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Feasibility Study of Utilizing Steel Slag and Cathode Ray Tube Glass as Aggregate Replacement for Road Base

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ABSTRACT

The growing amount of waste materials and the shortage of landfill space highlights the urgency for alternative ways to recycle and reuse waste materials. Recycle and reuse waste materials would indirectly contribute to reducing the landfill space required for their disposal. This paper attempts to compare the physical and mechanical properties of by-product material (steel slag) and waste material (Cathode Ray Tube (CRT) glass) that could potentially be used as substitutes for natural aggregates in the construction of road pavements. This paper discusses the feasibility of utilizing recycled steel slag and CRT glass which meet the test requirements for natural aggregates utilized for pavement construction. The study method for laboratory work was carried out following the American Society for Testing and Materials (ASTM) specifications. Physical and mechanical testing's, i.e. specific gravity, water absorption, soundness and Los Angeles abrasion tests, were carried out to determine the suitability of using steel slag and CRT glass in the construction of road pavements. Test results indicate that steel slag and CRT glass can be used as substitutes for natural aggregates due to their satisfactory physical and mechanical properties. It can be concluded that the use of steel slag and CRT glass as a replacement for natural aggregate resulted in the sustainable management of road base paving application.

Keywords: Waste Materials, CRT Glass, Steel Slag Aggregate, Natural Aggregates, Road Base.

1. INTRODUCTION

In line with the global awareness of the need to preserve and conserve the environment, many studies have been carried out on the re-use of by-products and waste products such as the utilization of waste construction materials. The use of by-products and waste products not only help to preserve and conserve the environment, but it also provides solutions for landfills problems. At present, many studies are being carried out on the use of by-products material such as steel slag, aggregates in road construction, and substitute for fine or coarse aggregate in the surface layer of the road or road base and sub base. Studies have shown that the use of steel slag able to impart good physical and mechanical properties to road pavements in comparison to conventional aggregates. Studies have also proven the benefits of cost reduction when utilizing steel slag as aggregates in road construction [1]. Other studies in glass material, results of laboratory tests have shown that the recycled glass materials used as a substitute for fine and medium aggregates have similar geotechnical properties as the natural aggregates [2-3].

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The use of waste materials not only solves environmental problems but also helps to reduce construction cost whilst providing a sustainable road construction method [4-5]. The use of steel slag as aggregates in road construction reduces the cost of extracting and processing natural aggregates. The steel industry can reduce the cost of treating and disposing of a large number of steel stockpiles [6-7].

The use of steel slag as a natural aggregate replacement material has been widely used in road construction as it has high density and hardness properties [8]. Meanwhile, the use of Cathode Ray Tube (CRT) glass as a fine aggregate substitute was proven effective. The use of CRT glass has a good impact as a fine aggregate substitute in concrete and mortar mixing. The silica element on the CRT glass has pozzolanic properties hence it can substitute the river sand in concrete mixtures [9]. Karim et al. [10] stated that pozzolanic presence contributes to the enhancement of material properties and gives the adds value to other properties. Both the granite and steel slag have a rough surface texture, which gives them the ability to improve internal friction and thereby strengthen the bond between the materials in the mixes [11]. The benefits of using steel slag in road construction are that it provides better interlocking and friction, thus resulting in better stability, rutting resistance and skid resistance when compared with natural materials [8]. Besides, CRT glass has a smooth surface and an angular grain shape [12-13]. The study of the use of CRT glass and its effectiveness as a road layer material is still new. Therefore, research has to be carried out to identify the potential use of by-products material, i.e. steel slag and electronic waste, i.e. CRT glass, as alternative recycled materials for use in road construction.

This study focuses on comparing the physical and mechanical properties of a by-product material (steel slag) and a waste material (CRT glass) used as substitutes for the natural aggregates used in the construction of pavement road base material. Comparison of the physical and mechanical properties is based on the standard laboratory tests conducted on the samples. The laboratory tests performed in this study follows the specifications set by the American Society for Testing and Materials (ASTM).

2. MATERIAL AND METHODS

2.1 Materials

Three types of aggregates were used to prepare the specimens in this study: granite (natural aggregate), steel slag (by-product material) and CRT glass (waste material). The aggregates were sieved into separate samples based on the sizes specified by the standards specifications of ASTM. The natural aggregates used in this study were obtained from Kajang Rock (M) Sdn Bhd, Selangor. The steel slag was supplied by Lion Titco Resources Sdn Bhd, Banting Selangor and is categorized as Electric Arc Furnace (EAF). The residual product generated from the melting of scrape produces steel categorized as EAF as well as in the conversion iron to steel categorized as Basic Oxygen Furnace (BOF) [8,14]. 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 components of the CRT glass were separated using laser cutting methods. The CRT glass components were processed by crushing and grading to obtain angular glass particles.

The aggregates used for the preparation of the samples in this study is a type of granite rock of the size 75 μm to 20 mm (control sample). The size of the steel slag used as coarse aggregates ranges between 4.75 mm and 20 mm while those glass CRT used as fine aggregates ranges from 75 μm to 4.75 mm. The proposed material should be able to show that they have sufficient properties which meet the standard specification. The steel slag and CRT glass used should be able to meet the stipulated test requirements for natural aggregates used for the same purpose. The tests were carried out to determine the physical and mechanical properties such as specific gravity, water absorption, soundness and Los Angeles abrasion tests.

2.2 Specific Gravity and Water Absorption

The specific gravity and water absorption tests for coarse aggregates were carried out in accordance with ASTM C127 [15] and ASTM C128 [16] respectively. The specific gravity of aggregates is determined in order to establish the strength or quality of the material. Specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Aggregates with low specific gravity are generally weaker than those with higher specific gravity. Meanwhile, water absorption is defined as an increase in the mass of aggregates due to water penetration into the pores of the particles during a specific period, but not including the water adhering to the outside surface of the particles; it is expressed as a percentage of dry mass. The requirement for a standard water absorption limit is less than 2%.

2.3 Soundness Test

The test for soundness was carried out according to ASTM C88 [17] to determine the aggregates' resistance to disintegration in a saturated solution of magnesium sulphate. An aggregate sample is subjected to several cycles (usually five cycles) of submergence in a sulphate solution (magnesium sulphate, $MgSO4$) followed by air-drying. After a specified number of cycles, the aggregate samples were washed and sieved to determine their mass loss. The aggregates were separated into several size range and tested independently. The final reported loss value (as a percentage of total aggregate mass) is a weighted average of the mass loss for each size range. For the soundness test, standard requirement limit is less than 18%.

2.4 Los Angeles Abrasion Value (LAAV) Test

The Los Angeles Abrasion Value (LAAV) test was carried out according to ASTM C131 [18] to evaluate abrasion, shifting and cracking as well as any combination of the three characteristics in a steel drum. The test was conducted only on coarse aggregate samples consisting of granite and steel slag samples.

Varying sample sizes in the amount of 5000 grams were put in the drum together with a specific number of steel balls. The drum was rotated up to 500 times at a speed of 33 rpm. The aggregates were removed from the machine and 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 per cent of the original weight. Meanwhile, the requirement for a standard value of LAAV is less than 50% for road base aggregate.

3. RESULTS AND DISCUSSION

3.1 Specific Gravity

Figure 1 shows that the specific gravities of granite, steel slag and CRT glass are 2.68, 3.55 and 2.54, respectively. Steel slag has the highest specific gravity value compared to granite and CRT glass. The specific gravity for steel slag is 32% higher than that of the natural aggregate (granite). Aggregate samples with high specific gravity values are usually stronger [11]. This indicates that the steel slag sample is stronger than the granite and CRT glass samples.

Figure 1. Specific gravity of the samples.

3.2 Water Absorption

The result for water absorption test presented in Figure 2 shows that the granite, steel slag and CRT glass samples used in the present study meet the standard requirements. The water absorption values for granite, steel slag and CRT glass are 0.49%, 1.80% and 0.19%, respectively.

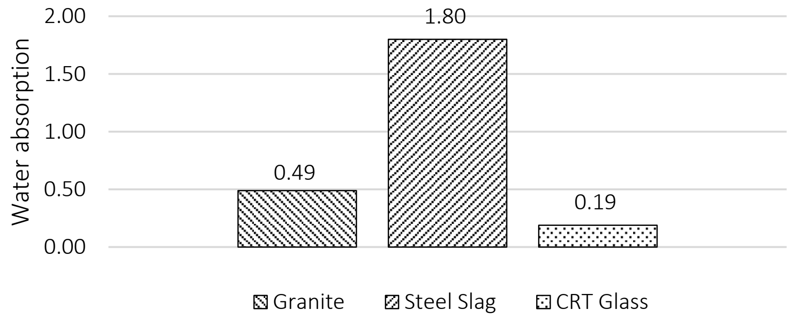

Figure 2. Result of the water absorption.

Hence, these results are acceptable according to the ASTM C127 specifications. The water absorption value for steel slag is higher than those for granite and CRT glass. This indicates that the steel slag has a high porosity, therefore it can absorb more water in comparison to granite and CRT glass. Romero et al. [13] pointed out that a high water absorption by the aggregates indicates a high porosity of the aggregate sample. However, the value obtained for the steel slag with the standard requirement is less than 2%.

3.3 Soundness Test

The soundness test was carried out on varying sizes coarse sample aggregates and the results are presented in Figure 3. The data indicate that steel slag has the lowest soundness value while granite has the highest value. These soundness values are acceptable according to the ASTM C88 specifications of less than 18% for road construction work. The soundness values of granite, steel slag and CRT glass are 0.20, 0.02 and 0.41, respectively. These results show that steel slag has higher durability and stability in contrast to granite and steel slag. This indicates that the sample is highly durable and has the ability to resist bad weather conditions, in particular freezing and thawing. Taha et al. [19] have proven that steel slag has a positive, stable and good material properties and a good soundness value. Therefore, steel slag can be used as a granular base for road construction.

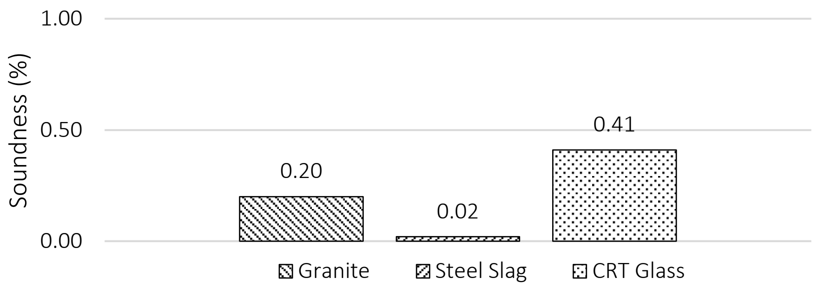

Figure 3. Soundness of the aggregates.

3.3 Los Angeles Abrasion

The result of the Los Angeles abrasion test for granite and steel slag shown in Figure 4 indicates that both aggregates are acceptable according to the ASTM C131 specifications of less than 50% for road construction work. The Los Angeles values for granite and steel slag are 34.12% and 21.50%, respectively, and are much smaller than the specified value. The smaller value for steel slag indicates that steel slag aggregates have a good wear resistance and mechanical properties. The present study has shown that steel slag has good mechanical properties, therefore, suitable to be used as aggregates replacement for road base application [1,8].

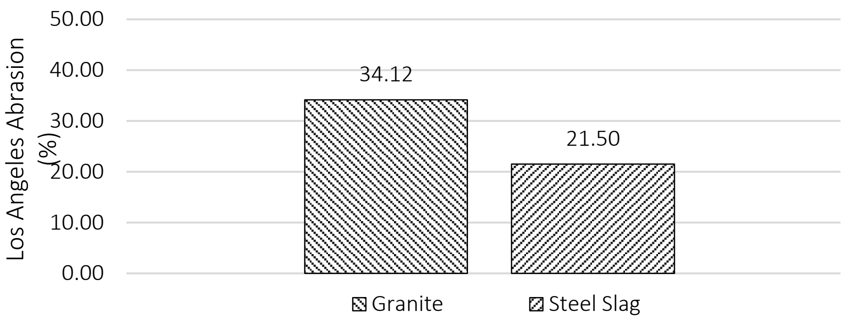

Figure 4. Result for the Los Angeles Abrasion

4. CONCLUSION

All test results for physical and mechanical properties indicate that steel slag and CRT glass can be used as substitutes for natural aggregates and meet the requirements for natural aggregates used for a similar purpose. Based on the results, steel slag has higher specific gravity and water absorption values in comparison to natural aggregates. This is due to the higher porosity of the steel slag aggregates. Steel slag shows an excellent result for the soundness test, indicating that it has high durability and can resist bad weather conditions, in particular freezing and thawing. In addition, the values for LAAV are satisfactory, indicating that the steel slag has adequate strength for use as pavement aggregates.

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