
Properties of crumb rubber concrete paving blocks with SBR latex

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ABSTRACT. The objective of this research is to investigate the potential of using crumb rubber as a partial substitute for coarse sand in the production of concrete paving block (CPB). Laboratory trials were conducted to investigate the effect of crumb rubber particle size. A comparison was also made between CPB mixtures containing various percentages of crumb rubber to determine the optimum crumb rubber content and water-cement (w/c) ratio. Styrene-butadiene rubber (SBR) latex was added to the mixtures of crumb rubber CPB and mechanical properties were evaluated. A total of 276 CPB were fabricated and tested in laboratory to determine the density, skid resistance and the compressive strength. The design strength level ranging from 31 to 43 MPa was achieved using w/c ratios of 0.45 to 0.55. The test results indicated that there was a systematic reduction in the strength with the increase in rubber content. Scanning electron micrograph showed that inclusion of SBR latex into the matrix did not improve the mechanical properties of the CPB. Results also revealed that a w/c ratio of as high as 0.55 without any SBR latex at 15 % rubber content by total sand volume might be practically used to produce crumb rubber CPB which achieve the target compressive strength of 30 MPa.

KEYWORDS: concrete paving block, styrene-butadiene rubber, crumb rubber, density, compressive strength, skid resistance.

1. Introduction

In Malaysia, the amount of waste tires has been increasing due to increased number of vehicles. This has led to future problems relating to the environment issues. Accumulation of discarded waste tire is a major concern because waste rubber is not biodegradable even after a long period of landfill treatment (Epps, 1994). Therefore the demand for more effective applications for recycling waste tires has been intense.

Existing or commercial concrete is characterized as a composite material with high compressive strength, moderate tensile strength and with a low toughness (Li *et al.*, 2004a). For pavement traffic application, it is anticipated that an ideal CPB should have high tensile strength and high toughness. Therefore, high strength and high toughness concrete has to be developed. It is found that the higher the strength, the lower the toughness for a normal concrete. Therefore, without modifications, it is difficult to develop high strength and high toughness concrete. Owing to the very high toughness of waste tires, it is expected that adding crumb rubber into concrete mixture can increase the toughness of concrete considerably (Toutanji, 1996; Siddiquw and Naik, 2004; Li *et al.*, 2004b). Previous laboratory studies by (Eldin and Senouci, 1993; Khatib and Bayomy, 1999; Ling, 2008) have shown that the introduction of waste tire rubber considerably increase toughness, impact resistance, and plastic deformation of concrete, thus offering a great potential to be used in sound barriers, retaining structures and pavement structures.

Unfortunately, there is a little documented research on the use of waste tires in Portland cement concrete mixtures, particularly in CPB mixtures. Therefore there is a need to investigate the applicability for the CPB mixtures with crumb rubber. It is known that the strength of paving block containing crumb rubber is expected to be lower than those without crumb rubber due to the weak bonding between the paste and aggregates. However, polymers such as styrene-butadiene rubber (SBR) latex could improve the strength, toughness and bondability of cement matrix (Chen and Liu, 2007). Hence, this study investigates the potential of using crumb rubber as a partial substitute for sand replacement in the production of CPB. Considering the potential improvement in strength and bonding between rubber and other particles, it is the objective of this study to investigate the effect of addition SBR latex in the concrete mixtures.

2. Materials Used

The materials used to develop crumb rubber CPB in this study consisted of ordinary Portland cement (OPC), natural aggregate, water, superplasticizer, crumb rubber and SBR latex. OPC from Pvt. Ltd. Sdn. Bhd. was used throughout the laboratory trials. This is the most widely used, general purpose cement conforming to MS 522, BS 12 and ASTM Type II.

Natural river sand having a maximum particle size of 4 mm was used as a fine aggregate for CPB. The sand has fineness modulus of 2.62 and dry rodded density of 1670 kg/m^3 . The sand was dried in an oven at the temperature of $110 \pm 5^\circ\text{C}$. The nominal size of the coarse aggregate used was less than 10 mm. The aggregate had a dry rodded density of 1530 kg/m^3 . All aggregate used was washed and air-dried on the laboratory floor.

Crumb rubber was obtained from car tires by mechanical shredding. The gradation of crumb rubber used in this study was close to that of the sand. In the preliminary of this study, three particle sizes of crumb rubber were used: 1 – 3 mm, 3 – 5 mm and combination of both as a partial substitute for sand in the production of CPB. The density for 1 – 3 mm and 3 – 5 mm crumb rubber were 686 kg/m^3 and 727 kg/m^3 , respectively.

SBR latex with an antifoamer was used as a polymeric admixture in this study. The density and total solid of SBR latex used were 1.02 g/cm^3 and 50.0 %, respectively. All the materials used in this study are commercially available in Malaysia.

3. Experimental Program

A total of three parts of laboratory trial mixtures were prepared. The detail is discussed in the following section. The mixed materials used were approximately 8.5 kg for each batch of three paving block specimens. The recommended or common practice used of superplasticizer for CPB was 0.6 % by cement weight. Therefore, this percentage was added to each batch of CPB mixtures. The weight ratio of coarse to fine aggregate of all paving blocks was kept to 1: 2 throughout laboratory trials except in Part I.

3.1. Mix Proportioning

In Part I mixtures, three different crumb rubber sizes were investigated. The three different categories: (a) 1 – 3 mm (b) 3 – 5 mm and (c) combined (1) & (2) of crumb rubber were used to replace coarse sand at equal amount of 10 % by weight. As for the mix proportion, the control specimen (without crumb rubber) was set at 1:0.60:2:3.67 (cement:water:aggregate:sand) to yield a 1 kg/m^3 mixture proportions.

The crumb rubber size of categories (c) was selected as a replacement for equal part of sand by volume in Part II laboratory trials. Eight designed crumb rubber contents of 5 %, 10 %, 15 %, 20 %, 25 %, 30 %, 40 % and 50 % by total sand volume were prepared for each batch of paving block specimens. In this part, the effects of three w/c ratios at 0.45, 0.50 and 0.55 were examined based on some basic mechanical properties of crumb rubber CPB.

Finally, three percentages of crumb rubber contents at 10 %, 20 % and 30 % with optimum water-cement ratio of 0.50 were recommended from Part II for further SBR dosage trials. In Part III, four different percentages of SBR (1 %, 2 %, 3 % and 4 %) were used to determine the optimum SBR that could yield highest strength in control and crumb rubber CPB.

3.2. Concrete Paving Block Preparation

The CPB were fabricated in steel moulds with internal dimensions of 200 mm in length, 100 mm in width and 60 mm in depth. The mix was poured into the mould in two layers of about equal depth. Compaction was applied manually using a hammer for each layer. The CPB were then removed from the steel moulds one day after casting and kept in laboratory at 30 °C average temperature with approximately 65% relative humidity for 7 and 28 days until tested.

3.3. Test methods

A range of tests were carried out to determine density, skid resistance and compressive strength at 7 and 28 days of the paving block specimens. Each value represents the average of three samples. The skid resistance of paving block was determined using a British Pendulum Skid Resistance Tester as specified by ASTM E303 (ASTM, 2003).

The compressive strength was tested by increasing the load at a rate of 0.30 kN/s to the nominal area of block specimen. Prior to the loading test, the block specimens were soft capped with two pieces of plywood on both ends to ensure a flat surface for testing to prevent point loading of the specimen. The compressive strength was calculated by dividing the failure load by the loading area of the block specimen.

4. Experimental results and discussions

4.1. Density

Result from Part I-density indicates that crumb rubber CPB density decreased to as low as 2.06, 2.06 and 2.11 g/cm³ when 10 % of total sand weight was replaced by 1-3mm, 3-5mm and 1-5mm crumb rubber, respectively. This was expected because of the low density of rubber particles. Moreover, increase in rubber content increases the air content, which in turn reduces the density of the mixtures. This may be due to the non-polar nature of rubber particles and their tendency to entrap air in their

rough surfaces. Also when rubber is added to a concrete mixture, it may attract air as it has the tendency to repel water, and then air may adhere to the rubber particles. Therefore, control specimen without any rubber particles produced a higher density at 2.17 g/cm^3 as compare to crumb rubber CPB.

Figure 1 shows the Part II-density, the reduction pattern is similar for three different w/c ratios. At the same percentage of rubber content, density of CPB mixtures is slightly increased when the w/c ratio in the mixture is increased. The density of crumb rubber CPB increases from 1.99 to 2.16 g/cm^3 , from 2.01 to 2.18 g/cm^3 and from 2.03 to 2.21 g/cm^3 , at 0.45 , 0.50 and 0.55 w/c ratios, respectively, with increasing crumb rubber content. It was observed that there was about 10 % reduction in the density when 50 % of the total sand was replaced by crumb rubber, irrespective of the w/c ratio. However, the decrease in density of crumb rubber CPB is negligible when rubber content is lower than 10 – 20 % of the total aggregate volume (Khatib and Bayomy, 1999).

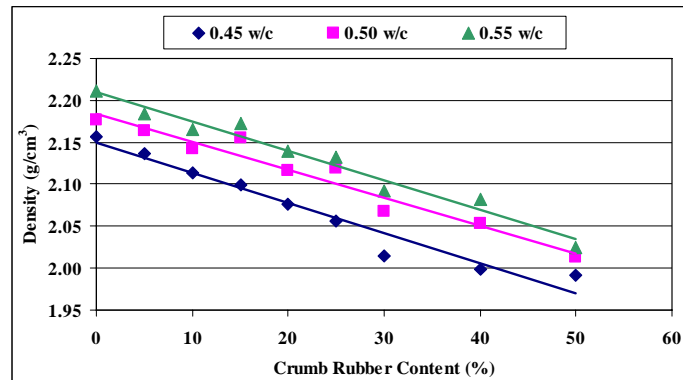


Figure 1. Density of CPB for different crumb rubber content and w/c ratios

For Part III-density, increasing the percentages of SBR dosage up to 4 % would increase the density of SBR latex-CPB. This is mainly attributed by the addition of SBR latex in concrete mixtures which increases the water content, consequently increases the weight of the concrete mixtures. The rate of density ranged from 2.17 to 2.24 g/cm^3 for the control SBR latex-CPB but from 2.11 to 2.20 g/cm^3 for the SBR latex-CPB mixed with crumb rubber, depending on the variation in SBR latex and rubber content.

4.2. Compressive strength

Part I-compressive strength indicated that the initial 3 and 7 day compressive strength of all mix CPB samples were approximately 9 and 17 MPa respectively. However, comparing the 28 day compressive strength, control specimen seemed to perform better than those mixed with different size of crumb rubber.

Part II-compressive strength results presented in Figure 2 indicate a systematic reduction in compressive strength with the increase in crumb rubber content. For 20 % and 10 % replacement of sand with crumb rubber by volume, the 28 day compressive strength of crumb rubber CPB about 26 and 32 MPa are achieved. For 50 % replacement of sand volume is replaced by crumb rubber, compressive strength of 42 MPa decrease to 12 MPa which indicates about 70 % reduction in strength. However, for the 7 day strength, the average rate of strength reduction is a little less than of 28 day strength which are about 7.6 %, 11.4 % and 10.6 % for 0.45, 0.50 and 0.55 w/c ratios, respectively.

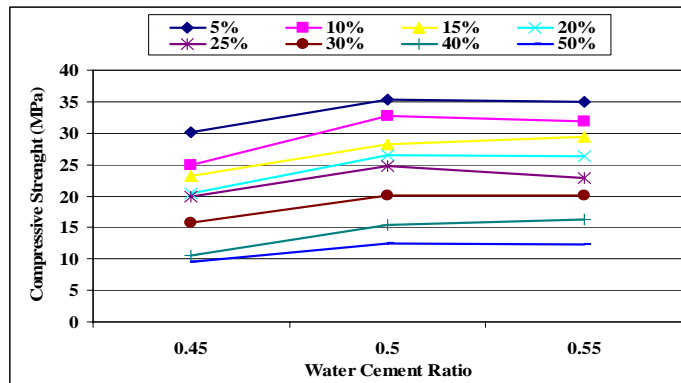


Figure 2. 28 day compressive strength of CPB for different crumb rubber content and w/c ratios

Figure 2 also summarized the effect of w/c ratio on CPB containing different percentages of crumb rubber content. At high w/c ratio (0.50 and 0.55), it is indicated that the beneficial effect of crumb rubber were pronounced on compressive strength compare to low w/c ratio (0.45) at the same percentages of crumb rubber. From the practical view point, concrete paving block should not exceed 15 % crumb rubber of the sand volume due to the severe reduction in compressive strength.

A microscopy study (SEM) was also performed to look for insight and observe the interface between particles in CPB. Fractures were obtained by 28 days compression from 20 mm fragments of the specimens. Prior the test, the dry specimens were coated with a thin layer of gold in a sputter.

The rubber-cement matrix interface was observed by SEM as shown in Figures 3 and 4. The micrographs were obtained using two different detectors which are backscattered electrons image (BEI), which is capable of distinguishing the cement (inorganic material) from the rubber (organic material) by electron contrast differences, and secondary electrons image (SEI), which shows better surface detail.

The microscopy analysis showed poor bonding and lack of adhesion at the boundaries of the rubber aggregate with cement paste. It is an additional factor contributing to the decrease of compressive strength of the less quantity of the solid

load carrying material and soft rubber particles may behave as voids in the concrete matrix.

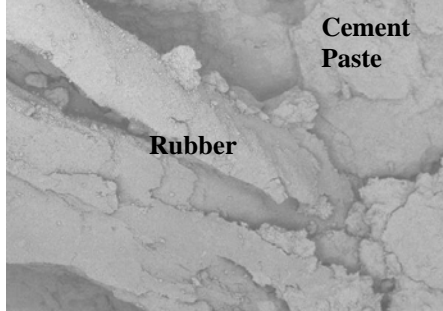


Figure 3. BEI fracture of specimen

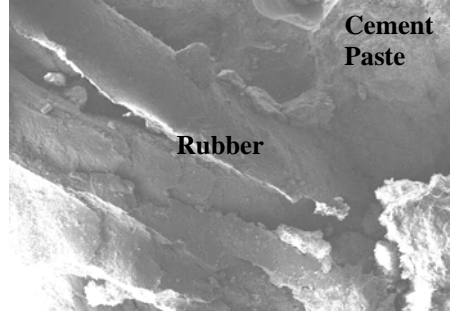


Figure 4. SEI fracture of specimen

Average statistical values of Part III-compressive strength and the number of tested specimens for each SBR latex-CPB at the level of 0 %, 10 %, 20 % and 30 % of crumb rubber replacement by sand volume are shown in Table 1. From these results, it is indicated that there is no significant improvement in compressive strength or bondability with the increasing percentages of SBR admixtures for all tested control and crumb rubber CPB.

Table 1. Paired t-test for SBR latex-concrete paving blocks

Rubber Content	SBR Content	Specimens	Mean (MPa)	Std.Dev.	t-value
0%	0%	3	32.35	2.246	0.659
	1, 2, 3 & 4%	12	33.41	2.582	
10%	0%	3	32.67	1.434	1.193
	1, 2, 3 & 4%	12	30.48	3.033	
20%	0%	3	24.62	1.007	1.843
	1, 2, 3 & 4%	12	26.42	1.192	
30%	0%	3	20.17	0.312	0.439
	1, 2, 3 & 4%	12	20.48	1.175	

Note: * $\alpha = 0.05$; $t_{\alpha} = 2.162$

Paired t-test was performed to determine whether the mean of compressive strength for crumb rubber CPB with SBR latex is different compared to without SBR latex. At the significant level of 0.05, it required a t_{α} , critical value of 2.162 with degrees of freedom of 13. To examine the relationship, t statistical values were calculated as shown in Table 1. The statistical analysis results show that at a 0.05 level of significance, the calculated t statistical values (t) are less than the critical value (t_{α}). Therefore, it is not possible to show a significant difference in the mean of compressive strength between control (0 %) specimens and 1, 2, 3, 4 % of SBR latex-CPB at each percentage of crumb rubber content.

In the first microscopy (Figure 5), a low concentration of SBR latex on the rubber surface was observed. The second microscopy (Figure 6) shows in detail the surface of the fiber in contact with the rubber particle. A low concentration fiber does not seem to significantly affect surface bondability. This weak attack may explain the low percentage of SBR latex subjected to large particles of rubber. Microscopic pictures and within the limited results presented in this study seem to disagree that there is better bonding between crumb rubbers and portland cement paste.

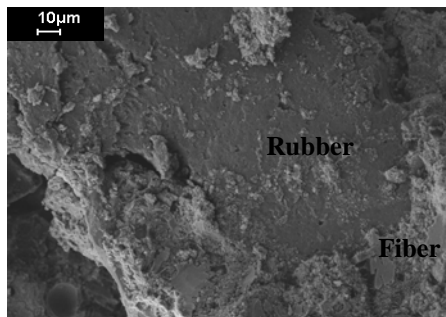


Figure 5. SEM observation of rubber-latex interface (Mag=250×)

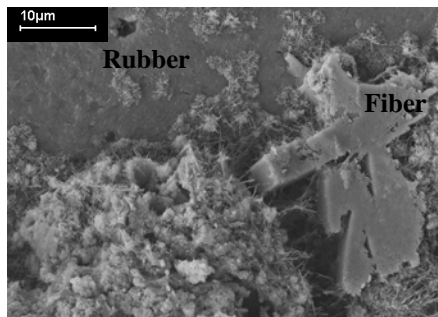


Figure 6. SEM observation of rubber-latex interface (Mag=1,000×)

4.3. Skid Resistance

For Part I-skid resistance, control specimen showed the higher British Pendulum Number (BPN) value of 92 than the three different sizes of crumb rubber CPB. Comparing the effect of crumb rubber sizes, 1-3 mm crumb rubber size gave the higher BPN value of 90 and was slightly better than 3-5 mm and 1-5 mm crumb rubber size but the differences were less than 10 %, which may be concluded as insignificant.

Figure 7 shows the relationship between w/c ratios and different rubber contents affected BPN values for Part II-skid resistance. There is a slight reduction in BPN values with the increase in crumb rubber content in CPB. This may be attributed to rubber particles appearing at facing layer decreased the contact area between test surface and pendulum slider caused the reduction in skid resistance. It is found that skid resistance is slightly higher for 0.45 w/c ratio at the same percentages of crumb rubber CPB. It might be contributed by the rough surface texture of the paving blocks creating more friction.

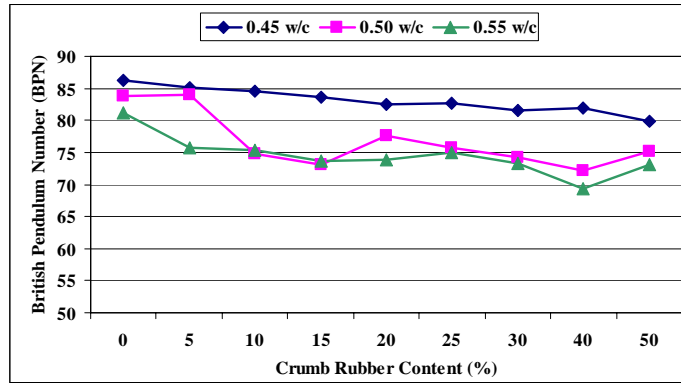


Figure 7. Skid resistance of CPB for different crumb rubber content and w/c ratios

Test results from Part III-skid resistance indicated that skid resistance decrease from 84 to about 75 when SBR dosage was increased from 0 % to 4 % for control SBR latex-CPB. This decrease of BPN value could be attributed to the smooth paving block surface, influenced by the higher water content. However, for the SBR latex-CPB mixed with crumb rubber indicated the opposite trend which BPN increased when SBR dosage increased. The rate of the skid resistance were ranged from 74 to 83 depending on the SBR latex and rubber content used in the concrete matrix. The addition of SBR in crumb rubber CPB allowed the rubber on the block surface to create more friction. Overall, all the SBR latex-CPB with and without rubber tested were satisfy ASTM requirement which BPN value are higher than 45.

5. Conclusions

From the study, the following conclusions were drawn:

- 1) The effect of crumb rubber size on the density and compressive strength of crumb rubber CPB is negligible. However, the 1-3 mm crumb rubber CPB provides slightly better skid resistance.
- 2) There is a systematic reduction in the density, compressive strength and BPN values with the increase in rubber content from 0 % to 50 %.
- 3) The effect of w/c ratio is significant, 0.55 w/c ratio produces higher density and compressive strength than 0.45 and 0.50 w/c ratios. However, skid resistance indicates the opposite trend which 0.45 w/c ratio gains a higher BPN value.
- 4) The density of SBR latex-CPB increased with addition of SBR latex up to 4 %. However, there is no significant improvement in bondability and compressive strength.
- 5) Crumb rubber CPB containing SBR dosages seems to have better skid resistance. However, the control CPB indicates the opposite trend.

6. Recommendations

In the preliminary laboratory test series, a wide range of information regarding mechanical properties of CPB incorporating crumb rubber and SBR latex were obtained. It is recommended to fabricate CPB containing rubber up to 15 % at commercial plant which is expected to achieve a target compressive strength of not less than 30 MPa (CMAA, 1996) at the age of 28 days without any SBR latex admixture. It is also suggested that crumb rubber CPB could be used in trafficking pavement, sidewalks, playground, etc., may be other viable applications. However, more study is needed to assess its resistance to impact loads and other engineering properties such as abrasion resistance before such a recommendation is drawn.

7. References

- American Standard for Testing and Materials., *Standard test method for measuring surface frictional properties using the British pendulum tester*, ASTM E 303, American, 2003.
- Chen B., Liu J., “Mechanical properties of polymer-modified concretes containing expanded polystyrene beads”, *Construction and Building Materials*, Vol. 21, 2007, p. 7-11.
- Concrete Masonry Association of Australia., *Specification for concrete segmental paving units*, MA 20, Australia., 1996.
- Eldin N.N., Senouci A.B., “Rubber-tire practices as concrete aggregate”, *J. of Mater. Civil Eng., ASCE*, Vol. 5, No.4, 1993, p. 478–496.
- Epps J.A., “Uses of recycled rubber tires in highways”, *Synthesis of Highway Practice 198, Transportation Research Board, National Research Council*, Washington, D.C., 1994.
- Khatib Z. K., Bayomy F. M., “Rubberized Portland cement concrete”, *J. of Mater. Civil Eng., ASCE*, Vol. 11, No.3, 1999, p. 206–213.
- Li G., Stubblefield M.A., Garrick G., Eggers J., Abadie C. Huang B., “Development of waste tire modified concrete”, *Cement and Concrete Research*, Vol. 34, 2004a, p. 2283-2289.
- Li G., Garrick G., Eggers J., Abadie C., Stubblefield M. A. Pang S. S., “Waste tire fiber modified concrete”, *Composites: Part B* 35, 2004b, p. 305-312.
- Ling T. C., “Engineering properties and structural engineering of rubberized concrete paving blocks”, PhD Thesis (unpublished), Universiti Teknologi Malaysia, 2008.
- Siddiquw R., Naik T.R., “Properties of concrete containing scrap-tire rubber- an overview”, *Waste Management*, Vol. 24, 2004, p. 563-569.
- Toutanji H.A., “The use of rubber tire particles in concrete to replace mineral aggregate”, *Cement and Concrete Composites*, Vol. 18, 1996, p. 135-139.