Engineering behavior of recycled granulated tire rubber-filled concrete incorporating palm oil fuel ash

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Abstract

Reutilization of waste materials instead of conventional aggregate can help to reduce the environmental pollution. The present study aims to investigate the feasibility and performance of using granulated tire-rubber particles (incorporating from 5% to 30% as substance of coarse aggregate) and 20% palm oil fuel ash (POFA) as cement replacement. The effect of waste tire rubber replacement was evaluated for mechanical strength of POFA concrete. The results showed that granulated tire rubber leads to concrete with lower compressive strength and showed suitable capability in flexural and tensile strength. Thus, there is an opportunity for industry to develop rubberized POFA concrete products that can be used on commercial basis. This can lead to sustainable urban development from both economic and environmental perspectives.

Keywords: waste tire; palm oil fuel ash; rubberized concrete; mechanical strength

I. INTRODUCTION

Disposal of scrap tire rubber constitutes a large portion of solid waste, which has turned into a worldwide environmental concern. Tires are non-degradable by nature. In several countries, tire rubber is being burned and used as fuel, which can result in serious hazards unless health considerations are carefully considered [1]. In some cases, millions of tires have been discarded into open fields in a form of scrap or waste. These stockpiles are dangerous not only due to the potential environmental threat, but also providing a breeding ground for mosquitoes since tires often hold water inside which remained warm enough for optimal mosquito breeding. Mosquitoes create a nuisance and may increase the likelihood of spreading disease. Waste tire creates a fire danger, since a large tire pile is flammable [2 – 5] reutilization of scrap tire is an interesting alternative to discard tire without any major environmental problems. Khaloo *et al.,* [6] studied the properties of concrete containing high-volume rubber particles. They observed that the workability of concrete is affected by the interaction of tire particles and mineral aggregates. Zheng et al., [7] reported that the workability of concrete containing chipped tires was generally lower than that of the control concrete. Khaloo et al., [6] reported that the substitution of mineral aggregates with tire–rubber particles in concrete results in large reductions in ultimate strength and the tangential modulus of elasticity. Sukontasukkul and Tiamlom, [8] reported that the results on the compressive strength and elastic modulus both appeared to decrease when crumb rubber is incorporated into the mix. Ganjian *et al.,*

[9] observed that the tensile strength of concrete was reduced with replacement of rubber in both mixtures; also introduce rubber into concrete result to reduce the flexural strength as expected.

Palm oil industry is one of the most important agro-based industries in south east of Asia, particularly in Malaysia. Besides the production of crude palm oil, a large amount of solid wastes is also an output from the palm oil industry where this waste used as fuel in power generator result to the huge amount of ash. Palm oil fuel ash (POFA) is one promising pozzolan material [10] because silica is the main component of POFA. Awal and Hussin [11] have highlighted that concrete gain maximum strength when 30% of the cement was replaced with POFA, but further increase in the ash content would reduce the strength of concrete gradually. Increasing in fineness of POFA would lead to greater concrete strength development than the coarser one [12].

This study presented an investigation of mechanical properties of rubberized concrete incorporating granular rubber particle in replacements of coarse aggregate and showed the effect of size and amount of rubber particles in properties of rubber concrete. Whole data were compared to the normal control concrete mix. The mechanical properties investigation included the compressive strength, indirect tensile strength and flexural strength.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

Ordinary Portland Cement (OPC), Type I which meet standard EN 197-1-CEM I – 42.5 N was used for this research. POFA was grinded by modified Los Angles abrasion test machine for at least four hours until the percentage retained on sieve No. 325 (opening 45 µmm) was less than 0.5%. The grinding is necessary because finer particle POFA can enhance strength bonding in cement paste [13, 14]. The mix proportion of concrete was designed base on ACI method [15]. Natural river sand was used as the fine aggregate in this research in compliance with ASTM C33. In order to avoid of affecting the water cement ratio, the sand was maintained to the saturated surface dry (SSD) stipulated in ACI-219 before use. Crushed granite stone was used as the coarse aggregate. The maximum aggregate size of 12.5 mm according to ASTM C33 was chosen to produce high-workability concrete without segregation. Tire rubber granules, with size from 5 to 8 mm were chosen as partial replacement of conventional coarse aggregate. Table 1 shows the physical properties aggregates used in this work. A high range water reducer was used to achieve the desired workability.

Table 1: Physical properties of aggregate

Aggregate	Fine aggregate	Coarse aggregate	Rubber granules (5-8 mm)
Specific gravity	*2.63*	2.68	1.364
Water absorption (%)	1.38	0.7	0.82
Fineness modulus	2.5	-	-

A. Mix proportions

The OPC was partially replaced with 20% POFA not only for reutilize the waste materials, but to improve the mechanical properties of concrete, especially in terms of compressive strength. The w/b was kept constant at 0.43 and super plasticizer, 1% by weight of cement, was taken for mixtures and control batch as well. The mixtures were designed as 5%, 10%, 20% and 30% by volume of total conventional coarse aggregate with coarse granular tire rubber aggregate. The rubberized concrete showed by *R xCP20* which *x* representing the percentage of rubber replacement and CP20 stand as concrete containing POFA with 20% of the total amount of OPC. Concrete mix proportion specifications are shown in Table 2.

B. Testing

Cylindrical specimen with 200 mm height and 100 mm diameter was used for compressive strength test and indirect tensile strength test according to ASTM C39 [16] and ASTM C496 [17] respectively. Prism specimens were used for flexural strength test with size of 100×100×400 mm according to BS188: part 118:1983 [18]. All concrete specimens were covered with wet burlap in the laboratory, and then specimens were de-moulded after 24 hours of casting, and were kept in water curing tank for 28 days base on ASTM C192 [19] standard practice. Totally, 5 batches were prepared in this study. The specimens included 72 cylindrical (200×100) mm specimens for compressive and indirect tensile strength, 54 specimens of prism (100×100×500) mm for flexural test. Each time, 3 specimens of cylinders were tested for compressive strength and indirect tensile strength after 7, 28, 56 and 90 days, and the 3 beam specimens were tested on flexural test at age 7, 14 and 28 days of curing.

III. RESULTS AND DISCUSSION

A. Compressive strength

The result of compressive strength tests for rubberized concrete is shown in Figure 1, illustrates the average of three specimens appeared on the bar chart. It was observed that the compressive strength reduced by the increase in percentage of rubber particles. In early age, 7 days, the compressive strength of granules rubberized concrete showed decreasing from 33.07% to 59.1% by increasing the amount of rubber aggregates in compare to normal concrete. The compressive strength in long term, 90 days, showed the lower reduction in compressive strength from 28.62% for 5% rubber aggregate to 53.23% for 30% replacement of rubber aggregate. This is due to POFA showed the better rate of compressive strength development after 28 days._Generally, the granules rubberized POFA concrete showed suitable strength progress at later age. It may attribute to the pozzolanic reaction between calcium hydroxide and reactive silica in POFA [10]

The reduction of compressive strength is due to a lack of proper bonding between the cement paste and rubber particles in comparing to aggregate and cement paste in control batch. In addition, lower stiffness of rubber particles compare to aggregate is another reason that reduces the concrete mass stiffness and lowers its load-bearing capacity [2, 6, 9, 20].

B. Tensile strength

The results of tensile strength tests are presented in Figure 2. The splitting tensile strength tests were tested at the age of 7, 28, 56 and 90 days. Tensile strength of POFA rubberized concrete in early strength, 7 days, showed slightly 4.1% reduction in strength for 5% replacement comparing to normal concrete. The results of 28 days showed that normal concrete had the better strength than both POFA and POFA rubberized concrete. The outcomes obviously showed that there is significant reduction in value when coarse aggregate replaced with the granule rubber aggregate further amount of 20%. The 28 day tensile strength of normal concrete obtained to 4.78 MPa while POFA rubberized concrete showed 3.58 MPa and 2.77 MPa for 20% and 30% substitution of coarse tire rubber aggregate respectively. This reduction can be explained by the lack of strong bonding between cementitious paste and rubber particles. [3, 5, 9].

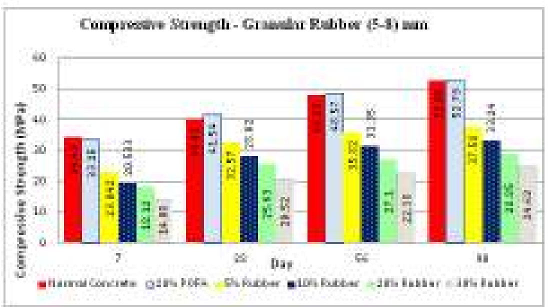

Figure 1: Compressive strength of granular rubberized concrete containing POFA

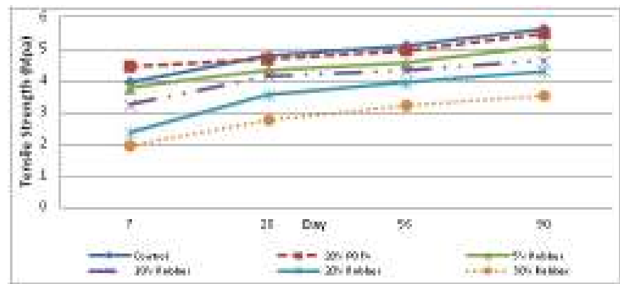

Figure 2: Tensile strength of granular rubberized concrete containing POFA

C. Flexural Strength

The flexural test was tested at age of 7, 14, 28 and 90 days. The results of flexural strength tests are shown in figure 3. The reduction of flexural strength observed in rubberized concrete but in early strength, 7 days, was varying from 2.4% to 20%, and it increased in late strength from 9.4% to 29.52% for 5 to 30 percent replacement.

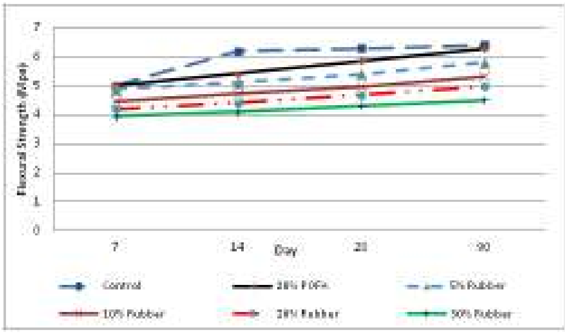

Figure 3: Flexural strength of coarse granular rubberized concrete

IV. CONCLUSION

- Compressive strength of rubberized concrete depended on two factors; grain size and shape of rubber aggregate and percentage of replacement. In general, it was observed that compressive strength was reduced with increasing the amount of rubber particles in concrete. In addition, according to the experimental result, in line with the finding of other researchers, the maximum amount of replacement should be limited to maximum 30% of total volume of natural fine aggregate when the structural concrete is needed.
- Flexural strength and tensile strength were reduced with the increasing of rubber replacement in concrete. Although the loss of strength due to using rubber aggregate on flexural strength and tensile strength were less than compressive strength. The rubber granules aggregate showed acceptable results in flexural strength.
- Replacement of rubber particles showed larger capacity in displacement and deformation in compared to plain concrete. It was because the rubber aggregate known as materials withstands a bigger ability to deform under carrying loads than the natural aggregate.

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