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ABRASION AND IMPACT RESISTANCE INVESTIGATION OF CRUMBED RUBBER CONCRETE (CRC)

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ABSTRACT

Large volumes of rubber tyres are disposed of annually and only a small quantity are recycled. This paper examines the abrasion and impact resistance of crumbed rubber concrete (CRC), which uses crumbed rubber from used tyres as a partial replacement for the fine aggregate. Furthermore styrene-butadiene rubber (SBR) latex was added to some of the crumb rubber mixes to gauge its effect. Laboratory tests focused on the slump, compression strength, abrasion and impact resistance of traditional concrete, rubberized concrete with rubber content of 10% and 20% and SBR modified rubberized concrete. A comparison of the experimental results for the abrasion resistance and impact resistance of traditional concrete, rubberized concrete and rubberized concrete with SBR latex was conducted. Test results indicated that although rubberized concrete had slightly lower compression strength than traditional concrete it is still possible to produce rubberized concrete with satisfactory strength using good concrete mix design and appropriate rubber content. Results also showed that CRC has better impact and abrasion resistance than traditional concrete.

KEYWORDS

SBR latex, crumbed rubber concrete, abrasion, impact resistance.

INTRODUCTION

According to World Business Council for Sustainable Development (WBCSD 2008), annually 1.5 billion new tyres are produced around the world and one billion tyres reach the end of their lives. There are four billion used tyres being stockpiled or placed in landfills worldwide. In Australia 48 million equivalent passenger unit (EPU) tyres (equivalent to 500k tons) reached their end of life each year, however only 30% of them were recycled (Hyder 2012). Tyre stockpiles can pose environmental and fire risks and dumping used tyres is a waste of useful material and resources. At the same time in the concrete industry, more and more waste materials like plastic fibres, steel fibres, waste glass and recycled bricks have been used in concrete without significant detriment to the mechanical properties.

Research on crumbed rubber concrete (CRC) started in the 1990s. Most research has shown that the compressive strength of rubberized concrete decreases as the rubber content increases, but CRC has more ductility and higher toughness compared with traditional concrete. The factors that might affect CRC strength and performance include different rubber size, replacement percentage, rubber pre-treatment condition, different cement types and other mineral or polymer additives (e.g. Topcu 1995, Khatib and Bayomy 1999, Aiello and Leuzzi 2010). However, limited work has been done on the abrasion resistance and impact resistance of CRC. Since CRC has potential to be used extensively in pavements, abrasion resistance and impact resistance are important properties. In this paper mixes based on traditional concrete, CRC and SBR modified CRC were tested to investigate and compare their compressive and tensile strength as well as their abrasion and impact resistance.

Abrasion resistance depends on the finishing conditions of the concrete surface, the compressive strength of the concrete, the strength and content of coarse aggregates and the internal bonding between concrete aggregate and cement paste (e.g. de Brito 2009). Some additions such as polymers, steel or polymer fiber and silica fume can improve the abrasion resistance of concrete. Conflicting views about CRC abrasion resistance were found in reported research. Kang et al. (2012) reported 160%, 183%, 225% and 333% increase in abrasion resistance of CRC at rubber percentage of 9%, 12%, 15% and 18% than traditional concrete, while the compressive strength reduction were 20%, 24%, 27% and 38%. Shen et al.(2013) assessed the abrasion resistance of latex modified porous concrete through wear loss test and reported that the abrasion resistance of CRC with coarse or fine rubber was 13% and 23% higher respectively than control concrete. Ozbay et al. (2011) followed TS 2824 EN 1338 abrasion resistance test, using 0-3mm sized rubber to replace sand in the concrete and reported a decreased abrasion resistance of CRC than normal concrete and it decreased with increasing rubber percentage. However, the use of ground granulated blast furnace slag was found to improve abrasion resistance. Sukontasukkul and Chaikaew (2006) carried out the rotating cutter abrasion test method (ASTM C944-95) using rubber mix of 0-3.35mm and 0-0.85mm at replacement levels of 10% and 20%. Lower abrasion resistance of CRC than the control concrete was reported.

Experimental studies on the impact resistance of rubberized concrete started in the late 1990s. Fattuhi and Clark (1996) conducted drop-weight tests on plain concrete and rubberized concrete slabs and reported that the rubberized concrete slab exhibited wider cracks. Topcu and Avcular (1997) reported that the impact dynamic stresses and damage were reduced in rubberized concrete due to its lower elastic modulus and higher plastic energy absorption capacity. Al-Tayeb et al. (2013) conducted impact tests on concrete beams containing 1 mm rubber particles and reported that dynamic fracture energy improved by 85-279% at rubber contents of 5-20%. It increased with increasing rubber content. Liu et al. (2012) conducted impact tests on plain concrete, rubberized concrete and steel fiber reinforced rubberized concrete using a Split-Hopkinson Pressure Bar device and reported increased dynamic fracture energy and dynamic increase factor (ratio of Dynamic compressive strength to static strength) with the increasing strain rates, rubber sizes and rubber content. The possible reason might be that higher rubber content and larger size could absorb more dynamic energy.

TEST MATERIALS AND MIX DESIGNS

Used Materials

General purpose cement manufactured by Adelaide Brighton Cement was used in this research. Both 20mm and 10mm stone were used as coarse aggregate and natural sand was used as fine aggregate. Both coarse and fine aggregate were oven dried a day before the mix to reduce the moisture content to a minimum. Rubber from different resource might have different mechanical properties which will inevitably affect CRC performance. In this study crumb rubber from waste tyres was supplied by Chip Tyre Pty Ltd. and was clean, containing no steel belting or steel fiber. It consists of three different nominal sizes: 0.15mm, 1.18mm and 2.36mm at a weight ratio of 1:1:1. All rubber was used directly from bags without any pre-treatment. Figure 1 shows the particle size distribution of the sand and rubber mix. The specific gravity of stone, sand and rubber were 2.73, 2.6 and 0.85 respectively. Styrene-butadiene rubber (SBR) latex manufactured by BASF was used to modify the CRC in this research. It is a liquid with solid content of 49%. To maintain similar workability for all five mixes both plasticizer (Rheoplus 75 from BASF) and super-plasticizer (Glenium 107 Suretec from BASF) were used in this research.

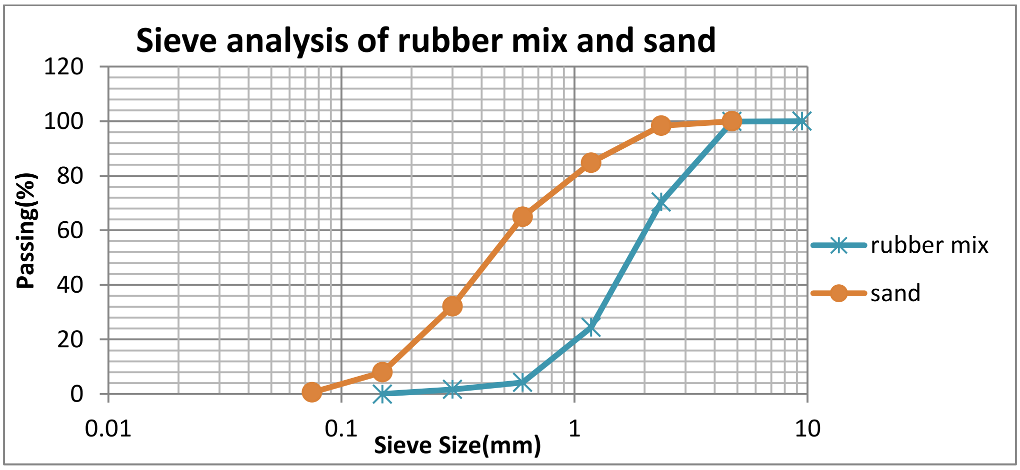


Figure 1. Particle distribution of rubber mix and sand aggregate

Mix Design

The concrete was mixed as required by Australian Standard AS 1012.2(1994). The proportions for all five mixes are shown in Table 1. The water cement ratio of the control mix and normal CRC mix was 0.45 and for the SBR modified CRC mix it was 0.40. The same cement content was used for all five mixes and the effect of latex addition on the total volume and weight was ignored. Sand was replaced by rubber at volume percentage of 10% (RC10) and 20% (RC20). For latex modified CRC 10% SBR (weight percentage of cement) was used and both 10% (RC10-L10) and 20% (RC20-L10) rubber contents were investigated. A constant volume of plasticizer and super-plasticizer was used for easier comparison of the workability over the five mixes.

Table 1. Different mix designs (kg/m3)

	TC	RC10	RC20	RC10-L10	RC20-L10
Cement	432.0	432.0	432.0	432.0	432.0
Sand	604.0	543.6	483.2	543.6	483.2
20mm stone	592.0	592.0	592.0	592.0	592.0
10mm stone	592.0	592.0	592.0	592.0	592.0
Rubber	0	18.8	37.6	18.8	37.6
SBR Latex,solid	0	0	0	43.2	43.2
Latex,water	0	0	0	45.0	45.0
Water	196.0	196.0	196.0	127.8	127.8
Total water	196.0	196.0	196.0	172.8	172.8
W/C	0.45	0.45	0.45	0.4	0.4
Plasticizer	1.9	1.9	1.9	1.9	1.9
Super-plasticizer	3.9	3.9	3.9	3.9	3.9

For the SBR modified CRC, sand and stone was put into the mixer first, then half of the total water was added and mixed for two minutes. After resting for two minutes the cement and remaining half of the water was added and mixed for around two minutes. The last step was adding the mixture of rubber and latex and mixing for two minutes. The rubber-latex mixture was pre-mixed beforehand and allowed to stand for five minutes. In this procedure adding water before latex is very important or the latex would form a thin film around the aggregate and prevent aggregates from absorbing the water (Lee et al. 1998). For normal CRC the mix procedures were based on the control mix and the only difference was the rubber being premixed with cement before being added to the mixer in order to enhance the bond between rubber and the cement matrix.

RESULTS

Slump and Strength Test Results

Slump, compressive strength, indirect tensile strength, abrasion and impact resistance tests were conducted in this research. The slump of the fresh mixes was measured according to AS1012.3.1 (1998) and the results are summarized in Table 2. This shows that CRC has better workability than the control concrete. The possible reason might be that the increased air content of CRC due to addition of rubber could increase the mixture slump. However, it did not increase with increasing rubber content.

Table 2. Slump test results

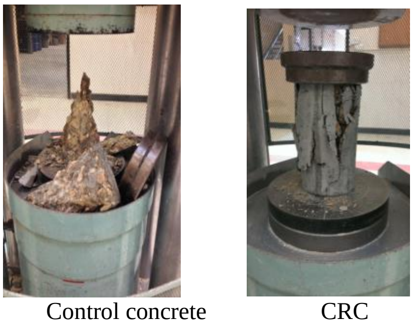
Mixes	Slump (mm)
TC	45
RC10	85
RC20	75
RC10-L10 & RC20-L10	Self-compacting concrete, slump not measured

Three specimens for each mix were tested for compressive strength (CS) and indirect tensile strength (TS). The average CS and TS results and the ratio comparing them to the control mix values are summarized in Table 3. The control mix had the highest compressive strength and indirect tensile strength. RC10 had 10% CS and 4% TS reductions compared with the control concrete. The reductions of CS and TS for RC20 were 27% and 12% respectively. SBR modified CRC showed significant strength reduction (50% on CS and 30% on TS). The reason for this drop in strength has been attributed to the very high workability and segregation caused by the combination of SBR and super-plasticizer. Overall the tensile strength reduction of CRC was less than the compressive strength reduction.

Table 3. Compressive and indirect tensile strength test results

Mixes	CS-28day compressive strength (MPa) (ratio)	TS-28 day indirect tensile strength (MPa) (ratio)
TC	43.6 (1.00)	3.6 (1.00)
RC10	39.2 (0.90)	3.4 (0.96)
RC20	31.8 (0.73)	3.2 (0.88)
RC10-L10	23.2 (0.53)	2.6 (0.74)
RC20-L10	21.0 (0.48)	2.5 (0.70)

The failure modes of the compressive strength test were different for the control concrete and CRC. As shown in Fig. 2 unlike control concrete which exploded and was crushed into little pieces, the CRC cylinders mostly held together due to the crumb rubber particles bridging the cracks.



Control concrete CRC

Figure 2. Different compressive failure mode

Abrasion Resistance Test Results

In this investigation a wire brush test was used to measure the abrasion resistance. A crimped stainless steel wire brush (50x6mm) was mounted in a drill press and rotated on the surface of specimen under a constant load. The specimens were 100x65mm discs. The weight of the specimen was measured before the test and at every 2 minutes up to 8 minutes. The average weight loss percentage is summarized in Table 4. Both RC10 and RC20 showed slightly lower but comparable abrasion resistance compared with the control mix. RC10-L10 showed 25% better abrasion resistance than the control concrete. The only mix that had lower abrasion resistance than the control concrete was RC20-L10.

Table 4. Abrasion resistance results

Mixes	Average weight loss percentage (ratio)
TC	16% (1.00)
RC10	17% (1.06)
RC20	18% (1.13)
RC10-L10	12% (0.75)
RC20-L10	20% (1.25)

Impact Resistance Test Results

The drop weight method of impact testing recommended by ACI Committee 544 (1988) was followed in this research work. 150 mm x 63.5 mm disc specimens were fixed onto a flat base plate. A 63.5 mm steel ball was placed on top of the specimen and positioned by a bracket. A 4.54 kg standard, manually operated hammer with a 457mm drop was repeatedly released and dropped on the specimen until initial minor cracking was observed and then until it broke apart. The number of blows at minor crack and final breaking was recorded and assessed as the impact resistance ability of the specimen. Four specimens and tests were conducted for each mix. Table 5 shows the results of the average number of blows at initial crack and breaking for each mix.

Test results indicated that all of the CRC and SBR modified CRC had higher impact resistance than the control concrete. Both RC10 and RC20 showed around 45% increase at initial crack and 58% increase at breaking. RC10-L10 had the highest impact resistance for both initial crack and breaking, at 62% and 67% higher respectively than the control concrete. RC20-L10 showed the lowest initial crack impact increase of 24%, but still showed a considerable breaking impact increase of 46%.

Table 5. Impact resistance test results

Mixes	Average number of blows at crack (ratio)	Average number of blows at breaking (ratio)
TC	5.3 (1.00)	6.0 (1.00)
RC10	7.8 (1.48)	9.5 (1.58)
RC20	7.5 (1.43)	9.5 (1.58)
RC10-L10	8.5 (1.62)	10.0 (1.67)
RC20-L10	6.5 (1.24)	8.8 (1.46)

CONCLUSIONS

For the mixes in this study, only 10% compressive strength reduction occurred with 10% rubber replacement percentage while a 27% reduction was found for 20% rubber content. However, the RC20 mix had a compressive strength of 31.8 MPa, which is enough for most infrastructure requirements. The indirect tensile strength reduction rate was much lower. CRC at rubber content of both 10% and 20% showed comparable abrasion resistance with the control mix while the RC10-L10 mix showed 25% better abrasion resistance than the control concrete. Both the CRC and SBR modified CRC had higher impact resistance than the control concrete, with a 40% to 60% increase noted. The 10% SBR modified RC10-L10 mix performed even better than the normal CRC, with 62% and 67% increases in first crack and breaking impact resistance. Overall the comparable or improved abrasion and impact resistance combined with adequate compression and tensile strength of all of the CRC mixes, combined with the positive environmental impact of recycling waste tyres, makes them promising materials in road pavement construction and potentially some structural applications. As current study only focused on 28 days CRC under normal temperature, future research should include long-term performance of CRC due to rubber aging or under extreme temperature conditions.

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