Concrete Incorporated with Optimum Percentages of Recycled Polyethylene Terephthalate (PET) Bottle Fiber

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Abstract: Plastic solid waste generation increases every year with the current consumption habit prevalent in the society nowadays. The improper disposal of plastic has been a major concern to the environment as it is not easily degradable. The issue of environmental pollution caused by Polyethylene Terephthalates (PET) has been extensively discussed and the best solution proposed is recycling. Therefore, one of the potential means to the problem is to recycle polyethylene terephthalate (PET) in the construction industry as fiber concrete (FC). FC is a composite material resulting from the addition of fibers to ordinary concrete. The objective of this research is to determine the mechanical properties and the optimum percentages of recycled polyethylene terephthalate (PET) fibers in ordinary concrete. In this study, straight and irregular recycled polyethylene terephthalate (PET) fibers were used. The fibers were simply cut from polyethylene terephthalate (PET) plastic bottles. The length and width of recycled polyethylene terephthalate (PET) fiber were fixed at 50 mm and 5 mm respectively. The percentages of recycled PET fibers added in the concrete mix were 0.5%, 1%, 1.5% and 2.0% respectively according to the volume of concrete to continue research of Ochi et al. (2007). A water-cement ratio of 0.45 was accepted for all ranges. The tests that were conducted included the slump test, compressive strength test and splitting tensile strength test. The specimens were tested on day 7 and day 28 after the concrete was mixed. The results obtained from each test indicated that when the percentage of recycled polyethylene terephthalate (PET) fiber used increases, the values obtained from the slump test and compressive strength test decreases while the value obtained from the splitting tensile test increases.

Keyword: PET, fiber concrete, compressive, tensile.

1. Introduction

Concrete is widely used as a construction material all over the world due to its high compressive strength, long service life and low cost [1-3]. Moreover, the rapid development of the construction industry also contributes to the high demand of tall and long-span concrete structures. Unfortunately, concrete is known as a material with good compression strength but low tensile strength [4-5] The low level of tensile strength is caused by phenomena such as plastic or hydraulic shrinkage with the formation of unwanted micro and macro cracks[6].Therefore, to improve the properties of concrete, numerous studies on fiber concrete (FC) have been performed.Fibers that are added in concrete mix perform better than normal concrete due to the sewing effect that fibers have on cracks [6-10].

Recently, the amount of plastic consumed annually had been increasing steadily [11-12]. Polyethylene terephthalate (PET) is one of the most common consumer plastics used in the world especially for manufacturing beverage containers and other consumer goods[12]. The production of PET exceeds 6.7 million tons/year and has been dramatically increasing in the Asian region due to recent increasing demands in China and India [3]. However, polyethylene terephthalate (PET) bottles are usually thrown away every day after every single use as beverage containers and most of them are discarded into landfills. Unfortunately, this is becoming a serious problem as plastic waste is not degradable and may cause environmental disturbance [13-15]. The problems concerned with the management of numerous different types of waste, the scarcity of space for landfills and ever-increasing production costs as led to the search for

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alternative solutions such as the use of waste in concrete mixes[14-16].

There is a high awareness on the need to provide alternative usage for recycled materials, especially in the construction field. This resulted in the idea of making use of one of the most common consumer plastics used such as polyethylene terephthalate (PET) to produce fiber concrete (FC). FC can enhance crack control and ductility in quasi-brittle concrete and can be an alternative for mass consumption which is an important issue in recycling waste material[17]. Marzouk et al. (2007) [18] studied recycled PET bottles with 30 mm-long fibers. The fiber surface is supposed to provide sufficient friction energy. The authors claimed that a high percentage of fiber content produced fiber bundles during mixing and pouring (less workability). Binder and superplasticizer tend to help concrete to achieve a better distribution. The outcome shows that PET has weak interfacial bonds with cement paste in the pull-out load.

Faisal et al. (2016) [19] exhibited that compressive strength increases when up to 2% of cement content is replaced with PET fibers. As the fiber content increases, concrete strength also increases. Khairunisa (2012) [20] used a waste bottle with irregular shape PET fibers. The authors claimed that the concrete mixture was not the only factor that contributed to the improvement of the compressive strength of fiber concrete. The fiber size and shape are also important for preventing slip out fiber at high stress load to exhibit FC performance.

A higher number of fibers in concrete will increase the fiber interlocking mechanism between fiber and the concrete matrix. Therefore, this research aimed to prove the advantage of lamellar shape PET fibers in fresh and hardened recycled PET fiber concrete.

2. Recycle (PET) fiber

Polyethylene terephthalate (PET) is one of the most common consumer plastics used. Fig 1 (a) and (b) presented the recyclable PET plastic bottle:

(a)

(b)

Fig 1:Recycled polyethylene terephthalate (PET) plastic bottles; (a) Bottle waste; (b) PET Symbol

Polyethylene terephthalate (PET) widely employed as a raw material to manufacture products such as blown bottles for soft drinks and containers for the packaging of food and other consumer goods [21]. PET bottles had taken the place of glass bottles as a storing vessel for beverage due to it being lightweight and the ease of handling and storage. The exponential growth in plastic waste from packaging incited a search for alternative means of recycling [22].

The sorted post-consumer PET waste is usually crushed, pressed into bales and offered for sale to recycling companies. Recycling companies will further treat the post-consumer PET waste by shredding the material into small fragments. PET flakes are used as raw material for a range of products. Thus, a lot of PET waste is available for recycling applications.

2.1 Properties of PET

PET is a hard, stiff, strong and dimensionally stable material that is usually used as packaging for carbonated beverages, water and many food products. Its crystallinity varies from amorphous to fairly high crystalline. Polyethylene terephthalate polyester (PETP) can be highly transparent and colourless but thicker sections are usually opaque and off-white. Polyethylene terephthalate is produced from ethylene glycol and dimethyl terephthalate as shown in Fig 2 [19]. PET consists of polymerized units of the monomer ethylene terephthalate, with repeating $C_{10}H_8O_4$ units[19]. Table 1 show mechanical properties and physical properties of PET.

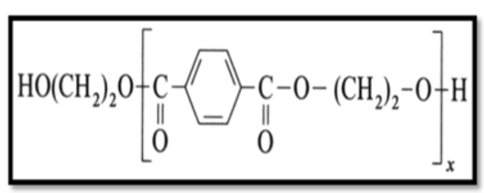


Fig 2: Chemical composition of PET fiber [19]

Table 1: Properties of PET [20]

Mechanical Properties	
Coefficient of friction	0.2-0.4
Hardness – Rockwell	M94-101
Poisson's ratio	0.37-0.44 (oriented)
Tensile modulus (GPa)	2-4
Tensile strength (GPa)	80
Physical Properties	
Density (g.cm^{-3})	1.3-1.4
Flammability	Self-Extinguishing
Limiting oxygen index (%)	21
Refractive index	1.58-1.64
Resistance to ultra-violet	Good
Water absorption - equilibrium (%)	<0.7
Water absorption - over 24 hours (%)	0.1

Parthasarathy et al. (2016) [17] discussed the thermal and mechanical properties of virgin PET, recycled PET and their blends. The study of thermal properties was based on differential scanning calorimetry (DSC) and thermo gravimetric analysis (TGA). The tensile tests at ambient and elevated temperature were used to study the mechanical properties. Granules of three different grades of PET were supplied by Leading Synthetics Pty:

i. 100% virgin PET.
ii. 100% recycled food grade PET.
iii. 100% recycled fiber grade PET.

The procedures were the blends of virgin PET and recycled food grade PET that were prepared in the following weight rations:

i. 90% virgin PET 10% recycled PET
ii. 80% virgin PET 20% recycled PET
iii. 70% virgin PET 30% recycled PET
iv. 50% virgin PET 50% recycled PET

2.2 Advantages of PET

The growth in the use of plastic is due to its beneficial properties which include extreme versatility and ability to be tailored to meet specific technical needs, good safety and hygiene properties for food packaging, durability and longevity, resistance to chemicals, water and impact, excellent thermal and electrical insulation properties, comparatively lesser production cost and superior aesthetic appeal[22]

3.0 Materials and Experimental Work

3.1 Materials preparation

The materials used in this research included Ordinary Portland Cement Type 1 (OPC: TYPE 1) which was based on MS EN 197-1: 2014 with a grade of 42.5 N, Fine Aggregates (FA) size of (0.075-5) mm, Coarse Aggregates (CA) size of (5-20) mm, Superplasticizers (SP), water and recycled PET fibers with 50 mm long and 5 mm width. The selected length and width of recycled PET fibers were 50 mm and 5 mm respectively to continue the research of Fraternali et al. (2011). The preparation of materials and recycled PET fibers are shown in Fig 3.

3.2 PET fiber Preparations

Polyethylene terephthalate (PET) plastic bottles were collected and cleaned before being cut into fiber form. The process of collecting the plastic bottles took around four months. After the bottles were collected, they were cleaned and dried to get rid of any impurities. Next, the recycled PET bottles were cut into smaller pieces to make the next process easier. Finally, the recycled PET pieces were cut into the desired size and shape which was 50 mm in length and 5 mm in width. The processes of PET fiber are indicated in Fig 3.

(a) Collecting the PET

(b) Cleaning and drying

(c) Cut into size and shape (50 mm long, 5 mm width)

Fig 3: The preparation of recycled PET fibers

3.3 Concrete Mix design

Mix design is the process conducted to select the most suitable ingredients of concrete and to determine their relative quantities to achieve the target strength concrete with C35. In this study, the concrete proportioning was designed using the Trial Mix. Table 2 shows the proportion of the materials needed in this study based on DOE method.

Table 2:Mix design of concrete

Quantities	Cement (kg)	Water (kg)	FA (kg)	CA (kg)	PET (kg)
Normal	24.50	11.03	24.75	57.58	0.00
0.5% PET	24.50	11.03	24.75	57.58	0.10
1.0% PET	24.50	11.03	24.75	57.58	0.21
1.5% PET	24.50	11.03	24.75	57.58	0.31
2.0% PET	24.50	11.03	24.75	57.58	0.41
TOTAL	**122.50**	**55.15**	**123.75**	**287.90**	**1.03**

The total of 60 specimens were prepared in this research are cube mould with size (100 x 100 x 100) mm (30 specimens) and cylinder size (150 x 300) mm (30 specimens). Five types of mixes were prepared where the control specimens prepared with 0% volume of fibers followed by 0.5%, 1.0%, 1.5% and 2.0% of recycled PET fibers added into the mix. The concrete properties were tested after a curing period of 7 days and 28 days respectively. Compressive test was conducted as specified in the test method BS 1881-116:1983, Part 116: Method for the determination of compressive strength of concrete cubes while for the splitting tensile strength test was conducted based on BS EN12390-6:2000, Part 6: Tensile splitting strength of test specimens.

4.0 Result and Discussion

The analysis of the results obtained from the data collected from the laboratory tests. An analysis was done according to the parameters used in controlling the effect of the percentage of recycled PET fibers in concrete under curing conditions of 7 days and 28 days respectively. In this part, it consists of result for fresh (Slump test) and hardened concrete (compressive strength test and splitting tensile strength test).

4.1 Fresh Concrete

Fig 4 showed a decrease of workability was recorded when adding PET to the mix. Based on the concrete mix design by using the DOE (Department of Environmental) method, the slump range target of this mixture was between 60 mm to 180 mm [23]. The normal concrete in the experiment showed that the slump of concrete was 96 mm which lied between the target range of 60 mm and 180 mm and the slump kept decreasing with the addition of fiber into concrete mixture. The reason behind this decrease is due to present of PET fibers in concrete causes more friction between the particles and this leads to less workability in the mixtures. Besides, the high content and large surface area of the fibers can easily absorb the cement paste thereby increasing the viscosity of the concrete mixture [24-25]. As the PET content increases, the plasticity and consistency of fresh concrete will decrease. The effects of recycled PET fibers on the slump test between a normal concrete mixture and a mixture with PET fibers are shown in Fig 5.

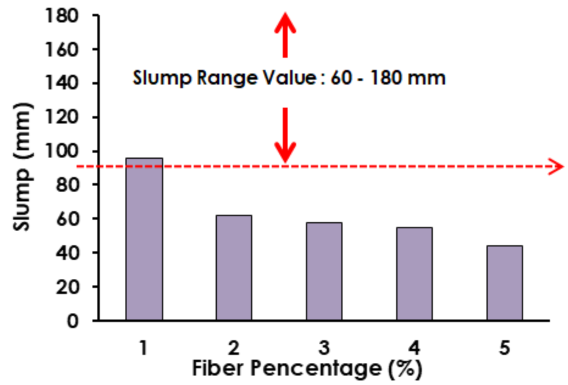


Fig 4: Slump versus the volumetric content of fibre (%)

(a)

(b)

(c)

(d)

(e)

Fig 5: Slump test for each mix; (a) Normal Concrete, (b) 0.5% PET fiber, (c) 1.0% PET fiber, (d) 1.5% PET fiber, (e) 2.0% PET fiber

4.2 Harden Concrete

4.2.1 Compressive Strength

Fig 6 express the pattern of compressive strength values. The target strength of the concrete was 35 N/mm^2. However, by increasing the percentage of PET fibers, the compressive strength values of recycled PET fibers in the concrete mixture decrease. 1.0% PET fiber concrete showed the best fiber distribution among other fiber concrete during the analysis stage process. The addition of fibers tends to cause bundling during mixing and pouring, also known as fiber balling. Fiber balling weakens by the high possibility of fiber surfaces coming in contact with one another. The area between fiber surfaces is the weakest point in concrete; microcracks and macrocracks caused by compression loading easily appear in this area [26-28].

The length of fibers was set to be 50 mm long and 5 mm width due to the previous research of N. Banthia et al. (2006) [29] which showed plastic measuring 30 mm in length improve the compressive strength compared to PET measuring 10 mm and 20 mm in length respectively. From the test results, it was evident that the long fibers reduced the compressive strength more than the short fibers. In general, the rate of reduction in strength was found to decrease with the increase in the percentage of recycled PET fibers and also the length of the PET fibers.

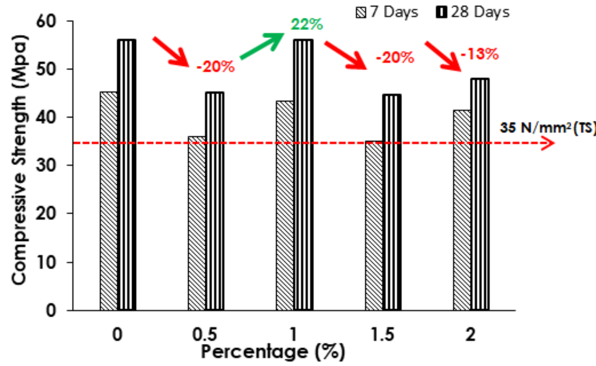
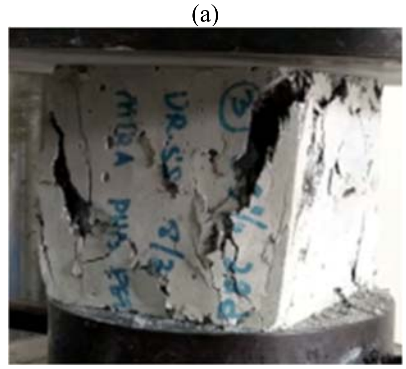


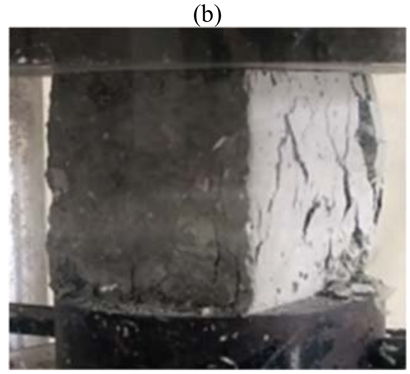
Fig 6: Result for Compressive strength of PET fibers

Figure 7 showed the real observation of cube specimens of every batch that went through the compressive strength test.

(a)



(b)



(c)

(d)

(e)

Fig 7: Real observation of specimens: (a) 0% PET fiber, (b) 0.5% PET fiber, (c) 1.0% PET fiber, (d) 1.5% PET fiber, (e) 2.0% PET fiber

4.2.2 Splitting Tensile Strength

Fig 8 present the pattern for the splitting tensile strength values. According to the results, the splitting tensile strength increased only with the addition of fibers up to about 1.0% after which, the tensile strength decreases with the addition of more fibers. Both of the tests for the specimens aged 7 days and 28 days showed that the splitting tensile strength increases only up to 1.0% addition of PET fibers in concrete. The outcomes indicated that the fibers must be uniformly distributed in the mixture and the fiber proportions must be carefully selected.

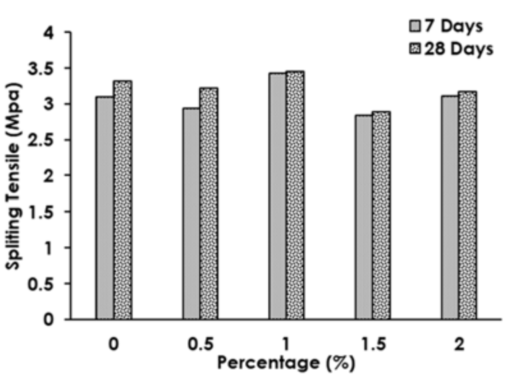


Fig 8: Splitting tensile strength of PET fibers

The splitting tensile strength increases by about 10% with the addition of 1.0% PET fiber in concrete compared to the normal concrete. The splitting tensile strength increased due to the bridging mechanism of recycled PET fibers and after certain rations it reduced the bond strength between concrete materials [22-25]. Fig 9 shows the fiber bridge in the concrete matrix bonding.

Fig 9: Fiber bridge in fiber concrete

When the stress reaches tensile strength of concrete, the stress is transferred to the PET fibers. The fibers can arrest the propagating macro cracks, thus improving the splitting tensile strength [27] It was shown that normal concrete cylinders failed abruptly once the concrete cracks whereas recycled PET fiber concrete could retain its shape even after the concrete cracks. This shows that the macro plastic fiber reinforced concrete has the ability to absorb energy in the post-cracking state [28-31].In general, specimens containing PET fibers were found to be more capable of resisting the splitting load after failure without full disintegration. Fig 10 showed the real observation of the cylindrical specimens of every batch which underwent the splitting tensile strength test.

(a)

(b)


(c)


(d)


(e)

Fig 10: Real observation of cylindrical specimens: (a) 0% PET fiber, (b) 0.5% PET fiber, (c) 1.0% PET fiber, (d) 1.5% PET fiber, (e) 2.0% PET fiber.

5. Conclusion

In a nutshell, the compressive strength of the concrete showed a fluctuating condition as the percentage of recycled PET fibers added into the concrete increased. However, the test results for all percentages of fiber concrete showed no significant difference compared to normal concrete. The overall results for the compressive strength test showed that every batch of concrete mix passed the target strength of concrete which was 35 N/mm^2 and 1.0% of PET concrete showed the best value of compressive strength test among the other fiber concrete. As for splitting tensile strength test, the tensile strength increases about 10% when 1.0% of PET fibers was added to concrete compared to normal concrete. Based on the tests that had been conducted in this research, the optimum percentage of recycled PET fibers to be added into concrete was 1.0%.

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