Effect of calcium carbonate treated crumb rubber and oil palm fruit fibre on the mechanical properties of mortar

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Abstract. The present research was conducted to trace the influence of calcium carbonate by treating crumb rubber and exploiting oil palm fruit fibre (OPFF) incorporated mortars. The mechanical properties of treated crumb rubber and the addition of OPFF mortar being added at 0.5% OPFF and crumb rubber replacement of 0-30% by volume of aggregate were examined. The composites were subjected to compression, split tensile test, ultrasonic pulse velocity (UPV) and flexural test. The use of calcium carbonate by treating crumb rubber showed a recovery in the losses of rubberized mortar strength. The percentage 0.5% of OPFF added to the composite showed enhancement to the compressive strength, split tensile strength, UPV and flexural strength of the mortar composites. These findings provide a future possibility for using such wastes to decrease the negative effect on the environment they cause and increase the mechanical properties of composites they are added to.

1. Introduction

The disposal of waste materials is one of the most controversial environmental affairs all around the world. Accumulation of unwanted waste tires in landfills is a significant concern simply because even after a long-period waste rubber is not biodegradable. Usually, tires that are used by vehicles that have a 3-4 year expiry are disposed-off as waste tires. This assemblage of waste tires is collected and dumped in free landfills. The US Environmental Protection Office has announced that around 3 billion waste tires have been disposed of in stockpiles and various sites such as forests, valleys and deserts with a yearly approximate of 242 Million and around 77% from this annual cumulating becomes illegally thrown and stockpiled in landfills [1]. Considering that waste tires landfills take huge spaces and this over time attracts mosquitoes and other insects by becoming a bread crumb for such organisms which causes serious health anxiety to the environment [2]. As a precaution, the Health and Environment Control in South Carolina launched a crumb rubber sponsored project to encourage researchers to promote the re-use of waste tires particularly in civil engineering to overcome the environmental damage caused by the waste crumb rubber [3]. On the other hand, different projects were employed for the riddance of waste tires that include but not restricted to recycling for the creation of different rubber materials, ground rubber employments in playgrounds, utilized in asphalt rubber adjusted concrete and recently in civil engineering as a composite material in the pattern of tire crumb, tire ash and tire chips coarse aggregate and fine aggregates and adding to cement mixes [4, 5]. Various forms of crumb rubber have been used as a composite material in concrete production. The integration of rubber material in concrete has several advantages to enhance
properties of concrete, such as great freeze-thaw properties [6], improve the thermal insulation [7], support in cracking of concrete and shrinkage by decreasing the length and width of the crack due to the delay of the start time for the cracking and shrinkage [8]. Aside from that, reuse rubber is an inexpensive material as compared to original coarse and fine aggregate; therefore, it can decrease the building material price even if it had diminished compressive strength and tensile strength and some other strength characteristics. Consequently, several proportions of rubber, accelerators, admixtures, water content and mix proportions have been employed to increase the durability and more investigation research is needed to reach great production [9, 10]. Rubber from recycled tired can be produced in several sizes, for instance, rubber chips (10mm-50mm), crumb rubber (1mm-4.75mm), granulated rubber (4.75mm-10mm), and rubber powder (500um-1mm). Relying on its size, using recycled rubber could be utilized as a partial replacement for coarse and fine aggregates in the concrete. The finest particle size of rubber indicates that the best results for mechanical strength and thermal and acoustic behavior can be reached [11]. Moreover, the coarse rubber aggregate affects the mechanical properties more negatively than the fine rubber aggregate.

Natural fibers are essentially agricultural by-products that are considered wastes and are mostly acquired at no payment from factories. There are a few natural fibers available such as oil palm trunk fiber, coconut fiber, OPFF, bamboo etc. [12] reported oil palm fiber as a waste product obtained by extracting oil from palm oil fruit. Palm oil tree is referred to as Elaeisguineensis that is observed principally in East Africa [13]. OPFF is an original fiber created throughout the extirpation process of oil palm crude from oil palm fruit bunch as soon as boiling and removal of the palm kernel seeds from the fruit bunch. OPFF is the most easily available of all these fibers that gives more reasons for researchers to execute on it for excellent benefits and participate in decreasing the amount of this by-product. The purpose of this research was to employ the use of crumb rubber and OPFF as an additive to building materials to firstly help find a solution for the environmental issues they cause and also discover whether there are any beneficial changes on the mechanical properties of mortar by treating crumb rubber with calcium carbonate and using OPFF in the mortar (considering this fiber is free of cost). The mechanical properties of mortar showed improvement and also enhanced the properties of crumb rubber mortar.

2. Materials
Portland cement type η in compliance with [14] was used in this experiment. Stone dust fine aggregate with a maximum particle size passing sieve No.4 (4.75mm) was added to the mix design. This aggregate was obtained from a quarry in Selangor, Malaysia and conforms to the specification of [15]. Furthermore, crumb rubber utilized as a partial replacement for sand that was grated to the same particle size as fine aggregate. The crumb rubber particles were examined to be clean from any contamination, and the compacted density was measured to be 676 kg/m³. OPFF was acquired free of charge from a palm oil extraction factory in Labu, Malaysia. For convenience, the fibre that was used in the mixing design was cleaned by washing in a concrete mixer with water. The OPFF was air-dried in an open container and cut into small lengths of 3-5 cm. Figure 1 displays the OPFF as acquired from the factory and washing it before being used in the mix design.
3. Methodology

3.1 Mix properties
The mix design employed in this experimentation conforms to [16] for a water-cement ratio of 0.485 and cement to sand ratio of 1:2.75. Then the crumb rubber replacement of 0%, 10%, 20%, and 30% by the volume portion of aggregate including an extra amount of OPFF of 0.5% by mass of cement content was utilized.

3.2 Mixing Procedure
The pre-treatment of the crumb rubber particles was carried out by mixing the crumb rubber with calcium carbonate and water in a small mixer until the homogeneous mix was remarked (approximately 2 minutes) and then dried to reach surface dryness via an open container. Coated crumb rubber was air-dried for 24 hours and used as treated crumb rubber aggregate. Figure 2 shows the waste tire aggregate before and after treatment in the laboratory test respectively. Fine aggregate, cement and crumb rubber aggregate were placed in the bowl mixer and was allowed to mix for 2 minutes. Additional 2 minutes of mixing was given when one-third of the water and the OPFF were added. The remaining water was poured gradually until a homogenous mix was achieved throughout the mass.

Figure 1. Process of OPFF. Acquired from palm oil extraction factory (top left), washed in concrete mixer (top right), air dried (bottom left) and cut into lengths of 3-5 cm (bottom right).
Table 1. Mix proportions for treated tire crumb mortars (for 1 m$^3$).

| Designation | Cement (kg) | Fine aggregate (kg) | Rubber tyre (kg) | Water (kg) | Fiber (kg) |
|-------------|-------------|---------------------|------------------|------------|------------|
| F0CR0       | 500         | 1375                | 0.0              | 283.75     | 0.0        |
| F0CR10      | 500         | 1237.5              | 55.81            | 280        | 0.0        |
| F0CR20      | 500         | 1100                | 112              | 275.5      | 0.0        |
| F0CR30      | 500         | 962.5               | 167.5            | 271.4      | 0.0        |
| F5CR0       | 500         | 1375                | 0.0              | 283.75     | 2.5        |
| F5CR10      | 500         | 1237.5              | 55.81            | 280        | 2.5        |
| F5CR20      | 500         | 1100                | 112              | 275.5      | 2.5        |
| F5CR30      | 500         | 962.5               | 167.5            | 271.4      | 2.5        |

Figure 2. Crumb rubber before and after treatment.

Workability Test
In this study, the viability of all mix design values was decided by using flow table for mortar in accordance with the specifications of [17].

Density Test
Density is considered an important parameter in materials selection for construction purposes. Density of treated tire crumb specimen with and without OPFF was measured.

Water Absorption Test
Water absorption is defined as the amount of water absorbed by a material under well-defined circumstances. By immersion, the sample of the water absorption was conducted according to the specifications of [18].

Compressive strength
The samples were created in accordance with the requirement stated in [19] for cube samples.

Split tensile strength
The test for split tensile was carried out utilizing the procedure and principle described in [20] and water cured for 7 and 28-days before testing by using sprinkler method curing.

Flexural strength
The flexural test was carried out on test samples of size 40x40x160 mm supported at 100mm center to center in accordance with the specification of [21].
Ultrasonic pulse velocity
Non-destructive UPV test is to check the quality of mortar, where in this test, the strength and quality of mortar were evaluated by estimating the velocity of an ultrasonic pulse passing through a mortar cube.

4. Results and Discussion

4.1 Workability
A linear decrease in the workability of the high rubber content was observed, which implies that the content rubber of 30% leads to a minimal workability value. This decline is mainly due to the absorption nature of the treated tire crumb particles. The particles become coated with calcium carbonate therefore the more tire crumb content treated the more absorption takes place. An average of three measurements was used from each specimen for all mix matrixes and the detailed data is displayed in figure 3. The workability decreases continuously up to 30% replacement of crumb rubber. Treated crumb rubber with the addition of OPFF caused a decrease in workability more than adding only OPFF or crumb rubber individually in the matrix (figure 4). The reduction in workability is due to the addition of OPFF that has a high water absorption nature.

![Figure 3. Workability of treated tire crumb mortar.](image-url)
4.2 Density

The utilization of tire crumb aggregate as a construction material offers high benefits in terms of reduction in self-weight of concrete. The density of the treated tire crumb samples was measured and observed showing a decrease in density with a record of 1.03%, 10.5%, and 15.8% for crumb rubber content 10%, 20%, and 30% respectively compared to the reference sample (figure 5). The accessibility of OPFF in the matrix did not influence the density of the samples significantly due to its low quantity occupying not much space in the specimens (figure 6). In addition, the presence of fibre does not affect the density of mortar samples due to the volumetric quantity of the space taken by the fibre inside the samples.

Figure 4. Workability of treated tire crumb mortar containing crumb rubber and crumb rubber with OPFF.

Figure 5. Density of treated tire crumb specimen without OPFF.
4.3 Water Absorption

Water absorption test revealed that for the mortar mixture having only tire crumb particles without the fibre, the value of water absorption goes up as the volume of treated tire crumb increases (figure 7). The increase in absorption is generated by air gaps entrapped among the cement and tire crumb particles. Moreover, adding OPFF increases the absorption even more due to the high absorption ability of both treated tire crumb and the fibers (figure 8).

Figure 6. Density of treated tire crumb including OPFF.

Figure 7. Water absorption of samples containing treated tire crumb.
4.4 Compressive strength

The test on mortar specimens was to incorporate treated fine tire crumb aggregates in the samples from 0-30%. The control sample neither tire crumb nor OPFF to work as a reference comparable with the other samples. The average result for compressive strength of the control sample was registered to be 24.28MPa, 29.60MPa and 39.90MPa at 3, 7 and 28-days respectively. The incorporation of tire crumb produced lower compressive strength and this reduction increases with any additional tire crumb content. The compressive strength of the tire crumb including OPFF at 0.5% by mass of cement content was examined. The addition of OPFF was aimed to enhance the compressive strength of tire crumb mortar specimen. The compressive strength of specimens with treated tire crumb aggregate was recorded to reduce the compressive strength compared to the control sample by 11%, 25%, and 35% at 10%, 20%, and 30% replacement by fine aggregate respectively. The addition of 0.5% OPFF in the treated crumb rubber specimen improved the compressive strength. The improvement in compressive strength was accompanied with an increase in curing period. This enhancement can be attributed to the hydration progresses it gives a greater bond strength experience. The addition of hydrogen into macromolecular chains that improves the compression resistance property of fibers.

Figure 8. Water absorption of samples containing treated tire crumb and OPFF.

![Water absorption graph](image)

Figure 9. Compressive strength of treated tire crumb samples.

![Compressive strength graph](image)
4.5 Split tensile strength
It was remarked that the substitution of tire crumb by the fine aggregate in mortar decreases tensile strength. As OPFF was added, the mortar mixture changed the strength reduction manner of the specimen. By adding the OPFF in the mortar matrix at replacements 20 and 30% of crumb rubber it was observed that there is an improvement in the split tensile strength. In contrast, at 10% replacement, it remarked a reduction in the split tensile strength. The crack pattern in the samples with the testing materials was completely similar to a single line crack across the diameter of the samples. The control specimens with no fibre showed a split into two elements while those specimens with fibre were recorded to remain a single element (no split) as shown in Figure 11.
Figure 12. Crack pattern samples obtained under split tensile test.

Figure 13. Split tensile strength test result for treated tire crumb mortars.

Figure 14. Split tensile strength test for treated tire crumb with OPFF (0.5%) mortars.
4.6 Flexural strength
The conjunction of crumb rubber in the mortar sample was reported to degrade the flexural strength which continuously diminishes with the increase of crumb rubber content. This pronouncement is similar to the results summarized by [22]. Nevertheless, it was recognized that the increase in crumb rubber content improves the ductility of the mortar sample which could be remarked on the curve. The impact of OPFF was studied by the addition of 0.5% by mass of the cement content and the result is displayed in Figure 14. It was observed that the flexural strength and ductility yielded showing better performance than the control specimen. The highest peak loads were remarked at 0.5% OPFF showing the resistance of the fibre to tension force that exerted on the sample preventing early cracking. In addition, the performance of 0.5% OPFF in the composite has shown that OPFF would offer good potentiality when added to the crumb rubber incorporated mortar specimens to augment the losses resulting from the tire crumb replacement. In comparison with the control sample for the flexural strength test, it was observed that the maximum load reduced to 11.68%, 17.95%, 27.36%, at 10%, 20%, and 30% crumb rubber content, respectively. On the other hand, addition of fibre to the matrix caused a reduction in flexural strength to 10.13%, 22.9% at 20%, 30% respectively, while at 10% crumb rubber with fibre showed increment in maximum load by 0.19% that means the performance of OPFF in the composite proves to offer good potentiality when added to the tire crumb incorporated mortar samples. Comparing the mixtures with the control sample, the deflection increased when crumb rubber and OPFF were used in the matrix by 12.32%, 29.8%, and 34.8% at 10%, 20%, and 30%, respectively, and crumb rubber content without fibre by 14.74%, 32.14%, and 40.88% at 10%, 20%, and 30% respectively.

![Figure 15. Flexural strength of mortar sample containing CR.](image-url)
4.7 Ultrasonic pulse velocity

The UPV values for rubberized mortar mixtures at all levels of crumb rubber replacement at the age of 28 days illustrated that the UPV values decreased. The value of UPV for the control specimen was 4.765 km/sec and using this value as a reference, the replacement of crumb rubber at 10%, 20, and 30% the UPV values dropped to 4.601 km/sec, 3.758 km/sec, and 3.668 km/sec, respectively. This is due to the existence of crumb rubber, which entraps the air on its surface (air content increases as the replacement of sand with rubber crumb increases). With the addition of 0.5% OPFF without crumb rubber, the value of UPV increased from 4.765 km/sec to 4.780 km/sec. However, the addition of OPFF to the mixture matrix does not affect the UPV values considerably, according to [23], since it did not have much influence on the density of the resulting hardened mortar sample. The velocity of ultrasonic pulses traipsing in a solid relies on the properties of the material and its density.
5. Conclusion

The value of the workability diminished as the amount of rubber content increased, this shows that a rubber content of 30% leads to the lowest workability. Treated crumb rubber permutation causes a reduction in the workability more than by adding 0.5% OPFF in the mixture. The compressive strength of the consolidated mortar sample with crumb rubber was recorded to decrease with the increase of crumb rubber content. The addendum of OPFF was remarked to improve the compressive strength at 10% to 30% for treated tire crumb mortars respectively. By introducing crumb rubber in the mixture the strength properties declined and that might be due to the low engagement contribution of the raw materials in the mix.

The split tensile strength was recognized to decrease with the increase in crumb rubber substitution in comparison with the reference sample. The split tensile strength was realized to improve at the addition of OPFF content for treated crumb rubber 20% and 30% samples except at 10%. The flexural strength test on crumb rubber mortars displayed an increment in ductility with an increase in crumb rubber and OPFF content. The flexural peak load was achieved with treated crumb rubber substitution of 10%, 20%, and 30% which was increased more when adding 0.5% OPFF. The addition of 0.5% OPFF showed the best performance in both ductility and flexural peak load for all crumb rubber content.

UPV values reduced with the increase of crumb rubber content. However, it was remarked that the assessment of UPV in the mixture specimen with crumb rubber and OPFF, fall within the range of good to excellent.

Regarding the water absorption test, it was observed that water absorption increased when the treated crumb rubber substitution was added. This increase was due to the impact of treatment by using calcium carbonate on crumb rubber that caused the creation of air voids, as a result, gives room for water absorption. The highest absorption was recorded with the maximum content of crumb rubber by 30% and 0.5% OPFF.

Both treatments of crumb rubber with OPC and calcium carbonate enhanced the strength properties for the crumb rubber. On the other hand, both treatments absorbed more water and reduced the workability test. The addition of OPFF in mortar specimens by 0.5% of the mass of cement content offered the best performance in terms of strength properties (split tensile strength, compressive strength, and flexural strength). As a result, it improved the strength properties by comparing it with the control specimen. Using crumb rubber and OPFF in mortar leads to the removal of those materials from the environment. Moreover, decreasing the utilization of natural materials, also these wastage materials are considered as a positive economical substitution.

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