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The Combined Effects of Polyethylene Terephthalate and Rubber Crumb as Fine Aggregate in Concrete

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ABSTRACT

Currently, the need to incorporate recycled materials such as plastics and rubbers as replacements to raw materials is becoming more important than ever before. In this study, the combined effects of Polyethylene Terephthalate (PET) and rubber crumb (RC) as fine aggregate replacement in concrete are investigated. This study evaluated the mechanical (compressive strength and flexural strength) and durability properties (electrical resistivity and water absorption) of the concrete. The fine aggregate was replaced 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 RC (up to 10%) the compressive strength of concretes did decrease. The same trend followed for the flexural strength in which strength was reduced as the replacements level increased. The electrical resistivity increased with the increased of PET and RC replacement in concrete. Meanwhile, the water absorption of concretes increased with the increased of PET and RC replacement. Overall, the PET and rubber crumb can be utilized up to certain percentages in replacing fine aggregates in concrete.

Keywords: *Recycled Materials; Polyethylene Terephthalate; Rubber Crumb; Fine Aggregate; Partial Replacement*

1. INTRODUCTION

Solid waste management especially plastic bottles and rubber tires has been a major environmental concern around the world due to their large-scale productions and high demand in scale revolution. According to Waste Management Association of Malaysia [1], in 2013, the statistics of average waste composition generated in Malaysia for plastics and rubber were 39.1% and 3.4% respectively. The plastics and rubber-generated daily were about 585 metric tonnes and 229 metric tonnes respectively. The growing amount of waste plastics and waste rubber has resulted in an environmental crisis due to their disposal problems. Generally, they are disposed by landfill treatment. However, this practice of disposing is becoming unacceptable because of the scarcity of landfill sites. Since they are not easily biodegradable even after a long period of landfill treatment, the use of these waste material as partial replacement in concrete is an alternative to disposal. The modification attributed by these waste materials to factors such as versatility, ease of raw materials obtainment, low cost, ease of fabrication, high mechanical strength, impermeability to water, great durability and for sustainability [2]. Several researches have been carried out studies on the use of tire rubber particles [3-5] as aggregate in concrete or mortar as one of the efficient ways for solid

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management and sustainable development. Meanwhile, the use of waste polyethylene terephthalate particles as partial replacement of aggregate in concrete production is the most economical way of recycling [6-9]. In addition, the utilization of these waste materials in concrete resulting in saving of natural resources and preventing the environmental pollution [10-12]. Therefore, using recycled materials as replacements of construction materials is a highly preferable option. In responding to these matters, this paper highlighted the evaluation of mechanical and durability properties of concrete made of polyethylene terephthalate (PET) and rubber crumb (RC) as partial fine aggregate replacement in concrete. The outcome of this research will help the material engineers to recognize the potential of these waste materials and their use for real world applications.

2. EXPERIMENTAL METHODS

2.1 Material Preparations

The PET is a residue produced from shredded bottles. The PET used in the present research was obtained from Jupiter Previlege Sdn Bhd, North Port Klang. The RC was obtained from Yong Fong Rubber Industries, Port Klang. The RC is manufactured by a special mill where scrap rubber tire is ground and screened into smaller size of particles. The size of PET and RC used was fixed 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 aggregates used were cleaned from all inorganic impurities. 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 being added into the concrete mixture. The tap water free from contamination was used for the mixing and curing purposes.

2.2 Mix Proportions

Sixteen (16) series of blended specimens comprising three (3) different replacement levels of PET and RC, that are 10%, 20%, and 30% were prepared using 0.5 w/b ratio and this w/b ratio was 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. A controlled mixture of cement and fine aggregates without PET and RC was also produced to compare the results. The concrete mixture was designed using Design of Normal Concrete mixes method [13]. For other materials used, the amount depends on the replacement of PET and RC to fine aggregate. The strength behaviour of concretes was assessed by compressive strength and flexural strength tests while the durability behaviour was assessed by electrical resistivity and water absorption tests.

2.3 Sample Preparations

The size of cube specimens used was 100 mm for compressive strength and for electrical resistivity, prism size of 100x100x500 mm for flexural strength test, while a cylinder of 50 mm diameter by 100 mm height for water absorption test were prepared. All concrete

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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 procedures used for curing are in accordance to ASTM C192/C192M-16A [14].

3. TEST METHODS

3.1 Sieve Analysis

The sieve size used to determine the particle size distribution of aggregate has square openings and the test sieve size was according to BS EN 933-1:2012 [15]. The results of the sieve analysis were drawn in grading curve and the curve is compared with that as stipulated in ASTM C136/C136M-14 [16]. The grading curves of the fine and coarse aggregate used confirmed and satisfied the grading requirement of ASTM C136/C136M-14. This is important as well graded aggregates can reduce the quantity of water and cement in concrete mix, whereby the smaller particles 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 meaning that the coarse aggregate used in this study was of an average size of 14 mm.

3.2 Slump Test

A slump test which was in accordance to BS EN 12350-2:2009 [17] on the fresh concrete was conducted to determine the workability of the concrete. The targeted slump was between 30 mm to 60 mm. The slump values obtained from the study were shown in Figure 1.

3.3 Compressive Strength

The compressive strength test was conducted on the control, PET, RC and PET-rubberised concretes as in accordance to BS EN 12390-3:2009 [18]. The compressive strength result can be calculated from the failure load divided by the surface area of specimen as stipulated in BS EN 12390-3:2009. The compressive strength values obtained were shown in Figure 2.

3.4 Flexural Strength

The test was conducted on 100x100x500 mm specimens by referring to the requirement of ASTM D3043-00 [19]. The load capacity applied at such a rate to increase the stress of 0.06 ±0.04 N/(mm^{2}s). The maximum load on the scale was recorded as the breaking load. The flexural strength values obtained are shown in Figure 3.

3.5 Electrical Resistivity

The electrical resistivity test was conducted by referring to the requirement of BS EN 14617-13:2013 [20]. The electrical resistance was measured by applying a current passing through the specimens using two electrodes which are copper plates attached to the ends of a uniform cross-section of the specimen. The electrical resistivity values obtained are shown in Figure 4.

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3.6 Water Absorption

The measurement of the water absorption was determined based on BS 1881-122:2011 [21]. The cylindrical specimens 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 that is by having them immersed in water for 30 minutes, 60 minutes, 120 minutes and 240 minutes. The percentage of water absorption values obtained are shown in Figure 5.

4. RESULTS AND DISCUSSION

4.1 Workability

In the fresh state, the slump test was adopted to ensure the mixtures achieved the targeted slump which was between 30 mm to 60 mm. Figure 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 designed slump. It shows that 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. The slump value for PET concrete decreased from 50 mm to 40 mm with increasing of 10% to 30% of PET in concrete. This reduction can be attributed to the fact that PET has non-uniform shapes with very thin thickness resulting in less fluidity. The past researchers [22-23] have proven that the slump was prone to decrease sharply with the increment of the PET content in concrete mixes.

The submersion of RC in NaOH before mixing resulting in increasing 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 are 44 mm, 48 mm and 52 mm respectively. Rubberised concrete has been found to be workable than conventional concrete as the rubber content increased. This is in line with Khatib and Bayomy [24] research work on rubberised concrete. Figure 1 shows the slump results for control, PET, RC and PET-rubberised fresh concretes.

With the combination of PET and RC in the concrete mixes resulted in increased in the slump values. The graph showed that at combination of 30% PET and 30% RC gave higher slump.

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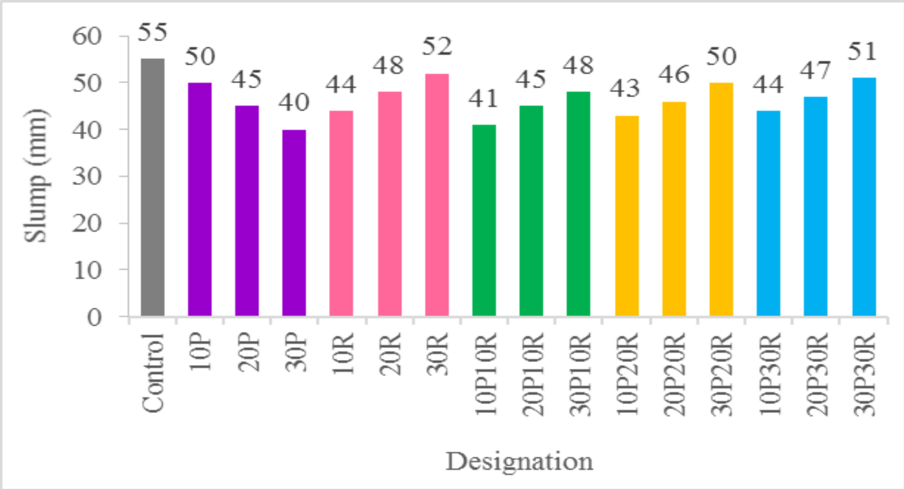

Figure 1: Slumps for control, PET, RC and PET-rubberised fresh concretes

4.2 Compressive Strength

Figure 2 shows the compressive strength obtained from the control, PET, RC and PET-rubberised 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 PET-rubberised concretes. This might be due to the fineness of fine aggregates which is higher compared to PET-rubberised particles thus resulted in higher strength. Studies conducted by past researchers [25-26] indicated that the fineness of the material have some influence 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 increasing 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 [27] using different percentages of rubber in concrete (5%, 10% and 15%) by volume also noticed that by increasing the 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. This might be caused by the spongy effect of RC. Several authors mentioned that pretreatments of rubber waste such as with 10% NaOH saturated solution to wash the rubber surface can increase the adhesion between the cement paste [28-29]. A study [30] 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 RC in concrete, the compressive strength decreased with increased PET and RC. 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. From the study, it shows that the only 10% of PET and 10% of RC gave the maximum compressive strength of these two combinations.

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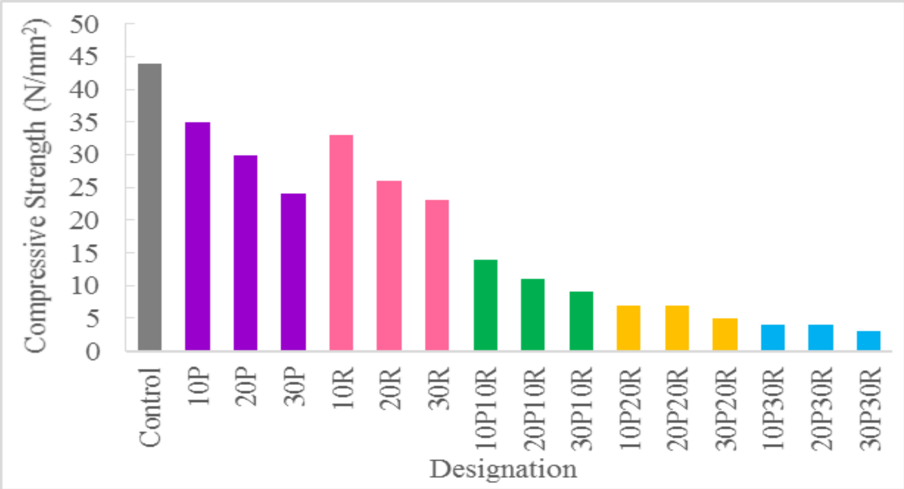

Figure 2: Compressive strength taken at 28 days of curing

4.3 Flexural Strength

Figure 3 shows the flexural strength obtained from the control, PET, RC and PET-rubberised concrete taken at 28 days of curing. From the graph, it shows that the flexural strength for control concrete was higher compared to PET, RC and PET-rubberised concretes. The flexural strength of control concrete was recorded as 5.6 N/mm^2. The percentage of flexural strength of 10P, 20P and 30P were 4.7 N/mm^2, 4.5 N/mm^2 and 4.3 N/mm^2 respectively. It shows that the flexural strength of PET concrete is prone to decrease with the increase of the PET percentage level. This trend can be attributed to the decrease in adhesive strength between the surface of plastic particles and the cement paste as mentioned in a previous study by Baboo *et al.*, [31]. For 10R, 20R and 30R, the flexural strength taken were 4.6 N/mm^2, 4.4 N/mm^2 and 4.1 N/mm^2 respectively. The RC concrete showed higher value compared to PET concrete due to better bonding effect of RC particles. Meanwhile, the flexural strength for 10P10R, 20P10R and 30P10R were 3.9 N/mm^2, 3.7 N/mm^2 and 3.5 N/mm^2 respectively. For the replacement of 20% RC, the flexural strength for 10P20R, 20P20R and 30P20R were 3.2 N/mm^2, 2.9 N/mm^2 and 2.7 N/mm^2 respectively. While for the replacement of 30% RC, the percentage of flexural strength for 10P30R, 20P30R and 30P30R were 2.4 N/mm^2, 1.9 N/mm^2 and 1.5 N/mm^2 respectively. From the data collected, it can be concluded that with the increasing of PET and RC in the concrete, the flexural strength had decreased. This might be due to the increasing of voids and weaker bonding between the materials in concrete. This is in line with the previous study [32] which revealed that the flexural strength of PET-rubberised concrete decreases with the increasing of percentage of PET and RC.

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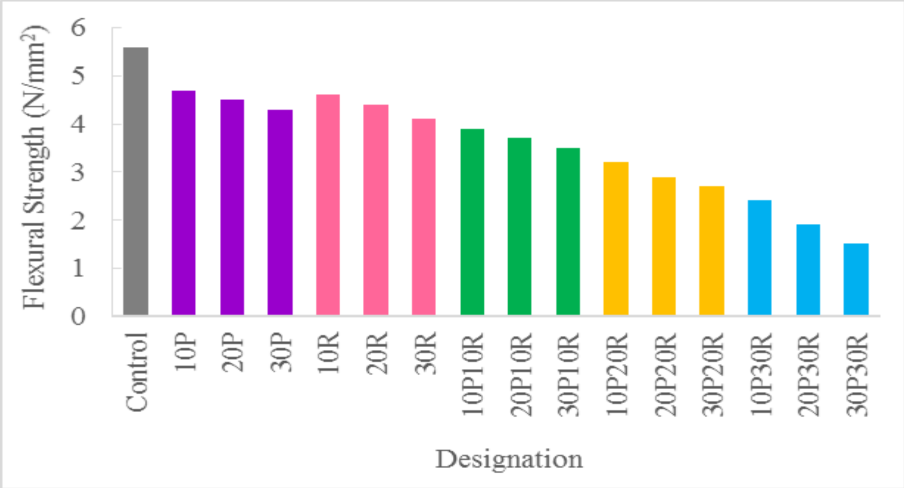

Figure 3 : Flexural strength taken at 28 days of curing

4.4 Electrical Resistivity

From Figure 4, it can be seen that the electrical resistivity for control concrete was lower compared to PET, RC and PET-rubberised concretes. The electrical resistivity recorded was $21.5x10^3\Omega$-cm. The electrical resistivity of 10P, 20P and 30P were $24.4x10^3\Omega$-cm, $26.4x10^3\Omega$-cm and $28.3x10^3\Omega$-cm respectively. The electrical resisitivity increases as the PET increases. This is in line with a study by Ashraf *et al.*, [33] in which they measured the dielectric properties and electrical conductivity on cement paste with different PET replacement levels. They reported that 10% of PET, compared to the control specimen, resulted in good electric loss due to the decrease in the cement porosity. For 10R, 20R and 30R the electrical resistivity taken were $32.9x10^3\Omega$-cm, $34.0x10^3\Omega$-cm and $35.3x10^3\Omega$-cm respectively. This is agreed with previous research [34-35] which mentioned that rubber content in concrete performs as an electrical insulator which influences the resistivity of RC concrete, making it higher than that of plain concrete. Meanwhile, for 10P10R, 20P10R and 30P10R were $37.3x10^3\Omega$-cm, $39.7x10^3\Omega$-cm and $42.4x10^3\Omega$-cm respectively. For the replacement of 20% RC, the electrical resistivity for 10P20R, 20P20R and 30P20R were $44.6x10^3\Omega$-cm, $47.4x10^3\Omega$-cm and $49.6x10^3\Omega$-cm respectively. While for the replacement of 30% RC, the electrical resistivity for 10P30R, 20P30R and 30P30R were $52.3x10^3\Omega$-cm, $54.5x10^3\Omega$-cm and $57.4x10^3\Omega$-cm respectively. These showed that the electrical resistivity of PET-rubberised concretes resulted in higher electrical resistivity value and the highest value will be achieved with higher content of RC. Knowing the fact that PET and RC are insulators that do not conduct electricity, therefore mixes concretes of PET and RC will definitely resulted in longer time taken for the electrical to pass thus resulted in higher resistivity values. According to Ho *et al.*, [36] electrical resistivity measurements can be used to estimate the probability of significant corrosion in which when the electrical resistivity was greater than $20x10^3\Omega$-cm, the corrosion rate can be negligible. Thus, all the specimens that have been produced in this study are probably suitable for bridge construction due to high resistance to corrosion.

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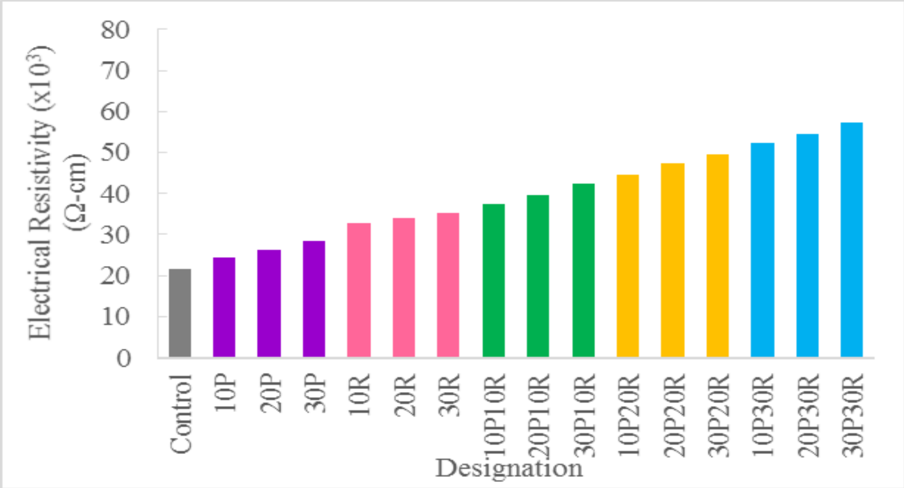

Figure 4 : Electrical Resistivity taken at 28 days of curing

4.5 Water Absorption

From Figure 5, it can be seen that the water absorption for control concrete (4.47%) was lower compared to PET, RC and PET-rubberised concretes. From the figure, it shows that the combination of PET and RC in concretes showed a higher percentage of water absorption followed by rubberised 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. 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 [37] reported that, smaller size particles of fine aggregate made the particles 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.

While, the percentage replacement levels of PET also affects the water absorption of concrete, which increased with the increment of PET and RC which will increase the percentage of water absorption in concrete. Thus, it showed that the durability of concrete decreased with the increased PET and RC percentages. The reason is that higher PET and RC content in concrete will restrict and prevent the cement paste to bond together, therefore allowing increment of poresizes. Several researchers [38-40] observed an increase in the immersed water absorption of concrete incorporating PET and RC. 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 [41] stated that for the performance of good quality concrete for water absorption should be less than 10% absorption by mass.

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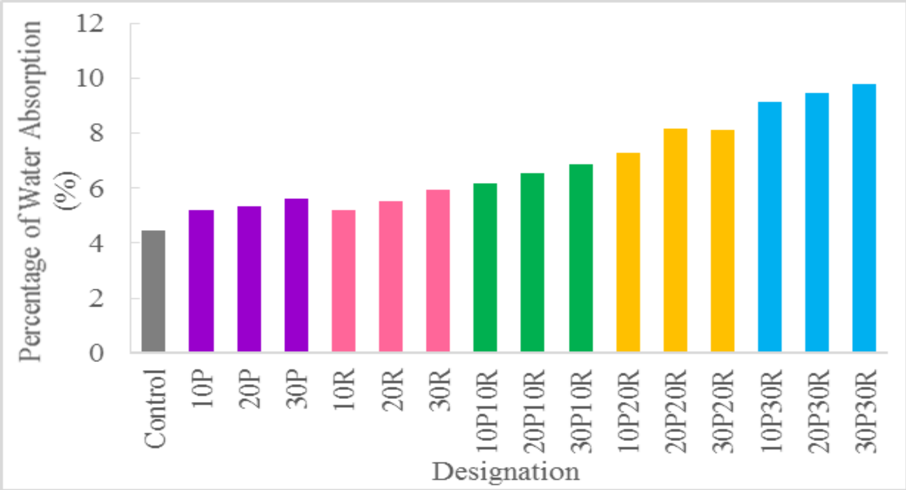

Figure 5 : Water Absorption taken at 28 days of curing

5. CORRELATIONS BETWEEN COMPRESSIVE STRENGTH WITH FLEXURAL STRENGTH, ELECTRICAL RESISITIVITY AND WATER ABSORPTION

Figure 6 shows a relationship between flexural strength and compressive strength. The linear graphs were plotted and the R^2 values obtained for control concrete and PET-rubberised concrete were 0.9042 and 0.8522 respectively. The R^2 were close to unity. Therefore, it shows that there are interdependent correlations between the flexural strength and compressive strength with high coefficient of determination obtained.

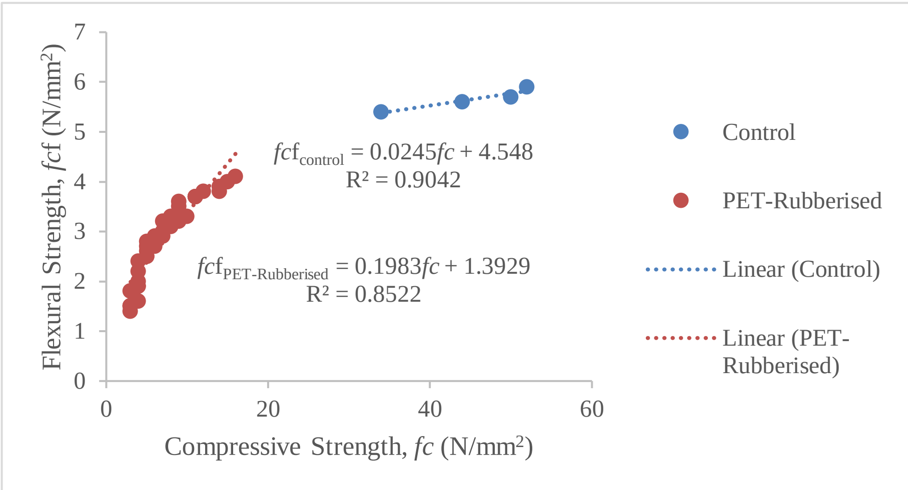

Figure 6 : Correlation between flexural strength and compressive strength

Figure 7 shows a correlation between electrical resisitivity and compressive strength. An inverse linear graphs plotted and the R^2 values obtained for control concrete and PET-rubberised concrete were 0.8299 and 0.853 respectively. The R^2 were close to unity. Therefore, it shows that there are interdependent correlations between the electrical resistivity and compressive strength with high coefficient of correlation obtained.

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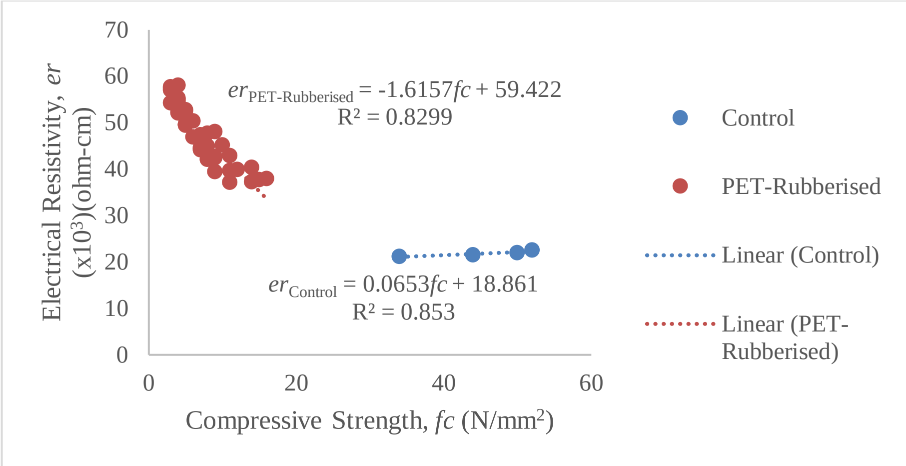

Figure 7 : Correlation between electrical resisitivty and compressive strength

Figure 8 shows a relationship between water absorption and compressive strength. An inverse linear graph was plotted and the R^2 values obtained for control concrete and PET-rubberised concrete were 0.8388 and 0.8951 respectively. The R^2 were close to unity. Therefore, it shows that there are interdependent correlations between the water absorption and compressive strength with high coefficient of correlation obtained.

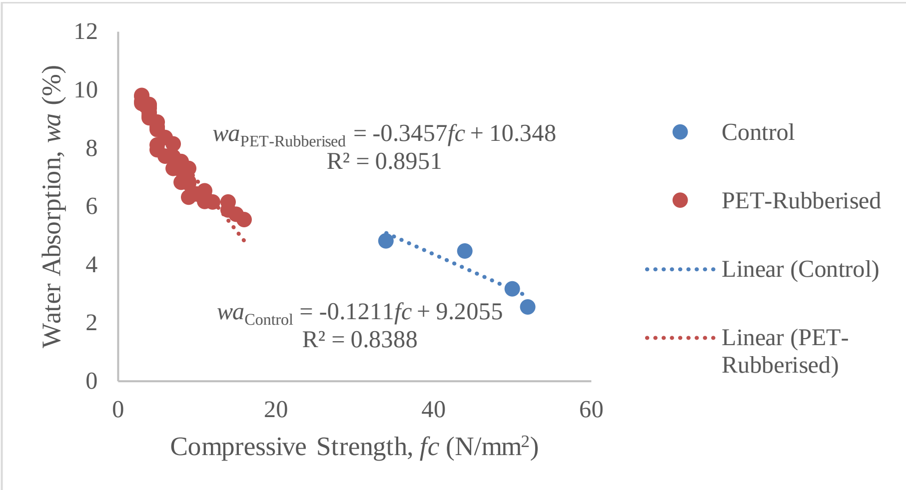

Figure 8 : Correlation between water absorption and compressive strength

5. CONCLUSIONS

From the investigation carried out, it can be concluded that the values of slump for all mixes are within the slump design. The replacement of fine aggregate with PET and RC at all replacement level reduced the compressive strength and flexural strength, however the strength increased with age of curing. The optimum replacement of PET and RC chosen were 20% and 10% each. While for the electrical resistivity, all the values obtained from the concrete satisfy the requirements of good quality concrete with higher resistance to corrosion i.e. having more than $20 \times 10^3 \Omega$-cm values. The values of water absorption taken at all curing

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days satisfied the requirements of good quality concrete i.e. less than 10% absorption by mass.

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