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Investigation on Polyethylene Terephthalate (PET) Waste Fiber Performances in Concrete Material

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Abstract: Polyethylene Terephthalate (PET) has good properties that can innovate and improve concrete properties. PET is a hard, durable, and waterproof material with excellent thermal and electrical insulation. The goals of this study are to determine the compressive strength and flexural strength of the various percentages of recycled PET in concrete and to evaluate the optimal percentage of recycled PET fibres in concrete. The PET of this study collected from Universiti Tun Hussein Onn Malaysia and residential area at Parit Raja. Straight and irregular recycled PET fibers have been selected for this analysis. The fibers were cut simply from PET bottles. Recycled PET fiber length and width were set at 50 mm and 5 mm, respectively and the percentages are 0.5%, 1.0%, 1.5%, and 2.0% of the PET fibers. Tests have been performed in the form of a slump test, a compressive strength test and a 3-point bending test to assess the mechanical properties and the optimum percentage of PET fibers. All the specimens followed according to American Standard ASTM E976, 1999) and conducted in UTHM laboratory. The results shows that by increasing the percentage of PET fibers in concrete, the flexural strength values also improved on 0.5% PET specimen than normal concrete by 6% and compressive strength values on 1%, 1.5% and 2.0% PET specimens. The highest value for compressive strength test was on 1.0% of PET specimen while the highest value for flexural strength was on 0.5% of PET. Based on the tests conducted in this report, the optimum percentage of recycled PET fibre that can be added to concrete is 1.0 %. For recommendation increase the number of specimens in order to obtain more accurate results.

Keywords: Compressive Strength, Flexural Strength, Pet Fiber, Concrete, Performances, Mechanical Properties

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1. Introduction

Additional materials in concrete such as fibers can be classified as polypropylene (PP), polyethylene terephthalate (PET), polyethylene, polystyrene (PS), polycarbonate, nylon, aramid, and polyester reused product. Polyester reused products such as glass, rubber, and cellulose among other materials [1]. Fibers that are included as advance in concrete mix perform better than existing concrete. The number of fibers within the concrete determines its resistance to compression. Sewing impact that fibers have on cracks beside other preferences in terms of toughness, ductility, affect strength (durability), abrasion, and fatigue [2]. These ecological preferences have had a positive impact on the application of fibers in structures, especially those with low-reliability structures, such as slabs for inspection, walls, columns and foundations. Polyethylene Terephthalate (PET) has good properties that can innovate and improve concrete properties. PET is a hard, durable, and waterproof material with excellent thermal and electrical insulation.

Environmental pollution caused by polyethylene terephthalate (PET) is getting worse these days. Most PET bottles used as beverage containers become waste after their usage. That problem can be reduced by undergoing the recycling process. The use of recycled PET fibers in a concrete mix can help to reduce environmental issues. This is done by reducing the growing amount of PET plastic bottles thrown into landfills. Polyethylene terephthalate is also known as bottle fibers material. There are many advantages of the use of plastics in concrete The increase in the use of plastics is due to its beneficial properties which are complete versatility and tailor-made ability to meet specific technological needs, lighter weight compared to competing materials which reduce fuel consumption during transport, durability and endurance, chemical and water resistance and impact resistance [3]. Therefore, it is important to study the optimum amount of recycled PET fibers which can be added to the concrete mix so that it would be appropriate for utilize within the development industry.

2. Overview Previous Research

Previous research on the use of PET waste fiber in concrete and building materials have been performed. PET waste fiber has been used as aggregates in the concrete mix, which can produce some positive effects on the physical or mechanical properties of the concrete. Other than that, Polyethylene terephthalate (PET) is also used in concrete as fiber in reinforcement and as a binder in replacing cement. Table 1 shows the various studies which were conducted on utilization recycled Polyethylene terephthalate (PET) fiber.

Table 1 : Summary of journals and its description

No	Author/Year	Outcomes
1	(Mohammed & Rahim, 2020)	Polyethylene terephthalate (PET) fibre capable of raising the cracking load of high-strength concrete beams and shows the ability for crack control within the elastic range.
2	(Ullah Khan & Ayub, 2020)	Both fibers and strips demonstrated a ductile behavior, so investigating the hybrid usage of PET fibers and strips is advised.
3	(Al-Hadithi et al., 2019)	1.5% of Polyethylene terephthalate (PET) contains maximum compressive strength and elasticity modulus, flexural strength, and elasticity modulus. The final result would be better compared with existing concrete in all mechanical properties.
4	(Pereira et al., 2017)	PET in concrete enhanced the mechanical properties of organic concrete in terms of compression, stress and bending.
5	(Marthong & Marthong, 2016)	Reducing macro cracks due to fiber-bridging operation contributes to an overall durability improvement for PFRC examples.

6	(Kodadadi & Khodaii, 2018)	Reinforced concrete beams with 0.5% polyethylene terephthalate (PET) samples capable of managing shrinkage cracks and increasing the structural ductility of reinforced concrete structures
7	(Foti, 2013)	Due to the addition of PET strips, the cracking load was not dramatically changed but a more ductile concrete behavior.
8	(Foti, 2011)	The post-cracking actions of plain concrete parts will have an outsize effect with the addition of a terribly bit of fibers from recycled and cut PET bottles, which will greatly increase specimen toughness.
9	(Kim et al., 2010)	The reused reinforced concrete specimens of PET fibre had relative ductility indices approximately 7–10 times higher than those of the non-reinforced fibre specimens.
10	(Choi et al., 2009)	The circular form of the WPLA particles and their zero absorption have increased the slump of WPLA concrete, which reduces the absorption of the fine aggregate.

Based on the table 1, we can infer that the study of recycled PET fibers in a concrete mixture was carried out by early researchers on the basis of the table 1. The aim of victimization recycled PET waste within the construction industry was to save lots of the environment because the quantity of plastic waste generated increasing day by day and it cannot be decomposed easily. The studies targeted a lot of on numerous water-cement ratios within the concrete mixture design. All of those studies were conducted to develop a better characteristic of fiber concrete for future use additionally to saving the environment.

3. Material and Procedure

The foundation components of concrete are cement, water, coarse and fine aggregates. The British Standard (BS) was used as standards for selected materials used in the Malaysian construction industry.

3.1 Material Preparation

The materials used in this research included Fine Aggregates (FA) which maximum sized was 4.7mm and passing the sieving process according with BS EN 933-1, Coarse Aggregates (CA) sized maximum 20mm and passing through sieving based on BS EN933-1, Ordinary Portland Cement Type 1 (OPC: TYPE 1) which was base on MS EN 197-1: 2014, water, superplasticizer and recycled PET fibers with 25mm long and 5mm width. Preparation of materials and recycled PET fibres as seen in Figure 1.

(a) (b)

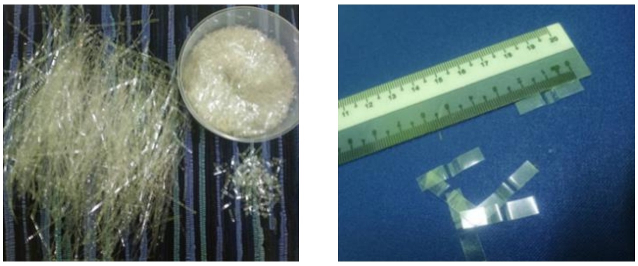
(c) (d)

Figure 1: Preparation of materials: (a) Coarse Aggregates, (b) Fine Aggregates, (c) PET fiber (d) Superplasticizer

3.2 Preparation of PET fiber

Polyethylene terephthalate (PET) plastic bottles have been collected and cleaned before being cut into fibre form. The procedures for the cutting of recycled PET bottles are listed in the following paragraph. The process of collecting the PET bottles took around 1 weeks. PET bottles was collected from Universiti Tun Hussein Onn Malaysia (UTHM) and residential area at Parit Raja. After the bottles were collected, clean and dry the recycled PET bottles to get rid of any contaminant on bottles. Next, the recycled PET bottles were cut into smaller pieces. Finally, the recycled PET pieces were cut into desired size and shape which is 25mm in length and 5 mm in width as shown in Figure 2.

(a) (b)



(c) (d)

Figure 2: Process of preparation PET bottles fiber: (a) Collect PET bottles, (b) Clean and dry PET bottles, (c) Cut PET bottles in pieces, (d) Cut PET bottles into required size.

3.3 Design Mix

In order to form a concrete sample, all materials blended together. The mixing design to choose the most suitable concrete components and to determine the relationship between the materials in order to achieve the desired power. For normal and PET concrete strength, 3 concrete cube samples respectively were produced using grade 35 concrete. Table 2 shows the weight of all materials needed for the mixing process.

Table 2: Mix design of concrete

Quantities (kg)	Per m^3	Total
Cement	500.00	77.50

Water	225.00	34.90
Fine Aggregates	505.00	78.30
Coarse Aggregates	1175.00	182.15
PET fibers	420.00	0.66

3.4 Specimens

There are two types of molds which are cube shaped specimens and prism shaped specimens were measured 100mm x 100mm x 100 mm and 100mm x100mm x300mm respectively. For compressive strength test, 6 specimens each of normal mix, 0.5%, 1.0%, 1.5% and 2.0% PET were used. For the concrete mixing phase, cube molds measuring 100mm x 100mm x 100 mm and prism molds measuring 100mmx 100mm x 300mm were prepared. The concrete specimens were soaked in clean water for a 7 and 28 days for curing process. All the materials were weighed first before the casting process. Table 2 indicates the weighting scale used for the preparation of the sample. For the casting process of concrete specimens, a concrete mixer was used. Figure 3 demonstrates the concrete mixer used for the casting of concrete specimens.

Figure 3: Mixing process: (a) The mixer has been filled with part of the water, (b) Materials have been added to the mixer, (c) Materials have been mixed for a period of time, (d) Pour the concrete into mould.

3.5 Test Setup Acoustic Emission

The prims were labelled with the coordinate pattern before the test was carried out to determine the position of the crack after the test. The surface of the prism was then smoothed for installation of the AE sensor. This is done in order to ensure proper bonding between the AE sensor and the concrete surface. The AE win software must be set up after installation of the AE sensors and before testing. After all of the configuration procedures have been completed, a load can be applied to the beam. Below demonstrates the research setup for the acoustic emission test.

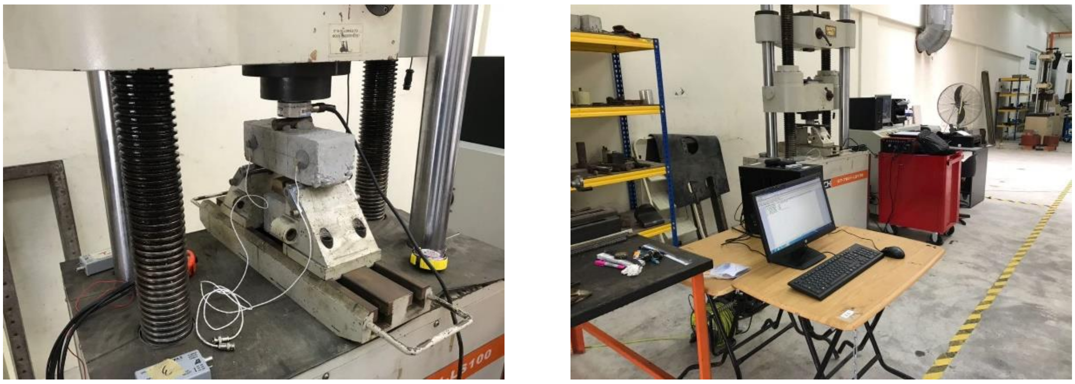


Figure 4: Test setup: (a) Setup Acoustic emission on prism, (b) Setup a computer to run AE win software.

4. Results and Discussion

Analysis of the findings obtained from the laboratory test data. The study was conducted on the basis of the parameters used to evaluate the impacts of the percentage of recycled PET fibres in concrete under curing conditions of 7 days and 28 days respectively. This part consists of the results of slump test, flexural strength test and the compressive strength test.

4.1 Slump test

The slump test did not involve the results of all the parameters that influence the workability of the mixture. The mean slump value ranged from 63 mm to 97 mm. All the values of the concrete slump fall and rise within the range of the slump value. The lowest slump value was recorded at 1.0 % of PET fibre in concrete. Indirectly, it shows that 1.0 %of PET is the optimal amount of PET fibre in concrete to achieve the highest workability. Figure 4 and Figure 5 demonstrate the slump test carried out and the condensed data in the form of a graph, respectively.

(a)

(b)

(c)

(d)

(e)

Figure 5: Concrete slump for each mixture

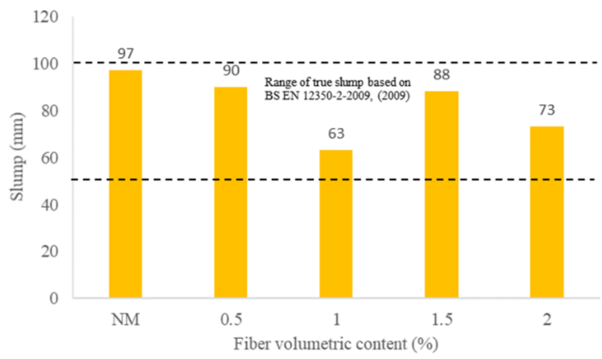


Figure 5: Slump test results

According to BS EN 12350-2:2009 (2009), the true slump is about 75 mm ± 25 mm. However, as additional materials are applied to concrete, its slump value and workability can change accordingly. Figure 5 showed that the value for the usual concrete slump was 97 mm, which ranged from 50 mm to 100 mm. However, with the inclusion of 0.5 % of PET fibres in concrete, the slump value decreased to 90 mm, which was a 7 % difference from the control concrete value. The rest of the PET fiber concrete continuously decreased by 1.0 % PET, 1.5 % PET, 2.0 % PET recorded 63 mm (35 % decrease), 88 mm (9 % decrease) and 73 mm (25 % decrease) of slump values respectively from control concrete value.

Generally, the use of PET fibre decreases the workability of concrete because fibre has a comparatively larger particle size compared to fine aggregates. The difference in the size of the particles produces more friction and reduces the workability of the mixtures. In addition, the high content and wide surface area of the fibers can quickly absorb cement paste, enhancing the viscosity of the concrete mixture [13]. As a result, when the amount of PET fibre increases, the strength and plasticity of fresh concrete will decrease.

4.2 Flexural Strength Test

Flexural strength testing was conducted at 7 and 28 days of age on concrete prisms. The average data was shown in the form of a graph in Figure 6. The load was applied without impact and increased gradually until the specimen failed.

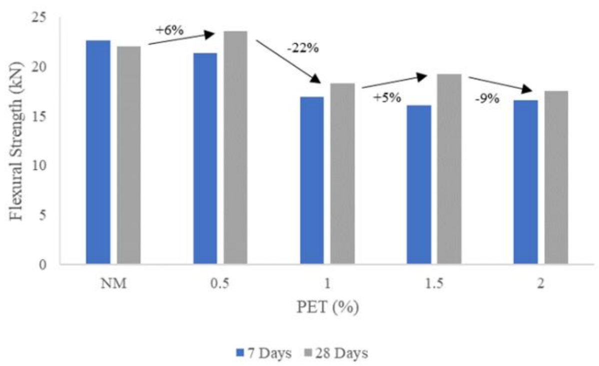


Figure 6: Graph flexural strength against PET fibers

Based on Figure 6, an inverted bell-shaped curve similar to the compressive strength of PET fibers concrete was obtained. Flexural strength improved from standard concrete to PET 0.5% with values 23.54 MPa after a curing time of 28 days. Indirectly, makes 0.5% of PET fibers as an optimum value for PET fibers in concrete. Increased strength was seen from 7 days to 28 days of curing with every percentage of PET fibre involved except for the usual mixture of concrete. It demonstrates that the PET fibers responds well to other materials inside concrete on 0.5% PET than normal concrete.

4.3 Compressive Strength Test

Figure 7 shows the data of compressive strength test presented in the form of a graph.

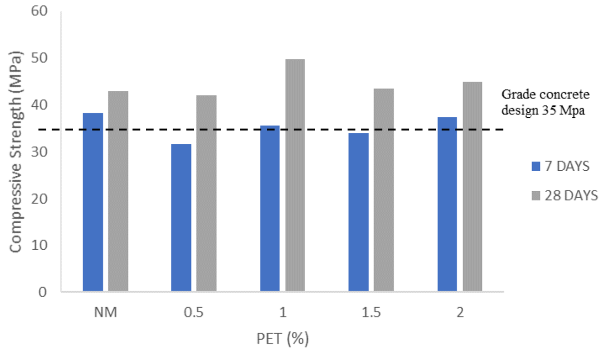


Figure 7: Compressive strength against percentages of PET fibers

The compressive strength pattern shown in Figure 7 above. The concrete strength of the target was 35 N/mm^2. However, by increasing the percentage of PET fibres, the results have shown that the compressive strength values of the recycled PET fibres in the concrete mixture have also improved on 1.0%, 1.5% and 2.0% PET specimen than normal concrete and 6% increased the flexural strength on 0.5% PET specimen. Result showed for compressive strength on day 7, the normal concrete results were 38.3 MPa, 31.7 MPa for 0.5 % of PET, 35.6 MPa for 1.0 % of PET, 33.9 MPa for 1.5 % of PET and 37.4 MPa for 2.0 % of PET for concrete.

The results for day 28 concrete cured also showed a decreased compressive strength value for normal concrete resulted 43.0 MPa while concrete with 0.5 % of PET, 1.0 % of PET, 1.5 % PET and 2.0 % PET resulted values of 42.1 MPa, 49.8 MPa, 43.5 MPa and 45.0 MPa respectively. The graph of compressive strength with various percentages of recycled PET fibres showed fluctuations. The graph showed that 1.0 % of PET fibre concrete had the highest value. This was due to the inclusion of fibres that contributed to uneven dispersion in concrete.

However, 1.0 % of PET fibre concrete displayed the better distribution of fibre among other fibre concrete during the phase of analysis. As a result, 1.0 % of PET fibre concrete provided the highest compressive strength value. Adding fibres tends to cause bundling during mixing and pouring, also known as fibre baling. Fiber balling is impaired by the high chances of fibre surfaces coming into contact with each other. The region between the fibre surfaces is the weakest point in concrete; microcracks and macrocracks caused by compression loading are easily visible in this area. [12]

5. Conclusions

All concrete specimens that containing PET fibre were tested using a flexural strength test (3-point bending). The maximum load value is the concrete efficiency measure. Usually, high-quality concrete capable of withstanding a higher load value. As a result, specimens containing 1.0 % PET fibre had the highest load compared to other specimens that containing other percentages of PET. The concrete sample with 1.0% PET is the best concrete performance.

On the other side, a compressive strength test was also performed on all specimens. The concrete specimen with 1.0% of PET fibre with the value of 49.8MPa achieved the maximum compressive strength on day 28. In conclusion, the higher the concrete performance, the larger the compressive strength.

Based on the tests conducted in this report, the optimum percentage of recycled PET fibre that can be added to concrete is 1.0 %. While a decrease in slump value and variations in compressive strength have been observed, the concrete specimen containing 1.0% recycled PET fibre has obtained the highest value in terms of strength. In the flexural strength test, the addition 1.0% of PET fiber demonstrated the highest value compared to the other mixtures.

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