International Journal of Infrastructure Research and Management
Vol. 11 (S), September 2023, pp. 41 - 49

A STUDY ON POLYETHYLENE TEREPHTHALATE (PET) AS PARTIAL REPLACEMENT OF FINE AGGREGATE IN CONCRETE MIXTURE

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ABSTRACT

A major concern in today world is the growth of construction sector which leads the demand of construction material such as cement and aggregate to increase rapidly. As aggregate is non- renewable resource, the continuous of mining and quarrying activities will create more negative effect to the environment and shortage of aggregate in the future. In addition, polyethylene terephthalate (PET) is one of the most widely used plastics in the world, especially in the production of containers for beverages. However, after single use, most PET bottles used as beverage containers are thrown out and activities such as landfill and incineration take place on the management of disposed PET bottles. Therefore, PET as a replacement of aggregate is a mutualism solution that can solve both of the problems. The aim of this research is to determine the effects of polyethylene terephthalate (PET) as partial replacement of fine aggregate in concrete mixture. In all, 15 past studies between 2012 and 2021 were reviewed and discussed based on the findings on workability, density and compressive strength of concrete, and the replacement ratios of vary from 5% up to 60% by volume. It was found that the workability, density and compressive strength on concrete with partial replacement of polyethylene terephthalate (PET) as fine aggregate showed that there was a reduction in term of these three parameters as the replacement of PET as fine aggregate increases. However, two researchers observed that at 5% of replacement level gives a positive effect on the compressive strength of concrete.

Keywords:
Fresh Properties; Mechanical Properties; Recycled Plastic; Polyethylene Terephthalate; Fine Aggregate; Partial Replacement.

INTRODUCTION

Concrete is the most commonly used construction material worldwide which consists of four fundamental ingredients: cement, coarse concrete, fine aggregate and water. Estimated usages of concrete are up to 11 billion metric tons each year (Umasabor & Daniel, 2020). The general ratio of concrete is 1:2:4 which represent cement, fine aggregate and coarse aggregate; hence concrete consists approximately 85% of aggregates. In conjunction with this, aggregate materials are the most extracted natural resources in the world and the multinational construction industry consumed the equivalent of RM1.45 trillion in 2018 alone. Extraction of aggregates has changed the very essence of rivers and other natural ecosystems and may have major adverse social impacts in the area or country. In addition, Polyethylene Terephthalate (PET) is a type of plastic waste which is increasing directly proportional to human waste. According to Waste Atlas (2013), plastic is occupying 9.27 % in average global waste composition.

In Malaysia, the composition of plastic waste is the second highest in the overall generated waste (WWF Malaysia, 2020). Despite that, the plastic waste problem is causing the scarcity of landfill in the coming years. Recycling the PET waste in the form of construction material as a substitute for aggregates in concrete is one of the methods to minimize the effect on the environment and cut the cost of disposal (Adnan & Dawood, 2020). The possibility of replacing aggregates with PET can develop a new market for PET post- consumer and also provide an alternative option of material selection in construction industry. Therefore, the suitability of PET as a substitution of aggregates in concrete has to be studied. This paper will contribute to the community as a whole and

ISSN Print: 2811-3608
ISSN Online: 2811-3705
https://iukl.edu.my/rmc/publications/ijirm/
DOI:10.63646/j.jdsti.202311SI05

towards individual, including us, the researchers. Data produced from this paper will be used to show comparison and to serve as a future reference for researchers on the subject of plastic waste in concrete and how it can improve the environment, industries and mankind.

The objective of this paper is to determine the effects of PET on the workability, density and compressive strength of concrete. Hence, summarization of previous research that has been conducted on using Polyethylene Terephthalate (PET) as a partial substitution of fine aggregate in concrete mixing between 2012 and 2021 were reviewed and discussed in this paper. In all, 15 studies were been studied, and the replacement ratios vary from 5% up to 60% by volume. Besides, this paper also presents the performance of different percentage of PET as fine aggregate replacement in workability, density and compressive strength of concrete based on each researcher's findings as well as the optimum percentage of PET in concrete.

LITERATURE REVIEW

Concrete is essentially a mixture of cement, coarse aggregate, fine aggregate and water. Apart from these basic constituent materials, admixtures are often added to the concrete mix to alter its properties. Fresh concrete, obtained by mixing these materials is workable and can be molded into various forms and shapes. This unique characteristic of concrete gives it the flexibility necessary to construct wide range of structures (Adel et al., 2014). Furthermore, cement undergoes a chemical reaction with water within a few hours of mixing, forming a hardened paste. This reaction is commonly known as the hydration of cement. The characteristics of fresh and hardened concrete are determined by the form and proportion of the constituent materials used in the concrete mix, the handling and positioning of the mix, and the curing of the concrete structure after being cast (Sivakugan et al., 2018).

Polyethylene Terephthalate (PET)

Polyethylene Terephthalate is a thermoplastic polymer for general purposes which belongs to the polymer polyester family. Polyester resins are known for their exceptional combination of mechanical, thermal, chemical resistance and dimensional stability properties. Other properties of PET are shown in Table 1. Islam et al., (2016) stated that in its natural form, PET is a semi- crystalline, highly flexible and colorless resin. It can be semi-rigid or rigid, depending upon how it is processed. It also shows great dimensional stability, impact resistance, chemical and solvent resistance. PET can be processed to fibers, fabrics and food packaging films. PET has been used as a container resin since 1997. Since then, due to its properties and comparatively low cost, the use of PET has continued to expand.

Table 1: Properties of PET material (Askeland & Wright, 2016)

Material	PET
Density (kg/m^3)	1320 – 1340
E (GPa)	2.2 – 2.5
Tensile Strength (MPa)	55
% Elongation	300
Impact Strength (J/m^2)	2

Problem of Plastic Waste

The development of plastic has outpaced that of virtually any other material since the 1950s. Many of the plastic products we make are meant to be thrown out after being used only once. As a result, plastic packaging accounts for nearly half of the globe's plastic waste. Out of 9 billion tons of plastic worldwide, only 9% of the plastic produced has been recycled. Others eventually end in dumps, landfills or in the ecosystem. If current use rates and waste management policies persist, then there will be about 12 billion tons of plastic debris in landfills and the ecosystem by 2050 (Waste Atlas, 2013). Despite that, Recycling and management of plastic waste are amongst the priority activities of environmental protection. A large portion of overall pollution is compensated for by plastic which has contaminated the earth. In natural conditions, plastics takes 400 – 500 years to decompose (Belmokaddem et al., 2020). For recycling, the most commonly used plastic contaminants should be considered, such as PET bottles and PE bags. Besides, there is also a poor recycling rate for plastic waste that greatly adds to environmental pollution. Therefore, in different uses such as acting as aggregate in concrete, plastic waste should be used. (Saikia & Brito, 2012).

METHODOLOGY

Methodology used for this research is review method in which will be carried out to evaluate the performance of PET as fine aggregate replacement in various ratios against controlled concrete. Review method is a collection and summarization of all empirical evidence approach to research in which one or more variables are changed by the researcher and any change in other variables is observed and evaluated.

Data Collection

In this paper, the experimental data were collected from relevant past articles which has been studied by previous researchers. In all, 15 past articles that has been conducted on using Polyethylene Terephthalate (PET) as fine aggregate in concrete mixing between 2012 and 2021 were collected and discussed in this research. Moreover, the collection of experimental data from past articles were in terms of replacement ratio of Polyethylene Terephthalate (PET) as fine aggregate in concrete mixing, workability and density of concrete, and concrete compressive strength.

Data Analysis

All of the data which have been collected from 15 past articles were evaluated in Microsoft Excel. The collected data were combined together and plotted in a line graph based on three types of tests; workability (slump test), density test and compressive strength test which have been conducted by previous researchers. Overall, the plotted line graphs in this paper were the workability against replacement ratio, density against replacement ratio and compressive strength against replacement ratio.

RESULTS AND DISCUSSION

Workability of Concrete

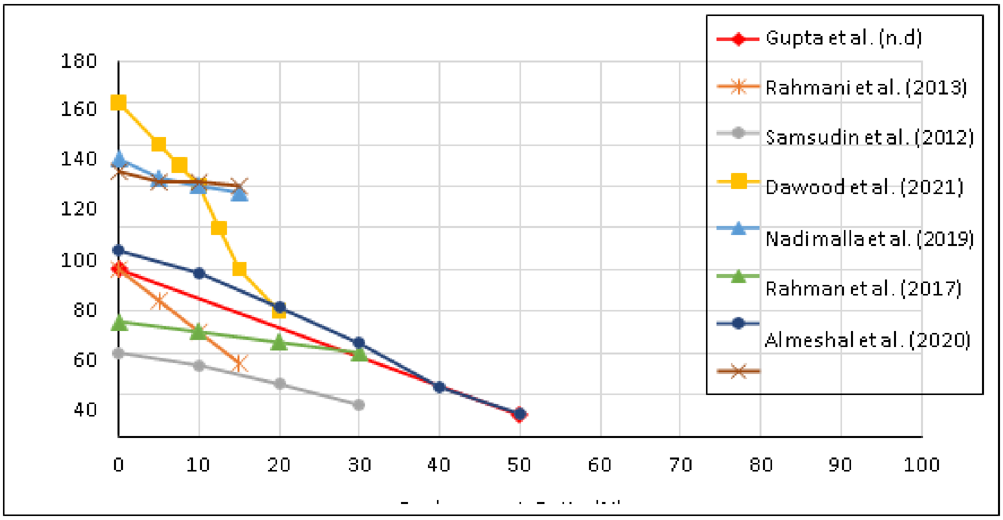

Figure 1: Variation of concrete workability with different replacement ratios of PET as fine aggregate.

Slump test was performed to determine the workability of concrete. From 15 past articles, 8 of them have performed the slump test. In all of the studies as shown in Figure 1, increasing the replacement ratio of PET as fine aggregate leads to a decrease in the slump of fresh concrete. According to Nadimalla et al. (2019) research, they analyzed when replacing 5%, 10% and 15% of fine aggregate with PET particle, the slump of concrete mixtures decreased 6.8%, 9.8% and 12% respectively compared with the slump from the controlled concrete mixture which was similar to Rahman et al. (2017) research. This is because compared to the natural sand, PET particles have a more precise surface area due to their particles shape. Thus, there will be more friction between the particles in the mixtures which leads to less workability.

Dawood et al. (2021) reported that slump values of concrete mixture containing PET as replacement of fine aggregate with 0-20% ratios was occurred in a huge reduction rate when compared with other researchers. At 15% of replacement ratio, the slump reported was reduced by 50% as compared to the slump obtained from controlled concrete mixture. Also, at 20% of replacement ratio, the slump obtained was decreased by 62.5% compared with the slump from the controlled concrete mixture. The authors ascribed this behaviour to the fact the PET particles which have irregular shapes and sizes that were not round as the natural sand. Furthermore, Almeshal et al. (2020) and Gupta et al. (n.d) observed that slump reduced 88% and 87.5% respectively for a concrete mixture containing 50% of PET replaced as fine aggregate when compared with the slump obtained from controlled concrete mixture. Additionally, concrete mixtures with different specific weights of particles may cause segregation problem and poor consistency of mixture, especially light particles such as PET. This problem was raised by authors who discussed the use of PET as fine aggregate in concrete mixing. They also stated that to prevent segregation problem, PET particles should be coated with a hydrophilic chemical type coating. (Almeshal et al., 2020; Gupta et al., n.d). Besides, several researchers advocate the use of superplasticizer to improve the workability for concrete mixture which containing PET particles (Dawood et al., 2021; Saikia & Brito, 2014; Rahmani et al., 2013).

Density of Concrete

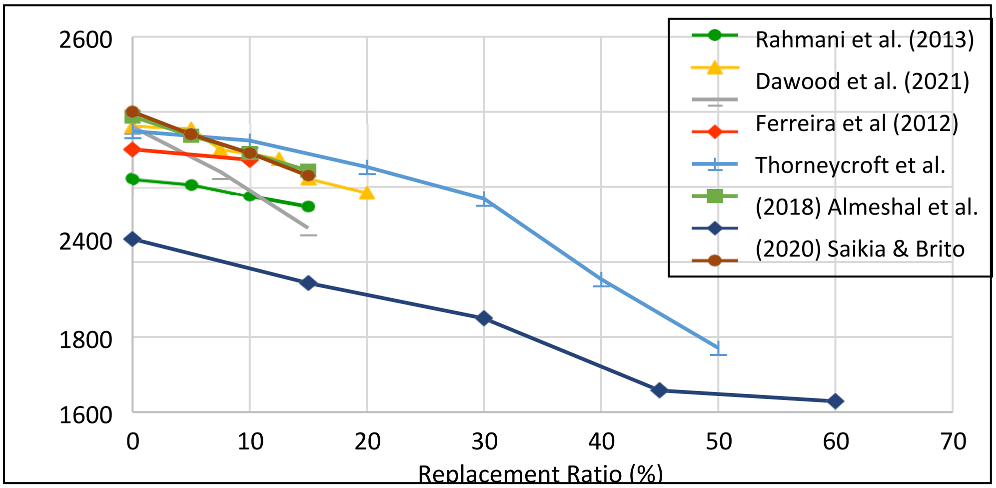

Figure 2: Variation of 28-days concrete density with different replacement ratios of PET as fine aggregate.

The low density of Polyethylene Terephthalate (PET) leads to a reduction in density of concrete. The replacement of PET as a fine aggregate generally decreases the density of concrete regardless of the ratio of the replacement. Figure 2 presents the results obtained from previous studies; 8 out of 15 previous studies have conducted the density test on hardened concrete at 28 days of age. The density of concrete decreases as the replacement ratio of PET as fine aggregate increases. Saikia & Brito (2014) reported the density of concrete with 5% of replacement ratio of PET was 2336 kg/m3 and with 10% of replacement ratio of PET was 2290 kg/m3. Hence, the density of controlled concrete was 2387 kg/m3. It was proved that the 5% and 10% replacement ratios of PET as fine aggregate were affecting the density of concrete to decrease by 2.1% and 4.1% respectively. Similar to Dawood et al. (2021) research, they observed when replacing 10% and 15% of fine aggregate with PET particles, the density of concrete reduced by 3.7% and 5.9% respectively compared to the controlled concrete.

Besides that, Rahmani et al. (2013) observed that the density of concrete not significantly decreased when fine aggregate was replaced with PET particles. At 5%, 10% and 15% of replacement level of PET decreases the density by 0.7%, 2.1% and 3.3% respectively compared to the controlled concrete. Despite the outcomes obtained from the density of concrete containing PET particles as fine aggregate, all of the previous studies stated that the specific gravity of PET particle is more lesser compared to specific gravity of natural fine aggregate. Thus, resulting in the reduction of the weight of produced concrete which concluded that the density of concrete was continuously decreases as the replacement ratio of PET as fine aggregate increases.

Compressive of Concrete

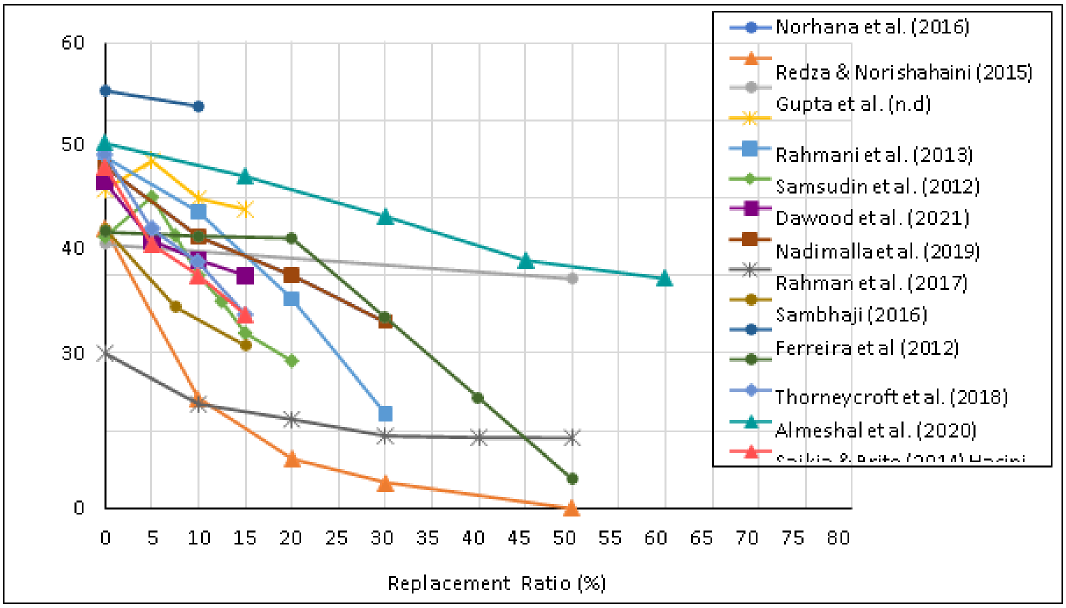

Figure 3: Variation of 28-days concrete compressive strength with different replacement ratios of PET as fine aggregate.

Compressive strength is perhaps the most important of the many parameters that evaluate concrete performance. The quality of concrete is often assessed based on compressive strength. Several parameters such as the Polyethylene Terephthalate (PET) particles shapes and sizes, and water to cement ratio may influence the compressive strength of PET concrete. Figure 3 shows the outcomes collected from all of the 15 previous studies which indicate the effect of PET on the compressive strength of concrete as a fine aggregate at 28 days of age. Also, the figure presents that all studies resulted that the compressive strength of concrete decreases as the replacement ratio of PET increases.

Redza and Norishahaini (2015) observed that the compressive strength of concrete resulting in a major reduction when the replacement ratio of PET as fine aggregate increases. The compressive strength of concrete decreased by 60.4% as compared to the controlled concrete when 10% of fine aggregate replaced with PET. At 20%, 30% and 50% of replacement level, the compressive strength of concrete reduced by 82.1%, 90.6% and 100% respectively compared to compressive strength obtained from the controlled concrete. Their findings have declines more significantly than findings from other researchers. This is due to the PET particles they used were non-uniformly shaped. In addition, large flaky PET particles reduced compressive strength more drastically than small flaky PET particles. Moreover, in Ferreira et al. (2012) studies, the concrete compressive strength was decreased by 27.8% and 41.7% at 7.5% and 15% of replacement level. They stated that this problem which were the PET particles will not interact with cement paste unlike natural aggregates, therefore the interfacial transition zone (ITZ) in concrete containing PET particles is weaker compared to the controlled concrete, which decreases the resulting compressive strength.

However, Rahmani et al. (2013) observed that the compressive strength of concrete containing 5% replacement ratio of PET particles as fine aggregate increased and gradually decreases as the replacement ratios of PET increases. At 5% of replacement level, the compressive strength of concrete increased by 8.9% when compared with the controlled concrete samples. But after increasing the replacement level to 10% and 15%, the compressive strength started to reduce by 11.7% and

15.18% respectively compared to the controlled concrete samples. The authors mentioned that the uniformly shaped and sized PET particles used in the concrete may give a positive effect on the concrete compressive strength in small ratio of replacement. Furthermore, Dawood et al. (2021) also reported that when replacing 5% of PET as fine aggregate in concrete leads to an increase in the concrete compressive strength. The compressive strength of concrete increased by 14.6% which was 40.1 N/mm2 as compared to compressive strength of 35 N/mm2 obtained from the controlled concrete. Besides, at 7.5% of replacement ratio, the compressive strength has no significant change when compared with the controlled concrete. They explained that the structure of the PET particles is affected by the mode of failure when the applied load approaches the ultimate load which means the internal stresses are transferred from shear stresses to tensile stresses, which increasing the concrete strength.

CONCLUSION

The workability of concrete containing PET particles which conducted in slump test was reduced due to the increased surface area of PET particles, and its irregular shape and size results in stiff concrete which is difficult to handle.

The density of concrete values of concrete containing PET particles was lower than the those of conventional concrete due to the light specific gravity of PET particle, which resulting in the reduction of the weight of the produced concrete.

As the replacement ratio of PET particle increases, the compressive strength values of concrete decreases. This trend can be ascribed to the reduce in adhesive strength between the surface of the PET particle and cement paste. However, some researchers found that concrete containing small amount of PET particles helps in increasing its compressive strength. They discussed that the structure of the PET particles is affected by the mode of failure when the applied load approaches the ultimate load (the internal stresses are transferred from shear stresses to tensile stresses, which increasing the concrete strength.

The optimum percentage of PET in concrete as fine aggregate was 5% replacement level. In fact, for 5% of PET content, the average reduced percentages obtained from workability, density and compressive strength of concrete were 9.8%, 1.4% and 8.8% respectively compared to controlled concrete. On the other hand, with further increase of PET contents, the parameters were decreased even more. Besides, in Rahmani et al. (2013) and Dawood et al. (2021) researches, they observed that 5% of PET content attributed to a positive slope of an average increment of 11.5% in the compressive strength.

Eventually, it can be justified that waste PET bottles in the form of particles can be reused as a partial replacement of fine aggregate in concrete technology. There would be an improvement in physical and mechanical properties of concrete d it also can be an environmentally friendly solution for waste PET bottles.

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