Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.
Copyright © 2015 ISEC Press
ISBN: 978-0-9960437-1-7

AN INVESTIGATION INTO THE TECHNIQUES FOR IMPROVING THE PROPERTIES OF CRUMB RUBBER CONCRETE

STEPHANIE SOMERVILLE, REMADEVI DHANASEKAR, TRAVIS FRAME, and T.G. SUNTHARAVADIVEL

School of Engineering and Technology, Central Queensland University
Rockhampton, Australia

Motor vehicle tires are discarded every year where the majority ends up in land fill. This poses a serious ecological threat as the tires contain many toxic components and contribute to a loss of biodiversity. From the economic and environmental perspectives, inclusion of recycled rubber in concrete would reduce costs as well as conserve the component materials used in concrete. Past studies have indicated poor-mechanical properties of concrete with the sole inclusion of recycled tire rubber. This paper presents an experimental investigation to improve the workability and hardened properties through sodium hydroxide surface treatment of recycled crumb rubber, and silica fume. Ten concrete mixes were prepared with the volumes of recycled rubber ranging from 10% to 30%. The test results were compared with a control concrete mix. The investigation indicated that favorable strength could be achieved with the addition of 10% treated rubber. Test results and analysis details are presented in the paper.

Keywords: Recycled rubber, Workability, Optimum percentage, Sodium hydroxide, Strength.

1 INTRODUCTION

Concrete, being the integral part of many structures, plays a vital role in modern society and its benefit to everyday life is immense. The Australian industry alone produces more than 24 million cubic meters of concrete each year (CCAA 2008). The cement industry produces 5–7 % of the global CO_2 emissions and for each ton of cement 900kg of CO_2 is released into the atmosphere (Benhelal 2013). Extensive research has been carried out to produce environmentally friendly green concretes to reduce the air pollution. To date, supplementary cementatious materials such as fly ash, silica fume and blast furnace slag have successfully been used as cement replacement. Similarly, steel fibers, glass fibers, carbon fibers and industry by-products such as washed lime stone have also been used for aggregate replacement. Recycled rubber is one of the products identified as an aggregate in this paper.

2 REVIEW OF LITERATURE

There are three broad categories that refer to the physical size of recycled tire rubber; namely, chipped, crumb and ground rubber. Crumb rubber is graded in the range of

0.425–4.75 mm and is typically a suitable replacement for coarse sand. Chipped rubber is a suitable replacement for gravel with particles ranging 13–76 mm, and ground rubber may replace cement or other fine powders with particle sizes in the range of 0.075–0.475 mm (Ganjian 2009).

Compressive strength of concrete is commonly used as the basic mechanical property to effectively determine the concrete's suitability for any application. Aiello and Leuzzi (2010) replaced fine and course aggregates with crumb and chipped rubber and found that the compressive strength loss for coarse aggregate replacement was much more profound than that of fine aggregate replacement. A 50% aggregate replacement by recycled rubber showed a decrease in strength of 70% to 85% of compressive strength (Guneyisi 2004, Ganjian 2009). However, Valadares (2012) found that a higher tensile strength was achieved when the rubber particles had larger dimensions, due to the rubber particles delaying crack initiation and propagation.

Research findings stated that higher rubber volumes reduced the unit weight of concrete due to their low specific weight. For example, a 50% aggregate replacement resulting in a 75% reduction in unit weight of the fresh concrete mixture was reported by Guneyisi (2004). Also documented that, with an increase of rubber content there was a reduction in the workability (Toutanji 1996, Albano 2005, Batayneh 2008). Microstructural investigations of concrete with rubber as an aggregate confirmed these findings and attributed this reduction in slump to the rough surface of the rubber, which increases the friction between the particles in the mixture (Reda Taha 2008).

Considering the previous studies in the field of concrete with recycled rubber as an aggregate, this paper aims to determine an optimum percentage addition of recycled tire rubber to achieve good workable concrete with optimum compressive, tensile and flexural strengths in comparison with a control mix (containing no recycled rubber particles).

3 EXPERIMENTAL PROGRAM

3.1 Materials and Concrete Mix Design

Ten different concrete mixes were prepared with varying amount of crumb rubber (recycled rubber) replacement as per detail in Table 1.

Table 1. Summary of concrete mix specifications.

Mix Type	Detail
Mix 1– C1	Control mix and 0% crumb rubber
Mix 2 – R10	C1 mix coarse sand was replaced by 10% crumb rubber
Mix 3 – R20	C1 mix coarse sand was replaced by 20% crumb rubber
Mix 4 – R30	C1 mix coarse sand was replaced by 30% crumbed rubber
Mix 5 – TR10	C1 mix coarse sand was replaced by 10% surface treated crumb rubber
Mix 6 – TR20	C1 mix coarse sand was replaced by 20%surface treated crumb rubber
Mix 7 – TR30	C1 mix coarse sand was replaced by 30% surface treated crumb rubber
Mix 8 – SF10-R10	C1 mix cement was replaced by 10% silica fume and coarse sand was replaced by 10% crumb rubber
Mix 9 – SF10-R20	C1 mix cement was replaced by 10% silica fume and coarse sand was replaced by 20% crumb rubber
Mix 10 – SF10-R30	C1 mix cement was replaced by 10% silica fume and coarse sand was replaced by 30% crumb rubber

Crumb rubber aggregate (from truck tires) used in the concrete mix had a particle size ranging from 2.35 mm to 4.75 mm. The cement used was commercially available general purpose (GP) cement. A water reducing admixture, *MasterPolyheed 8875* was also used in the mix. The concrete mix contained 10mm and 20mm gravel as coarse aggregates and fine aggregates of coarse and fine manufactured sands. In this study, the coarse sand was replaced by 10% to 30% of the crumb rubber. The crumb rubber used in mixes 5, 6 and 7 were surface treated with sodium hydroxide solution (NAOH) similar to that used by Youssf (2014). For this process, crumb rubber particles were washed in tap water to remove impurities then, submerged in a 10% NaOH solution for 30 minutes and finally rinsed repeatedly in tap water until the rinse water reached a PH of 7. The water was drained and the treated crumb rubber particles were left to air dry.

A 25 MPa, 85 mm slump mix containing water–cement ratio (W/C) and aggregate–cement ratio (A/C) of 0.60 and 6.84 respectively was used as the control mix.

3.2 Specimen Preparation

The concrete was mixed using a 100 L capacity drum mixer. Care was taken to ensure uniformity across all mixes during the mixing process. Extra precautions were taken to ensure adequate mixing of the concrete mixes containing silica fume due to the fine size of the particles. This was to ensure uniformity within the mix, and to prevent the formation of agglomerations by the densified silica fume (Terrence 2005).

Cylindrical specimens of diameter 100 mm × height 200 mm were used for compression tests and split tensile test. For flexural tests, rectangular beam specimens with uniform cross section of 100 mm × 100 mm and length of 350 mm were used. A total of 40 cylindrical specimens and 30 beam specimens were tested. Specimens were wrapped in plastic sheets and cured for 56 days. Age of all specimens was 56 days. For each test, the average test result was used for analysis.

4 RESULTS AND DISCUSSION

4.1 Workability

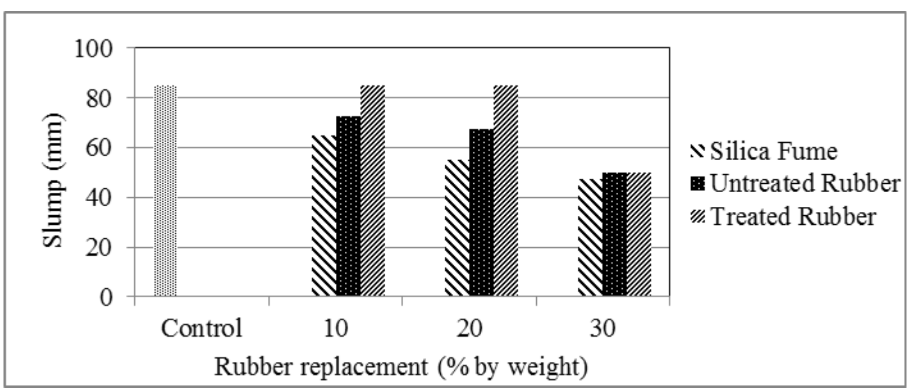

Figure 1. Results of workability test.

The average slump of each concrete mix is shown in Figure 1. It was observed from figure that there was a decrease in workability with an increase in rubber percentage. The workability of the rubber treated with sodium hydroxide seemed to be effective as the slump obtained with 10% and 20% coarse sand replacement by treated rubber is similar to that of the control mix slump. However addition of 30% treated rubber showed a sharp decline in workability to a level that was similar to the untreated rubber's workability. This attributes additional rubber in the concrete mix may reduce the workability regardless it's pre-treatment. The addition of silica fume also decreased the workability of the control concrete mix by 24% with the addition of 10% rubber replacement.

4.2 Hardened Concrete Strength Result

Compression, split tensile and flexural tests were conducted to find the hardened properties of all ten mixes according to Australian Standards. These strength test results were compared with those of the control mix to determine an optimum mix that provides the maximum strength comparable to the control mix. Summary of the mean strengths and their coefficient of variation (CoV) are given in Table 2. The CoV showed that the test results were within an acceptable range of variance and are, therefore, can be considered as reliable results.

Table 2. Strength test results summary.

Mix Type	Compressive Strength (MPa)		Flexure Tensile Strength (MPa)		Split Tensile Strength (MPa)	
	Mean	**CoV**	**Mean**	**CoV**	**Mean**	**CoV**
Mix 1– C1	25.93	3%	2.39	11%	2.53	7%
Mix 2 – R10	17.74	7%	1.81	4%	2.32	2%
Mix 3 – R20	14.20	1%	1.78	4%	1.84	7%
Mix 4 – R30	9.70	0%	1.49	13%	1.55	5%
Mix 5 – TR10	19.15	3%	2.33	7%	2.86	3%
Mix 6 – TR20	13.31	7%	1.47	14%	1.80	1%
Mix 7 – TR30	10.97	1%	1.32	6%	1.64	12%
Mix 8 – SF10-R10	16.77	7%	1.69	1%	2.06	1%
Mix 9 – SF10-R20	13.35	7%	1.50	5%	1.77	7%
Mix 10 – SF10-R30	10.37	8%	1.49	2%	1.38	1%

4.2.1 Compressive Strength

In line with the findings of other researchers, Aiello and Leuzzi (2010) the compressive strength test results showed a reduction in strength with increased percentage of rubber. Among all nine experimental mixes, the TR10 mix gave a compression strength closest to the control mix. The TR10 mix compressive strength was 19.15 MPa which was 74% of the control specimen compressive strength. A rapid decline in strength was noted when the addition of recycled rubber was greater than 20% replacement of coarse sand. This result correlates with the findings of Issa and Salem (2013). Additionally, all recycled rubber compression specimens stayed intact after failure and showed no signs of brittle failure.

4.2.2 Flexural Strength

Table 2 shows that the general trend of the flexural strength was indirectly proportional to the amount of recycled rubber in the concrete mix. The flexural strength of the TR10 mix was found to be close to that of the control mix, while the R10 and SF10+R10 specimens showed a strength of 76% and 70% of the control mix strength respectively. Therefore, it can be stated that the addition of silica fume has no significant impact on the flexural strength of the concrete with recycled rubber as an aggregate. The R10 and SF10+R10 mixes have had a similar flexural strength, implying that the rubber particles had a weak rubber-cement bond. The TR10 mix flexural strength showed that there exists good bond development between the cement and treated rubber aggregates. Therefore, it is evident that higher rubber content was detrimental to the concrete properties.

4.2.3 Split Tensile Strength

The tensile strength reduced with the increase of rubber content as shown in Table 2. The specimens with 20% rubber content showed a 30% strength reduction compared to the control mix. Specimens with 10% rubber addition have shown the best result. The TR10 mix showed an increase of 13% in split tensile strength, while the R10 and SF10+R10 specimens showed a reduction in split tensile strength of 8% and 18% respectively in comparison with the control mix. Valadares (2012) found that a higher tensile strength was achieved when the rubber particles had larger dimensions. However, in this research treated rubber had smaller dimension as a replacement for coarse sand, and still showed an increase of 13% over that of the control mix.

5 CONCLUSION AND RECOMMENDATIONS

This investigation indicates favorable results from the surface treatment of rubber with sodium hydroxide. On the basis of experimental investigation, the optimum replacement percentage is found to be 10% treated rubber (NaOH surface treatment). As this is the lowest percentage examined in this research, further work is recommended to examine replacement in the range of 5% - 15% to confirm whether or not any other local optimum exists. In comparison with the control mix, the workability of the treated rubber mix was equal; flexural strength achieved 98% matched value; and split tensile strength showed an increase of 13%. However, there is a reduction of 26% of compressive strength.

Acknowledgements

The authors would like to thank Central Queensland University for providing financial assistance that led to the successful completion of this research. The authors are indebted to the assistance provided by senior laboratory technical staff Paula Frame, civil engineer Brendan Cox and final year civil engineering student Laurie Schreck.

References

Albano, C., Camacho, N., Reyes, J., Feliu, J., and Hernandez, M., Influence of Scrap Rubber Addition to Portland I Concrete Composites: Destructive and Non Destructive Testing, *Composite Structures*, Elsevier, 71(3), 439-446, December, 2005.

Aiello, M., and Leuzzi, F., Waste Tyre Rubberized Concrete: Properties at Fresh and Hardened State, *Waste Management*, Elsevier, 30(8), 1696- 1704, August, 2010.

Batayneh, M., Marie, I., and Asi, I., Promoting the Use of Crumb Rubber Concrete in Developing Countries, *Waste Management*, Elsevier, 28(11), 2171-2176, November, 2008.

Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A., Global Strategies and Potentials to Curb CO2 Emissions in Cement Industry, *Journal of Cleaner Production*, Elsevier, 51, 142-161, July, 2013.

Cement Concrete and Aggregates Australia (CCAA), The Industry– Overview, 2008. Retrieved from www.concrete.net.au/industry/overview on September 7, 2014.

Ganjian, E., Khorami, M., and Maghsoudi, A., Scrap–Tyre–Rubber Replacement for Aggregate and Filler in Concrete, *Construction and Building Materials*, Elsevier, 23(5), 1828-1836, May, 2009.

Guneyisi, E., Gesoglu, M., and Ozturan, T., Properties of Rubberized Concretes Containing Silica Fume, *Cement and Concrete Research*, Elsevier, 34(12), 2309- 2317, December, 2004.

Issa, C., and Salem, G., Utilization of Recycled Crumb Rubber as Fine Aggregates in Concrete Mix Design, *Construction and Building Materials*, Elsevier, 42, 48-52, May, 2013.

Reda Taha, M., El-Dieb, A., El-Wahab, M., and Abdel-Hameed, M., Mechanical, Fracture, and Microstructural Investigations of Rubber Concrete, *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, 20(10), 640- 649, October, 2008.

Terrence, C. H., Silica Fume User's Manual – Technical Report, *Silica Fume Association*, 2005. Retrieved from http://www.silicafume.org/concrete-manual.html on February 02, 2015.

Toutanji, H., The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates, *Cement & Concrete Composites*, Elsevier, 18(2), 135- 139, 1996.

Valadares, F., Bravo, M., and de Brito, J., Concrete with Used Tire Rubber Aggregates: Mechanical Performance, *Materials Journal*, American Concrete Institute, 109(3), 283-292, May, 2012.

Youssf, O., EIGawady, M., Mills, J., and Ma, X. An Experimental Investigation of Crumb Rubber Concrete Confined by Fiber Reinforced Polymer Tubes, *Construction and Building Materials*, Elsevier, 53, 522-532, February, 2014.