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THE EFFECT OF CONCRETE'S PROPERTIES ON PARTIAL REPLACEMENT OF FINE AGGREGATE WITH DIFFERENT SIZE RANGES OF POLYETHYLENE TEREPHTHALATE (PET) IN CONCRETE MIXTURE

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ABSTRACT
Human beings use up to 50 billion tonnes of aggregate every year and the extraction of aggregate give severe impacts to the environment. Therefore, finding an alternative material to replace aggregates in the concrete mixture is necessary. Plastic pollution is the scourge of humanity. Plastic waste that causes significant challenges in recycling and leads to massive plastic pollution. This study aims to investigate tthe effects of utilizing polyethylene terephthalate (PET) as a partial replacement for sand in concrete by using two different range of PET which are 2mm-1.18mm and 1.18mm-600µm. The effects on the properties of concrete such as compression were examined. A group of five concrete mixtures containing PET was prepared as a partial substitute for sand with the replacement of 0%, 5%, 10%, 25% and 50%. Concrete was cast to determine the behavior of fresh and hardened concrete in terms of workability, unit weight and compressive strength. The experimental results showed an increment in workability, reduction in unit weight, the replacement harmed the compressive strength of concrete at varying percentage of replacement and sizes of PET. However, this study had proved that the plastic waste can be replaced by specific percentages and sizes

Keywords:
Compressive Strength, Concrete, Polyethylene Terephthalate, PET, Workability

INTRODUCTION

Aggregates like gravel, crushed rock, and sand are the second most traded and extracted Earth's resource after water, and human beings use up to 50 billion tonnes of aggregate year (UNEP, 2019). In the BBC Future article by Beiser (2019), Pascal Peduzzi, an environmental scientist, points out that it is impossible to extract 50 billion tonnes of any resource every yearwithout severe impacts to the environment. Therefore, finding an alternative material to replace aggregates in the concrete mixture is necessary. Numerous types of plastic waste are produced worldwide, only 9% of them have been and 12% incinerated, with the remaining 79% just being disposed to the nature environment. These plastics include Polyethylene Terephthalate (PET), Polypropylene (PP), high-density polyethylene (HDPE).

In Malaysia, the problem is worsening with the increase of single-use plastics for food, beverage, and goods packaging for delivery and takeaway since thelockdown of the Covid-19 pandemic. In 2020, Malaysians utilized 148000 tonnes of plastic only for food packaging due to the pandemic (Yeo, 2021). The Worldwide Fund for Nature- Malaysia (2020) also did a study and presented that Malaysia's per capita plastic usage is 16.78kg per capita in 2019 and ranks second in Asia. Plastic usage is still increasing yearly despite many programs being held to move people away from single-use plastics. Cestari (2020) points out in the study that plastics could assist on creating a sustainable future and help on reducing plastic pollution because they are strong, durable, waterproof, light, easyto shape, and recyclable which are essential aspects for construction materials. UNEP (2018) findings show that 1 million plastic beverage bottles are bought every minute and 5 trillion single-use plastic bags are used globallyper annum. Half of all plastics were produced to be single-use and then just dumped. Plastics harm millions of living things yearly, from birds to fish to other marine organisms.

According to Parker (2019), plastic has harmed roughly 700 species, including the endangeredspecies. Dumped fishing gear or discarded plastic products strangled the majority of the creatures, including seals, whales, turtles, and others. The usage of waste materials in the construction industry is widely explored. Various waste substances and industrial by-products, including glass, fly ash, ceramic, slag, and recycled concrete aggregate are used with and without the natural aggregates. The presence of several research on the use of various forms of waste material to solve some of the existing global issues, including waste pollution and the dwindling of non-renewable natural resources. This includes the attempts to utilize Polyethylene Terephthalate (PET) waste to partially substitute aggregate in concrete production. PET, abbreviated as PETE, is the shortened form for Polyethylene Terephthalate, the chemical name for polymer and comes with the recycling code of number 1 usually can be found at the bottom of the PET products. PET is one of the most widely used thermoplastics in the world (Hardin, 2021). It is a semi-crystalline and naturally transparent plastic. In the textile industry,PET can be known as polyester, while when used as packaging for food or beverage, it is generally known as PET or PET resin. PET plastic is the most commonly used thermoplastics mainly in the packaging and textile industry (Habib, 2021). These polymers are given preference over others due to their differentiation properties like outstanding stiffness and strength due to the presence of a large aromatic ring in the PET especially when the polymer chains are aligned with one another in an orderly arrangement by stretching.

In previous research, 66.67% or 14 research had been done based on the replacement of coarse aggregate and only 33.33% or seven studies are based on fine aggregate replacement. The gap was identified in the method of using plastic waste to replace fine aggregate. Therefore, PET as the plastic waste was proposed to replace the fine aggregate in the concrete mixture in this research. Besides that, another research gap can also be obtained from the reviewing of published research article journals. 76.19% or 16 research had been done based on the replacement of plastic waste in concrete mixture using one specific size range of plastic wasteor the sizes of the plastic waste was not considered. While only 23.81% or five studies have beendone based on various sizes of plastic waste replacement in the concrete mixture. The gap was identified in the testing variable based on various sizes of plastic waste replacement in the concrete mix. Therefore, various sizes of PET as plastic waste were proposed to replace the aggregate of concrete mixture in this research.

METHODOLOGY

The study was conducted in five phases. Phase one of this study was preliminary studies which include literature studies, collection of data and the studies on materials properties. The second phase was PET treatment. In this phase, PET bottles collected from the plastic waste were transformed into fine PET fragments by shredding and cutting of PET waste bottles. Before the fine PET fragments can be used to be partially replaced into concrete mixture, it had been sieved and those passing through 4.75 mm sieve size was only used in the concrete production. Next the study was carried on with the concrete sample preparation which is in phase 3. The concrete samples were prepared with water-cement ratio of 0.55 and with 0%, 5%, 10%, 25% and 50% of PET replacement in concrete mixture. After that, the study then entered phase 4 - testing stage. Two types of testing that had been conducted were fresh concrete testing by slump test and hardened concrete testing which include density and compressive strength test. Finally, the data obtained from all of the tests were analysed.

In this research, the PET is replaced by volume instead of weight. In order to gain the volume to be used for replacing the fine aggregate in concrete mixture by various percentages and size ranges of PET, a mould or container firstly prepared to be filled fully with fine aggregate of the river sand. Once the container is fully filled with sand weight, a record the reading is taken. After that, the same container is used again but this time filled full with PET and then it was weighed. Next, to find the ratio of PET over fine aggregate by using the obtained weight from the container with PET dividing the obtained weight from the container with fine aggregate (sand).

The volume of PET used to replace the fine aggregate can be obtained by multiple the ratio of PET over fine aggregate with the PET weight that calculated. A total amount of 54 (100mm x 100mm) samples were prepared for density test followed by compressive strength test that tested at the curing age of 7 and 28 days.All of the samples had been tested for slump test before they were being casted. Three cubes were tested on density and compressive strength test for both curing age of 7 and 28 days to obtained the accuracy of results by using the average. Table 1 showed the standard and guidelines used for the lab tests and Table 2 showed the mix proportions.

The data were tabulated and analyzed by using bar chart for slump and density test to show the differences between the concrete with and without partial replacement of PET. While for compressive strength test, the data was tabulated and analyzed through a best fit line in the graph where the optimum compressive strength of concrete with PET can be observed.

Table 1: Summary of standard used

Test	**Standard**
Slump Test	BS EN 12350-2
Density Test	BS 1881: Part 114
Compressive Strength Test	BS 1881: Part 116

Table 2: Mix Proportions of Concrete Mixture

NO.	**Mix**	**0.018 m^3 (kg)**				
		OPC	**Coarse Aggregates**	**Fine Aggregates**		**Water**
				Sand	**PET**	
1	PFA 0% (Control)	5.106	16.576	10.138	0.00	2.812
2	PFA 5%	10.212	33.152	19.262	1.014	5.624
3	PFA 10%	10.212	33.152	18.248	2.028	5.624
4	PFA 25%	10.212	33.152	15.207	5.069	5.624
5	PFA 50%	10.212	33.152	10.138	10.138	5.624

RESULTS AND DISCUSSION

The results obtained from the laboratory testing include slump test, density test and compressive strength test. In this research, there are for types of concrete which is the control mix with 0% of PET, concrete with 5%, 10%, 25% and 50% of PET partially replaced the sand in the concrete mixture. Two size ranges of PET were used in the replacement which include 2mm to 1.18mm and 1.18mm to 600µm. The compressive strength of various concrete mixes including varying percentages and sizes of PET will be studied in this chapter. Additionally, the workability of concrete mixtures and concrete density were explored.

Slump Test

Slump tests were conducted to determine the workability of the concrete mixtures. Throughoutthis procedure, the relationship between the control mix and the concrete mixtures that partially replaced by different percentages and size ranges of PET can be determined

Figure 1: Comparison of Slump (mm) between Control Mix and Partially Replacement of 2mm-1.18mm PET.

Figure 1 which showed the bar chart of slump readings for the slump test for control mix and the concrete mixes that replace with various percentages of 2mm to 1.18mm of PET which prepared to be cured for 7 days and 28 days. This comparison is necessary to detect the pattern on how the workability of the concrete behave. The design slump range was specified to be 30-60 mm. The slump test was carried out for each mix after the concrete mixing process and all of the slump values obtained were true slumps. By referring to the slump test results, it can be said that the 5% PET mix had the same workability as the control sample but the workability increased when the percentage of PET increased starting at 10% until 50% of PET replacement in the mixture. Based on Suryakanta (2019), smooth surface of aggregate gives a poor bond while a rough texture aggregate shows a good mechanical bond with cement. Thus, the increment of workability of concrete mixture with the increasing of PET replacement percentage was due to the smooth surface of the PET aggregate since smooth surface cannot generate stronger bond between the cement past and aggregate as how a rough surface fine aggregate did.

Figure 2 showed the slump readings and bar chart for the slump test for control mix and the concrete mixes that replace with various percentages of 1.18mm to 600µm of PET which prepared to be cured for 7 days and 28 days. The design slump range was also specified to be 30-60 mm and any values outside of this range will consider failed. The concrete 5% PET mix had the lowest workability compared to the control sample and other percentage of PET replacements of smaller size range of PET had a greater surface area ,so more cement was used to cover the entire surface of aggregates resulting in lower workability.The workability only started to become higher when the PET replacement reached 25% and 50 % PET mixes result in highest workability.

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Figure 2: Comparison of Slump (mm) between Control Mix and Partially Replacement of 1.18mm-600um PET.

By comparing the results in Figure 1 and 2, the workability of concrete mix was affected by the sizes and the surface texture of PET aggregate. The larger sizes of PET aggregate as well as PET aggregate with a softer surface texture compared to sand resulted in improving the workability of concrete mixes.

Density Test

According to Figure 3, it can be concluded that the control mix samples were denser than other mixes that contained PET in either samples that prepared for testing at 7 or 28 days of curing age.By referring to Alexander & Mindess (2019), the concrete that had the density between 2100 to 2500 kg/m^3 can be classified as ordinary or normal weight concrete and 1450 to 1900 kg/m^3 can be known as structural lightweight concrete. Therefore, the control, 5% PET, 10% PET and 25% PET mixes can be known as normal weight concrete while 50% PET mix is structural lightweight concrete

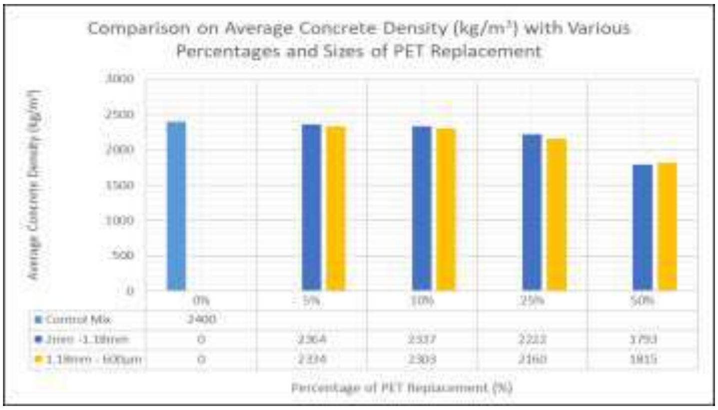

Figure 3: Comparison on Average Concrete Density (kg/m^3) with Various Percentages and Sizes of PET Replacement.

According to Material Properties ORG (2021), the density of PET is 1350 kg/m^3 while sand have a density of 1500 kg/m^3 showed PET was less dense than sand. Hence, the concrete with higher percentage of PET will give low density as plastic is lighter compared to the typical sand that used in concrete production. In addition, smaller size range of PET also resulted in lower density since the smaller size PET is lighter than the larger one. The 50% PETmix had the lowest as-received dry unit weight of 1793 kg/m^3 for PET size 2mm to 1.18mm and 1815 kg/m^3 for PET in the size of 1.18mm to 600µm.

Compressive Strength Test

The main objective of this research was to study the compressive strength of concrete containing various percentages and size ranges of PET then compare them with the compressive strengthof the control sample. The concrete samples were cured for a period of 7 and 28 days before being removed from the curing tank for testing on compressive strength. The designation compressive strength of control mix concrete is 25MPa at 28 days and there were a total numberof 54 100mm x 100mm concrete cubes to be tested in this research (27 cubes for both 7 and 28days).

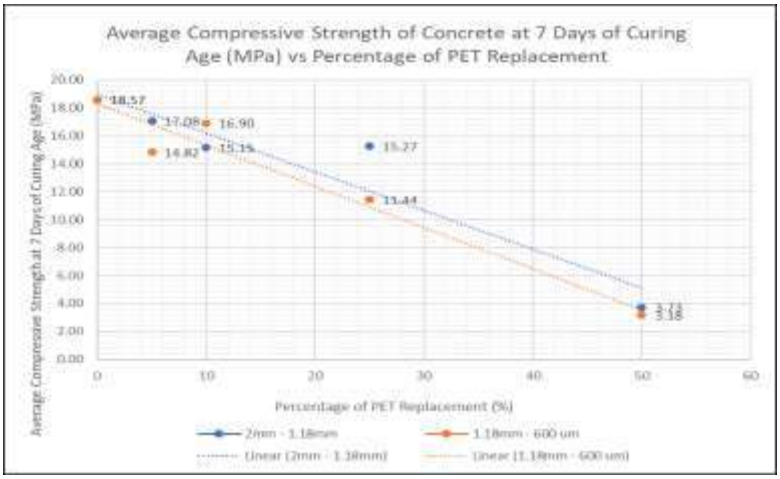

Figure 4: Average Compressive Strength of Concrete at 7 Days of Curing Age (MPa) vs Percentage of PET Replacement

At 7 days of curing age, 27 concrete cubes were tested and the results obtained can be referred to Figure 4. The highest compressive strength of concrete that achieved at 7 days of curing ageis the control sample giving 18.57 MPa. The mixes that contained larger size range of PET, 2mm to 1.18mm have a better performance under compressive strength compared to the smallest size range of PET in 1.18mm to 600µm. According to Jamal (2017), sharp and rough aggregates have a higher surface-to-volume ratio and smaller aggregates can fill up most of the void in the concrete mixes, resulting in better bond characteristics. By right, the smallest size of particle will give better interaction of bonding between the cement and aggregate contain inthe mixtures, but due to the smooth surface, flaky and elongated shape of 1.18mm to 600µm PET it resulted to lower strength compared to the 2mm to 1.18mm PET that had sharp edges andrough texture which created strong bonding in the mixture.

As the percentage of PET replacement in the concrete mixture increased, the compressive strength of the concrete became weaker. For 5% PET mixes the compressive strength acquiredis 17.08 MPa for the replacement using 2mm to 1.18mm PET and 14.82 MPa for 1.18mm to 600µm.

10% PET mixes have the strength of 16.90 MPa and 15.15 MPa, 25% PET mixes give 15.27 MPa and 11.44 MPa while 50% PET mixes show 3.73 MPa and 3.18 MPa in respectiveof 2mm to 1.18mm and 1.18mm to 600µm of PET sizes. The average optimum compressive strength of the concrete with the replacement of PET in mixture at 7 days of curing age is 17.08 MPa obtained from the 5% of 2mm to 1.18mm PET mix.

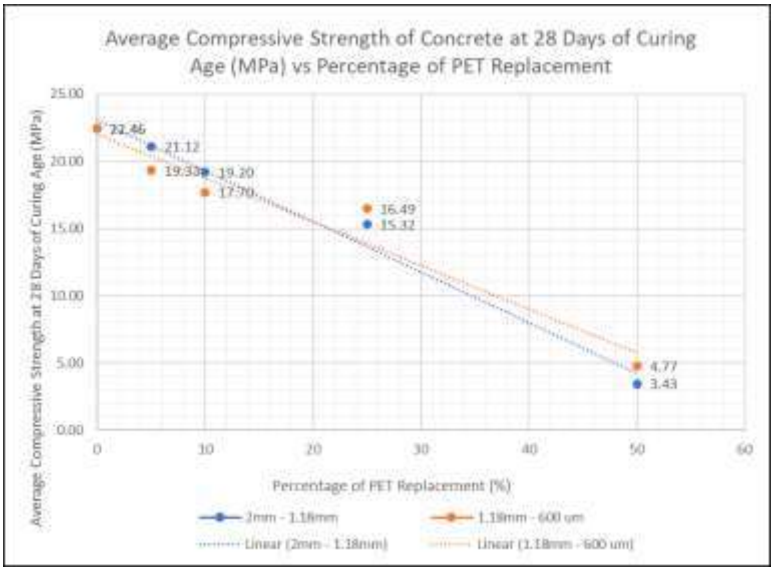

Figure 5: Average Compressive Strength of Concrete at 28 Days of Curing Age (MPa) vs Percentage of PET Replacement.

Besides testing on 7-day of curing age, concrete specimens also had been tested on 28th day as the concrete achieve 99% of its strength. At 28 days of curing age, 27concrete cubes were tested and the results obtained can be referred to Figure 5. The control sample reached the highest compressive strength among the concretes at 28 days of curing age give 22.46 MPa but it achieved the designation compressive strength of control mix concrete of 20 MPa at 28 days. The control mixes obtained an average of 22.46MPa. Based on (Krasna et al., 2019), coarse aggregate plays an important role in concrete production as its properties determine the strength of concrete. This indicating the significant of the mix proportion are suitable and are set to test for replacement. When compared to the smallest size range of PET in 1.18mm to 600mm, the mixes that comprised a larger size range of PET, 2mm to 1.18mm, performed better under compressive strength. Because of the smooth surface, flaky, and elongated shape of 1.18mm to 600mm PET, it has lower strength than 2mm to 1.18mm PET, which has sharp edges and rough texture and hence creates strong bonding in the combination.

Most of the results obtained showed the increasing in compressive strengthfrom 7 days to 28 days of curing age except for the results on 50% of 2mm – 1.18mm PET replacement showed a decrement from 7 days 3.73 MPa to 28 days 3.43 MPa. This is expected due to the bonding between PET and aggregates showed the surface of the materials were weaker compared to the controlled sample. The 50% replacement have shown the declining results which leads to a conclusion in which by replacing the fine aggregates with waste materials are not suitable.

CONCLUSION

In conclusion, the smooth surface of PET plastic increased the workability of concrete containing it, resulting in a weaker bonding between the cement paste and the coarse aggregate.The workability of the mixtures improved as a result of this situation. The concrete with higher percentage of PET will give low density as plastic is lighter compared to the typical sand that is used in concrete production. In addition, smaller size range of PET also results in lower density since the smaller size PET is lighter than the larger one. For 5%, 10%, 25% and 50% of 2mm to 1.18mm PET concrete mixes, the compressive strength decreased by 6%, 14.5%, 31.8% and 84.7% respectively, compared with the control mix at 28 days of curing. While for 5%, 10%, 25% and 50% of 1.18mm to 600μm PET 75 concrete mixes, the compressive strength decreased by 13.9%, 21.2%, 26.6% and 78.8% respectively, compared with the control mix at 28 days of curing. Apart from that,the compressive strength decreased as the proportion of PET in concrete increased compared to the control mix. The optimum compressive strength for the concrete with the partialreplacement of PET is archived by 5% of PET replacement in the PET size range of 2mm to 1.18mm giving 17.08 MPa and 21.12 MPa respectively for 7 and 28 days of curing age. A feasibility study should be completed on the use of plastics as partial replacement for sand in concrete production should be undertaken, particularly in terms of economics where the costs of sand and shredded plastic are compared, as well as the provision of significant areas of land for plastic waste disposal.

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