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Strength and Microstructure Properties of Double Layered Concrete Paving Blocks Containing Waste Tyre Rubber Granules

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Graphical abstract

Abstract

This paper aims to examine the effect of replacing the natural aggregate with waste tyrerubber granules. Waste tyrerubber granules were used as aggretate replacement in the pavingblock at four different percentage: 10%, 20%, 30%, and 40%. The paving blocks were tested in terms of their strength and the characteristics of their microstructure by measuring compressive strength, flexural strength, splitting tensile strength, and skid resistance. Field scanning electron microscopy (FESEM) and Fourier Transform Infra-Red(FTIR) analysis werecarried out on the paving block specimen. When 10% of the natural aggregate was replaced with waste tyrerubber granules, there was no substantial difference in the compressive strength but the flexural and splitting tensile strength increased to a certain extent. When more than 20% of waste tyrerubber granulesis incorporated in the paving blocks, the strength is acutely reduced even though there is a growth in ductility. The results proved that even after failure, the paving blocks did not shatter but still stayed imperforated. Double layer rubberized concrete paving blocks (DL-RCPBs) are more flexible and soft to the surface, and thus provide a better ride quality. This characteristic makes it suitable for trafficked roads. DL-RCPBs (30% and 40%) with low strength characteristics could be used on roads that not required high strength and may be viable for other applications, depending on the percentage of waste tyre rubber used. DL-RCPB with higher waste tyre rubber content exhibit higher skid resistance especially on dry surface but reduced on slippery surface. Two main factors that influence the skid resistance are high elasticity and rough surface texture of waste tyre rubber. It is suggested that DL-RCPBs could be introduced as one of alternative concrete paving block (CPB) that can be used in paving application.

Keywords: Rubber; strength; microstructure; double layer; paving block

■1.0 INTRODUCTION

Many countries view waste tyre management and disposal as a huge problem that can have much negative effects on the environment. The high quantity of the manufacture of tyres and their endurance result in tyres being one of the most crucial problems of waste management. Tyres are difficult to be recycled or to be put through additional processing because its structure enables it to tolerate severe mechanical and climate conditions. Besides that, their physical structure is bulky and their chemical composites are not biodegradable. A tyre is able to remain in a landfill for up to a century. Tyres do not disintegrate into their chemical elements because they have thermoset properties which increase their melting point. Non-biodegradable substances, such as rubber and plastic, build up and interfere with the ecosystem [1]. The increasing disposal of motorized vehicles directly leads to the accumulation of waste rubber tyres.A massive amount of waste tyres is disposed of every year, which leads to many complications [2].The Department of Environment has prohibited the act of open burning and illegal disposal of waste tyres to protect the balance of the ecosystem and decrease the amount of air pollutants. The process of rubber shredding is only employed by several companies to shred rubber into crumbs or powder. Therefore, measures that assimilate the use of civil engineering applications should be taken advantage of to determine monetary and ecologically friendly ways to reuse tyres [3-5]. The use of waste tyres as a supplement to concrete paving blocks is a potential solution to this problem.Concrete research involves the alteration and conversion of certain characteristics of concrete by adding suitable substances or elements to the material. Waste tyre particles are used as a concrete aggregate to overcome or reduce the inelasticity, fragileness, and low loading toughness of concrete [6]. Flexible and malleable waste tyre rubber could develop and enhance the characteristics of concrete [7-8]. Globally, recycled materials are used extensively in highways and rubberized concrete [9-11]. In this paper, the strength and microstructure properties of double layered rubberized concrete paving block were investigated.

■2.0 EXPERIMENTAL

2.1 Materials

Type I ordinary Portland cement (OPC) was used in this investigation. Crushed granite with sizes of less than 10 mm were used as coarse aggregate and local natural river sand was used as fine aggregate in the concrete mixtures. The coarse and fine aggregates had a specific gravity of 2.50 and 1.65, and water absorption of 0.49% and 0.70%, respectively. In order to maintain the feasibility of the concrete mixtures, a Glenium C380 superplasticizer was used. This superplasticizer is chloride-free, and has been formulated to comply with the requirements of ASTM C494 [12] for Types A and F admixtures. Waste tyre rubber granules used in this study were produced by Yong Fong Rubber, Malaysia and composed of 48 % styrene-butadience rubber (SBR), 47 % carbon black, 1.9 % extender oil, 1.1 % zinc oxide, 0.8 %, sulfur, 0.7 % accelerator and 0.5 % strearic acid [13]. Rubber granules were produced by the mechanical shredding process and the suitability of using it to substitute natural aggregate is dependent on its size (Figure 1). Two particle sizes of rubber granules, which are 1 mm to 4 mm and 5 mm to 8 mm, were used in this study as a partial substitute for the fine and coarse aggregate in the production of concrete paving blocks.

Figure 1 Waste tyre rubber granules

2.2 Sample Preparation And Curing Conditions

Ordinary Portland cement, coarse and fine aggregate, water, and admixture (0.3% SP) were used to make two series of concrete mixes (Table 1). The ratio for cement: aggregate: sand was 1: 1.7: 1.5. Series I (Layer 1) used waste tyrerubber granules of 5 mm to 8 mm in size as the coarse aggregate and was 10 mm thick; whereas Series II (Layer 2) used wastetyrerubber granules of 1 mm to 4 mm as the fine aggregate and was 70 mm thick. The concrete mix had a water to cement (w/c) ratio of 0.47. A steel mould of 200 mm in length, 100 mm in width, and 80 mm in depth as shown in Figure 2 was used to manufacture the concrete paving blocks (CPB). The process of creating both the CPBs began at the same time in two separate concrete mixers. First, Series II was poured into the steel mould and vibrated on a concrete vibrating table for 5 seconds. Then, Series I was poured on top of the concrete in the steel mould then vibrated for another 5 seconds. A day after casting, the concrete blocks were demouldfrom the steel moulds and cured in air at approximately 27 °C and 65% relative humidity for 7 and 28 days until the testing.

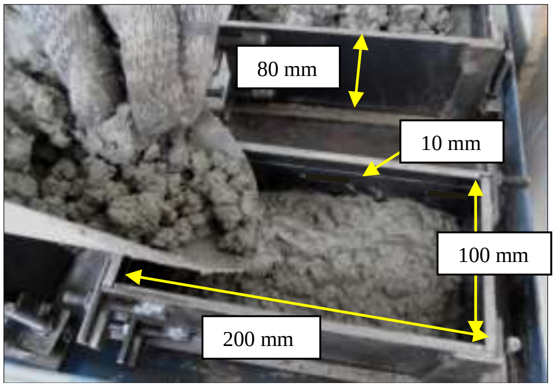

Figure 2 Sample preparation

2.3 Compressive strength

In the field of engineering, hardened concrete has to have high compressive strength. The British Standard test method, BS EN 1338Part 3[14] was followed to test the compressive strength of the double layered rubberized concrete paving block (DL-RCPB). The specimens were soft capped with two pieces of 3 mm plywood and then a compression machine compressed the blocks with a maximum capacity of 3000 kN with a loading rate of 2.5 kN/s. The average of five data recordings were calculated to obtain the compressive strength.

2.4 Flexural Strength

In order to carry out a flexural test, a transverse force which is perpendicular to its longitudinal axis was applied onto a rectangular CPB to generate shear and tensile stresses. A marker was used perpendicularly to mark a line down the centre of the top of the blocks. The CCPB and DL-RCPB was tested under a central line load simply supported over a span of 150 mm. The Tinius Olsen Universal testing machine was the instrument to test the flexural strength. A displacement of 0.40 mm/min was set. Each data displays the average of five samples. Two support rods were used to hold the specimen up while the centre point was subjected to the load until the specimen ruptures (Figure 3). The data acquisition system immediately documents the deflection and energy absorption, the modulus of rupture (MOR) and the modulus of elasticity (MOE) were measured [15].

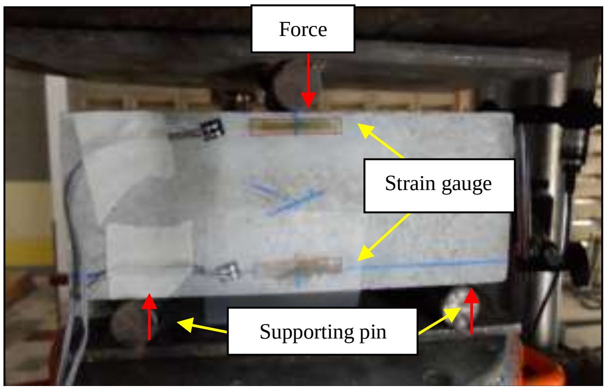

Figure 3 Flexural strength test (Three point load)

Table 1 Mix proportion of Double Layer Rubberized Concrete Paving Blocks

Block Label	Mix proportion		Cement content (kg/m^3)	Water/ Cement ratio	Rubber content (%)
	Series I (C:A:S)	Series II (C:A:S)	Series I&II	Series I&II	Series I&II
CCPB	1: 1.7: 1.5	1: 1.7: 1.5	489	0.47	0
DL-RCPB (10 %)	1: 1.5: 1.5	1: 1.7: 1.35			10
DL-RCPB (20 %)	1: 1.35: 1.5	1: 1.7: 1.2			20
DL-RCPB (30 %)	1: 1.2: 1.5	1: 1.7: 1.05			30
DL-RCPB (40 %)	1: 1.0: 1.5	1: 1.7: 0.9			40

CCPB: Control concrete paving block
DL-RCPB: Double layer rubberized concrete paving block

2.5 Splitting Tensile Strength

The Tinius Olsen Universal testing machine with a loading rate of 0.40 mm/min was used to test the splitting tensile strength. The specimen's length and thickness was measured five times and then the average of the measurements was calculated before the air-cured specimens were tested. Two rigid bearers with contact surfaces of a 75mm radius, and two plywood bearing strips with the width of 15 mm, thickness of 3 mm, and length of 230 mm were also used as the specimen was centered on the plywood strips (Figure 4). A plywood strip was placed on the specimen before being loaded according to the British Standard test method, BS EN 1338 [14].

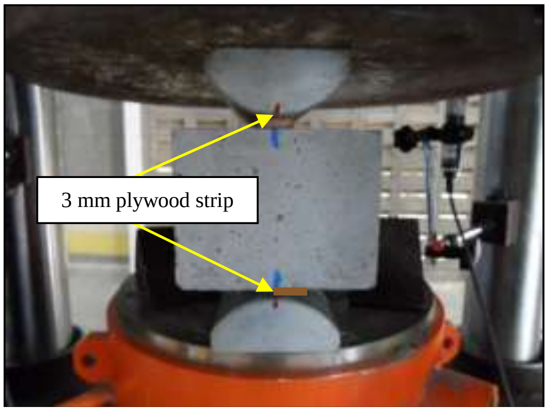

Figure 4 Splitting tensile strength test

2.6 Field Emission Scanning Electron Microscopy (FESEM)

The field emission scanning electron microscope(FESEM) method is a flexible way to examine the microstructure of a particular substance. In this study, the Hitachi SU 8020 FESEM was used to investigate the properties of the samples. In order to characterize the morphological properties of the samples, the samples, except for the powdered ones, were first cut into tiny sizes. After that, the samples were arranged horizontally at 180° for a surface analysis, vertically at 90° for a cross-sectional analysis of the thickness. The microstructures of the samples were magnified at 1000x with an operation power of 2 kV.

2.7 Fourier Transform Infra-Red (FTIR)

Waste tyrerubber that were in powder form were analyzed with the PerkinElmer Spectrum 100 FT-IR spectrometer. 100 mg of Potassium bromide was used for every mg of the sample during the FTIR analysis with the spectrometer. A total of 32 scans were collected from 4000 to 650 cm^{-1} at 32 cm^{-1}resolutions and averaged.

2.8 Skid Resistance

A British Pendulum illustrated in Figure5(a) was used in accordance to BS EN 1338 [14] to evaluate the skid resistance. A slider with a length of 126 ± 1 mm was placed on the block surface. The surfaces of the specimen and the slider were lubricated with water without removing the slider from its arranged position. The pendulum arm and pointer were placed horizontally and then released using the release mechanism. At the initial stage of the return swing, the pendulum arm was caught and the position of the pointer on the scale was recorded to the nearest whole number. The lifting handle was used to raise the slider to return the pendulum arm to its original position. Before releasing the pendulum again, the surface and the slider were relubricated with water. Each surface was assessed five times with the pendulum, as shown in Figure5(b).

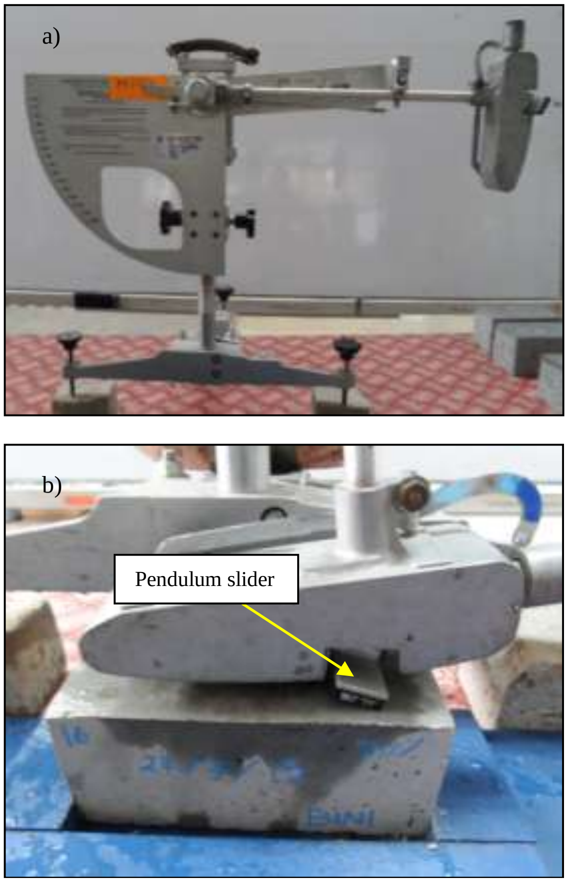

Figure 5 (a) British pendulum (b) Skid resistance test

■3.0 RESULTS AND DISCUSSION

3.1 Compressive Strength

As shown in Figure6, the amount of replaced aggregate is inversely proportionate to the compressive strength of the block; as the amount of coarse or fine mineral aggregate increases, the compressive strength of the block decreases. Each value displays the mean of five measurements. Generally, the blocks with a 10% waste tyrerubber content fulfilled the requirement in BS EN 1338for the 28-day compressive strength test, which is not less than 40 MPa for paving blocks of 80 mm thickness to carry traffic load. This could be due to the minimal percentage of rubber content in the CPB.At the 28th day, the compressive strength of the 10%, 20%, 30%, and 40%DL-RCPB were 46 MPa, 43 MPa, 37 MPa, and 29 MPa, respectively. This indicate that the weak interfacial bond between the rubber and cement mortar due to the hydrophobic nature of rubber was the main factor of the reduction in strength [3]. The bonding between rubber and cement were easily overcome and create cracks when continuous compressive load were applied [16-20].

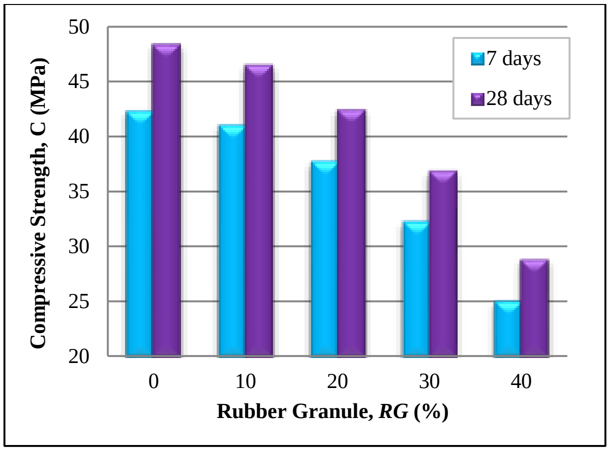

Figure 6 Compressive strength of RCPB with 10 mm facing layer

3.2 Flexural Strength

According to Figure7, the MOR values for the blocks werelowered when the waste tyre rubber granules was included. As the volume of replaced aggregate increases, the flexural strength of the block decreases; when tyre rubbers were replaced at 30% and 40%, the flexural strength was reduced by 21% and 23%, respectively. From the early age, all the specimens achieved the minimum flexural strength of 3 MPa, which is based on the Concrete Segmental Pavement, T-44 [21].The modulus of elasticity (MOE) results illustrated in Fig. 8 indicate that the additional of waste tyre rubber may decrease the MOE but still in acceptable range. Trafficked pavements, unlike sidewalks, require blocks that are able to withstand more tension.Therefore, the DL-RCPB were found to be more suitable than the current CPB due to its higher resistance towards tension.

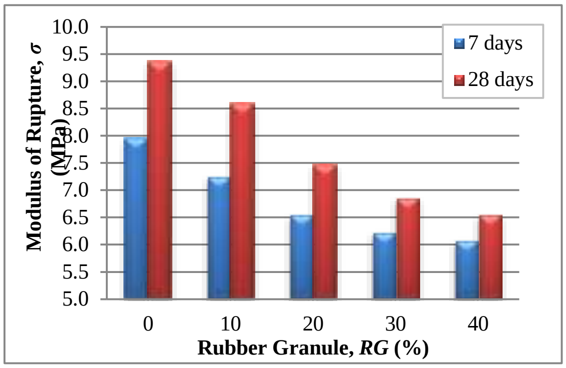

Figure 7 Modulus of rupture of DL-CPBs containing waste tyre

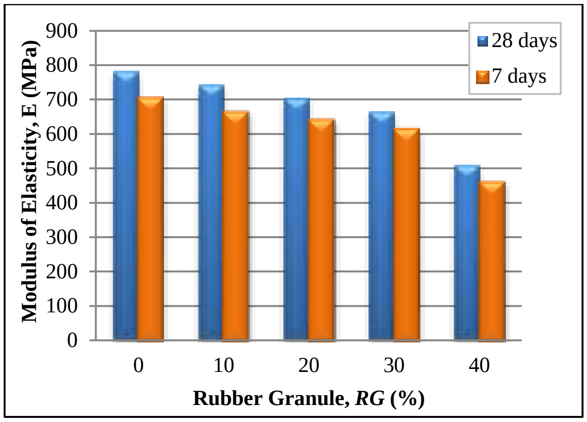

Figure 8 Modulus of elasticity of DL-CPBs containing waste tyre

3.3 Splitting Tensile Strength

The results of the splitting tensile strength for DL- RCPB were illustrated in Figure9. The results showed that the splitting tensile strength of the tested CPB samples was varied between 2.4 and 5.0 MPa as the rubber content and curing age increased from 0 to 40% and from the 7th to the 28th day of age, respectively. It can be observed that as the waste tyrerubber content of the CPB was raised, the compressive strength of the block was decreased. However, the decrease in compression strength is higher than the decrease in splitting tensile strength. The CCPB and DL-RCPB up to 30 % waste tyre rubber substitution surpassed the splitting tensile strength requirement of not less 3.6 MPa that was described in BS EN 1338 [14]at the early age (28 days). When the rubber content increased to 30% of the total sand volume, the splitting tensile strength of the block was significantly lowered as much as 15%. When the rubber percentage is further increased to 40%, the reduction of the splitting tensile strength was as much as 20%. Figure10 shows the results of the splitting tensile strength test on the CCPB and the DL-RCPB (40 %). As shown in the figure, the DL-RCPB does not split cleanly into two halves unlike the usual behaviour of the CCPB, which has a well-defined split.

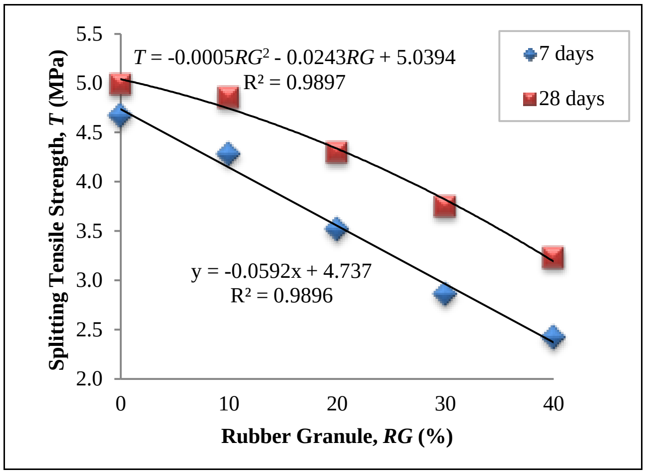

Figure 9 Splitting tensile strength of DL-RCPBs

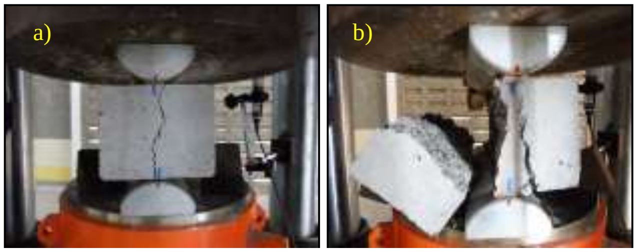

Figure 10 Splitting pattern for CCPB (a) and DL-RCPB (40%) (b)

3.4 FESEM Image

The microstructure of the DL-RCPB that was observed with the FESEM method was illustrated in Figure11. Other than the FESEM examination, the compositions of the rubberized concrete were qualitatively analyzed by an energy dispersive X-ray (EDX) analysis as shown in Figure12. The main elements present were carbon, silicon, aluminum, and calcium. The rough and non uniform surface of the waste rubber particle was observed in Figure 11.It was found the rough surface of waste tyre rubber was not fully covered by cement paste which results in lack interaction bonding between tyre particle and cement. Voids also can be observed in Figure 11, due to the hydrophobic nature of rubber that repel water and results in voids once the concrete was hardened.

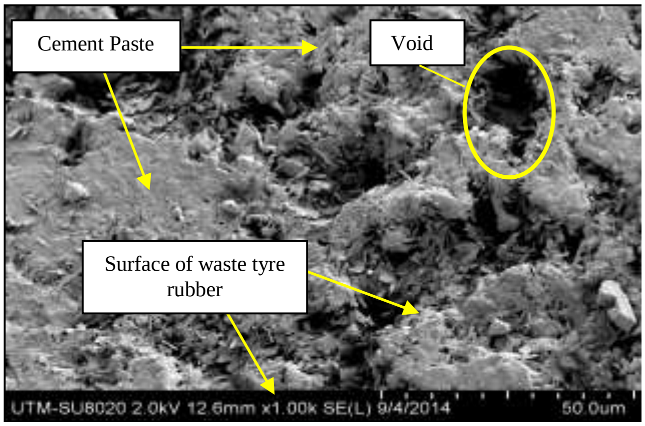

Figure 11 Surface of the waste rubber particle

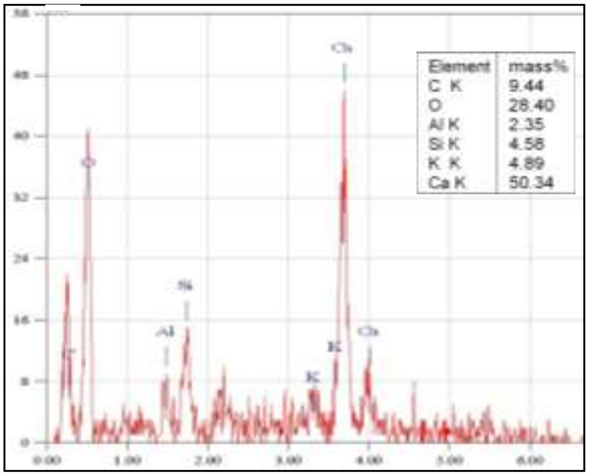

Figure 12 Energy Dispersive X-ray (EDX)

3.5 Fourier Transform Infra-Red (FTIR)

Figure 13 demostrate the FTIR spectrum of waste tyre rubber.Waste tyre rubber were composed of 48 % styrene-butadience rubber (SBR), 47 % carbon black, 1.9 % extender oil, 1.1 % zinc oxide, 0.8 %, sulfur, 0.7 % accelerator and 0.5 % strearic acid [13]. It was found that the plane banding appears at 1600 cm^{-1} wavelength, assigned to the plane vibrating of aromatic =C-H and C=C groups of Polystrene. The evolution of isoprene, dipentene and different unsaturated volatile products takes place at higher temperatures. The FTIR study showed that from 3600 – 4000 cm^{-1}, the plane bending vibrations of =C-H of vinyl groups and trans –CH=CH- at 1620 cm^{-1} of butadiene [22].

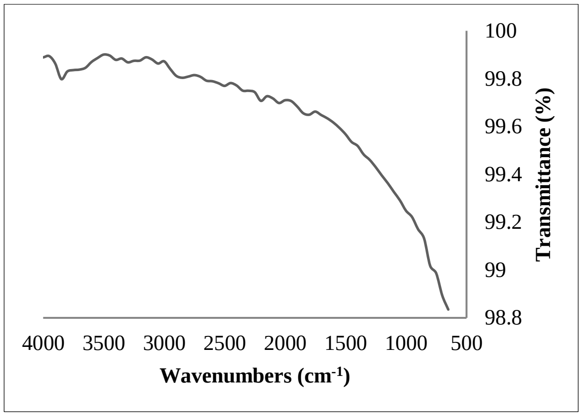

Figure 13 FTIR analysis of waste tyre rubber

3.6 Skid Resistance

Overall, Fig. 14 shows that the DL-RCPB has a higher skid resistance than CCPB because of two main factors: high elasticity and rough surface texture. These factors cause more friction to occur as the pendulum goes across the block surface. Additionally, with rubber content as a constant factor, the British pendulum number (BPN) for RCPBs that have a dried surface are higher than a wet surface. This is understandable since friction was reduced on a slippery surface, thereby lowering skid resistance. The skid resistance of the concrete block with 40% of rubber was lowered by 23% whereas the control block's skid resistance was lowered by 9.8%. However, the control specimens and all double layer RCPBs produced fulfilled the minimum BS EN 1338 requirement.

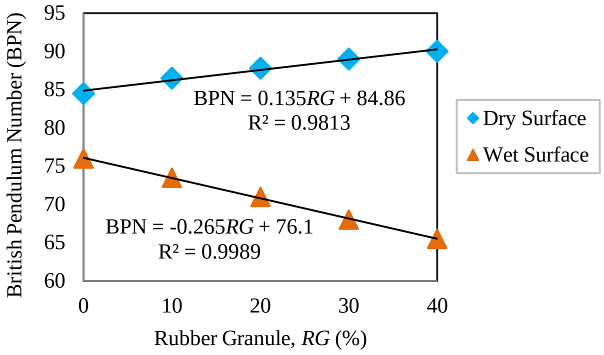

Figure 14 Skid resistance of DL-RCPBs

■4.0 CONCLUSION

This study illustrate the results for the effect of using waste tyre rubber granules as an aggregate replacement on the microstructure, compressive strength, flexural strength, splitting tensile strength and skid resistance of double layer rubberized concrete paving blocks. The effects on the compressive strengthof DL-RCPB are dependent on the percentage of rubber content. For trafficked pavement application, it is suggested that the percentage of waste tyrerubber should not exceed 20 %. However, substitution of waste tyre rubber up to 30 % can be considered since all sample meets the standard requiment forflexural and splitting tensile strength. DL-RCPBs are more flexible and soft to the surface, and thus provide a better ride quality. On the other hand, DL-RCPBs (30 % and 40%) with low strength characteristics could be used on roads that not required high strength and may be viable for other applications, depending on the percentage of waste tyre rubber used. DL-RCPB with higher waste tyre rubber content exhibit higher skid resistance especially on dry surface but reduced on slippery surface. DL-RCPB has a higher skid resistance than CCPB because of two main factors: high elasticity and rough surface texture.This may not give much effect since CCPB and DL-RCPBs meets the minimum requirement in standard. Hence, it is suggested that DL-RCPBs could be introduced as one of alternative CPB that can be used in paving application.

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