylindrical concretes

The results in **Table 5** show that the slump value decreased with increasing PTFE fiber content. This behavior may be attributed to the irregular fiber-like shape and random distribution of PTFE particles, which increased internal friction and obstructed the flowability of the fresh concrete mixture. Although PTFE has very low water absorption, its physical form reduced the workability of the concrete at higher PTFE contents.

Figure 5. Fiber distribution in concrete beams

Mechanical Strength Results

An evaluation of the mechanical test results shows that the incorporation of PTFE fibers significantly influenced the splitting tensile and flexural behavior of concrete. Compared with the control mixture, all PTFE-containing mixtures showed lower splitting tensile strength and flexural strength. However, the reduction did not follow a strictly linear trend with increasing PTFE fiber content, as shown in **Table 6** and **Figure 6**.

Table 6. Mechanical Strength Results of Concrete Mixtures

Mix ID	PTFE Content (%)	Splitting Tensile Strength, mean (MPa)	Reduction (%)	Flexural Strength, mean (MPa)	Reduction (%)
PTFE-0	0.0	3.264	0.000	4.504	0.000
PTFE-0.2	0.2	2.863	12.316	3.060	32.060
PTFE-0.4	0.4	3.038	6.924	3.478	22.780
PTFE-0.6	0.6	2.961	9.283	3.777	16.141
PTFE-0.8	0.8	2.661	18.474	3.810	15.409

The results in **Table 6** show that the incorporation of waste PTFE fibers reduced both splitting tensile strength and flexural strength compared with the control concrete. The reduction in splitting tensile strength ranged from 6.924% to 18.474%, while the reduction in flexural strength ranged from 15.409% to 32.060%. This indicates that untreated waste PTFE fibers were not effective in improving the tensile-related mechanical performance of concrete.

Figure 6 illustrates the relationship between waste PTFE fiber content and the tensile-related mechanical performance of concrete. The flexural strength increased from 3.060 MPa at 0.2% PTFE fiber content to 3.810 MPa at 0.8%, indicating a slight improvement among the PTFE-containing mixtures. However, all flexural strength values remained lower than that of the control concrete. In contrast, the splitting tensile strength increased from 2.863 MPa at 0.2% to 3.038 MPa at 0.4%, but then decreased to 2.961 MPa and 2.661 MPa at 0.6% and 0.8%, respectively .

This trend indicates that a small amount of PTFE fiber may contribute to limited crack-bridging or filler effects, but higher PTFE contents do not improve tensile performance. The decrease in splitting tensile strength at higher fiber contents is likely related to the smooth, hydrophobic, and low-friction surface characteristics of PTFE, which reduce adhesion between the fibers and the cement matrix. Weak fiber–matrix bonding limits stress transfer and may promote fiber pull-out rather than effective crack bridging. Therefore, although PTFE fibers can be incorporated into concrete as a waste-utilization material, untreated PTFE fibers are less effective as mechanical reinforcement without surface modification or mix design optimization (Figueiredo et al., 2022; Foti., 2011; Manso-Morato et al., 2024).

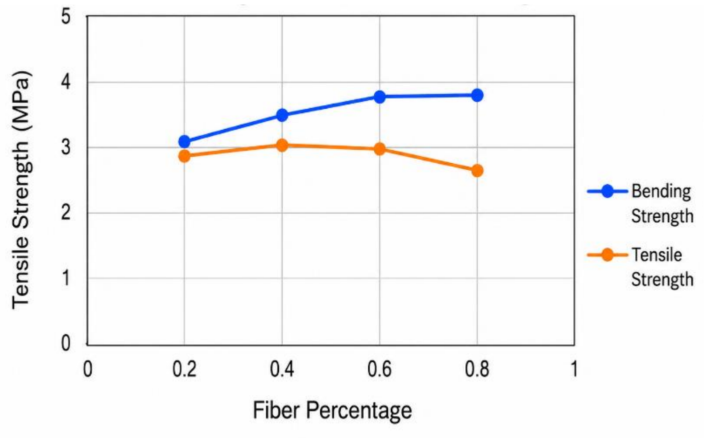

Figure 6. Variation in splitting tensile strength and flexural strength of concrete containing different percentages of waste PTFE fibers. The results show that flexural strength tends to increase slightly with increasing PTFE fiber content from 0.2% to 0.8%, whereas splitting tensile strength reaches its highest value at 0.4% and decreases at higher PTFE fiber contents

The reduction in mechanical strength can be attributed to the unique surface characteristics of PTFE fibers. PTFE possesses very low surface energy and a low coefficient of friction, resulting in weak adhesion between the fiber surface and the cement paste. Consequently, the interfacial transition zone (ITZ) between PTFE fibers and the cementitious matrix is likely weaker than that observed with other polymer fibers (Standar Nasional Indonesia., 1997; Su et al., 2022).

Figure 7. Failure patterns of concrete beam specimens after flexural strength testing

In addition, the hydrophobic nature of PTFE may inhibit effective wetting by cement paste, leading to localized voids and reduced stress transfer. Under loading, the fibers tend to be pulled out rather than effectively bridge cracks, resulting in lower splitting tensile and flexural strengths. Similar observations have been reported for polymer-based materials with poor fiber–matrix bonding characteristics. Unlike recycled PET fibers, which have been reported to improve crack resistance and ductility through better mechanical interlocking with the cement matrix (Ochi et al., 2007; Fraternali et al., 2011), PTFE fibers exhibit non-stick surface characteristics that limit bond development and reduce load-transfer efficiency.

CONCLUSION

This study evaluated the mechanical performance and sustainability potential of concrete incorporating waste polytetrafluoroethylene (PTFE) fibers derived from industrial seal production. Waste PTFE fibers were mechanically processed into irregular fiber-like particles and added to concrete mixtures at 0.2%, 0.4%, 0.6%, and 0.8% by weight of concrete. The results showed that increasing PTFE fiber content reduced the workability of fresh concrete, as indicated by the decrease in slump from 125 mm in the control mixture to 75 mm in the mixture containing 0.8% PTFE fibers. This reduction was mainly attributed to the irregular shape and random distribution of PTFE particles, which increased internal friction and limited the flowability of the fresh mixture. The incorporation of untreated waste PTFE fibers also decreased the splitting tensile and flexural strength of concrete compared with the control mixture. The splitting tensile strength decreased by 6.924%–18.474%, while the flexural strength decreased by 15.409%–32.060%. These reductions indicate that untreated PTFE fibers were not effective as reinforcing fibers under the conditions investigated in this study. The lower mechanical performance was mainly associated with the smooth, hydrophobic, chemically inert, and low-friction surface characteristics of PTFE, which limited adhesion between the fibers and the cementitious matrix and reduced load-transfer efficiency. Although direct incorporation of untreated waste PTFE fibers did not improve tensile-related mechanical properties, the material still has potential as a waste-utilization filler in concrete, particularly from an environmental sustainability perspective. The findings suggest that waste PTFE can be incorporated into concrete for plastic waste valorization, but its application as a mechanical reinforcement requires further improvement. Future research should focus on surface treatment, fiber modification, optimum fiber geometry, improved mix design, and durability evaluation to enhance fiber–matrix bonding and support the development of more sustainable concrete materials.

AUTHOR CONTRIBUTIONS

Conceptualization, LZ and OHA; methodology, LZ, OHA, and AH; software, OHA and AH; validation, LZ and AH; formal analysis, LZ, OHA, and AH; investigation, OHA and AH; resources, LZ and OHA; data curation, OHA and AH; writing—original draft preparation, OHA and AH; writing—review and editing, LZ, OHA, and AH; visualization, OHA and AH; supervision, LZ; project administration, LZ; funding acquisition, LZ.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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