Properties of Crumb Rubber Concrete Paving Blocks with and without Facing Layer

T. C. Ling & Hasanan Md Nor
Department of Geotechnic and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia

ABSTRACT: This paper presents a recent study on the investigation of recycled waste tyre (crumb rubber) as aggregate in the production of concrete paving block (CPB). A series of tests were carried out to determine and compare the properties of crumb rubber CPB prepared with and without facing layer. The results showed that the crumb rubber CPB without facing layer had little effect on the dry density, compressive strength, flexural strength, sound absorption and skid resistance. However, the abrasion index was higher for the specimens without facing layer. Using 1-3 mm and 1-5 mm crumb rubber as the replacement of fine sand for face layer and coarse sand for body layer, respectively at the level of up to 30 %, CPB with 28-days modulus of rupture of not less than 2.75 MPa can be produced without facing layer, while 2.54 MPa for the CPB with facing layer.

Key words: Crumb rubber, Concrete paving block, Facing layer, Mechanical properties

1 INTRODUCTION

One of the today's major problems and which will continue to do so for the foreseeable future is the environmental pollution resulting from industrial wastes and waste living materials. Particularly among the waste materials in the advancement of civilization are discarded waste tyres, because the amount of waste tyres is increasing more and more due to large number of cars, trucks and off-road tyres are discarded all over the place. Environmental solid waste problems have been increasing concern due to the majority of these discarded tyres either shredded and then landfilled or stockpiled, (Fattuhi and Clark, 1996). The accumulations of discarded tyres provoke fire and health hazards (Sukontasukkul and Chaikaew, 2006). In order to prevent environmental pollution, the policy is evolving and much effort has been put into solving waste tyres problem on a world wide basis. The use of waste tyres as construction material in both developed and developing countries is being encouraged (Eldin and Senouci, 1993; Fattuhi and Clark, 1996).

This study investigated the possibility of using crumb rubber as aggregate in production of concrete paving block (CPB), and the properties of these paving blocks with and without facing layer. Waste tyres have hardness and elasticity properties superior to those of rubber, good resistance to weathering, can be used for preventing impact damage, and for pavement construction materials, because of their low specific gravity which is lower than that of most construction materials. Furthermore, currently there is very limited amount of data on the use of crumb rubber for pavement used, particularly in the production of CPBs. Therefore, this study will contribute a significant impact for future investigation in this area of studies.

2 METHODS

2.1 Materials

The CPBs comprised of cement, aggregate, coarse sand, fine sand, waste tyre, water and additive. The recycled waste tyres used in this study were 1-3 mm and 1-5 mm crumb rubber.

2.2 Sample preparation

All samples were prepared in commercial plant production setting. In this study, two kinds of CPBs were made, one with a single layer, the other with double layers. Therefore, two independent mixers were used with different capacity and working in parallel to ensure facing layer being added for appearance. Table 1 shows the mixing ratio for the components of these paving blocks. Initially, aggregate, coarse sand, cement and crumb rubber were mixed in body mix mixer for approximately 1 min. After mixing for 1 min, water was added to the materials and mixed for another 1 min until the desired moisture content for these mixtures was obtained.

The mixtures were transferred from the pan mixer to a feed hopper. The amount in feed hopper was closely controlled by an automatic weighting system. The hopper discharged the correct amount of concrete into the mould in the CPB making machine with internal dimensions of 210 mm length, 105 mm width and 60 mm depth. The mould was filled by the body mix and first vibration and pressing were applied. The face mix was poured into the mould for second layer, and then final compaction and vibration were applied. The hydraulic ram was released and the head lifted to allow early stripping of CPBs (see Figure 1) from the steel moulds.

Table 1. Mixing ratio.

	Raw materials	Ratio
Base layer	Cement	15% of base weight
	Coarse sand	40% by base weight
	3/8" Aggregate	28% by base weight
	1-5mm Crumb rubber	30% by sand volume
Facing layer	Cement	30% of face weight
	Fine sand	50% by face weight
	1-3mm Crumb rubber	30% by sand volume

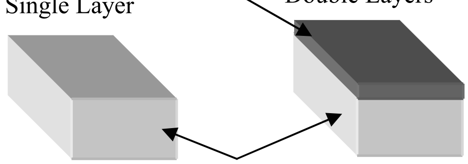

Figure 1. CPB with and without facing layer.

2.3 Mechanical properties

Compressive strength was determined using a Universal Testing Machine with a maximum capacity up to 3000 kN. The load was applied to the nominal area of paving block. Prior to the loading test, the paving block was soft capped with two pieces of plywood. The compressive strength was calculated by dividing the failure load by the loading area of the paving block. Each value represents the average results of five tests.

Mechanical resistance of best samples was determined by measuring the ultimate three-point bending strength (flexural test) and the elongation at failure (see Figure 2), as well as by computing the modulus of elasticity and the dry density. Each value represents the average of three samples. The ultimate strength is given by

$$\sigma = \frac{3}{2}\frac{LF}{WT^2} \quad (1)$$

Where the elongation at failure, ε, is given by

$$\varepsilon = \frac{6T}{L^2}\Delta\lambda \quad (2)$$

In these equations L is distance between fixed points (mm), F the failure stress (N), W the width of the sample (mm), T its thickness (mm), and $\Delta\ell$ its length (mm).

The elasticity modulus, σ/ε, is defined as the incremental ratio of the stress per deformation within the elastic limit:

$$\frac{\sigma}{\varepsilon} = \frac{L^3}{4WT^3}\frac{F}{\Delta\lambda} \quad (3)$$

The dry density, ρ, of the samples is given by

$$\rho = \frac{M}{V} \quad (4)$$

Where M is the mass (g) and V (cm^3) the geometrical volume of the sample.

Figure 2. Three point flexural test.

2.4 Acoustic properties

The acoustic measurement obtained for the crumb rubber CPBs were limited to the sound absorption coefficient. The method used to measure the sound absorption coefficient was that of impedance tube (ASTM C 384-98, American Society for Testing and Materials, 1998) to investigate the possibility of their being used as substitution insulation material for pavement. Cylindrical specimens with a diameter of 95 mm and a thickness of 50 mm were cored from rectangular crumb rubber CPBs. The sample was placed inside a thin cylindrical PVC sleeve, into which it fits snuggly. The sample assembly was placed against a rigid backing at one end of the impedance tube which is equipped with a sound source. A plane wave generated by the sound source was propagated along the axis of the tube. Microphones placed along the axis of the tube were used to detect the sound wave pressure transmitted to the sample and the portion of the wave that is reflected. Each value represents the average of three samples.

2.5 *Abrasion index*

The abrasion index test was carried out in accordance with the MA 20 method. The test began by setting up the specimen under the ball-race; the ball-race was then lowered down to the specimen surface and spun at the rate of 1000 revolutions per minute. Every 1000 revolutions, penetration were measured by a dial-gauge. Continue the test until the ball-race has completed 5000 revolutions, or until the dial-gauge has indicated a penetration of greater than 1.5 mm, whichever occurs first. The Abrasion index representing the minimum value obtained from five specimens.

2.6 *Skid resistance*

The skid resistance of CPB was determined using a British Pendulum Skid Resistance Tester and it was expressed as the measured British Pendulum Number (BPN) as specified by ASTM E303-93.

3 RESULTS AND DISCUSSION

3.1 *Mechanical properties*

Table 1 shows the results of dry density, compressive strength, modulus of rupture, modulus of elasticity and energy absorption capacity. For the dry density, compressive strength and modulus of rupture the specimens without facing layer showed higher values than with facing layer.

Table 2. Test specimens with 30% by volume of crumb rubber.

Specimen	With facing layer	Without facing layer
Dry density, ρ (g/cm^3)	1.90	1.91
Compressive strength (MPa)	13.2	15.8
Modulus of rupture, σ (MPa)	2.54	2.75
Modulus of elasticity, σ/ε (GPa)	0.17	0.20
Energy absorption (J)	1.64	1.30

Figure 3 shows the typical load–deflection curve of crumb rubber CPBs prepared with and without facing layer. The maximum load was lower for the paving block with facing layer than for the without facing layer. The modulus of elasticity increased slightly for the paving block without facing layer. To be expected, the inclusion of facing layer also increased the facture energy, indicating higher toughness for the specimens. Generally, crumb rubber CPB without facing layer tend to be brittle when modulus of elasticity value is higher, and crumb rubber CPB with facing layer tend to be ductile or flexible when this value is lower.

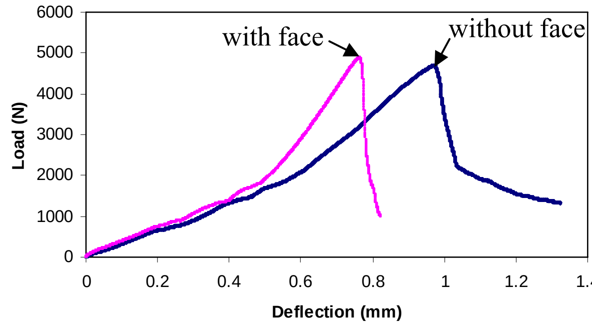

Figure 3. Flexural strength versus defection.

The toughness is known as energy absorption capacity and is generally calculated from the area under laod-deflection curve up to the point failure is plotted. For paving block with facing layer, the toughness was found to be larger than the without facing layer, even though the strength was lower. This was due to the higher post-peak response. The toughness of paving block with facing layer indicated that the paving block was able to absorb larger quantities of energy after the peak load and prior to the final failure.

The rubber-cement matrix interface was observed by scanning electron microscopy (S.E.M) as shown in Figure 4 and 5. The micrographs were obtained using two different detectors: one for backscattered electrons (BEI), which were capable of distinguishing the cement (inorganic material) from the rubber (organic material) by electron contrast differences, and one for secondary electrons (SEI), which show better surface detail.

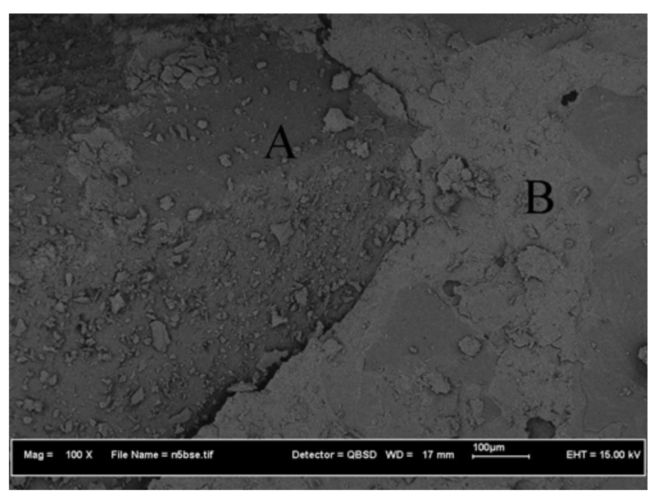

Figure 4. S.E.M image fracture of crumb rubber CPB without facing layer specimen with 30 % by volume of as received crumb rubber. BEI image. (A) Rubber particle; (B) Cement paste.

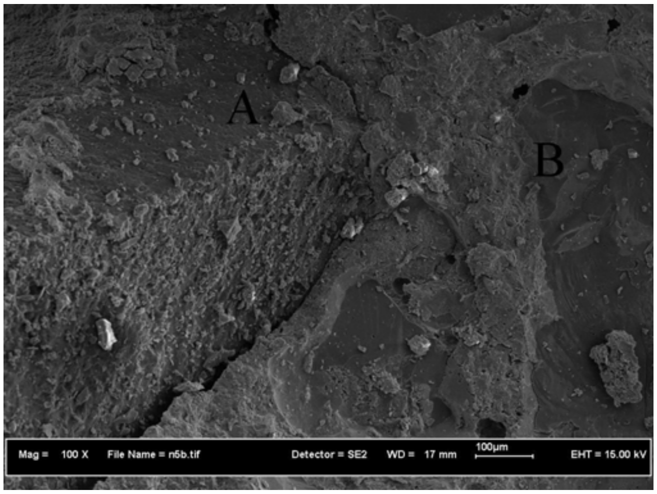

Figure 5. S.E.M image fracture of crumb rubber CPB without facing layer specimen with 30 % by volume of as received crumb rubber. SEI image. (A) Rubber particle; (B) Cement paste.

3.2 *Acoustic properties*

The results of sound absorption coefficients measured by the impedance tube method are shown in Figure 6. In general, the CPBs without facing layer were found to have slightly higher sound absorption coefficients than without facing layer over the entire frequency range (100–1600 Hz). This can be attributed to the fact that CPBs without facing layer contribute a higher porosity may due to the large sized pore surface, resulting in lesser frictional losses within the pore structure.

The sound absorption coefficients of the CPBs increased as the frequency increased. However, they decreased somewhat at a frequency of 1000 Hz and then increased again. This point of inflexion was due to the specific characteristic of crumb rubber reflecting sound at around 1000 Hz, but absorbing sound in the middle and high frequency ranges.

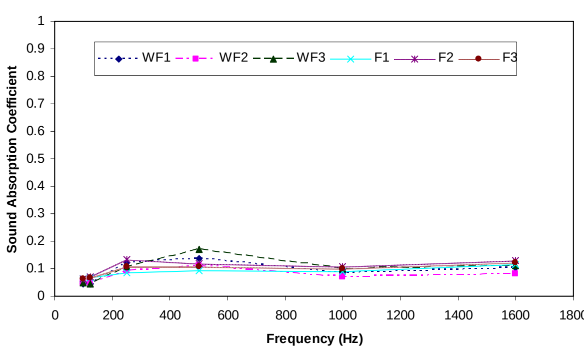

Figure 6. Sound absorption coefficients of the crumb rubber CPBs with and without facing layer (30 volume % of crumb rubber).

3.3 *Abrasion index*

Results in terms of abrasion index, I_a are shown in Figure 7. It was found that the rubber crumb CPBs without facing layer exhibited higher value of abrasion index than the paving blocks with facing layer, as indicated by increasing number of ball-race revolution with decreasing abrasion index. Comparison between the CPBs with and without facing layer indicates that the without facing layer present a superior performance. Even revolution up to 5,000, the abrasion index of rubber crumb CPBs without facing layer was still higher than 2.40 or I_a value (1.16) at 1,000 revolution of CPBs with facing layer.

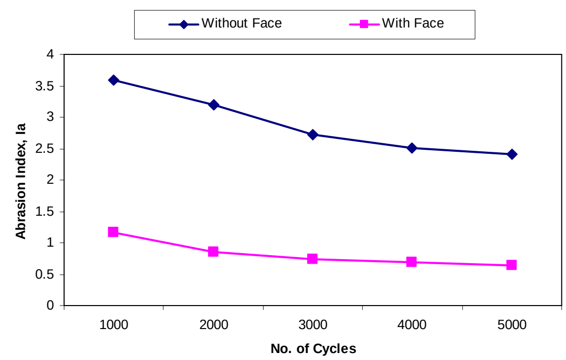

Figure 7. Abrasion index of the crumb rubber CPBs with and without facing layer (30 volume % of crumb rubber).

3.4 *Skid resistance*

Skid resistance was measured in accordance to ASTM E3030-93, four swings of the pendulum were made for each test CPBs surface. In general, the CPBs produced in this study satisfy ASTM requirement that BPN were higher than 45. It is found that skid resistance was slightly higher for CPBs without facing layer (76.7) compare to with facing layer (75.0). It was contributed by the rough surface texture of the paving blocks to create more friction as the pendulum passed across it.

4 CONCLUSIONS

1. Dry density of crumb rubber CPBs are not affected by the facing layer.
2. Compressive strength, modulus of rupture and modulus of elasticity are slightly higher for CPBs without facing layer than those with facing layer. Clearly, CPB with a facing layer does not contribute any additional strength.

3. The test results indicated the toughness of paving block with facing layer is able to absorb larger quantities of energy after the peak load and prior to the final failure.
4. Only abrasion index is significantly different for both types of paving blocks. Where, paving blocks without facing layer show a better performance than paving blocks with facing layer.
5. CPBs without facing layer are found to have slightly higher sound absorption coefficients than without facing layer. However it is not significant affect to apply both types of paving blocks for pavement application.
6. Both CPBs with and without facing layer are found to provide good skid resistance. In general, both satisfy ASTM requirement (BPN 45).

5 ACKNOWLEDGEMENT

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6 REFERENCES

ASTM C 384. 1998. Impedance and absorption of acoustical materials by the impendence tube method. *American Society for Testing and Materials Standard.*

ASTM E 303. 2003. Measuring surface frictional properties using British Pendulum Tester. *American Society for Testing and Materials Standard.*

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

Fattuhi, N. & Clark, L. 1996. Cement-based materials containing shredded scrap truck tyre rubber. *Construction and Building Materials* 10 (4): 229-236.

MA 20. 1996. Specification for concrete segmental paving units. *Concrete Masonry Association of Australia*.

Sukonrasukkul, P. & Chaikaew, C. 2006. Properties of concrete pedestrian block mixed with crumb rubber. *Construction and Building Materials* 20: 450-457.