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A Comparative Study of the Behaviour of Treated and Untreated Tyre Crumb Mortar with Oil Palm Fruit Fibre Addition

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ABSTRACT

An incorporation of waste tyre particles in concrete has been established to produce a green concrete. However, despite its advantages, strength reduction is an obvious handicap. To improve the strength, pre-treatments of the waste tyre particles and addition of Oil Palm Fruit Fibre (OPFF) were chosen and reported in this study. The addition of OPFF was to influence the internal structure in order to improve shrinkage and other strength properties. Performance of the composites in compressive, split tensile and flexural strengths, as well as shrinkage and microstructure were observed. Results showed better behaviour of the treated tyre crumb mortar rather compared to the untreated tyre, with the replacement of up to 40% by volume of the treated tyre crumb particles and 0.5- 1.0% OPFF addition by mass of cement content.

Keywords: Lightweight aggregates, treated, untreated, tyre crumb, oil palm fruit fibre, mechanical properties, unrestrained shrinkage

INTRODUCTION

Waste tyre material is regarded as one of the world's most persisting problems and needs to be utilised or recycled properly (Pedro et al., 2013). Several research studies have been on-going for the past decade to find a sustainable method of disposing of the waste tyres that are accumulating globally (Huang et al., 2004). The non-bio-degradable nature of the material has posed a serious challenge when establishing disposal sites and has thus become an environmental problem. Waste tyres comprise a significant portion of solid waste management activities which is a global environmental challenge. In many parts of the world, tyres are being burned to extract some important materials such as steel. In some cases, they are being burned as fuel, which could be harmful to human life and the environment at large (Brown et al.,

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2001). Recycling offers a promising avenue and the incorporation of this material in concrete could be an important solution due to the size of the construction industry. The construction industry is one of the largest avenues for recycling waste tyre materials, and hence, should be given appropriate attention.

Laboratory investigations have indicated that the substitution of waste tyre particles in concretes and mortars considerably increases their impact resistance, the toughness, plastic deformation, energy absorption, and fracture criteria of concrete. These offer many advantages when used in sound/crash barriers, retaining structures and pavements (Eldin & Senouci, 1993; Topcu, 1995; Lee et al., 1998; Khatib Bayomy, 1999; Taha, 2008). However, previous investigations have shown a considerable decrease in concrete strength properties when waste tyre particles are incorporated (Topcu 1995; Chung & Hong, 1995; Segre & Joekes, 2000; Kosievith et al., 2001; Li et al., 2004; Aeillo & Leuzzi, 2010; Chou et al., 2010). Chou et al. (2010) reported that the reduction of compressive and tensile strengths of the waste tyre incorporated concrete is an important problem to be solved. Some efforts have been made to improve some of these properties by adding other materials in concrete and mortars such as glass, ashes, bricks, polymers, silica fume, etc. (Nehdi & Khan 2001; Cairns & Kenny, 2004; Sánchez et al., 2008; Bektas et al., 2009; Turki et al., 2009; Correia et al., 2010; Silva et al., 2010; Wang & Huang 2010; Neno et al., 2011; Ahmad et al., 2012; Braga et al., 2012).

Onuaguluchi and Panesar (2014) investigated the mechanical and durability properties of concrete composites containing limestone powder pre-coated crumb tyre at 0%, 5%, 10% and 15% of fine aggregate by volumetric replacement. Also, silica fume at 15% cement replacement by volume was added to the matrix. It was observed that the strength improvement due to the coating of crumb tyre alone was negligible; instead silica replacement improves the mechanical properties of the mixtures significantly. Eldin and Senouci (1993), among the pioneers in this research area, reported that the compressive and tensile strengths of the composites decrease with the increase in size of the waste tyre aggregate. Moreover, the replacement of aggregate with coarse tyre aggregate was found to record lower workability. This is supported by Huang et al. (2004), who reported that a smaller diameter of waste tyre aggregate increases the mechanical strength of the composites and that stiffer coarse tyre aggregate produced from truck tyres could also add to the strength. Similarly, Benazzouk et al. (2007) reported that particles of waste tyre of less than 1 mm could significantly increase the strain capacity and toughness, reduce water absorption and decrease the sorptivity-value of the tyre infused concrete.

Also, the strength losses could be reduced by proper surface treatment of the waste tyre particles to improve the bond strength between the waste tyre particles and the paste (Li et al., 1998). The surface treatment should roughen the tyre particles to provide a better bond with the matrix which may yield higher strength properties (Segre & Joekes, 2000). Chou et al. (2010) reported that the surface treatment of waste tyre surfaces achieved with waste organic sulphur compounds is an easy and economical approach to improve strength properties. Apart from this, partial oxidation of the crumb tyre surfaces can also be used to improve the mechanical properties of waste tyre mortar (Chou et al., 2010b).

Raghavan et al. (1998) are amongst the few researchers to have carried out an investigation into the shrinkage of waste tyre concretes. The effect of incorporating two different shapes of rubber particles (granules 2 mm in diameter, and shredded of two sizes of 5.5 mm ×1.2 mm and 10.8 mm×1.8 mm) into cement mortar have been studied. It was discovered that plastic shrinkage cracking was reduced in all types of tyre incorporated samples in comparison to the control specimen, and the control specimen developed a crack earlier than the waste tyre incorporated sample at 5% by mass. The average crack widths were 0.9 mm and 0.4-0.6 mm for the control and waste tyre incorporated samples, respectively. It was also observed that the initial time of cracking started after 30 minutes for the control, while that of the 15% waste tyre was delayed until after an hour. Moreover, the higher the rubber shreds content, the smaller the width and length of crack.

Jingfu et al. (2009) investigated the shrinkage and strength behaviour of roller compacted concrete containing a waste tyre additive by studying the crack resistance behaviour of the roller compacted waste tyre concrete specimens. The drying shrinkage of roller compacted rubberised concrete was observed to be greater than that of the control sample, and the sample containing different amounts of tyre rubber exhibited similar shrinkage behaviour. The rate of drying shrinkage in the first month was found to be higher than in the later ages of the samples. The waste tyre concrete containing 50 kg/m^3 and the control without rubber were observed to have a similar shrinkage pattern, whereas the shrinkage increased with waste tyre contents of 100 and 120 kg/m^3. It was concluded that the drying shrinkage of waste tyre concrete does not reduce by increasing the tyre content, which is contrary to the observation made by Raghavan et al. (1998).

Most efforts made to improve the strength properties of waste tyre incorporated concretes and mortars involved the use of chemicals and additives. The use of the chemical could add to the overall cost of the resulting products due to its high cost. Natural fibres, mainly of oil palm fruit fibre (OPFF), have shown beneficial potentialities in concretes at lower dosage Aziz et al. (2014). However, it has not been utilised in waste tyre incorporated concretes and mortars despite its abundance at little or no cost.

Ismail and Hashim (2008) investigated the properties of concrete by using oil palm fruit fibre (OPFF) at 0.25%, and 0.5% of fibre by mass of cement, and the length of the fibre was 10, 30 and 50 mm. It was observed that the optimum fibre length is 30 to 50 mm, which increased the compressive strength by 39% when compared with the control and above 1% fibre lowered the strength. Ahmad et al. (2010) studied the influence of oil palm trunk fibre (OPTF) in concrete by addition of OPTF at 0%, 1%, 2% and 3%, water cement ratio of 0.5 and cement sand and aggregate ratio of 1:1.47:3.0. It was observed that the slump decreased with the increase in fibre content. The compressive and split tensile strength increased by 30% and 25% respectively at 1% fibre content, which decreased below the control when the fibre content increased beyond 1%. It was also observed that the resistance to attack by NaOH and NaCl was higher at 1% OPTF, and at 3%, it showed higher resistance to HCl attack.

An addition of waste tyre particles in concrete and mortars have been reported to yield low mechanical properties. Therefore, pre-treatment and additives could be used to enhance the mechanical performance of the specimens. Hence, this research was carried out to compare the performance of the pre-treated and untreated tyre crumb incorporated mortars both with the addition of oil palm fruit fibre (OPFF) in the specimens on the compression, split tensile and flexural strength, as well as the shrinkage and its microstructure. The mortar composite studied is a potential material for use in applications such as masonry and precast lightweight concrete walls.

MATERIAL PROPERTIES

The mortar composite was made from fine aggregate, tyre crumb, cement, OPFF and water. Composite Portland cement Type II - conforming to ASTM C150 (2001) - was used in all mixes. The fine aggregate was obtained from a quarry in Selangor, Malaysia, with properties that are in accordance with ASTM C 33 and C 127. The specific gravity, water absorption, density and fineness modulus of the fine aggregates are 2.63, 3%, 1702 kg/m^3 and 0.9, respectively.

The crumb tyre aggregate, with a maximum aggregate size of 2.36 mm, was supplied by Arayaja Enterprise Sdn. Bhd., Malaysia. The tyre crumb was graded in the same particle distribution as the fine aggregate. The untreated tyre crumb was supplied and graded from the factory, while the treated tyre crumb went through the cement powder pre-treatment, as adopted by Li et al. (1998). Pre-treatment was carried out by soaking the tyre crumb in water for 48 hours, and then surface dried (SSD) before mixing it with cement powder Type II Portland cement. The compacted density and fineness modulus values of the untreated tyre crumb aggregate are 589 kg/m^3 and 0.9, respectively, while the treated tyre crumb values are 668 kg/m^3 and 0.9, respectively. Figures 1(a) and (b) show the untreated and treated tyre crumb aggregates used in this work, respectively.

Natural fibre from an oil palm fruit bunch was supplied by the palm oil extraction factory Seri Ulu Langat Palm Oil Mill Sdn. Bhd. at Dengkil, Malaysia. The oil palm fruit fibre (OPFF) was washed to clean it from oil, dirt and fungi. Then, the OPFF were dried at room temperature and cut into 30-50 mm lengths.

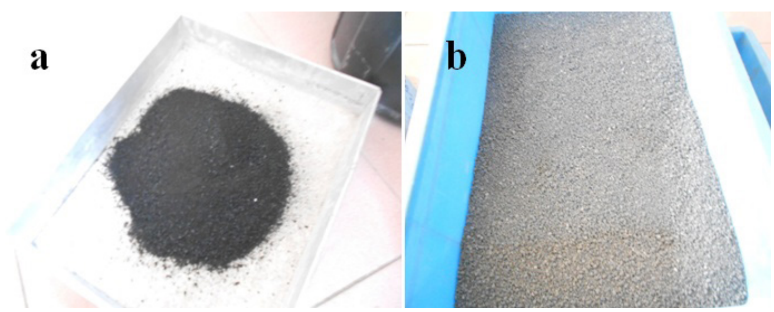


Figure 1. Tyre crumb aggregates (a) untreated; (b) treated

MIX PROPORTIONS

In line with ASTM C 109 (2005), the mortar mixes were prepared using a water-cement ratio of 0.485 and cement-to-sand ratio of 1: 2.75. The total water contents in all mixes include 3% moisture from the aggregates. The replacement of fine aggregates with tyre crumb was made at 10%, 20%, 30% and 40% by volume, and the addition of OPFF was made at 0.5%, 1% and 1.5% by weight of cement. The mixing was carried out in a bowl mixer with a maximum capacity of 0.005 m^3. The process was started by mixing the cement, aggregate and tyre crumb aggregates thoroughly for about 2 mins. Then, 1/3 of the water was added and allowed to mix for 2 more minutes before the remaining water was added for the final 2-min mixing operation. The first part of the water was added to enable the fibre to loosen and mix with the other constituents. A total of 32 mix designs were prepared with a targeted compressive strength of 17 MPa.

EXPERIMENTAL PROGRAMME

The tests were carried out to compare the performance of the treated and untreated tyre crumb materials under similar conditions. In all cases, the averages of three specimens were used. The samples made of mortars containing crumb tyre of 0-40% by volume and oil palm fruit fibre of 0-1.5% by weight of cement were tested in this research work. The workability test for the various mixes was measured in accordance with ASTM C1437 (2007). The compression and density/water absorption tests were performed using 50 mm mortar cubes in accordance with ASTM C109 (2005) and ASTM C642 (1997), respectively. In total, 288 cubes were tested at 3, 7, and 28-days. A three-point flexural test was carried out in accordance with ASTM C348 (2008). In total, 64 specimens, each with a prism size of 40 x 40 x 160 mm, were tested at a loading rate of 5 mm/m. The split tensile test was carried out on 128 cylindrical samples of 100 x 200 mm size at 7 and 28 days respectively as in ASTM C496/496M (2004).

The unrestrained shrinkage test was conducted on a specimen size of 70 x 70 x 280 mm in accordance with the ASTM C 341/341M (2006) specification. A total of 64 specimens were produced; 32 were observed in the laboratory at room temperature, while the remaining specimens were kept in a climate chamber at 23^0C and 50% humidity for 90 days. The change in length was measured using an extensometer every day for the first 21 days and subsequently three times a week for 39 days and finally at the 90th day.

Scanning Electron Microscopy (SEM) analysis was carried out to examine the microstructure of the mortar samples using a Hitachi 5.00kv machine. A mortar sample size of 40 x 40 x 10 mm was used. A total of 5 samples were taken from the 10% and 40% tyre crumb contents for the treated and untreated tyre crumb mortars at 0.5% oil palm fruit fibres and the control specimen. The upper and lower limits of 10 and 40% of the tyre crumb contents were considered for comparison and the 0.5% OPFF was chosen due to its overall performance in the composite.

RESULTS AND DISCUSSION

Workability

The workability of the treated and untreated mortar mixtures are shown in terms of flow values as in Figure 2(a), (b) and (c) for 0.5%, 1% and 1.5% OPFF, respectively. In all cases, the workability flow achieved is more than the required workability for the mortar of 110 mm. In general, increases in tyre crumb content will reduce the workability of the mixtures, regardless of whether they are treated or untreated. However, the losses for the treated tyre crumb mixtures are higher than for untreated mixtures because the coating is able to absorb more water. On the contrary, the untreated tyre crumb particles repel water, hence increasing workability. The addition of OPFF into the mixes further decreased the workability for both the untreated and treated tyre crumb mortars because of its higher absorption capacity.

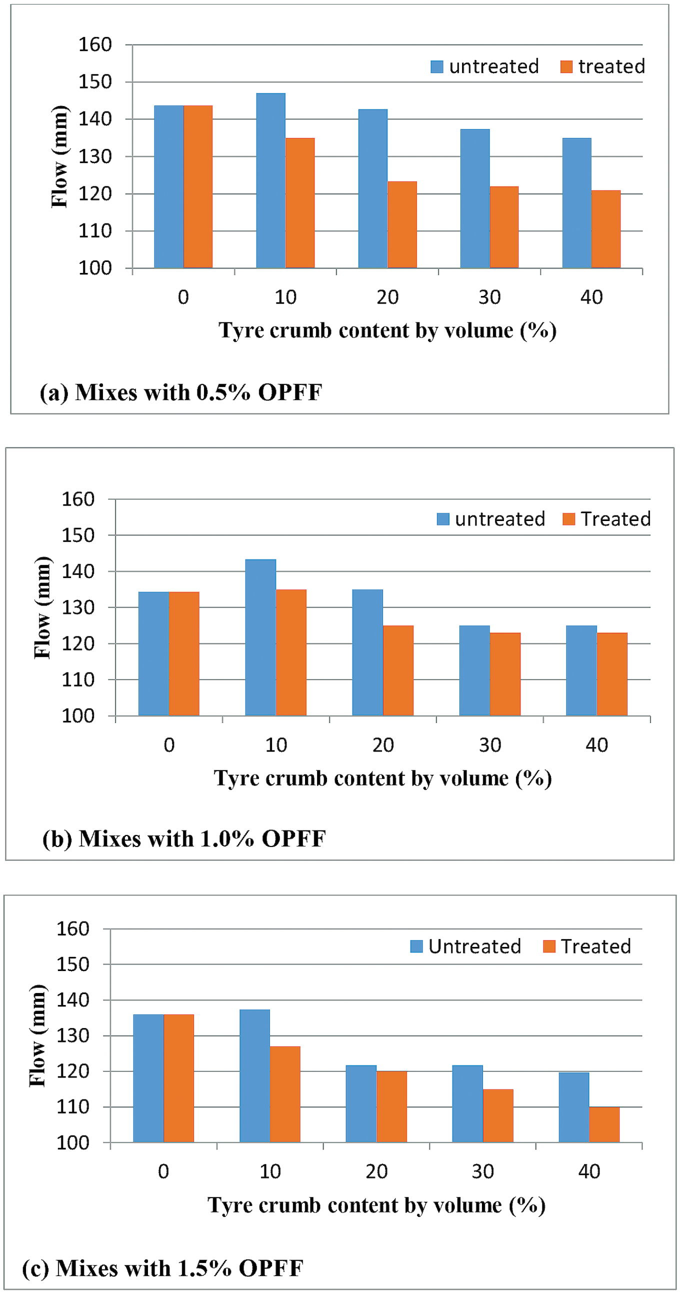
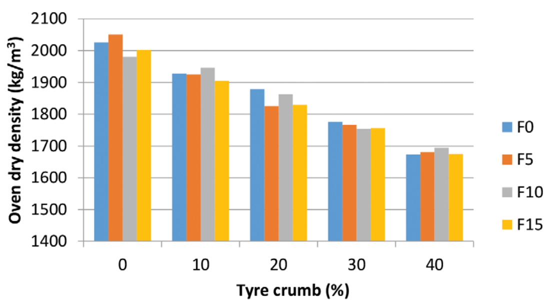


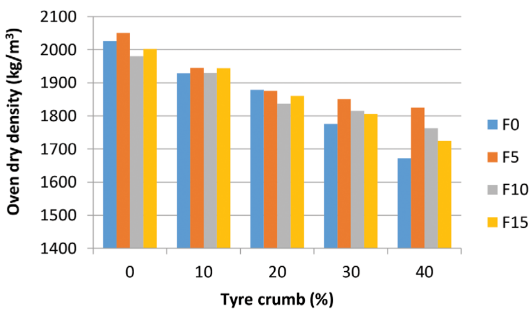
Figure 2. Workability of mortar composites (a) 0.5% OPFF; (b) 1% OPFF; (c) 1.5% OPFF

Density

The replacement of aggregates with tyre crumb resulted in a reduction in the unit weight of the hardened mortar specimens because of the low densities of the tyre crumbs. Figure 3 (a) and (b) show the density versus percentage of tyre crumb for untreated and treated samples, respectively. The density of the treated tyre crumb mortar showed a slightly higher value compared with the untreated tyre crumb mortars. The higher density of the treated samples came from the cement powder addition on the outer surfaces of the tyre crumbs that increased the unit weight of the tyre particles from 589 to 668 kg/m^3 from the untreated to treated tyre particles respectively. Generally, the untreated tyre crumb particles entrap air in their surface, which makes the mortars exhibit a lower density compared to the treated tyre crumbs which have fewer voids and hence entrap less air. Meanwhile, the presence of a low dosage of OPFF in the matrix did not affect the density of the specimens significantly, as it does not occupy space in the specimens and also it is light in weight. The density ranging between 1675-1950 kg/m^3 for all tyre crumb replacement mortar mixes, which is in a range of lightweight concrete of 1675-1950 kg/m^3, as reported by Neville (1995). However, it is higher than lightweight mortar made of polymer of 1346 kg/m^3 reported by Uygunoglu et al. (2013) and similar range of lightweight mortar using pumice aggregate of 1800 kg/ m^3 according to Hossain et al. (2011).



(a) Untreated Tyre Crumb



(b) Treated Tyre Crumb

Figure 3. Density of mortars with OPFF and (a) Untreated tyre crumb; (b) treated tyre crumb

Water Absorption

The water absorption capacities of OPFF were compared to the control specimen as shown in Table 1. The addition of 0-1.5% OPFF showed increases of 4.2% to 8.5% on the percentage of water absorption of the mixes as compared to the control sample. Natural fibre is well known for its high water absorption capacity; however, because only a small amount is used, its effect can be considered negligible. Obvious differences for the absorption capacity of the treated and untreated crumb tyre mortar are shown for the specimens with 0.5% OPFF added, as shown in Figure 4. In general, the treated tyre crumb mortars showed higher absorption than the untreated sample. However, the differences are not significant. The increased water absorption capacity of the treated tyre crumb mortars is a result of the coating treatment itself, which allows more water absorption.

Table 1
OPFF effect on water absorption

Sample Ref.	% of OPFF	Water Absorption (%)
F0	0.0	9.4
F5	0.5	9.8
F10	1.0	10.1
F15	1.5	10.2

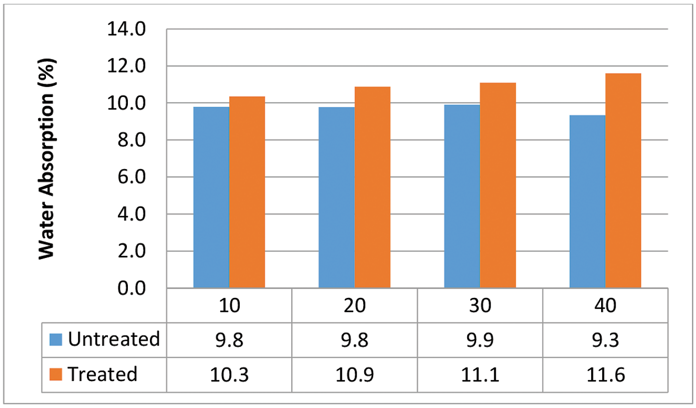


Figure 4. Water absorption of tyre crumb addition on mortar mixes with 0.5% OPFF

Compressive Strength

A compression test was first carried out on the samples with OPFF alone, as shown in Figure 5. In general, the addition of OPFF did reduce the strength of the mortar at 3, 7 and 28 days, except with the addition of 0.5%, which contributed to strength addition of about 4% at 28 days, revealing the best performance. Although this is not very significant, its advantage could be great when shrinkage is studied. The effects of the treated and untreated tyre crumbs were then studied on mortars with 0.5% OPFF, as in Figure 6. The replacement of aggregate with treated tyre crumb particles showed an improvement in the 7 days compressive strength by 0.11, 12.3, 12.4, and 14.4% for the replacement levels of 10, 20, 30, and 40%, respectively. Similarly, the same replacement at 28 days resulted in an improvement in the 28-days compressive strength by 5.2, 24.4, 22.5, and 20.1% for the replacement levels of 10, 20, 30, and 40%, respectively.

An improvement of the compressive strengths of treated tyre crumb resulted from a better adhesion of the roughly textured surface of the treated tyre particles, which provides better interlocking behaviour in the mortar matrix (Rangaraju & Gadka, 2012; Segre & Joekes, 2000). The SEM images of the treated and untreated crumb tyre mortar mixes obtained (Figure 7) indicated a similar texture. Furthermore, a clearer and larger air gap was observed at the interfacial zones (ITZ) of the untreated tyre crumb aggregate and the hardened cement paste, as shown in Figure 7(a), indicating a poorer bond than the treated one (see Figure 7b).

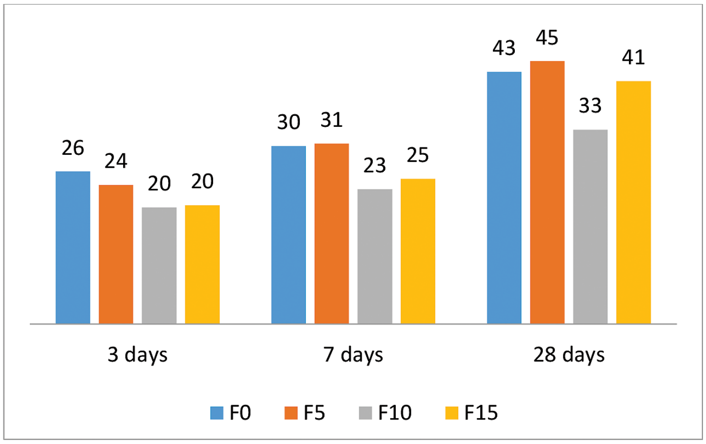


Figure 5. Compressive strength of mortar mix with 0%, 0.5%, 1.0% and 1.5% OPFF additions

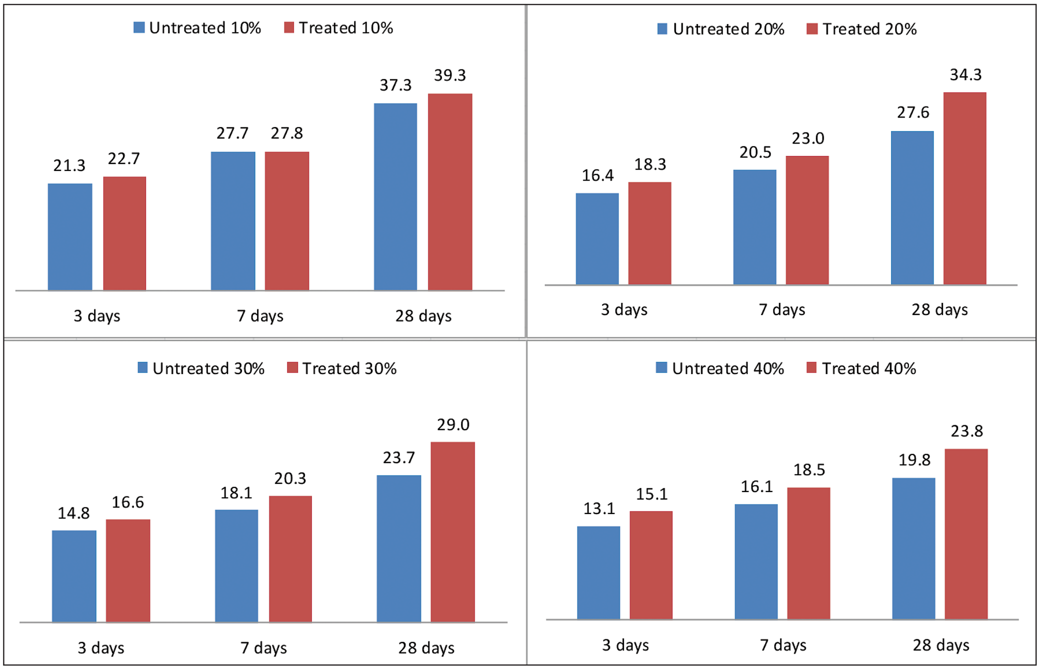


Figure 6. Compressive strength of mortars with untreated (CR) and treated (MR) tyre crumb additions

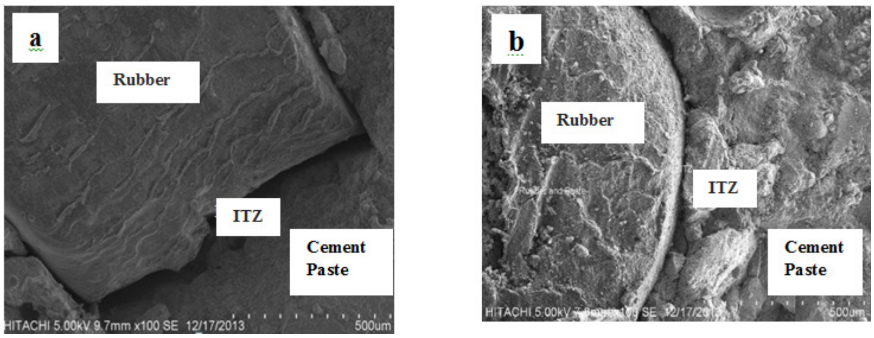


Figure 7. The SEM images of tyre crumb mortars (a) untreated; (b) treated tyre.

Split Tensile Strength

The split tensile strength of OPFF additions in the mortar mixes is shown in Figure 8. This shows that an addition of OPFF from 0.5% to 1.5% by volume contributed significantly to the strength of the composites. The maximum strength improvement was achieved by the addition of 0.5% OPFF, showing the best bond between the particles in the composite. As more OPFF was added, the tensile strength reduced due to the loosening bonds between the particles and the presence of more air voids.

Figure 9 shows the treated and untreated crumb replacement specimens with a 0.5% OPFF addition of mortar mixes after a 28-day curing period. The degradation of strength of the untreated crumb tyres is more obvious, particularly at 10% and 20% replacements. The strength reductions of untreated crumb tyre mortars are expected and these range from 28% to 50%. The same behaviour was reported by Edlin and Serouci (1993), Ganjian et al. (2009), and Najmi and Hall (2012). On the other hand, the treated crumb tyres showed a lower reduction by 1%, 13%, 38% and 47%, for the addition of 10%, 20%, 30% and 40% crumb tyres, respectively. Based on the compression, flexural and split tensile strength improvement in all the mixes containing treated tyre crumb particles, it can be concluded that the influence of the better surface texture of the treated tyre crumb, coupled with the interaction between the rough surfaces of the OPFF, helps in increasing a resistance to early failure, whereas the untreated tyre crumb mixes could easily slip on the surface due to the smoothness.

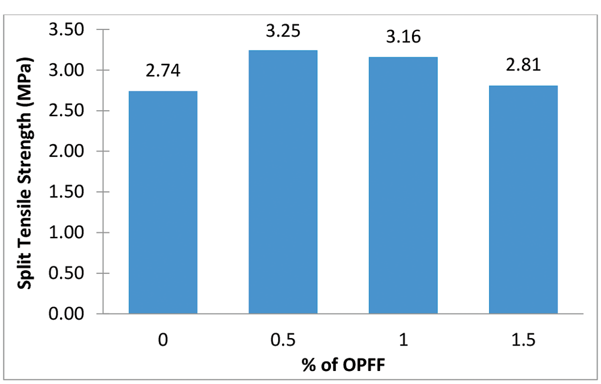


Figure 8. Effects of OPFF on the split tensile strength of the mortar mixes

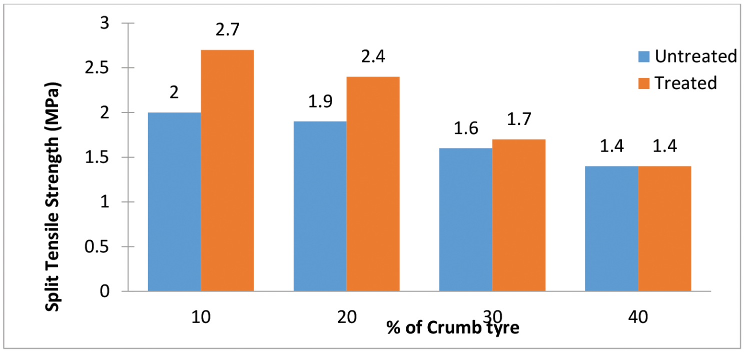


Figure 9. Effects of the treated and untreated tyre crumb on the split tensile strength of the mortar mixes

Flexural Strength

Figure 10 shows the effects of OPFF at 0.5, 1.0 and 1.5% by mass of cement content on the mortar's flexural strength. The influence of OPFF had less effect on the strength but extended the ductility of the material with the best percentage of OPFF addition being 0.5%, and this produced better strength and ductility as compared to the plain mortar, as shown in Figure 8.

The flexural test was conducted on the specimens with four different percentages of OPFF and four different percentages of tyre crumb (both treated and untreated), but only the best percentages of OPFF addition (i.e. 0.5%) for both the untreated and treated tyre crumb mortars were included. This is because the behaviour patterns of the samples, in terms of deflection, stiffness and ductility are the same and only the strength showed slight differences. Apart from this, all the composite mix specimens achieved a larger deflection than the normal weight mortar specimens, presenting more ductile behaviour due to the tyre crumb and oil palm fruit fibre additions. It was observed that the flexural strength and ductility of the treated tyre crumb yielded a better result than the untreated specimens with regards to flexure at all levels of tyre crumb additions. Table 2 shows the peak flexure load of treated and untreated tyre crumb and the percentage of improvement of the treated specimens as compared to the untreated one. The higher improvements observed in the treated tyre crumb incorporated mortars against the untreated was due to the textured surface of the treated tyre crumb particles, which resulted in a better interfacial bond between the tyre crumb particles and the matrix. This means that the OPFF is more effective in the distribution of internal stress in the treated tyre crumb mortars. The OPFF tends to bridge any tendency to initiate cracking due to higher tension forces, which results in higher flexural strength and ductility until the resistance is overcome.

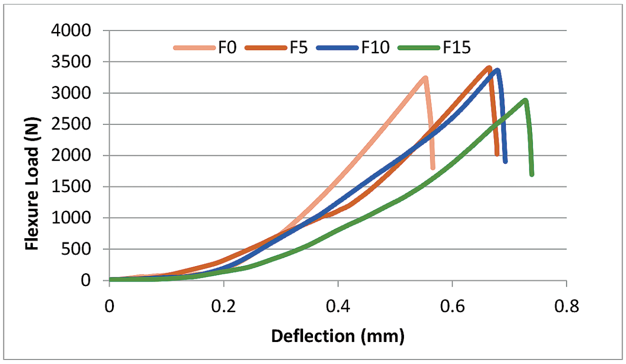


Figure 10. Effects of OPFF in the flexural strength of the mortar mixes

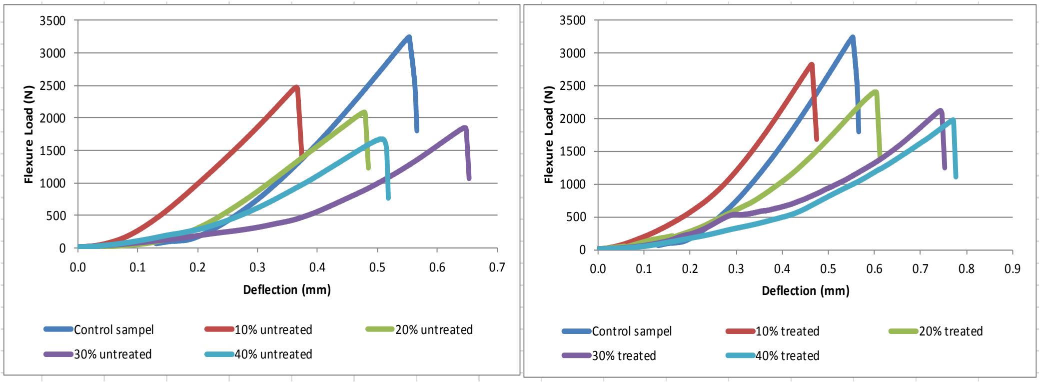


Figure 11. Flexural load vs. deflection of the untreated and treated tyre crumb and with the addition of 0.5% OPFF mortar mixes

Table 2
Flexural load improvement between the treated and untreated tyre crumb samples with 0.5% OPFF addition

Tyre crumb Content (%)	Untreated Tyre crumb (N)	Treated Tyre crumb (N)	Improvement (%)
10	2467	2824	14.5
20	2084	2405	15.4
30	1844	2118	14.9
40	1672	1979	18.4

Unrestrained Shrinkage

The shrinkage strains of the samples were monitored in either the controlled condition (i.e., climatic chamber) or in the uncontrolled laboratory condition. The effect of OPFF was first examined, whereby no tyre crumb was added. The addition of OPFF was compared to the control specimen, i.e. plain mortar in both the controlled and uncontrolled conditions. The results in Figure 12 show that the shrinkage strain increases with the increase in OPFF. This finding contradicts that of Ahmad et al. (2010), who reported that the OPFF fibre improved the shrinkage properties of the mortar.

The addition of OPFF in mortar composites containing untreated tyre crumb was observed to increase the shrinkage strain between 380-800 micro-strains, as shown in Figures 13 to 16, in both the climate chamber and at laboratory temperature. The maximum shrinkage strains of 680 and 710 micro-strains at 90-days were observed for climate chamber and laboratory climatic conditions, respectively. This result is in agreement with Toledo et al. (2005) and Ahmad et al. (2010), who reported on the shrinkage increment due to the addition of natural fibre. Natural fibre shows an increase in concrete shrinkage due to its higher porosity.

The shrinkage strains of the treated tyre crumb mortars containing OPFF are also shown in Figures 13 to 16. The shrinkage strain increases with an increase in the OPFF content without any particular pattern. A shrinkage strain of about 350-1000 micro strains was recorded for all the samples measured, regardless of the exposure conditions. In conclusion, there is no obvious difference in the shrinkage behaviour of the treated and untreated tyre crumb mortars. Also, in both specimens, no regular pattern was observed in terms of the maximum and minimum shrinkage strains.

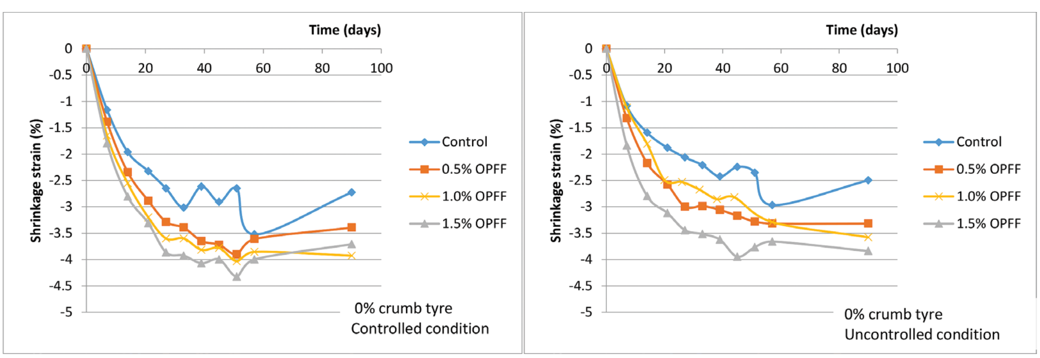


Figure 12. Effects of OPFF on the shrinkage properties of plain mortar in controlled and uncontrolled conditions

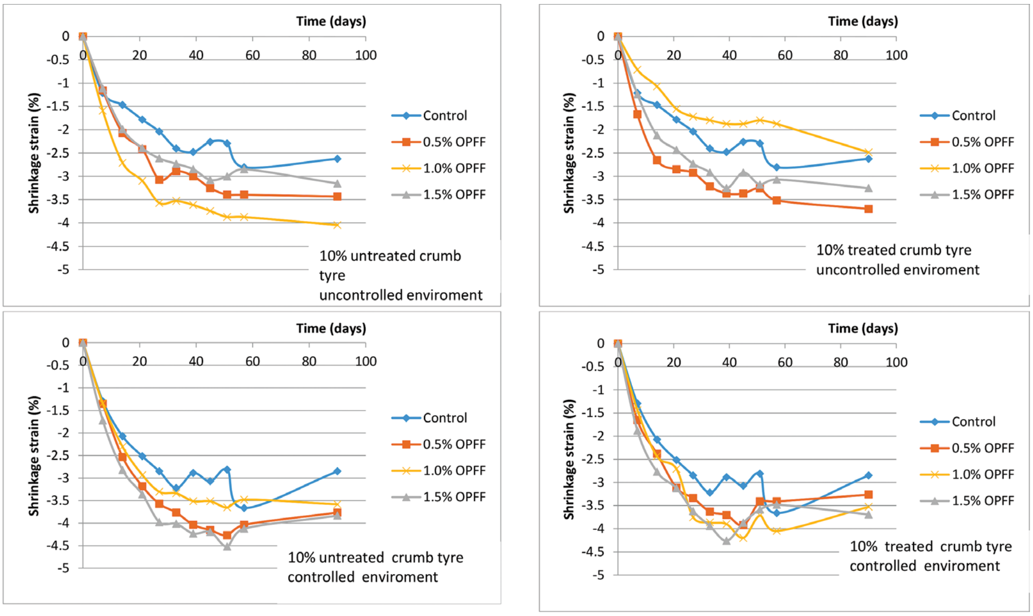


Figure 13. Shrinkage behaviour of 10% treated and untreated tyre crumb samples under controlled and uncontrolled conditions

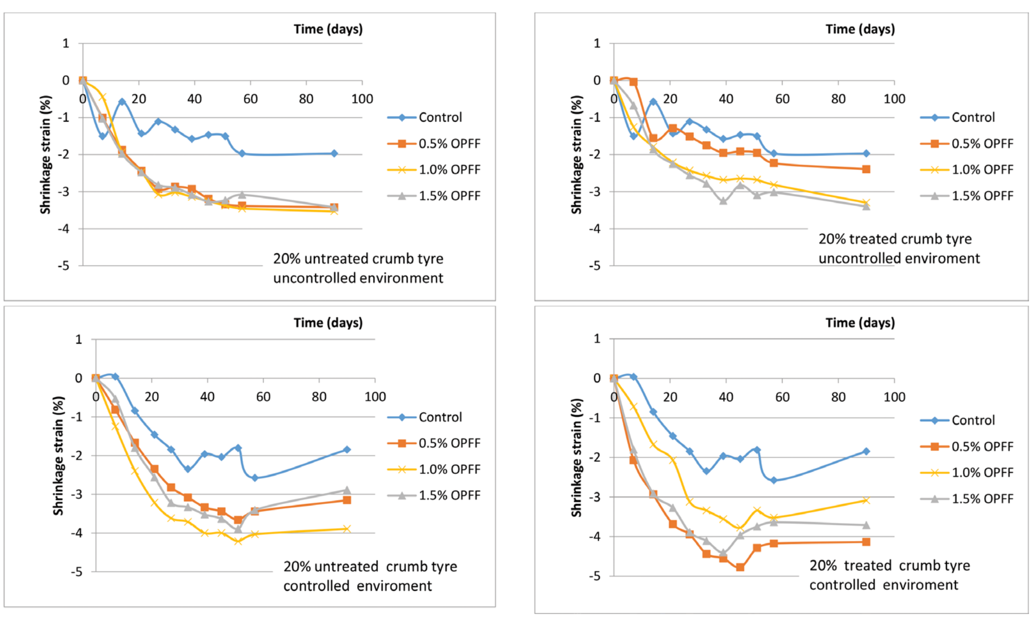


Figure 14. Shrinkage behaviour of 20% treated and untreated tyre crumb samples under controlled and uncontrolled conditions

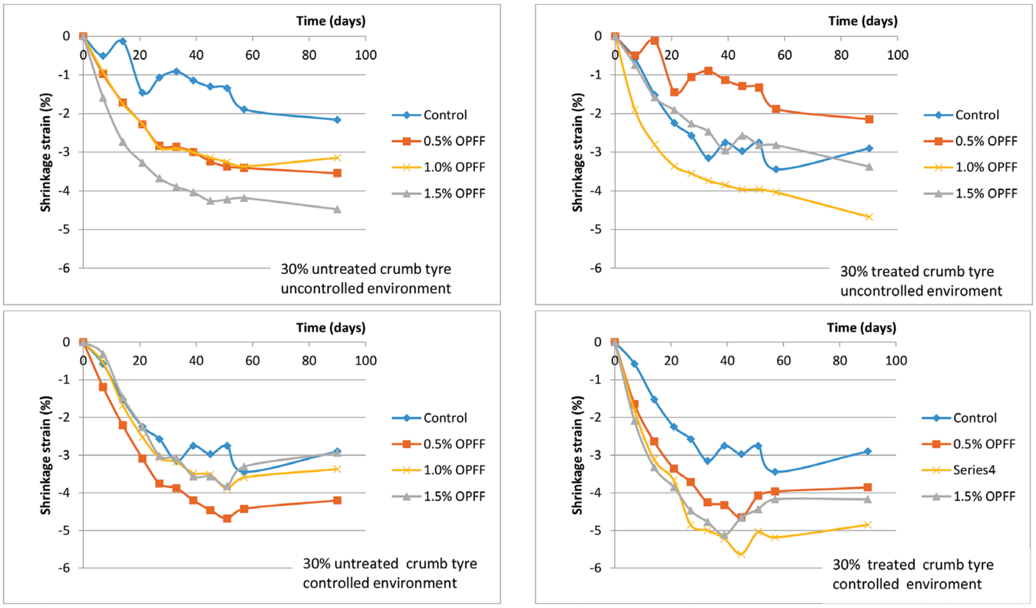


Figure 15. Shrinkage behaviour of 30% treated and untreated tyre crumb samples under controlled and uncontrolled conditions

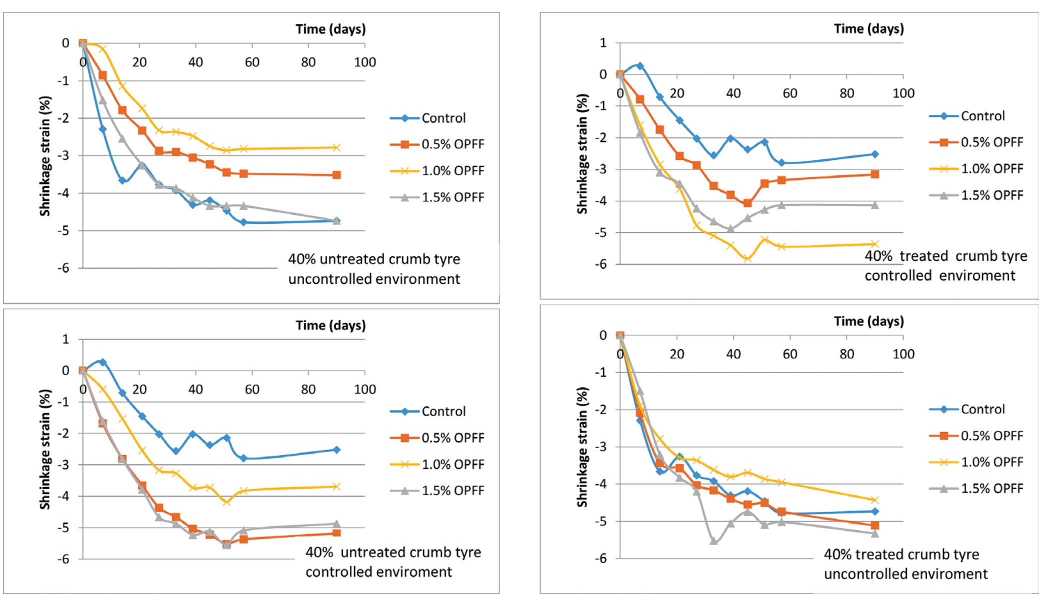


Figure 16. Shrinkage behaviour of 40% treated and untreated tyre crumb samples under controlled and uncontrolled conditions

CONCLUSION

The utilisation of tyre crumb particles as a replacement for aggregate in mortar composites is necessitated by the need to recycle waste tyres that are abundant and non-bio-degradable. However, the use of this material causes losses in strength properties. The losses were reduced by surface treatment and coating the tyre crumb particles with cement powder, coupled with the use of OPFF to redistribute the internal stress in the hardened samples to prevent sudden failure and improve performance. The results showed a promising avenue for producing a new composite mortar which demonstrates improved compressive, split tensile and flexural strengths compared with untreated tyre crumb incorporated mortars. Incorporating tyre crumb particles into the mortar matrix, as a partial replacement of the mineral aggregate, showed a decrease in the fresh concrete flowability and unit weight.

At hardened state, on the other hand, the results showed a promising avenue for producing a new composite mortar with pre-treated tyre crumb and OPFF addition that demonstrated better compressive, split tensile, and flexural strengths compared with the untreated tyre crumb incorporated mortars. Hence, it can be concluded that the replacement of up to 40% by volume of aggregate with pre-treated tyre crumb particles containing 0.5 to 1.0% OPFF addition have proven the mechanical properties of the new mortar composite. However, the addition of OPFF in both the untreated and treated tyre crumb specimens gave no particular pattern in terms of the shrinkage of mortar composite. Meanwhile, the microstructural investigation revealed that the decrease in the strength properties of the untreated tyre crumb mortars is due to soft, elastic and smooth surfaces of the tyre crumb particles, which reduce the bond between the tyre particles and the cement matrix.

REFERENCES

Ahmad, S., Elahi, A., Barbhuiya, S. A., & Farid, Y. (2012). Use of polymer modified mortar in controlling cracks in reinforced concrete beams. *Construction and Building Materials*, *27*(1), 91–96.

Ahmad, Z., Ibrahim, A., & Tahir, P. M. (2010). Drying Shrinkage Characteristics of Concrete Reinforced With Oil Palm Trunk Fibre. *International Journal of Engineering Science and Technology*, *2*(5), 1441-1450.

Ahmad, Z., Saman, H., & Tahir, T. (2010). Oil palm trunk fiber as a bio-waste resource for concrete reinforcement. *International Journal of Mechanical and Materials Engineering (IJMME), 5*(2), 199-207.

ASTM C33, A. (2004). Standard Specification for Concrete Aggregates. In *American Society for Testing and Material* (pp. 1-11). West Conshohocken, PA.

ASTM C109, A. (2002). Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens). *American Society for Testing and Material.* West Conshohocken, PA.

ASTM C127, A. (1993). Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate. *American Society for Testing and Material.* West Conshohocken, PA.

ASTM C150, A. (2001). Standard Specification for Portland Cement. *Annual Book of ASTM Standards*.

ASTM C341. (2006). Standard practice for length change of cast, drilled, or sawed specimens of hydraulic-cemet mortar and concrete. *American Society for Testing and Material*. West Conshohocken, PA.

ASTM C348. (2008). Standard specification for flexural strength of hydraulic-cement mortars. *American Society for Testing and Material*. West Conshohocken, PA.

ASTM C496. (2004). Standard specification for split tensile strengthof cylinderical concrete specimens. *American Society for Testing and Material*. West Conshohocken, PA.

ASTM C642, A. (2001). Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. *American Society for Testing and Material.* West Conshohocken, PA.

ASTM C1437. (2007). Standard test method for flow of hydraulic cement mortar. *American Society for Testing and Material.* West Conshohocken, PA.

Aziz, F. N. A. A., Bida, S. M., Nasir, N. A. M., & Jaafar, M. S. (2014). Mechanical properties of lightweight mortar modified with oil palm fruit fibre and tire crumb. *Construction and Building Materials*, *73*, 544-550.

Benazzouk, A., Douzane, O., Langlet, T., Mezreb, K., Roucoult, J., & Quéneudec, M. (2007). Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes. *Cement and Concrete Composites, 29*(10), 732-740.

Bektas, F., Wang, K., & Ceylan, H. (2009). Effects of crushed clay brick aggregate on mortar durability. *Construction and Building Materials*, *23*(5), 1909–1914.

Braga, M., de Brito, J., & Veiga, R. (2012). Incorporation of fine concrete aggregates in mortars. *Construction and Building Materials*, *36*, 960–968.

Brown, K. M., Cummings, R., Mrozek, J. R., & Terrebonne, P. (2001). Scrap tire disposal: three principles for policy choice. *Natural Resources Journal*, *41*(1), 9-22.

Cairns, R., & Kenny, M. (2004). *The use of recycled rubber tyres in concrete*. Paper presented at the Sustainable Waste Management and Recycling: Used/Post-Consumer Tyres. Concrete and Masonry Research Group and Held at Kingston University-London.

Chou, L. H., Lin, C. N., Lu, C. K., Lee, C. H., Lee, M. T. (2010). Improving rubber concrete by waste organic sulfur compounds. *Waste Management & Research, 28*(1), 29-35.

Chou, L. H., Yang, C. K., Lee, M. T., & Shu, C. C. (2010b). Effects of partial oxidation of crumb rubber on properties of rubberized mortar. *Composites Part B: Engineering*, *41*(8), 613-616.

Chung, K. H., & Hong, Y. K. (1999). Introductory behavior of rubber concrete. *Journal of Applied Polymer Science*, *72*(1), 35-40.

Correia, S. L., Partala, T., Loch, F. C., & Segadães, A. M. (2010). Factorial design used to model the compressive strength of mortars containing recycled rubber. *Composite Structures*, *92*(9), 2047–2051.

Eldin, N. N., & Senouci, A. B. (1993). Rubber-tire particles as concrete aggregate. *Journal of Materials in Civil Engineering, 5*(4), 478-496.

Filho, R. D. T., Ghavami, K., Sanjuán, M. A., & England, G. L. (2005). Free, restrained and drying shrinkage of cement mortar composites reinforced with vegetable fibres. *Cement and Concrete Composites*, *27*(5), 537-546.

Ganjian, E., Khorami, M., & Maghsoudi, A. A. (2009). Scrap-tyre-rubber replacement for aggregate and filler in concrete. *Construction and Building Materials*, *23*(5), 1828-1836.

Hossain, K., Ahmed, S., & Lachemi, M. (2011). Lightweight concrete incorporating pumice based blended cement and aggregate: mechanical and durability characteristics. *Construction and Building Materials, 25*(3), 1186–95.

Huang, B., Li, G., Pang, S. S., & Eggers, J. (2004). Investigation into waste tire rubber-filled concrete. *Journal of Materials in Civil Engineering*, *16*(3), 187-194.

Ismail, M. A., & Hashim, H. (2008). Palm oil fiber concrete. In *Proceedings of the 3th ACF International Conference Sustainable Concrete Technology and Structures in Local Climate and Environmental Conditions.* Ho Chi Minh City, Vietnam.

Jingfu, K., Chuncui, H., & Zhenli, Z. (2009). Strength and shrinkage behaviors of roller-compacted concrete with rubber additives. *Materials and structures*, *42*(8), 1117-1124.

Khatib, Z. K., & Bayomy, F. M. (1999). Rubberized Portland cement concrete. *Journal of Materials in Civil Engineering*, *11*(3), 206-213.

Kosievith, V., Pinto, C., & Hamassaki, L. (2001). *Rubber powder and Portland cement composites.* Brazil: Polythenic School, University of Sao Paulo.

Lee, H. S., Lee, H., Moon, J. S., & Jung, H. W. (1998). Development of tire added latex concrete. *ACI Materials Journal, 95*(4), 356–364.

Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie, C., & Huang, B. (2004). Development of waste tire modified concrete. *Cement and Concrete Research, 34*(12), 2283-2289.

Li, Z., Li, F., & Li, J. (1998). Properties of concrete incorporating rubber tyre particles. *Magazine of Concrete Research*, *50*(4), 297-304.

Najim, K. B., & Hall, M. R. (2012). Mechanical and dynamic properties of self-compacting crumb rubber modified concrete. *Construction and Building Materials*, *27*(1), 521-530.

Nehdi, M., & Khan, A. (2001). Cementitious composites containing recycled tire rubber: An overview of engineering properties and potential applications. *Cement Concrete and Aggregates, 23*(1), 3–10.

Neville, A. M., & Neville, A. M. (1995). *Properties of concrete* (Vol. 4). Longman, London.

Neno, C., Brito, J. D., & Veiga, R. (2014). Using fine recycled concrete aggregate for mortar production. *Materials Research*, *17*(1), 168-177.

Onuaguluchi, O., & Panesar, D. K. (2014). Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume. *Journal of Cleaner Production*, *82*, 125-131.

Pedro, D., de Brito, J., & Veiga, R. (2012). Mortars made with fine granulate from shredded tires. *Journal of Materials in Civil Engineering*, *25*(4), 519-529.

Raghavan, D., Huynh, H., & Ferraris, C. (1998). Workability, mechanical properties, and chemical stability of a recycled tyre rubber-filled cementitious composite. *Journal of Materials Science*, *33*(7), 1745-1752.

Rangaraju, P. R., & Gadkar, S. (2012). *Durability evaluation of crumb rubber addition rate on portland cement concrete*. Clemson University Report. USA.

Sánchez, E., Massana, J., Garcimartín, M. A., & Moragues, A. (2008). Mechanical strength and microstructure evolution of fly ash cement mortar submerged in pig slurry. *Cement and Concrete Research*, *38*(5), 717–724.

Segre, N., & Joekes, I. (2000). Use of tire rubber particles as addition to cement paste. *Cement and Concrete Research*, *30*(9), 1421-1425.

Silva, J., de Brito, J., & Veiga, R. (2010). Recycled red-clay ceramic construction and demolition waste for mortars production. *Journal of Materials in Civil Engineering*, *22*(3), 236–244.

Taha, M. M. R., El-Dieb, A. S., El-Wahab, M. A. A., & Hameed, M. E. A. (2008). Mechanical, fracture, and microstructural investigations of rubber concrete. *Journal of Materials in Civil Engineering*, *20*(10), 640-649.

Topcu, I. B. (1995). The properties of rubberized concretes. *Cement and Concrete Research*, *25*(2), 304-310.

Turki, M., Bretagne, E., Rouis, M. J., & Quéneudec, M. (2009). Microstructure, physical and mechanical properties of mortar–rubber aggregates mixtures. *Construction and Building Materials*, *23*(7), 2715–2722.

Uygunoğlu, T., Brostow, W., Gencel, O., & Topçu, İ.B. (2013). Bond strength of polymer lightweight aggregate concrete. *Polymer Composites*, *34*(12), 2125-2132.

Wang, H., & Huang, W. (2010). Durability of self-consolidating concrete using waste LCD glass. *Construction and Building Materials*, *24*(6), 1008–1013.