Mechanical and Geotechnical Properties of Recycled Waste Materials: The Feasibility of using Steel Slag – Cathode Ray Tube Glass as Aggregate Replacement for Road Pavements

Ahmad Yusri Mohamad, Maslina Jamil, Nur Izzi Md. Yusoff, Mohd Raihan Taha, Abd Rahim Awang

Abstract**: *The volume of waste generated in Malaysia and throughout the globe continues to increase. Waste management and protection of the environment should be given a priority, and this requires for studied to be carried out on the problem of waste management. One of the approaches that can be adopted in this regard is to reuse waste materials as recycled products. Mechanical and geotechnical tests, namely the Los Angeles abrasion tests, the Atterberg limit test, and the sand equivalent value, were carried out to determine the suitability of using steel slag and CRT glass in the construction of road pavements. The value obtained from the laboratory test is within the JKR standard specification (JKR/SPJ/2008-S4). The objective of this study is to investigate the mechanical and geotechnical properties of steel slag and cathode ray tube (CRT) glass in order to determine the feasibility of using both materials as a natural aggregate replacement in the construction of road pavements. The result for the Los Angeles abrasion test showed that steel slag has better wear resistance and mechanical properties compared to those of the natural aggregates (granite) use in this study. The result for the Atterberg limit test showed that all three samples (granite, steel slag and CRT glass) are non-plastic. While the result for the sand equivalent value test showed that the granite sample has the highest value, followed by CRT glass and steel slag. Thus, it can be concluded that steel slag and CRT glass are suitable substitutes for natural aggregates (granites) since they have been proven to meet the requirements for the natural aggregates with similar properties. This provides an alternative use for recycled materials and the possibility of using these materials as an aggregate replacement in the construction of road pavements.***

Keywords**: *Steel slag, CRT glass, recycled waste material, road pavement***

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* Correspondence Author

Ahmad Yusri Mohamad*, Department of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia. Email: P91989@siswa.ukm.edu.my

Maslina Jamil*, Department of Architecture and Built Environment, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia. Email: maslinajamil@ukm.edu.my

Nur Izzi Md. Yusoff, Department of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia. Email: izzi@ukm.edu.my

Mohd Raihan Taha, Department of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia. Email: profraihan@ukm.edu.my

Abd Rahim Awang, Polytechnics Muadzam Shah, Muadzam Shah, 26700, Pahang, Malaysia. Email: abdulrahimawang@yahoo.co.uk

I. INTRODUCTION

The generation of excessive waste and poor waste management has resulted in environmental pollution. The preservation of the environmental is a fundamental factor that should always be taken into account as it is closely related to the human health and well-being [1]. Concern about the environment, economy, technical and scarcity of construction materials in some countries have motivated researchers to find ways to recycle industrial waste materials [2]. The use of recycled materials has become a priority in road construction in an effort to minimize environmental impact whilst reducing construction costs [3].

A large number of studies have been conducted to find ways to use recycled waste materials as an alternative material in construction works. The study conducted by Taha et al. [4] has shown that recycled materials can be used in road or sub-site layer, for instance by combining recycled asphalt pavement with natural aggregates. The results of their study showed that recycled asphalt pavement can be used as a 100% natural aggregate replacement by using 3 to 7% cement mixtures as a stabilizer. Hamim & Md. Yusoff [5] investigated the possibility of using the waste from processing activities as a stabilizer in road pavements. They have determined that the use of this stabilizing material adds value to the pavement and that the stabilizer is very suitable for road maintenance work.

By-product materials, such as steel slag and cathode ray tube (CRT) glass, which is a component of electronic waste, are among the materials that can be used as recycled materials. Studies examining the generation of by-product materials (steel slag) in the steel industry have found that the amount of by-products generated each year has been increasing. Yi et al. [6] stated that in 2010 China, as a major producer of steel, generated a significant amount of steel and by-products of 626.7 million tons and 90 million tons, respectively.

Tiwari et al. [7] have shown that the demand for steel products in India is expected to increase from 99 million tons in 2013 to 125 million tons in 2016. Several sources have quoted from Yu-Gong et al. [8] that, in the EU, around 7.5 million tons of electronic waste are produced with an annual increase of between 3% and 5%. In 2013 China produced more than 32 million television sets, 37 million units of computer wastes and 43.11 million tons of CRT glass [8].

Steel slag is a by-product generated during the manufacture of steel [9] and is one of the most widely used recycled materials. Steel slag has similar properties to those of conventional aggregates, and because of this it has been widely used in road construction [9]; the high density and high hardness of steel slag makes it a suitable replacement for natural aggregates [10].

CRT glass waste includes the main components of electrical and electronic equipment such as computers, monitors, televisions, printers, refrigerators and components containing batteries [8]. Singh et al. [11] stated that CRT glass has a high silica content and the pozzolanic properties of the glass made it a suitable substitute for the river sand used in concrete mixtures. Disfani et al. [12] investigated the use of recycled glass samples retained on a 4.75-mm diameter sieve and found that this glass has a suitable geotechnical properties that allows for it to be used as an embankment fill material in roads.

The objective of this study is to investigate the mechanical and geotechnical properties of steel slag and CRT glass samples in order to establish the feasibility of using them as a natural aggregate replacement (granite) in road pavements. The mechanical properties and geotechnical properties were established through the Los Angeles abrasion tests and the Atterberg limit tests, respectively; the sand equivalent values were also tested and compared with the JKR standard specification (JKR/SPJ/2008-S4) [13]. The laboratory testing procedures were based on the American Society for Testing and Materials (ASTM) and British Standard (BS) standard test methods.

II. EXPERIMENTAL DESIGN

A. Materials

The aggregates used for preparing the samples in this study are the type of granite used as natural aggregates. The size of the granite rocks ranges from 75 µm to 20 mm. The sample used for the comparative study are steel slag and CRT glass. The size of the steel slag and CRT glass ranges from 4.75 mm to 20 mm for the coarse aggregate and from 75 µm to 4.75 mm for the fine aggregates, respectively.

The natural aggregates used to prepare the samples used in this study were obtained from Kajang Rock (M) Sdn. Bhd., Selangor. The steel slag samples were provided by Lion Titco Resources Sdn Bhd, Banting, Selangor. The steel slag samples were categorized as Electric Arc Furnace (EAF) process group type. Steel slag is a by-product generated in the manufacture of stainless steel through EAF and Basic Oxygen Furnace (BOF) processing. The CRT glass samples were obtained from Nippon Electric Glass (NEGM) in Shah Alam, Selangor. The CRT glass was subjected to several preparation processes. All CRT glass components were separated using laser cutting methods. The CRT glass component were processed by crushing and grading to obtain angular glass particles.

The materials (granite, steel slag and CRT glass) were sieved into separate samples based on the BS specifications for road base layer. Figure 1 shows the gradation of the curve limit for the road base layer. Three testing methods were used to establish the properties of the sample materials, namely the Los Angeles abrasion value, Atterberg limit and sand equivalent value tests.

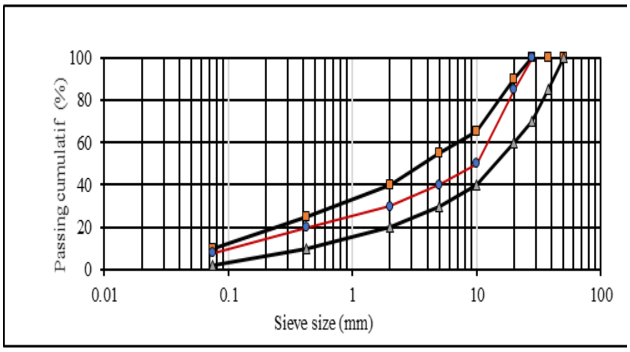

Fig. 1: Particle size distribution of the aggregates used in road base layer [13].

B. Los Angeles abrasion value test

The Los Angeles abrasion test was conducted in accordance with ASTM C131 [14]. The result of the Los Angeles abrasion test was evaluated based on the values of abrasion, friction, shifting and cracking in a steel drum. A sample of varying sizes of aggregates weighing 5000 grams was put in the drum along with a specific number of steel balls. The drum was rotated 500 times at a speed of 33 r.p.m. After completing the 500 rotations the aggregates were sieved using a 1.70 mm sieve. The percentage of age loss due to abrasion was determined by calculating the difference between the retained materials and the original sample weight. The difference in weight is reported as the percentage of the original weight.

C. Atterberg limit test

Atterberg limit is an important validation test for classifying natural aggregates. The determination of the Atterberg limit comprises of two different tests: liquid limit test and plastic limit test. The liquid limit tests using the cone penetrometer method and plastic limit test were carried out in accordance with BS 1377 [15].

D. Sand equivalent value test

The sand equivalent (SE) tests were performed to determine the relative proportions of clay size or plastic fines and dust in granular soils and fine aggregates passing a 4.75 mm (No. 4) sieve. The test was carried out in accordance with ASTM D2419 [16]. The samples were put in a cylinder and mixed with water and flocculating solution to isolate the fine dust clay particles from the remaining aggregate sample. The samples were shaken and left undisturbed on a vibration-free surface for 20 minutes. At the end of this period, the sand equivalent value was calculated as the height of sediment and is expressed as a percentage of the total height of flocculated material in the cylinder.

III. RESULT AND DISCUSSION

The results for the mechanical properties and geotechnical properties test of the granite, steel slag and CRT glass are shown in Table 1. Each test result is discussed in detail in the next section.

Table 1: Sample characterization result (granite, steel slag and CRT glass).

Parameter	Granite	Steel slag	CRT glass	JKR specification [13]
Mechanical properties				
Los Angeles abrasion value (%)	34.12	21.50	-	< 45
Geotechnical properties				
Atterberg limit				
Liquid limit (%)	24.00	16.60	15.25	-
Plastic limit (%)	Non-plastic	Non-plastic	Non-plastic	Non-plastic
Plastic index (%)	-	-	-	< 6
Sand equivalent value (%)	68.9	61.3	64.9	> 45

A. Mechanical properties

- **Los Angeles abrasion**

The results for Los Angeles abrasion test for granite and steel aggregates are shown in table 1. The values indicate that both aggregates meet the maximum JKR specification of 45% for road construction. The Los Angeles abrasion test values for granite and steel slag are 34.12% and 21.50%, respectively, and are significantly lower than the specified values. The smaller value for steel slag indicates that steel slag has a better wear resistance and better mechanical properties than granite. This is congruent with the findings of a study conducted by Hainin et al. [17]. Zumrawi & Khalill [18] stated that steel slag has a good mechanical properties and are therefore suitable for use as aggregate materials.

B. Geotechnical properties

- **Atterberg limit**

The Atterberg limit tests are evaluated based on the liquid limit and plastic limit tests. The values for the two tests were used to determine the plastic index value, and results showed that all tested samples are non-plastic.

The liquid limit tests were done using the cone penetrometer method, and the results for granite, steel and CRT glass samples are 24.00%, 16.60% and 15.25%, respectively. The result of the liquid limit shows that the samples are within the limits of the liquid and plastic properties. Based on the values obtained for the Atterberg limit test, all three samples are categorized as non-plastic. Non-plastic material samples have been shown to performs well in road construction [19].

- **Sand equivalent value test**

The values for the sand equivalent tests for all three samples are higher than the minimum 45% requirements in the JKR standard specification (2008). The granite sample has the highest value of 68.9%, followed by CRT glass (64.9%) and steel slag (61.3%). The high sand equivalent value indicates the lack of fine-grained content in the sample layer. The presence of dust (fine details) on the material surface reduces the material's resistance to wear [20].

IV. CONCLUSION

The values for the mechanical and geotechnical properties of the studied material are deemed to be good and meet the JKR standard specification. Test results indicate that the studied recycled materials (steel slag and CRT glass) can be used as a replacement for natural aggregates (granites) considering that both materials meet the requirements for a similar purpose. Based on the results for LAAV test, steel slag has smaller value than granite but both aggregates sample meet the maximum JKR standard specification of 45%. This indicates that steel slag has a better wear resistance and better mechanical properties than granite. For Atterberg limit, all three samples are categorized as non-plastic. The non-plastic material sample have been shown to performs well in road construction. In addition, the value for the sand equivalent tests for all three samples are higher than the minimum 45% requirements in the JKR standard specification. The high sand equivalent value indicates the lack of fine grained content in the sample layer. Therefore, it is concluded that recycled waste material, steel slag and CRT glass can be used as an alternative recycled materials and has promising potential for uses as an aggregate replacement for road pavements.

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AUTHORS PROFILE

Ahmad Yusri Mohamad is a postgraduate student at Department of Civil Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, 43600, Selangor, Malaysia. His research focused on material and structural engineering.

Maslina Jamil is an Associate Professor and Deputy Director at Centre for Collaborative Innovation, Universiti Kebangsaan Malaysia. Her research focused on engineering & material science.