SUSTAINABLE WASTE MANAGEMENT OF POLYETHYLENE TEREPHTHALATE (PET) AND RUBBER CRUMB IN CONCRETE

[1]NORHANA A.R., [2]KARTINI. K., [3]HAMIDAH M.S.

[1,2,3]Faculty of Civil Engineering, Universiti Teknologi Mara, Shah Alam, Malaysia
E-mail: [1]ann_trace@yahoo.com, [2]ce_kartini@yahoo.com, [3]hamid929@salam.uitm.edu.my

Abstract- Several recent studies have been conducted to investigate the possibility of waste materials in construction building especially Polyethylene Terephthalate (PET) and rubber crumb. From the studies, there is a wide range of possible civil engineering applications for these waste materials. In this context, this research was conducted to provide more data on the combination of both waste materials to be used as partial replacement in concrete. The performances of the concretes were assessed through its compressive strength, water absorption and skid resistance. The fine aggregate was replaced by PET and rubber crumb at 10%, 20% and 30% by weight of binder and tested for 7, 28, 60 and 90 days of curing. The results showed that by increasing the replacement of PET in higher proportion (up to 20%) and rubber crumb (up to 10%) the compressive strength of concretes decreasing. While, the water absorption of concretes increased with the increased of PET and rubber crumb replacement. For skid resistance, RC concrete were higher compared to control, rubberized-PET and PET concretes. The main findings of this investigation revealed that these waste materials could be used successfully as partial replacement for fine aggregates in concrete production.

Keywords- Polyethylene Terephthalate, Rubber Crumb, Waste Materials, Partial Replacement, Fine Aggregate.

I. INTRODUCTION

The concrete construction has been increased due to increasing demand of infrastructure development [1]. The use of aggregate as constituent in concrete production leads to a question about the sources of the natural aggregate since the process of manufacturing and producing the sand caused many environmental problems. Besides, the high cost of manufacturing process affects the housing cost in Malaysia either in rural or urban area [2]. Thus, researches into new and innovative uses of waste materials as partial replacement to fine aggregate are continuously advancing. Several studies have already confirmed the viability of waste materials in Portland cement give benefits in terms of durability, versatility and reduce the costs [3]-[4]. Besides, the productive use of waste materials is one of the ways to alleviate some of the problems of solid waste management [5]-[7].

In recent years, one of the most crucial environmental issues talked about all around the world is the disposal of plastic bottles and rubber tires. According to Waste Management Association of Malaysia [8], in 2011, the statistics of waste plastics and rubber were 12.4% and 8.4% respectively. The growing amount of waste plastic bottles and rubber tires resulted in environmental problems and represents a waste of useful resources. The accumulations of discarded waste tires have been a major concern because the waste rubber is not easily biodegradable even after a long period of landfill treatment. The motorcar waste tyres generated annually in Malaysia was estimated to be 8.2 million or approximately 57, 391 tonnes and about 60% of the waste tyres are disposed via unknown routes [9]. The disposal of plastic wastes has harmful effects on the environment due to their long biodegradation period. Researchers found that plastic can remain on earth for 4500 years without degradation [10]. Prior to the researches investigated, Bulent et al., [11] revealed that polyethylene terephthalate (PET) bottles and scrap automobile tires can be extensively recycled and reused in concrete. However, the research on the combination of PET and rubber crumb as fine aggregate replacement in concrete is still lacking. Therefore, this investigation intended to obtain the some properties of PET and rubber crumb in concrete.

II. TEST METHODS

2.1. Material Preparations

The PET (mineral water bottles without caps and plastic labels) and RC were obtained from a factory in North Port Klang. The PET is a residue produced from shredded plastic bottles and the size of PET used was up to 5 mm. The RC is manufactured by a special mill where scrap rubber tire is grinded and screened into smaller size of particles. The size of RC used was up to 5 mm. The other materials used in the concrete mixture were Ordinary Portland cement (OPC) Type 1. The fine aggregates used was mining sand with maximum size of 5mm, while the coarse aggregate used was crushed granite passing through 20 mm and retained on 10 mm sieve. The RC was soaked into 0.1N Sodium Hydroxide (NaOH) for 20 minutes to increase the hydrophilicity of the rubber particle surface. The RC later was filtered and air dried at ambient temperature before added into the concrete mixture. The tap water free from contamination was used for the mixing and curing purposes.

2.2. Mix Proportions

In brief, the PET concrete, RC concrete and rubberized-PET concretes were assessed by compressive strength, water absorption and skid resistance tests. Sixteen (16) series of blended specimens which comprises of three (3) different replacement levels of PET and RC, that are 10%, 20%, and 30% were prepared using 0.5 w/b ratio and kept constant in all the mixes. The series for 10%, 20% and 30% replacement of fine aggregate with PET and RC were designated as 10P, 20P, 30P, 10R, 20R and 30R respectively. Control concrete specimens were also be prepared to be used as reference point to compare the rubberized-PET concrete. The concrete mix was designed by using DOE method [12]. For other materials used, the amount depends on the replacement of PET and RC to fine aggregate.

2.3. Sample Preparations

Size of cube specimens used was 100x100x100 (mm^3) for compressive strength and prism size of 500x100x100 (mm^3) for skid resistance test, while 50 mm ø x 100 mm for water absorption test were used. All concrete specimens were placed in water curing tank at room temperature and the specimens were taken out for testing at 7, 28, 60 and 90 days. The method and procedure used for curing are in accordance to BS EN 12390-2:2000 [13].

III. TEST METHODS

3.1. Sieve Analysis

The grading curves of the fine and coarse aggregate conform and satisfied the grading requirement of BS EN 12620:2013 [14]. This is important as well aggregates can reduce the quantity of water and cement in concrete mix, whereby the smaller particle can fill the voids between the large particles. The fineness modulus of fine aggregate obtained was 3.45 which describes that the fine aggregates were mainly of 600 µm size. While, the fineness modulus of the coarse aggregate was found to be 3.26. It means that the coarse aggregate used in this study is of an average size of 14 mm.

3.2. Slump Test

Slump test on the fresh concrete was conducted to determine the workability of the concrete which was in accordance to BS EN 12350-2:2000 [15]. The slump values obtained were shown in Fig. 1.

3.3. Compressive Strength

The compressive strength test was conducted on the control, PET, RC and rubberized-PET concretes as in accordance to BS EN 12390-4:2000 [16]. The test was conducted on the cube specimens taken at ages of 7, 28, 60 and 90 days of water curing.

3.4. Water Absorption

The measurement of the water absorption was determined based on BS 1881-122:2011 [17]. At the age of 7, 28, 60 and 90 days, the cylindrical specimens of 50 Ø by 100 mm height were oven dried to constant mass at 105 ± 5 ºC for 72 ±2 hours. The specimens were stored in the air-tight containers before subjected to test. The specimens were immersed in water for 30 minutes, 60 minutes, 120 minutes and 240 minutes.

3.5. Skid Resistance

The skid resistance test was conducted in accordance to the requirement of BS EN 13036-4:2011 [18]. The test value obtained, is the mean of five readings taken on the prism specimens.

IV. RESULT AND DISCUSSION

4.1. Workability

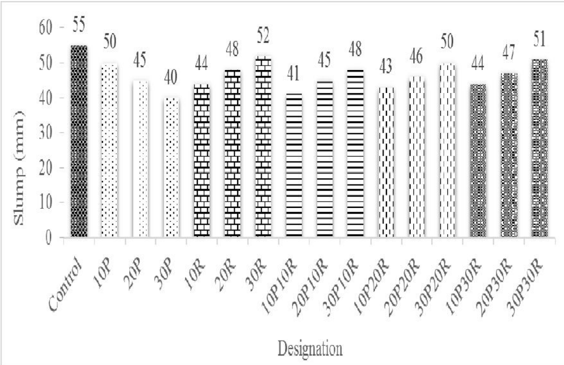

Fig.1. Slump values for control, PET, RC and rubberized-PET fresh concretes

In this study, the values of slump were determined as an indication of workability of fresh concrete. Fig. 1 shows the slump values of concrete containing PET and RC as partial replacement of fine aggregate. Based on the result, it shows that the values of slump for all mixes are within the slump design. It shows that the increasing of percentage replacement level of PET and RC affected the workability of the concrete. The slumps decreased as the replacement level of PET increased. This reduction can be attributed to the fact that PET have non-uniform shapes resulting in less fluidity. The slumps obtained for control mix was 55 mm. For 10P, 20P and 30P concretes mixes, the slump recorded 50 mm, 45 mm and 40 mm respectively. The past researchers [19], [20] have proven that the slump is prone to decrease sharply with increasing of the PET ratio. The inclusion of NaOH to the rubber crumb before mixing is to increase the hydrophilicity of the rubber particle surface. The slumps of RC increased as the replacement level of RC increased. The slump recorded for 10R, 20R and 30R stated as 44 mm, 48 mm and 52 mm respectively. Rubberized concrete has been found to be workable than conventional concrete as the rubber content increases. This is in line with Khatib and Bayomy [21] research work on rubberized concrete. Figure 2 shows the slump results for control, PET, RC and rubberised-PET fresh concretes.

4.2. Compressive Strength

Fig. 2 shows the compressive strength obtained from the control, PET, RC and rubberized-PET concrete taken at 28 days of curing. From the figure, it can be seen that the compressive strength of control concrete was higher compared to PET, RC and rubberized-PET concretes. This might be due to the fineness of fine aggregates which is higher compared to rubberized-PET particles thus resulted in higher strength. Studies conducted by past researchers [22], [23] indicated that the fineness of the material have some influenced in which it increases the compressive strength of hardened concrete. For the control concrete the compressive strength was 44 N/mm^2. The compressive strength of 10P, 20P and 30P were 35 N/mm^2, 30 N/mm^2 and 24 N/mm^2 respectively. Thus, it can be concluded that increased the PET replacement resulted in reduction in compressive strength. For 10R, 20R and 30R the compressive strength were 33 N/mm^2, 26 N/mm^2 and 23 N/mm^2. It also shows that the increasing of RC decreased the compressive strength. A study conducted by Ghaly and Cahill [24] using different percentages of rubber in concrete (5%, 10% and 15%) by volume also noticed that the increased of rubber content leads to a reduction of compressive strength. Between PET and RC, it showed that the replacement with PET produced higher strength compared to RC. However, several authors mentioned that pretreatments of rubber waste such as with 10% NaOH saturated solution to wash the rubber surface can increased the adhesion between the cement paste [25], [26]. A study [27] confirmed that the immersion of rubber in NaOH aqueous solution improved the adhesion leading to a high strength performances of concrete rubber composites. For the combination of PET and rubber crumb in concrete, the compressive strength decreased with increased of PET and rubber crumb. For the replacement of 10%, 20%, and 30% PET with 10%, 20% and 30% RC, the compressive strength obtained ranges from 9 N/mm^2 to 13 N/mm^2, 5 N/mm^2 to 7 N/mm^2 and 3 N/mm^2 to 4 N/mm^2 respectively. It shows that for the combination of PET and RC as the replacement increased.

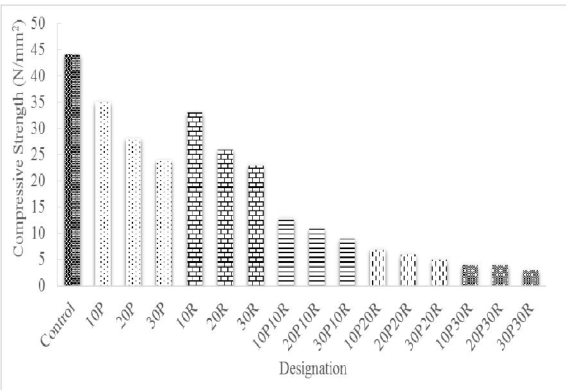

Fig.2. Compressive strength of control, PET, RC and rubberized-PET concrete taken at 28 days of curing

4.3. Water Absorption

Fig. 3 shows the percentage of water absorption obtained from the control, PET, RC and rubberized-PET concrete taken at 28 days of curing. From Fig. 3, it can be seen that the water absorption for control concrete was lower compared to PET, RC and rubberized-PET concretes.

The percentage of water absorption recorded was 4.47%. The percentage of water absorption of 10P, 20P and 30P were 5.18%, 5.34% and 5.6% respectively. For 10R, 20R and 30R the percentage of water absorption taken were 5.22%, 5.51% and 5.93% respectively. Meanwhile, for 10P10R, 20P10R and 30P10R were 6.15%, 6.54% and 6.85% respectively.

For the replacement of 20% RC, the percentage of water absorption for 10P20R, 20P20R and 30P20R were 7.3%, 8.14% and 8.11% respectively. While for the replacement of 30% RC, the percentage of water absorption for 10P30R, 20P30R and 30P30R were 9.12%, 9.46% and 9.77% respectively. These showed that the percentage of water absorption of rubberized-PET concretes was higher followed by rubberized concretes, PET concretes and control concrete.

This might be due to the particle size of PET and RC that influences the percentages of water absorption in concrete. Furthermore, the weight of fine aggregate passing 600 μm sieve was higher compared to PET and RC. According to sieve analysis, the weight of fine aggregate passing 600 μm sieve was 47.82 % while 43.94 % and 39.90 % for PET and RC respectively. A previous research (28) reported that, smaller size particles of fine aggregate make the particles to fill up the capillary pores structures that reduced water absorption in concrete, however in this study the particle size of PET and RC are coarser.

For the combination of rubberized-PET concretes, the percentage of water absorption increased with increased of PET and RC.

Thus, these showed that the durability of concrete decreased with increased of PET and RC percentages in rubberized-PET concrete. From the graph, it shows that water absorption for all mixes were higher than control mix concrete. Thus, too high RC content in concrete affected to water absorption in concrete as it restricted and unable for the cement paste to bond together that allow the increment of pores sizes.

However, the replacement of PET and RC with 10%, 20% and 30% for all mixes still achieved the required absorption of good quality concrete as the percentage of water absorption were below than 10% by mass. Neville [29] stated that for the performance of good quality concrete for water absorption should be less than 10% absorption by mass.

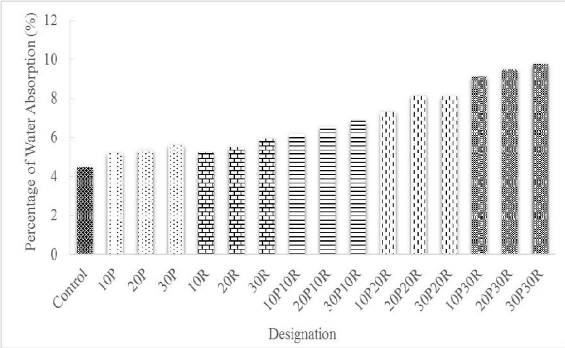

Fig.3. Water absorption of control, PET, RC and rubberized-PET concrete taken at 28 days of curing

4.4 Skid Resistance

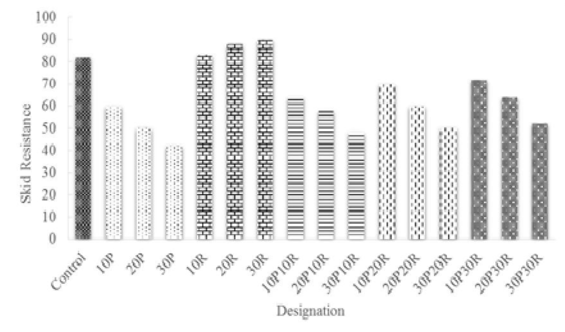

Fig.4. Skid Resistance of control, PET, RC and rubberized-PET concrete taken at 28 days of curing

From Fig. 4, it can be seen that the skid resistance recorded was 83, 88 and 90 for 10R, 20R and 30R respectively. It followed by control concrete which was 82. The skid resistance of 10P, 20P and 30P were 60, 50 and 42 respectively. Meanwhile, for 10P10R, 20P10R and 30P10R were 64, 58 and 48 respectively further increase the replacement of RC to 20%. The skid resistance for 10P20R, 20P20R and 30P20R were 70, 60 and 50 respectively. While for the replacement of 30% RC, the skid resistance for 10P30R, 20P30R and 30P30R were 72, 64 and 52 respectively. The skid resistance of RC concretes was higher followed by control concrete, rubberized-PET concretes and PET concretes. It was contributed by the rough surface texture of the specimens with RC in creating more friction as the pendulum passed across it. Thus, as an application to concrete pavements, RC concrete will provide more stable and durable mix for the flexible pavements. The serviceability and resistance to moisture will also be better compared to control concrete, rubberized-PET concretes and PET concretes. According to the value of skid resistance which were more than 65, it was classified as good and fulfilling the requirements even on of fast traffic [30].

CONCLUSIONS

The performance of Polyethylene Terephthalate (PET) and rubber crumb as fine aggregate in concrete was studied and major conclusions are as follows:

1. The replacement of fine aggregate with PET and RC at all replacement level reduced the compressive strength, however the strength increased with age of curing. The optimum replacement of PET and RC chosen were 20% and 10% each.
2. The degree of water absorption increases as the replacement of fine aggregate with PET and RC increases. However, all the values of water absorption taken at all curing days satisfy the requirements of good quality concrete i.e. less than 10% absorption by mass.
3. For the skid resistance, all the value satisfied the requirements of standard for pavements.

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