



Research Article

Investigation of some engineering properties of waste polytetrafluoroethylene (PTFE) fiber reinforced concrete

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ABSTRACT

In this study, a comparison was made between concrete with waste PTFE fiber and standard concrete. Both elastomeric and thermoplastic fluoropolymer find a wide use especially in automotive applications such as seals, pulley etc. A large amount of PTFE occurs during this applications production. PTFE fiber is not a conventional concrete additive. It is a waste material and it can be used as a concrete filler material. In order to investigate the behaviour of this waste material in the concrete, mixtures containing waste PTFE fiber in amounts of 25%, 50%, 75%, and 100% (by weight) in order to replace to the same amount of fine sand (0-1 mm) were prepared. The compressive strength, tensile strength, workability and unit weight of the waste PTFE fiber concrete investigated. It was observed that waste PTFE fiber concretes have sufficient strength to be used as semi structural concrete. The mechanical behaviours of waste PTFE fiber concrete and control concrete were very similar. Moreover, it was observed that the unit weight and workability of the waste PTFE fiber concretes were decreased. This study provides that reusing waste PTFE fiber as an artificial filler material in concrete gives a new approach to solve some of the solid waste problems by plastics.

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1. Introduction

The aggregate in concrete occupies about 70 percent of the volume, it is frequently looked upon as an inert filler and therefore not worthy of much attention concerning its possible influence on the mechanical properties of concrete. The most important mechanical properties of concrete are compressive and tensile strength. The ordinary portland cement concrete, which is designed based on compressive strength, does not meet many functional requirements as it is found deficit in aggressive environments, energy absorption capacity, time of construction, repair and retrofitting jobs (Patel and Shah, 2013). Therefore, there is a need to make fiber aggregates concrete, which is more durable to the conventional concrete as the ingredients of fiber aggregates concrete supply most efficiently to the various properties. A waste or synthetic aggregates are being increasingly used in concrete instead of natural sand and coarse

aggregate. Recently, many studies have been done on fiber concrete. One of them is "The Mechanical and Tribological Properties of PTFE Filled with PTFE Waste Powders" by Xiang and Tao (2006). And the other is "Concrete Containing Polyester Fibers" by Gurunandan et al. (2018). Utilization of industrial plastic wastes in construction industry investigated for many years. In countries where abundant industrial plastic wastes are discharged, these wastes can be used as potential material or replacement material in construction industry. It as an inert filler in concrete.

Experimental studies showed that fibers improve the mechanical properties of concrete such as flexural strength, compressive strength, tensile strength, creep behaviour, impact resistance and toughness (Topcu and Canbaz, 2007). Since the concrete is a brittle material, its tensile strength is low. Reinforcement is used to increase the low tensile strength. Normally, the reinforcement consists of plain steel bars, usually with circle sections.

Recently, there has been an increasing interest in several types of micro reinforcement as alternatives. Fibers can be metallic, mineral, natural, or synthetic organic (for instance, polypropylene and Polytetrafluoroethylene). The fibers can be mixed with concrete or can be sprayed onto the concrete surface. New types of fibers, new methods of fabrication and different types of applications are continuously being developed (Shah, 1981). For example, Liu et al. (2011), studied characterization of fiber distribution in steel reinforced cementitious composites with low water-binder ratio. They have found that the aggregate characteristics have significant effect on fiber distribution, with increase of aggregate size.

Today, many researchers are looking for materials that can replace aggregates in their fiber concrete experiments. In many developed countries, because of the increasing cost of natural fillers and the continuous reduction of natural resources, the use of waste materials is an alternative for making concrete. Waste materials, when properly processed, have shown to be effective as construction materials and readily meet the design specifications. Mannan et al. (2004) studied structural lightweight concrete has been produced using oil palm shells as aggregates in concrete. Kan and Demirboğa (2009a), pointed out the economic and environmental benefits to be gained from waste recycling are very big, since it will benefit both the environment and the construction industry in terms of cost reduction. Using the modified expanded polystyrene (MEPS) as aggregates for concrete, they have found that the new material improves some of the concrete properties and at the same time, it had negative effects to some of its properties. In addition, they found that by using a high amount of MEPS as aggregate, it had decreased the density of concrete. However, from an environmental perspective, using the waste MPES foams is very significant. While there is important research on many different materials for aggregate substitutes, such as coal ash (Nisnevich et al., 2006), blast furnace slag (Topcu and Boğa, 2010) or various solid wastes including glass (Park et al., 2004), expanded and modified polystyrene foams (Kan and Demirboğa, 2009b), paper and wood wastes (Elinwa and Mahmood, 2002). The only two that have been significantly applied waste glass and modified waste expanded polystyrene concrete. Bayasi and Zeng (1993) studied the effects of polypropylene (PP) fibers on the slump and inverted slump cone time of concrete mixes. Al-Manaseer and Dalal (1997), determined the slump of concrete mixes made with plastic aggregates. They reported that when using plastic aggregate instead of normal aggregate in concrete mix, the value of slump increases. The aim of the researches were to investigate some of the physical and mechanical properties of a laboratory-produced concrete to which had been added varying proportions of waste materials as aggregate. Initial experiments carried out to characterize the waste recycled aggregate and its suitability as concrete aggregate. It was concluded that the use of recycled aggregates in concrete usually have changed the concrete properties.

Tam and Tam (2006) stated that technology is being developed that will enable building materials to be progressively infused with recycled plastic constituent in

order to increase strength, durability and impact resistance, and enhance appearance. Pezzi et al. (2006) used plastic material particles incorporated as aggregate in concrete and evaluated the chemical, physical, and mechanical properties. The results showed that the addition of polymeric materials in proportion less than 10% in volume inside of a cement matrix does not imply a significant variation of the concrete mechanical characteristics. Researchers observed that if waste materials were segregated into degradable and non-degradable at the source, then it was easier to control environmental pollution. Waste PTFE is non-degradable material at the source.

PTFE finds an exceptional position in plastic industry due to its excellent chemical properties and heat resistance, electrical insulation and its significantly low friction coefficient. These properties recommend PTFE for numerous applications. Both elastomeric and thermoplastic fluoropolymer find a wide use especially in automotive applications such as seals, pulley etc. It also blended with other polymers as a composite material for special purpose applications (Khan et al., 2008). A large amount of PTFE occurs during this applications production.

In other words, during Teflon® material process occurs PTFE shaving. (Teflon is the commercial name of polytetrafluoroethylene polymer. Teflon is a polytetrafluoroethylene with fluorinated ethylene polymer. It was discovered by Roy J. Plunkett in 1938 in Du Pont and was commercialized in 1946.) That shaving is long and continuous and can reach lengths of 10 or 20 meters Waste PTFE fibers present non-regular cross sectional geometry, which enhances their bond characteristics. This waste is not recycled in any form at present. The amount of plastic waste materials generated increases each year. The waste PTFE shaving is one of the industrial plastic wastes, produced in large quantity has the potential to be used as fiber in concrete (Fig. 1).



Fig. 1. Waste PTFE shavings.

2. Materials

The waste PTFE fibers, we used in the experiments have obtained from a company producing PTFE seals in the industry. When producing PTFE seals in this factory, quite a lot of waste PTFE fibers are released. In general, this acquisition method of PTFE waste fibers is called the conventional method. In this study used to the conventional

method for the production of waste PTFE fiber. The generally description of this process is shown in Fig. 2. Conventional methods of particle size reduction include milling, grinding, jet milling, crushing, and air micronization. Detailed descriptions about the materials used, specimens tested and testing methods are essentials for an experimental investigation. The general properties of the PTFE fibers appear in Table 1.

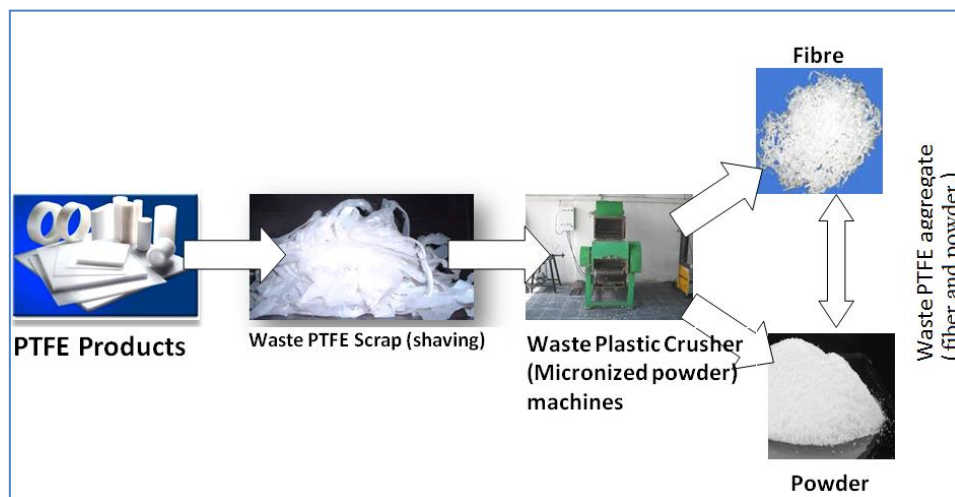


Fig. 2. Description of the process of waste PTFE aggregates.

Table 1. General specification of PTFE fiber.

Specifications of waste PTFE fiber	
Particle sizes and thickness	0.54-6.00 mm
Colours	White
Containing water scale	≤0.04%
Melting point	≥279 - 326°C
Standard relative density	2.15 - 2.17 kg/l (2.10)
Tensile Strength (MPa)	14 to 38
Compressive Strength (MPa)	24
Thermal conductivity	0.25 W/(m·K)
Water Absorption, 24 hrs (%)	< 0.01
TEFLON ® is a registered trademark of DuPont	

3. Methods

The materials used for the both control concrete and PTFE fiber concrete consisted of the normal Type I Portland cement. The control concrete has coarse aggregate having a maximum size of 16 mm, and fine aggregate was river sand with a maximum grain size 4 mm and a moisture content of 1.40%.

In this mixture, we did not want to have a fine aggregate within the range of 0-1 mm. This size of the aggregate adheres to the surface of the naturally slippery PTFE fiber, and its making even more slippery.

For the normal concretes, the fine aggregate were classified according to their aggregate sizes of (cumulative percentage passing) 0-0.25 (4%), 0.25-0.5 (16%), 0.5-1.0 (32%), 1.0-2.0 (43%), and 2-4 mm (65%). Coarse

aggregate were classified 4-8 (57%) and 8-16 mm (43%). Fineness moduli of fine aggregate mixture (by weight) were 3.61. Sands having fineness moduli of 2.5. The specific gravity of sand aggregate (0–4 mm) is 2650 kg/m³, and the specific gravity of coarse aggregate (4–16 mm) is 2700 kg/m³. The unit weight of sand aggregate (0–4 mm) is 1650 kg/m³, and the unit weight of coarse aggregate is (4–16 mm) 1480 kg/m³. The grain size distribution and the grading curves of the PTFE concrete natural aggregates are shown in Table 2 and Fig. 3, respectively.

Control concrete and various PTFE fiber contents as listed in Table 3. All concretes of C25 grade was designed as per the procedure given in BS and ASTM codes. Concrete was mixed in a tilting type drum mixer and the specimens were cast as per the recommendations of codes.

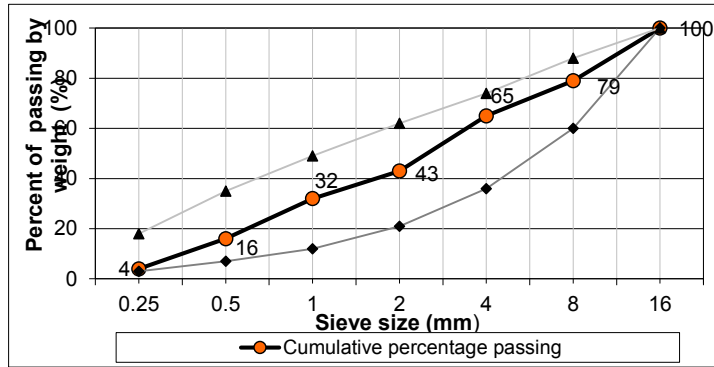


Fig. 3. Grain size distributions of the aggregate (0-16).

Table 2. Grain size distribution of the aggregate (0-16).

Sieve size (mm)	Cumulative percentage passing (%)
16.00	100.00
8.00	79.00
4.00	65.00
2.00	43.00
1.00	32.00
0.50	16.00
0.25	4.00

Approximately 300 kg/m³ of cement and 110-130 l/m³ of mixing water were used with 518 kg/m³ coarse aggregate and 1390 kg/m³ (598 kg/m³ for 0-1mm, 792 kg/m³ for 1-4mm) sand for the nonfibrous concrete mixture. PTFE fiber has replaced fine sand (0-1 mm) by

weight. The percentages of PTFE fiber within the fine sand aggregate were 0, 25, 50, 75, and 100% by weight. Concrete placed uniformly over the length of the mould in three layers and compacted satisfactorily. Once the samples were moulded, known processes were performed. With tests on hardened concrete unit weight, cylindrical compressive, strength was determined. Table 3 shows the mix proportions by weight of the mixture. On the fresh concretes the unit weight and slump tests were carried out, then 30 (Three samples for each percentage of PTFE mixing) standard steel moulds were used for casting of cylinders of 100 mm diameter and 200 mm height, were prepared. In this study, split tensile strength test was conducted on 100 mm diameter 200 mm cylinders at 28 days as per ASTM C 496-89. In splitting tensile test, as seen Fig. 4, a concrete cylinder, of the type used for compression tests, is placed with its axis horizontal between the platens of a testing machine, and the load is increased until failure by indirect tension in the form of splitting along the vertical axis takes place.

Table 3. Details of raw and fresh concrete containing waste PTFE fiber.

Mix Number	1*	C1	C2	C3	C4
Cement (kg/m ³)	300	300	300	300	300
W/C	0.45	0.45	0.43	0.43	0.42
% Vol. of waste PTFE fiber	0	25	50	75	100
Waste PTFE fiber (kg/m ³)	0	150	300	450	600
Sand (fine aggregate) (kg/m ³)	0-1mm	598	448	300	150
	1-4 mm	792	790	782	748
Total fine aggregate (kg/m ³) (PTFE+FA)	1390	1388	1380	1346	1310
Coarse aggregate (kg/m ³)	518	518	518	518	518
Net mix Water (l/m ³)	130	121	119	117	110
Raw Concrete Unit Weight (kg/m ³)	2338	2327	2317	2281	2238
Fresh Concrete Unit Weight (kg/m ³)	2330	2320	2300	2273	2212
Amount of entrapped air %	2	2.5	3	3.5	4
Slump (mm)	40	50	55	60	70
* Control samples					

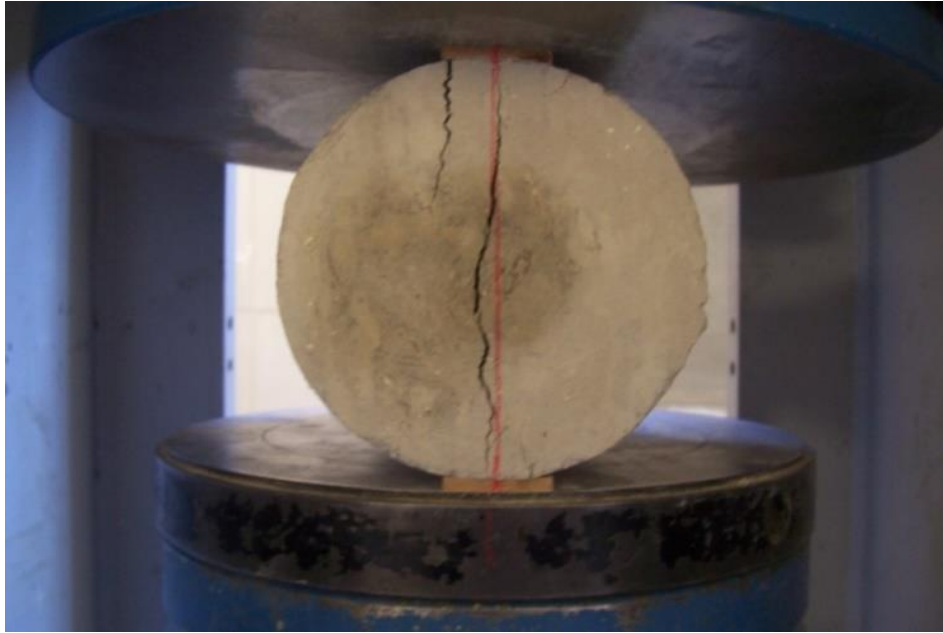


Fig. 4. Splitting tensile strength cylinder test.

4. Results and Discussion

After the experiments conducted on series of fresh and hardened concrete, properties for workability and strength were determined. Each sample was disassembled after testing to examine whether any segregation had occurred during compaction or testing. No significant migration of waste PTFE fibers was seen for any of the mixed specimens. It has made the compaction and consolidation of the concrete specimens into moulds easier.

4.1. Effects of PTFE fibers on unit weight

A lighter material than sand is added into the concrete in the place of sand, so the unit weight of concrete decreased. This is an expected situation. (The density of PTFE is about 2.1-2.2, but the density of sand is 2.6) Mix 1* contains only natural aggregate while corresponding Mixes C1 to C4 contains PTFE sand as the fine (0-1 mm) aggregate. The mix proportions of the Mixes 1* (Control samples) and C1 are nearly the same.

As the waste PTFE fiber aggregate ratio increases, concrete density decreases. With using natural fine sand in concretes allows decreasing the unit weight from 2330 kg/m³ to 2212 kg/m³. On the other hand, PTFE having ratio of 50% and 75% allows further decrease in unit weight. PTFE is not property of the water absorption, all of the mixing water used by the cement and aggregates. Changes in the unit weight depending on the PTFE aggregate ratio were examined.

4.2. Effects of PTFE fibers on workability

Workability of concrete is defined as the ease with concrete can be mixed transported placed and finished easily without segregation. In the research on concrete mixtures including PTFE fiber, it is seen that slump values

increase whereby the PTFE fiber increases. The slump value is 40 mm if there is no PTFE fiber in it (control samples). If there is then the slump value is 70 mm (having 100% PTFE fiber instead of sand). The most important reason for this is that PTFE fiber has not a high absorption ratio. Plastic aggregates neither absorbed nor added any water to the concrete mix. Due to this, non-absorptive characteristic concrete mixes containing plastic aggregates will have more free water. Consequently, the slump increased. As well as PTFE is slippery. The amount of water required to the mixture decreased by increasing the amount of PTFE. Additional research has been done on the unit weights of the fresh concretes. Although the measured fresh density is 2330 kg/m³ in normal concrete. The fresh density is 2212 kg/m³ in concrete including 100% PTFE fiber. This decline is directly connected with the fact that the density of the PTFE fiber is the same as the normal aggregate.

PTFE fibers does not absorb any liquid. Additional water is no added as a content of the PTFE fiber concretes. Thereby bringing the total water: cement ratio up to the order to 0.42-0.45. In general, when the amount of PTFE fiber was increased as for lighter densities the amount of water can therefore be decreased. In fresh concrete air content is relatively higher in PTFE concrete than normal concrete. PTFE fibers come in many shapes such as stripe or chips small fiber and other irregular shapes as shown in Fig. 1. And these obstruct in achieving full compaction of PTFE concrete. In addition, as can be seen from Table 3. Due to the amount of water required for wetting surfaces of the PTFE, material increased the amount of mixing water.

4.3. Effects of PTFE fibers on compressive strength

A comparison of the strength results of these two sets of mixes having comparable densities clearly shows that the effect of PTFE is negligible, both in terms of the

strength gain rate as well as the strength at 28 days. However, it was observed that the mixes containing PTFE aggregates always show a slight decrease in density. The compressive strength decreased with the addition of PTFE to a mixed specimen. Using 0% PTFE in the control mix increased the compressive strength of the concretes (27 MPa at 28 days). However, further increasing in PTFE content caused reduction in compressive strength.

The 28-day cylinder compressive strength of the resulting, having 100% PTFE aggregate concrete with unit weight of 2212 kg/m³ and respective strength of 18.20 MPa. The variation of compressive strength with the unit weight of concrete (and percent weight of PTFE) was presented in Table 4 and Fig. 5. As shown in Table 4, compressive strength decreasing with increasing unit weight because of the increasing ratio of PTFE. At the end of the unit weight tests on the hardened concretes, it was seen that unit weight increases when the PTFE increases.

It can be seen that the addition of PTFE causes a significant decreasing in the compressive strength. The waste PTFE fibers play an important role in decreasing compressive strength (up to 33%). In particular, C4 mix (have 100% PTFE) exhibited the minimum compressive

strength which more than likely is due to the presence of the PTFE fibers. When the waste PTFE fibers were added to mix, there was practically a slight decrease in the compressive strength of PTFE concretes. The compressive strength of the PTFE concretes is reduced significantly with an increase in the PTFE cement ratio due to the insufficient film formation. In general, the compressive strength of the PTFE concretes is low because of the insufficient strength development of cement matrix.

4.4. Effects of PTFE fibers on splitting tensile strength

The obtained splitting tensile strengths after 7 and 28 days are presented in Table 4. Each value is the average of three measurements. Fig. 6 shows that the splitting tensile strength tends to decrease with the increases of the percentage of waste PTFE replacement in the concrete mixture compared with the control mixes. According to the test results, the 28 days splitting tensile strength values are observed to decrease. The surfaces of the Teflon fibers are smooth. It does not stick because it is naturally lubricated. Therefore PTFE fibers having a low coefficient of friction. It can be easily pull out from concrete.

Table 4. Compressing strengths and splitting tensile strengths and unit weights of PTFE fiber concretes.

Mix Specification	Control mix	C1	C2	C3	C4	
Proportion of PTFE (amount of fine sand)	0%	25%	50%	75%	100%	
Compressing strength	7 days	23.00	22.80	19.25	18.20	17.00
	28 days	27.00	26.30	22.00	20.00	18.20
Splitting tensile strengths	7 days	2.53	2.51	2.30	1.95	1.70
	28 days	2.81	2.75	2.65	2.50	2.40
Fresh concrete density (kg/m ³)	2330	2320	2300	2273	2212	

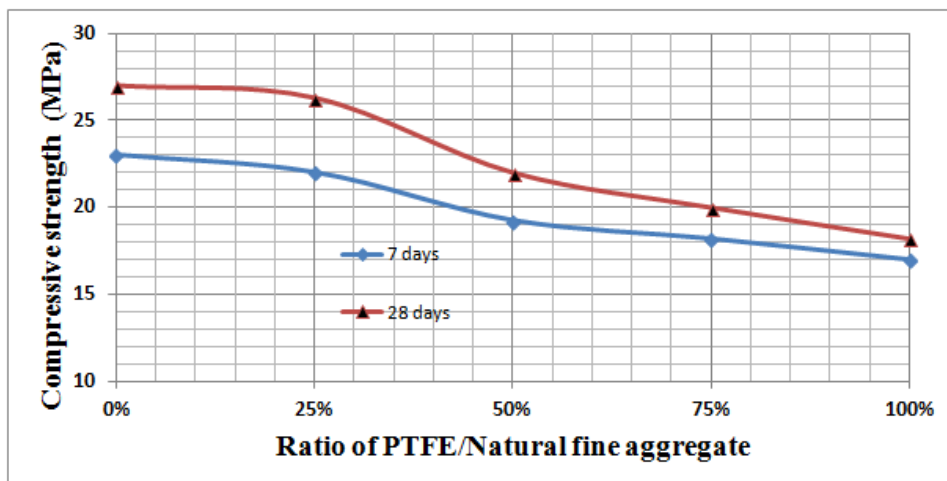


Fig. 5. Relationship between compressive strength and PTFE fiber at 7 and 28 days.

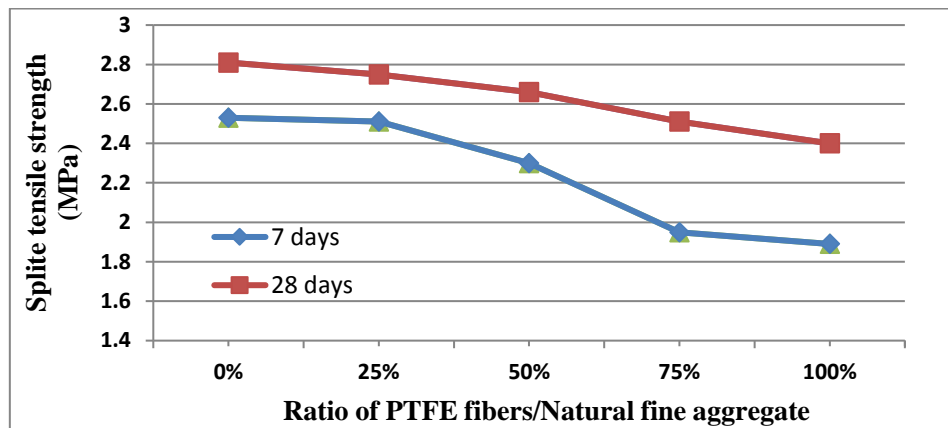


Fig. 6. Relationship between splitting tensile strength and % of replacement of waste PTFE at 7 and 28 days.

5. Conclusions

The test results showed that the waste PTFE fiber might be used as a filler substitute in concrete. Use of waste materials and by products not only helps in getting them utilized in cement concrete and other construction materials. It helps in reducing the cost of cement and concrete manufacturing but also has numerous indirect benefits such as reduction in landfill cost saving in energy and protecting the environment from possible pollution effects.

PTFE fiber reinforced concrete is typically used in nonload-bearing applications particularly where impact resistance is important. The use of PTFE fibers for control of cracking in slabs are still being debated due to the amount of fibers required to positively affect the amount of cracking and the subsequent effect on workability. The characterization of PTFE fiber wastes revealed that it is a valuable material with little variability of characteristics and that its recovery for semi structural concrete is possible. Proved the inclusion of PTFE fiber wastes in cement matrix does not change the rheological behaviour characteristic for concrete.

Due to the geometry of PTFE fibers, a homogenous distribution of fibers could not be achieved. Because these fibers are dispersed randomly in concrete mixture. Accordingly, an increase of PTFE fibers used in concrete decreased compressive strength. Compressive and tensile strengths all decrease when adhesion is not fully achieved in the concrete containing PTFE fiber. Non-absorbent aggregates like waste PTFE do not suffer with the disadvantage of water absorption, which makes production of the concrete difficult.

In fact, when we decided to do this work, we did not expect much from the results. We wanted to contribute to the studies on waste assessment. Alternative systems using recycled materials contribute to environmental waste reduction and the development of sustainable products for the building industry.

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