Efficiency of Polyethylene Terephthalate (PET) Waste Fiber in Concrete Material by Means of Ultrasonic Velocity Method

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Abstract — *Environmental pollution caused by polyethylene terephthalate (PET) is getting more and more critical these days. However, polyethylene terephthalate, also known as bottle fibre material, can be added to concrete as aggregate replacement material in order to reduce environmental pollution. Food and fruit containers can also be made from polyethylene terephthalate. Polyethylene terephthalate is also a hard and stiff material which is resistant to chemicals and water. It also has excellent thermal and electrical insulation. The objective of this research is to determine the performance of PET fibre concrete in undamaged and damage states. Then, the concrete samples were tested using the Ultrasonic Pulse Velocity (UPV) method. The UPV method is an effective non-destructive testing (NDT) method for ensuring quality control of concrete materials as it helps detect damages in structural components. The UPV method is conventionally used for the quality control of materials, mostly homogeneous materials such as welded and metal connections. The fibres were simply cut from PET plastic bottles. The length and width of recycled PET fibres were fixed at 25 mm and 5 mm respectively. The chosen percentages of fibre used were 0.5%, 1.0%, 1.5% and 2.0%. The specimens underwent the UPV test and the compressive strength test on day 7 and day 28. It was found that the concrete quality slightly decreased when the percentage of PET content increased. Finally, the optimum percentage suggested based on the results is 1% of PET fibre as it achieved the highest compressive strength and UPV compared to normal concrete.*

Keywords — *concrete, compressive strength, ultrasonic pulse velocity, PET concrete, undamaged concrete, damaged concrete.*

I. INTRODUCTION

Polyethylene terephthalate, also known as PET, is a polymeric material that is derived from methyl terephthalate, terephthalic acid and methylene glycol monomers. PET fibres are extensively used in the textile industry as a principal fibre and in other industries [1]. The use of fibre concrete has become extensive in recent years and use of PET fibres in concrete has witness global growth [2]. PET is a plastic resin which is also the most common type of polyester. It is one of the common consumer plastics used and widely employed as raw material in products such as mineral water bottles, soft drink bottles, container for food packaging and other consumer goods. The amount of PET consumed annually has been growing steadily due to its low density, strength, user friendly designs, fabrication capabilities, long life expectation, low weight and low cost. However, this can cause a setback in the waste disposal crisis that could lead to several environmental issues [3].

In the field of civil engineering research, the use of recycled PET in concrete has only just begun. Many studies indicate that recycled PET fibres produce different results depending on the percentage used and fibre shape.To solve the problem of environmental pollution caused by polyethylene terephthalate (PET), many researchers have started incorporating the use of PET in concrete. Unwanted micro and macro cracks can be filled up by PET fibres. This study mainly focuses on PET applications for concrete material.

Generally, the ultrasonic pulse velocity (UPV) method (BS 1881: Part 203), can be used to test concrete strength in situ. The UPV method is a non-destructive method related to the measurement of ultrasound speed through materials in order to predict material strength. It can also calculate low-strain elastic modulus and/or detect the presence of internal flaws such as voids, decay, cracks, honeycombs and other damage [4]. The UPV method can be applied to concrete and is applicable where destructive testing is not desirable. The main strength of the UPV method lies in finding general changes in conditions such as areas of weak concrete in a generally sound structure.

II. PREVIOUS RESEARCH OVERVIEW

During the past two decades, several research studies had explored the utilization of PET waste in concrete and construction materials. PET waste has been used in cement mortar and concrete as aggregates, as fiber in reinforcement and as a binder in replacing cement. Table 1 shows the various studies which were conducted on recycled PET fiber from the year 2007 until 2019.

Table 1: Summary of journals and its description

No.	Author/Year	Outcomes
1.	Kassa Belay *et al.* (2019)[8]	The flexural tests result show that the ductility and load carrying capacity at failure improved by 27.3 and 44.16%, respectively. There was delay in appearance of cracks and energy absorption increased by 60.55%. Flexural capacity also increased by 43.91% for the modified concrete mix as compared to the control.
2.	S. D. Silva *et al.* (2018)[9]	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.
3.	Bhogayata *et al.* (2017)[10]	The inclusion of metalized plastic waste (MPW) fibers in concrete improved the crack resistance capacity of conventional concrete. The presence of MPW fibers extended the ductility of cement paste against brittle failure and reduced the propagation of micro cracks of the hardened mass.
4.	Borg *et al.* (2016)[6]	The study investigated the use of recycled PET fibers, both straight and deformed, in concrete as a waste material by assessing their effect on mechanical properties and early age performance in concrete specimens.
5.	M. Nikbin *et al.* (2015)[11]	Conducted to investigate the feasibility of PET in NPC and LWPC as a partial substitution for natural fine aggregate and present an interesting approach for recycling this type of waste material in the civil engineering area.
6.	Fraternali *et al.* (2014)[12]	The study on the mechanical properties of Portland limestone cement-based concretes showed a 0.38 water/cement ratio and reinforcing R-PET fibers at 1% fiber volume content.
7.	Irwan *et al.* (2013)[13]	This paper presented the results of mechanical properties of PET FRC which are compressive strength, splitting tensile strength, and modulus of elasticity.
8.	A. S. Benosman *et al.* (2012)[14]	Performance and productivity of municipal solid waste management that will bring economic benefits for the local government.
9.	Foti. (2011)[3]	The use of PET bottles to obtain reinforcing fibers to increase the ductility of concrete.
10.	Akçaözoğlu *et al.* (2010)[15]	The utilisation of shredded waste Poly-ethylene Terephthalate (PET) bottle granules as a lightweight aggregate in mortar was investigated.
11.	Albano *et al.* (2009)[16]	PET-filled concrete blends show a decrease in compressive strength, splitting tensile strength and modulus of elasticity. The inclusion of PET implies defects in the internal structure of the concrete, producing a reduction in strength and a decrease in stiffness.
12.	Siddique *et al.* (2008)[17]	A detailed review about waste and recycled plastics, waste management options, and research published on the effect of recycled plastic

		on the fresh and hardened properties of concrete.
13.	Oumaya *et al.* (2007)[18]	An innovative use of consumed plastic bottle waste as sand-substitution aggregate within composite materials for building application.

Based on the Table 1, the evaluation of recycled PET fibers in concrete mixture had been done by the early researchers. From the year 2016 to 2018, the studies focused more on various inventions in terms of PET size and shape which is use up to 2% of PET. For the year 2015, the studies looked into the combination of PET fibers with other materials of chemical and use up to 15% of PET fiber. The recycled of PET research has been conducted on year 2013 to 2014 to determined the mechanical properties after mixing with concrete. Spectroscopic analyses have been conducted and use up to 7.5% of PET fiber with variety of testing on year 2012. Last but not least, from the year 2007 to 2011, waste PET bottles research have been conducted with mixing of concrete. All of these studies were conducted to develop better characteristic of fiber concrete for future use in addition to saving the environment.

III. MATERIAL AND PROCEDURE

A. 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, water and recycled PET fibers with 25 mm long and 5 mm width. The preparation of materials and recycled PET fibers are shown in Fig. 1.

(a) (b)

(c) (d)

(e)

Fig. 1: Preparation of materials: (a) Fine Aggregates, (b) Coarse Aggregates, (c) Cement, (d) Water and (e) PET fiber

B. PET fiber preparation

Polyethylene terephthalate (PET) plastic bottles were collected and cleaned before being cut into fiber form. The procedures involved in cutting recycled PET bottles are described in the following paragraph.

The process of collecting the plastic bottles took around 2 weeks. 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, namely 25 mm in length and 5 mm in width are shown in Fig. 2.

(a) (b)

(c)

Fig. 2: Preparation of materials: (a) Fine Aggregates, (b) Coarse Aggregates, (c) Cement, (d) Water and (e) PET fiber

C. Design Mixing

Design mixing is a process conducted to choose the best ingredients to produce concrete and to determine their relative quantities to accomplish the desired strength. In this research, the concrete proportions were designed using the Trial Mix. Table 2 shows the proportion of the materials required in this research.

Table 2: Mix design of concrete

Quantities	Per m^3	TOTAL
Cement(kg)	500.00	122.50
Water(kg)	225.00	55.15
Fine aggregates (kg)	505.00	123.75
Coarse aggregates (kg)	1175.00	287.90
PET fibers(kg)	420.00	1.03

D. Specimens and Tests

In this research, a total of 30 specimens used for a cylinder of (150mm x 300mm) in size respectively. 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. The ultrasonic pulse velocity test was conducted for undamaged and damaged states of specimens while compressive strength test was conducted as specified in the test method BS 1881-116:1983, Part 116: Method for the determination of compressive strength of concrete.

IV. 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 slump test, ultrasonic pulse velocity test and compressive strength test.

A. Slump

The concrete slump test was conducted to find out the workability of the concrete mix. Fig. 3 shows the all concrete mixes containing varying percentages of PET fibre. The mean slump value ranged between from 60 mm to 180 mm. All the concrete slump values fell within the range of the designed slump value. The higher the percentage of PET fibre in the concrete mix, the lower the slump value achieved. Basically, the use of PET fibre reduces the workability of concrete because fibre has a relatively larger particle size compared to fine aggregates. The difference in the particles size produces more friction and this causes reduced workability in the mixtures. Besides, the high content and large surface area of the fibres can easily absorb the cement paste, thereby increasing the viscosity of the concrete mixture [5]. Thus, when the PET fibre volume increases, the consistency and plasticity of fresh concrete will decrease.

Mazaheripour et al., (2011) made two suggestions to improve the workability of fibre concrete, namely to limit the volumetric content of fibres to a range of 0.1% to 1% and to add more water.

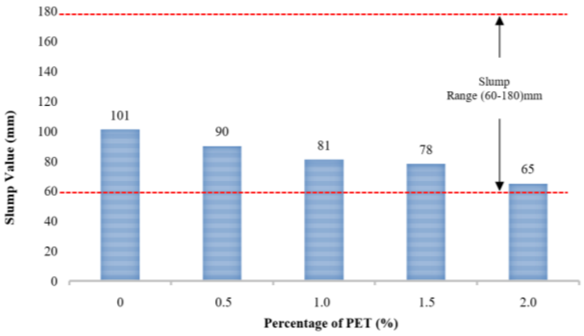
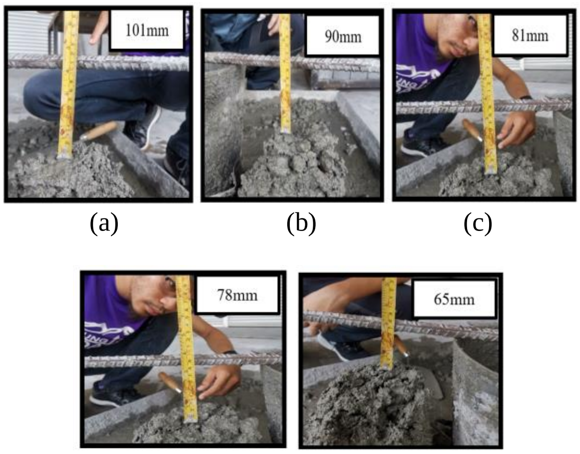


Fig. 3: Concrete slump value



(a) (b) (c)

(d) (e)

Fig. 4: Concrete slump value

However, the addition of water will negatively affect concrete strength. Therefore, plasticizer or water reducing admixtures are often used in fibre concrete to improve the workability of concrete mixes without increasing water content. Ochi et al. (2007) stated that there was no noticeable reduction in slump value when the PET fibre content reached 0.5% compared to the slump value of conventional concrete.

B. Ultrasonic Pulse Velocity Test for Undamaged and Damaged Specimen

The control specimen and the specimen containing 1% of PET fibre achieved a high velocity during the UPV test. The velocity recorded of concrete added with 1% of PET fibre at 28 days was slightly higher than that of the control concrete specimen. Meanwhile, the velocity values of all the damaged specimen decreased at 7 days and 28 days.

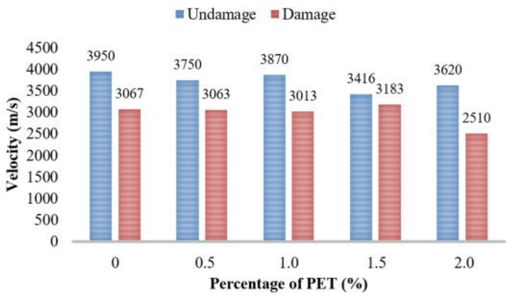


Fig. 5: Comparison between undamaged and damaged specimen at 7 days by direct transmission method of UPV test

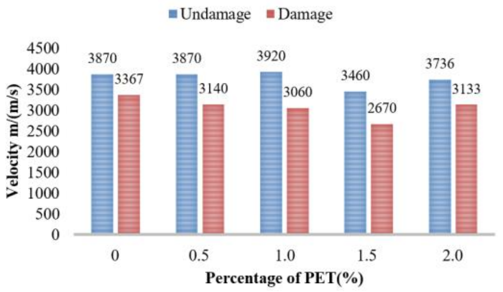


Fig. 6: Comparison between undamaged and damaged specimen at 28 days by direct transmission method of UPV test

Based on previous research [6], comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. Next, cracks, voids or flaws in concrete can obstruct the transmission of the pulse. Consequently, lower velocities are obtained as pulse strength is attenuated and passes around the discontinuity, thereby making the path length longer. Moreover, the density and modulus of elasticity of aggregates also affect the pulse velocity significantly.

C. *Compressive Strength Test*

In this research, only the control specimen was produced using natural main components of concrete without the addition of PET fibre. The study focused on the effect of concrete containing varying percentages of PET fibre.

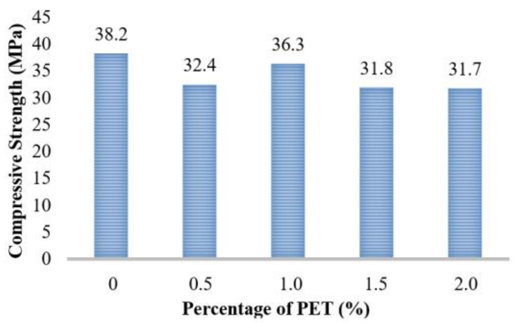


Fig. 7: Compressive strength of concrete mix at 7 days

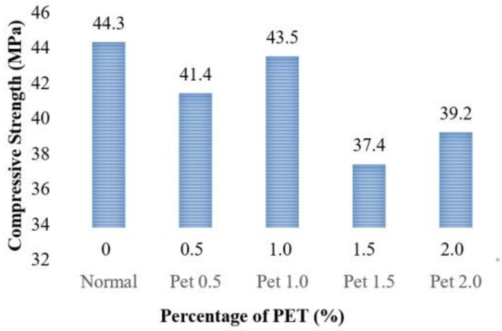


Fig. 8: Compressive strength of concrete mix at 28 days

Based on Fig.7, the compressive strength of the specimens at 7 days decreased by 15.18%, 4.97%, 16.75% and 17.02% for specimens containing 0.5%, 1%, 1.5% and 2% of PET fibre, respectively. Meanwhile, the specimen containing 1.0% of PET fibre achieved the highest compressive strength of 36.3 MPa compared to other PET fibre specimens. Meanwhile, at Fig.8, the compressive strength of the specimens decreased by 6.55%, 1.81%, 15.58% and 11.51% for specimens containing 0.5%, 1.0%, 1.5% and 2.0% of PET fibre, respectively. Thus, it can be concluded that the specimen containing 1% of PET fibre had the highest compressive strength. The area between fibre surfaces is the weakest point in concrete; microcracks and macrocracks caused by compression loading easily appear in this area [7].

This trend can be attributed to the decrease in adhesive strength between the surface of PET fibre and cement. Ochi et al. (2007) who studied 30 mm-long PET fibres claimed that the high percentage of recycled PET fibre content produced bundles during the mixing and pouring process.

D. *Relationship Between Velocity and Compressive Strength*

The relationship between compressive strength and pulse velocity at 7 days and 28 days for undamaged and damaged specimens is shown in Fig. 9, Fig. 10, Fig. 11, and Fig. 12.

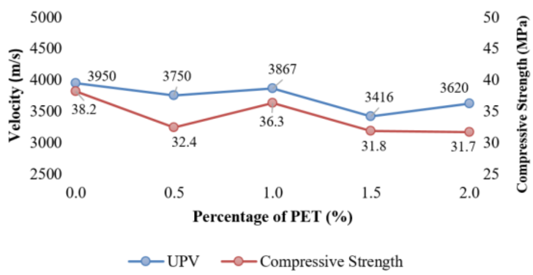


Fig. 9: Relationship between compressive strength and UPV at 7 days (Undamaged specimens)

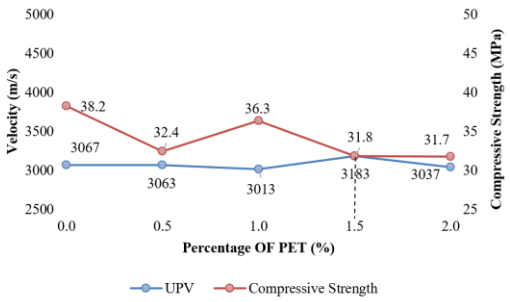


Fig. 10: Relationship between compressive strength and UPV at 7 days (Damaged specimens)

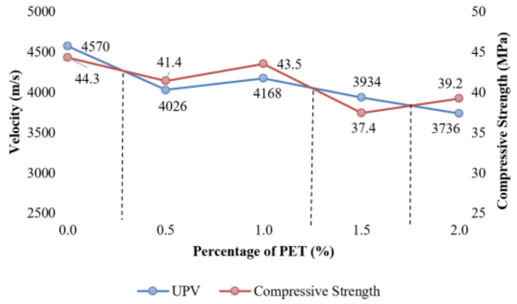


Fig. 11: Relationship between compressive strength and UPV at 28 days (Undamaged specimens)

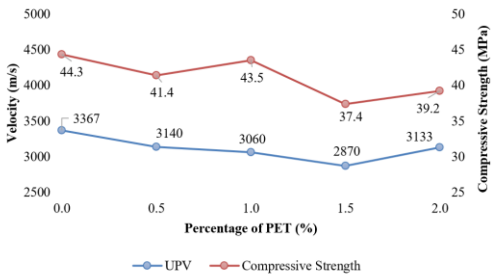


Fig. 12: Relationship between compressive strength and UPV at 28 days (Damaged specimens)

Based on the findings in Fig.9, Fig.10, Fig.11, Fig.12, it is indicated that concrete specimens with high velocity have the highest compressive strength. Generally, the ultrasonic pulse velocity (UPV) test is a non-destructive method used for measuring the speed of ultrasonic pulse passing through materials. This test is applicable for predicting concrete strength or distinguishing the presence of internal flaws, such as voids and cracks [8]. This particular factor affects concrete velocity. The intersection line that cross between UPV and compressive strength indicated the optimum percentage of PET.

Basically, wave propagation in solids is greater than in liquid and gases. Solid particle density is also higher than that of liquids and gases. When the density of a medium increases, the number of particles per unit area also increases. This results in easier energy transfer from one particle to the other due to vibration. Consequently, this phenomenon increases sound wave velocity propagation in solids compared to other states of matter.

V. CONCLUSIONS

All concrete specimens containing PET fibre were tested using the UPV test (direct transmission). The velocity value is an indicator of concrete quality. Generally, high quality concrete generates high velocity. Consequently, undamaged and damaged specimens containing 1.0% PET achieved the highest velocity compared to specimens containing other percentages of PET. Therefore, the concrete sample with 1.0% PET is considered a good quality concrete. On the other hand, a compressive strength test was conducted on all the specimens. The concrete specimen with 1.0% of PET fibre obtained the highest compressive strength of 43.5 MPa at 28 days. This concluded the relationship between the quality of concrete with respect to its compressive strength. To sum up, the higher the quality of concrete, the greater its compressive strength.

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