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Porosity and density characteristic of double-layer concrete paving blocks incorporating rubber granules

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Abstract. Porous cement concrete (PCC) is among the most effective voids reducer as compared to other types of concrete paver. The understanding on the techniques to produce durable pavement, the double-layer rubberized concrete paving blocks (DRCPB) was investigate in this study. Two rubber granules (RG) sizes, 1 mm to 4 mm, and 5 mm to 8 mm, were used as partial replacement aggregate to enhance the influence of DRCPB. The DRCPB containing 10 % (DRCPB-10), 20 % (DRCPB-20), 30 % (DRCPB-30), and 40 % (DRCPB-40) of RG designated with 10 mm, 20 mm, 30 mm, and 40 mm thick of top layer, and control concrete paving block (CCPB) were manufactured. Porosity and density test were carried out to analyse the durability characteristics of DRCPB. The results show that the porosity of DRCPB increased multiple when RG content increases from 0 to 40 % where the density of rubberized concrete is directly affected by the RG content.

1. Introduction

In general view of road pavement industry, the demand for producing low noise pavement has increased worldwide. Currently, optimum balance between the road primary function and higher noise reduction performance are essential, especially for the urban area. In this case, durable yet multi-functional concrete block pavement (CBP) is believed would give an added value to road pavement industry. It has been traditionally claimed that CBP provides durable road surface, easy to maintain and quick installation, great aesthetic, and road safety benefits due to the different tyre/road noise produced [1,2]. CPB is available in varies thicknesses (D) which are 50 mm, 60 mm, 80 mm and 100 mm [3]. Choosing the correct thickness along with the suitable application is vital. For domestic drives, paths and patios, 50 mm thick of CPB is used. The 60 mm thickness is used for car parks, domestic drives, footways, lightly trafficked areas and residential roads with less than five commercial vehicles per day. For CPB with 80 mm thickness (D), it is applied to aircraft pavements, factory floors, footways, industrial pavements, medium speed roads and residential roads with over five commercial vehicles per day. The 100 mm thickness is used in areas subjected to an exceptionally



high axle or point loads. The 80 mm CPB is usually adopted for general trafficking and this includes the heaviest loads. For industrial usage, the thickness of the block must be at least 80 mm. The usage of CPB offers more advantage compared to disadvantage. The application of this type of block reduce onsite wastage; low labour, installation and maintenance cost; early opening to traffic; excellent reuse value and low life-cycle cost; and also easy to maintain the subsurface utilities. Moreover, when it comes to the road user, CBP is found to be very effective as a part of the traffic control by alerting drivers when approaching road junction or intersection. The CBP has a good skid-resistance in wet condition and hence shorter stopping sight distance. In addition, CBP provides a durable surface that is comfortable to walk on, pleasant to look at, easy to maintain and ready for immediate use. Nowadays, application of CBP as main alternative to replace asphalt or concrete pavement for main roads and highway has not been implemented. In general, CBP is used as part of traffic control system and alert drivers with its noise and vibration when passing through it. The CBP is mainly used on road is normally situated at the road junction, traffic light and turning point. Besides, CBP is also famous for its advantages such as high durability and easy to be replaced. Asphalt pavement has low strength and operation durability resistance making it expensive for long-term maintenance. Consequently, replacing asphalt with CBP where durability is the primary consideration is a viable alternative. Rubberized concrete is generally defined as concrete incorporated with waste tyre rubber particles whereby the conventional aggregates or cement were partially replaced. Waste tyres used may vary in terms of origin, sizes, and shapes. Shredded or chipped tyres (with a size range of 13 to 17 mm) and granulated or crumb rubber (with a size range of 0.425 to 4.75 mm) are commonly used as an aggregate substitute in concrete. Moreover, ground rubber or rubber powder with size less than 0.475 mm is commonly used to replace a certain amount of cement. Hence, the aim of this study was to investigate the porosity and density characteristic of double-layer concrete paving blocks incorporating rubber granules.

2. Materials and method

2.1. Rubber granules

Rubber granules (RG) as shown in Figure 1, originated from the waste vehicle or automobile's tyres and produced using a mechanical shredding process was adopted for natural aggregates replacement in concrete. The RG was successively separated from steel by an electromagnetic process. Two particle sizes of RG, 1 mm to 4 mm and 5 mm to 8 mm, were used as partial substitutes of the fine and coarse aggregates, respectively. The recycled waste tyre (rubber granules) was supplied by Yong Fong Rubber, Malaysia.



Figure 1. Rubber granules 1 – 4 mm (Left) and 5 – 8 mm (Right)

2.2. Ordinary Portland cement

The type of cement used as binder material is OPC from Tasek Corporation Berhad, Perak. According to the manufacturer, the OPC used satisfied the requirements of ASTM C150/C150M [4] that includes cement composition for cement. Previously Hainin et al. [5] reported that the chemical composition of

the OPC was 70% CaO, 17.8% SiO₂, 3.9% Al₂O₃, 3.2% Fe₂O₃, 1.5% MgO, and 3.6% SO₃. The OPC similarly indicated a compound composition of 54.5% C₃S, 18.2% C₂S, 9.4% C₃A, and 10.5% C₄AF.

2.3. Aggregates

The Coarse aggregates used to manufacture DRCPB complied with the requirement of BS EN 12620 [6]. In addition, the concrete mix utilized unwashed river sand as fine aggregates obtained from Sungai Sayong, Malaysia. The natural aggregates used includes crushed granite with a maximum particle size of less than 10 mm and natural river sand as the fine aggregate of nominal size less than 5 mm. Two particle sizes of RG (1-4 mm) and (5-8 mm) are used as a partial substitution of fine and coarse aggregates.

2.4. Concrete mix design and mix proportion

The material used in concrete mixture consists of ordinary Portland cement Type 1, natural aggregates and superplasticizer. The mix proportion of (cement: aggregate: sand) is 1: 1.7: 1.5 and water to cement (w/c) ratio of 0.47. The mix is designed using the normal concrete mixes design method published by British Research Establishment (BRE). Two series of concrete mixes were prepared. The difference between the two series was the sizes and percentages of RG used as a substitution of natural aggregate. Where, 5 – 8 mm RG were used as a replacement of coarse aggregate in series I (Top Layer), and 1 – 4 mm RG as a substitution of fine aggregate in series II (Bottom Layer), respectively. The percentages of RG replacement are 10, 20, 30 and 40 %. The DRCPB were fabricated in steel mould with the internal dimensions of 200 mm in length, 100 mm in width and 80 mm in depth. Series II concrete mix was poured into the steel moulds and compacted on a vibrating table for 5 seconds. Then, series I concrete mix was poured on top of the concrete in the steel mould then compacted for another 5 seconds. Sufficient vibrating time is vital to get a uniform mix and avoid segregation. The DRCPB were removed from the steel moulds after 24 hours of casting and cured in air at room temperature approximately 27 °C and 65 % relative humidity for 7 and 28 days until tested.

2.5. Porosity and density test

Porosity and density of DRCPB were measured according to ASTM C642 [7]. In this study, each value presented is an average of readings for five samples. Experimental process starts by drying block specimen in oven at a constant temperature, 100±5 °C for not less than 24 hours. The block specimen is allowed to be cooled in air, preferably until the temperature is around 20 – 25 °C before start measuring the weight. After measuring the weight, the block specimen was placed back into the oven for second and third drying treatment to make sure that the block specimen is completely dried. In order to confirm the block specimen is totally dried, the difference between two successive values of weight is less than 0.5 % of the lowest value recorded. Next, the block specimen was submerged in water for not less than 48 hours until two measured weight value of the saturated-dried specimen at an interval of 24 hours shows an increment of weight less than 0.5 % of the larger value. Block specimen was then boiled for 5 hours and the mass of specimen was measured after cooling the specimen for not less than 14 hours. Lastly, apparent weight value was measured by suspending the immersed and boiled specimen by wire and the apparent weight in water was recorded.

3. Results and discussion

3.1. Porosity

Figure 2 and Figure 3 show the relationship between porosity and rubber content at 7 and 28 days of curing age with both graphs having an increasing trend. The porosities of DRCPB seem to be directly affected by the rubber content and TL thicknesses. Rubber particles are basically known as hydrophobic materials which repel water yet attract bubbles on their surfaces [8]. Excessive bubbles may affect the bonding between cement paste and RG particles. This will cause more voids to form when the cement starts to harden. From Figures, it is noticed that the porosity of DRCPB increased almost triple when RG content increases from 0 to 40 %. The CCPB recorded porosity of less than 8

% at 7 days curing age, while DRCPB (40) porosities ranged from 16.98 to 18.48 %. These values show 9 % increment when the TL becomes thicker. The TL of the block contains coarse RG. It is known when this layer is having less hardened cement paste, thus, the TL tends to have more voids. On the other hand, porosities at 28 days of curing age ranged from 4.75 to 5.57 % and 15.29 to 16.84 % for CCPB and DRCPB (40), respectively. Concrete curing aged eventually lowered the porosity of any particular concrete through continuous and sufficient hydration process. As reflected earlier, a similar hypothesis can be applied which relating RG rough surfaces and hydrophobic nature in creating more voids as the concrete hardened.

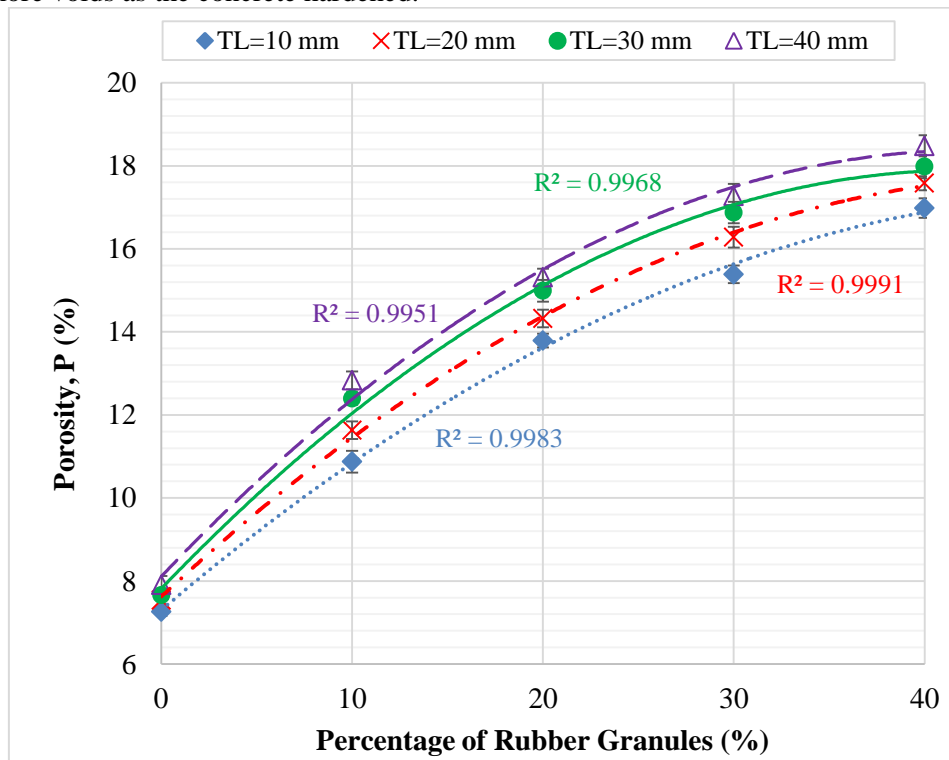


Figure 2. Relationship between porosity of DRCPB and percentage of rubber granules at 7d

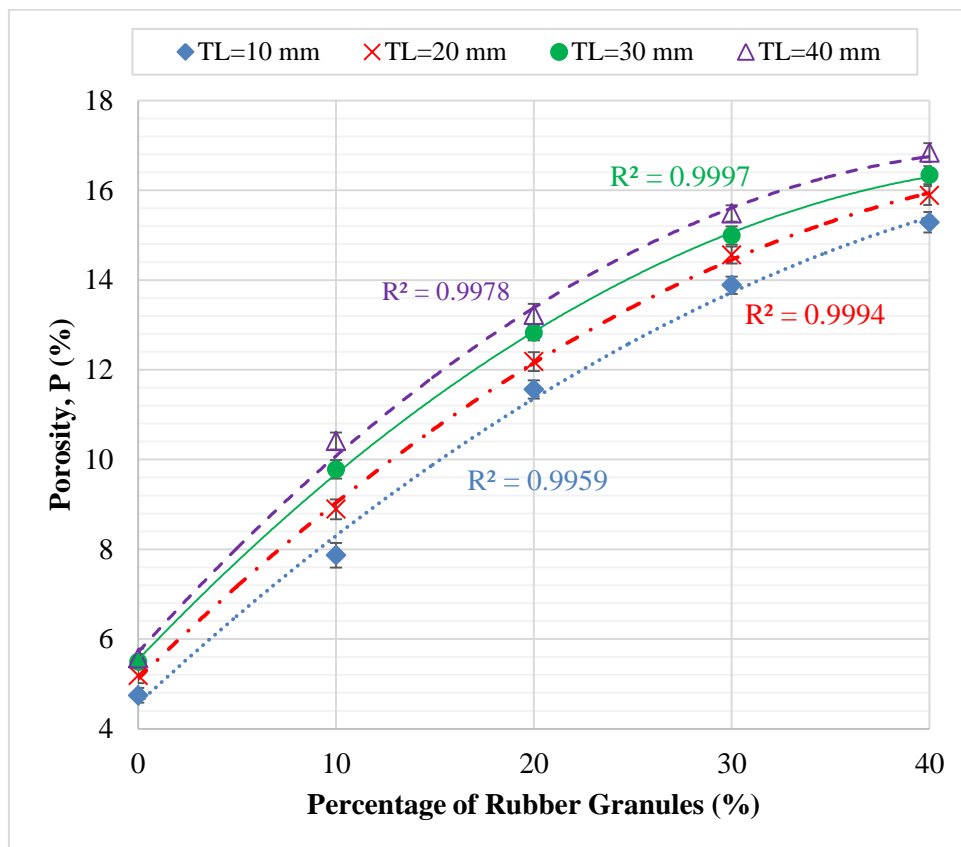


Figure 3. Relationship between porosity of DRCPB and percentage of rubber granules at 28d

3.2. Density

The density of the respective DRCPB reduced significantly at higher rubber content as shown in Fig. 4 and 5. At 7 day, densities lessen by 9 % from approximately 2287 kg/m³ for CCPB to 2085 kg/m³ for DRCPB (40). According to the best-fitted line (with a correlation coefficient of $R^2 = 0.98$ to 0.99) in Fig. 4, a linear relation between densities, rubber content and top layer (TL) thickness is observed. It shows a systematic reduction in density with the increase of rubber content regardless the TL thickness. At 28 days of curing age (Fig. 5), densities recorded are ranged from 2398 to 2117 kg/m³ for CCPB and DRCP, respectively. Significant reduction in density is spotted in Fig. 5 shows that the density of rubberized concrete is directly affected by the RG content. Greater densities reduction (up to 12 %) when 40% of RG is incorporated and TL thickness is maximized to 40 mm. The top layer of the block is made with coarser RG, hence lower block density is expected. Most researchers have made a hypothesis of concrete density reduction due to the lower density of RG particles as compared to conventional aggregate and sand. Indeed, from the result, it is observed that the addition of a higher percentage of RG particles tends to lessen the concrete density. Raffoul *et al.* [9], Thomas and Gupta [10], and Issa Salem [11] acquired similar result where the density of concrete is significantly affected by rubber content. Another hypothesis made by Siddique and Naik [12] is that the nature of RG particles surrounded with a rough surface and non-polar shapes tend to trap air during concrete mixing and affect the end product (hardened concrete) properties. This may result in high volume of voids in the hardened rubberized concrete.

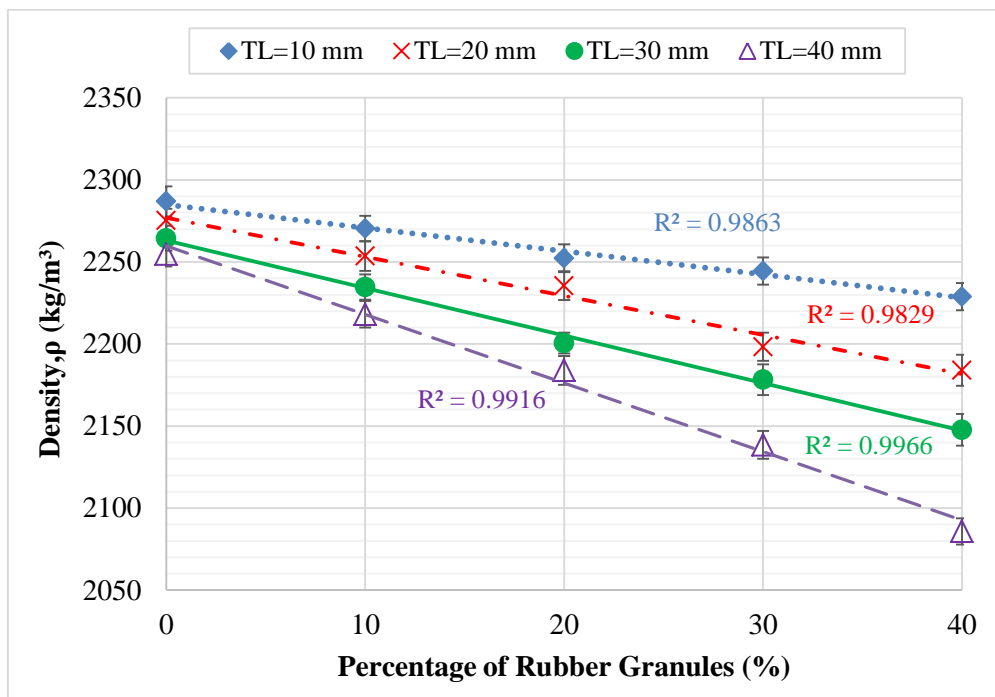


Figure 4. Relationship between density of DRCPB and percentage of rubber granules at 7d

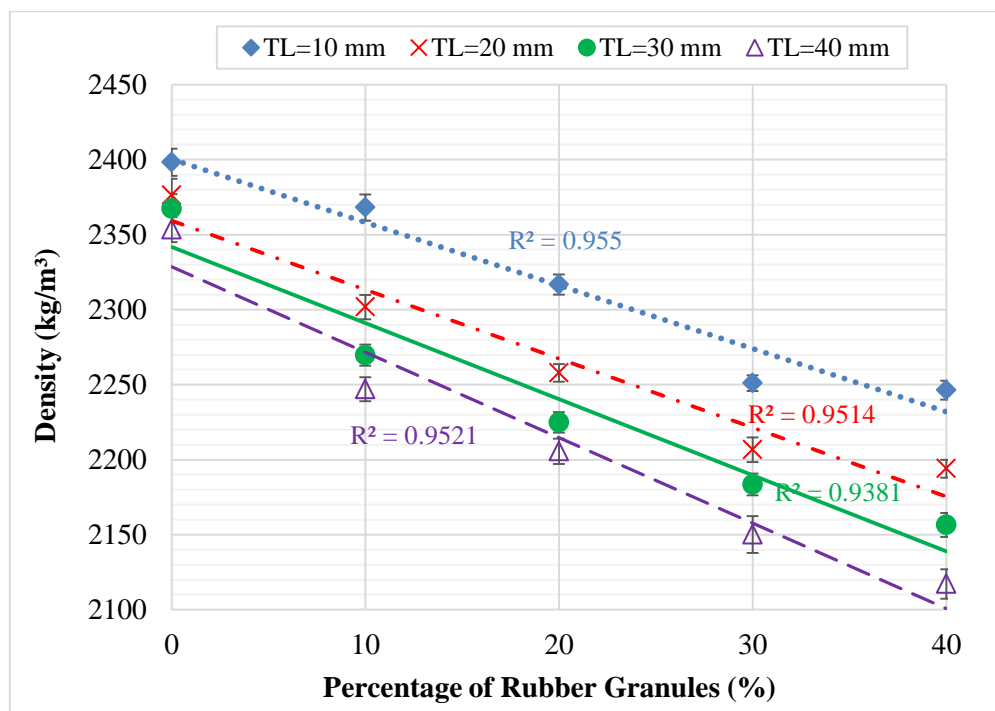


Figure 5. Relationship between density of DRCPB and percentage of rubber granules at 28d

4. Conclusions

- It is observed that the decrease in density is when part of the aggregate is substituted with rubber granules. The density reduction is in line with the fact that rubber granules particles are lighter than that of conventional aggregate.

- Concrete curing eventually lowered the porosity as hydration process continues and increased in microstructure stability.

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