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Chapter 1

Analysis of Steel Slag as the Replacement of Natural Aggregates on the Road Base

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ABSTRACT

Recyclable materials have been widely used as substitutes or additives in the pavement and the construction of the road base layers. In this study, recycled materials used are steel slag. The main objective of this study is to analyze the use of steel slag as the replacement of natural aggregates for the road base which this study focusing on identifying the physical and mechanical properties of steel slag. Steel slag is used as course aggregate with percentage of aggregate materials used are 30%, 40%, 50%, 70% and 100%. Some laboratory tests are carried out such as specific gravity and water absorption test, sand equivalent test, magnesium sulphate soundness test, and Los Angeles (LA) abrasion test, and aggregate crushing value (ACV) test. Based on the results of the experimental, it was found that the percentage of steel slag as the replacement of natural aggregates for the road base that meet all the requirement of AASHTO, ASTM and JKR/SPJ/2005 is 70% where it mix with 30% of natural aggregates. As conclusion, the use of steel slag for the road base could preserve the natural resources and thus save the environment.

Key Words: road base, aggregate, cathode ray tube glass, steel slag.

1. INTRODUCTION

The quantity of disposing waste material is increasing in road construction and thus, effective implementation and management are needed for recycle waste materials or recycling as a substance that provides good value (Hainin et al. 2014). Factors such as environment, economic, technical and deficiency of proper construction material have diverted the attention of experts towards the industrial waste materials (Aziz et al. 2014; Hainin et al. 2015). The use of alternative or recyclable materials could preserve the natural resources, save the environment and ecological systems from being disturbed (Hainin et al. 2012). Using recycled material is a high priority in pavement industry not only for reducing the construction cost but also for minimizing the environmental of road construction (Moon, Falchetto, Marasteanu, & Turos, 2013). In this study, the recycled materials used are steel slag.

Steel slag is a byproduct obtained from steel industry which is generated as a residue during the production of steel (Hainin et al. 2012, 2014, 2015; Aziz et al. 2014). Most of the

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developed countries have successfully incorporating steel slag as an aggregate in hot mix asphalt, road base, sub-base and soil stabilization in road works (Hainin et al. 2012). In 1998, up to 97% of the total generated steel slag has been used in different ways for the construction of high trafficked roads by Germany (Motz & Geiseler, 2001), while China in 2010 has recorded the annual output of steel and steel slag which is reached to 626.7 million tons and 90 million tons respectively (Yi et al. 2012).

Successful studies have revealed that the physical and mechanical properties of steel slag are equal or better than the conventional aggregates (Moon et al. 2013). Based on high frictional and abrasion resistance, steel slag is used widely in industrial roads, intersections and parking areas where high wear resistance is required. Steel slag has been widely used in road construction because it has high density and hardness (Hainin et al. 2014), and it was selected due to its characteristics which are almost similar to those of conventional aggregates (Hainin et al. 2012).

2. METHODOLOGY

Steel slag aggregates were obtained from Lion Titco Resources Sdn. Bhd, which is located at Banting, Selangor. The particles sizes are from 0 mm to 20.0 mm. The natural aggregate which is the gravel were obtained from the laboratory itself. Figure 1 shows the steel slag aggregate with particle size retained at 12.5 mm. Steel slag has rough surface texture which is same as the gravel.

Figure 1: Steel slag

The experimental work involved testing both steel-slag aggregates with conventional aggregates. All the parameters were obtained from tests performed at the Transportation Laboratory and Concrete Laboratory, Civil Engineering Programme, Universiti Kebangsaan Malaysia. All the specifications were referred to the Malaysian Standard (JKR/SPJ/2005), and the procedures of the experiments follow American Society for Testing and Materials (ASTM) and British Standard (BS). Table 1 shows the list of experimental and specifications used in this study. The physical and mechanical properties of steel aggregates are then compared with the Malaysian Standard which is JKR/SPJ/2005. There are 25 samples that were prepared for the overall laboratory test. The percentage of steel slag aggregates used for the replacement of the natural aggregates are shown in the Table 2. Control sample is prepared for the purpose of comparison and analysis.

Table 1 List of Experimental and Specifications

Testing	Procedures	Specification JKR/SPJ/2005
Physical Properties		
Specific gravity	ASTM C 127-88	-
Absorption	ASTM C 127-88	< 2 %
Sand equivalent	ASTM D 2419	> 45 %
Mechanical properties		
Soundness	ASTM C 88	< 18 %
Aggregate crushing value	BS 812:110	< 30 %
Los Angeles abrasion value	ASTM C 131	< 25 %

Table 2 Percentage Mass for Sample Preparation

Sample	Percentage of aggregates (%)	
	Natural Aggregates	Steel Slag
A1 (Control)	100	-
A2	70	30
A3	60	40
A4	50	50
A5	30	70
A6	-	100

Steel slag has been successfully used for the replacement of natural aggregates with the 70% steel slag is used as the substitution aggregates. A comparison of the result has shown that the steel slag can be used in bases and structural fills where very high stabilities are obtained. The physical and mechanical properties of steel slag in this study productively meet the requirements of a high class material. As compare to natural aggregate, it provides ideal durability, stability, resistance against abrasion and soundness. Some of the physical properties such as the specific weight, absorption, and sand equivalent for all aggregate types used in this study are shown in Table 3.

Specific gravity and water absorption is measured using ASTM C 127-88. The particle density of steel slag aggregate compared to natural aggregate (gravel) is denser and heavier material by approximately 20%. This may be an economic disadvantage, but it is not considered as it provides more advantages like high strength and durability. Its heavy weight also provides a high resistance to lateral movement on curves and washout protection in area subjects to flooding. Steel slag typically has higher water absorption than gravel. High values of absorption indicate of non-durable aggregates (Hainin et al. 2014, 2015).

The sand equivalent test is measured using ASTM D 2419. This test separates out a fine aggregate sample's sand and plastic fines and dust portion to determine the content of the latter. Lower sand equivalent values indicate higher plastic fines and dust content.

In the soundness test, it is measured using ASTM C 88. Steel slag is highly resistant to change by wetting and drying, freezing and thawing, extreme changes in temperature and chemical attract (Hainin et al. 2014). Slag weathering in atmospheric conditions is considered to be the one of the most appropriate methods of eliminating this adverse property. The weathering period varies depending on the application method and the type of slag itself. Therefore, it sometimes takes only several months of weathering in atmospheric conditions or occasional sprinkling with water (Barišić, Dimter, & Netinger, 2010).

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The toughness results of steel slag were obtained from the LA abrasion test which is measured by ASTM C 131. High abrasion resistance can results the steel slag to be used not only in surface layers of the pavement but also in unbound bases and subbases, especially in asphaltic surface layers (Yi et al. 2012). Lower numbers of LA abrasion indicates greater toughness and abrasion resistance.

On the other hand, the aggregate crushing value (ACV) test is measured by BS 812:110. This test were performed to determine the crushing value of the coarse aggregate and to assess suitability of coarse aggregates for use in different types of road. The ACV results were all within JKR specifications. These indicated that the material possess sufficient strength for utilization as road construction aggregates (Teoh, 2008).

3. RESULTS AND DISCUSSION

Engineering properties influence the level of performance and suitability of the material being used for road construction (Ling, Nor, & Hainin, 2009). Road are subjected to static and dynamic forces, including the harsh environment like rain, temperature, freezing and thawing (Hainin et al. 2015). The properties of steel slag is shown in Table 3.

Table 3 Properties of Steel Slag Used in This Study

Property	**Results**	
	Natural Aggregates	**Steel Slag**
Specific Gravity (ASTM C 127-88)	2.68	2.95
Absorption (ASTM C 127-88), %	0.49	1.80
Sand equivalent (ASTM D 2419), %	68.9	61.3
Magnesium Sulphate Soundness (ASTM C 88), %	0.08	0.02

3.1. Specific Gravity

Steel slag contains sufficient amount of iron oxide, therefore it has greater value of specific gravity as compare to the natural aggregates. It is found that the specific gravity for steel slag in this study is higher than the gravel which is 2.95 and 2.68 respectively. Researchers have evaluated the specific gravity of other construction materials and that of steel slag has fall within the range of 3 to 4 (Cooley, Prowell, & Hainin, 2009). Steel slag is about 20% heavier than the lime stone and granite. This may be an economic disadvantage, but is not considered as it provides more advantages like high strength and durability (Hainin et al. 2014). The high specific gravity and the proper interlocking due to angularity of steel slag result better stability and resistance against rutting as well (Hainin et al. 2015).

3.2. Water Absorption

Absorption is a measure of the amount of water that an aggregate can absorb into its pore structure. Pores that absorb water are also referred to as “water permeable voids”. The absorption of steel slag is also much higher than the gravel. Average absorption for natural aggregate and steel slag are 0.49% and 1.80%, respectively. High values of absorption indicate of non-durable aggregates.

3.3. Sand Equivalent

Sand equivalent quantifies the relative abundance of sand versus clay in soil. This test method provides a rapid field method for determining changes in the quality of aggregates during production or placement. A minimum sand equivalent value may be specified to limit the permissible quantity of claylike or clay size fines in an aggregate. It is reported that the sand equivalent for gravel and steel slag are 69% and 61% respectively. All samples had

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high percentage value, which were above the minimum threshold specified by JKR/SPJ/2005 specifications' requirements.

3.4. Soundness

The soundness test determines the aggregate's resistance to disintegration under the action of repeated wetting and drying using a saturated solution of magnesium sulphate. Table 3 indicates that steel slag had the lowest soundness value of 0.02%, while gravel aggregates had the highest one of 0.08%.

3.5. Los Angeles Abrasion Value Test

Los Angeles (LA) Abrasion Value is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specifies number of steel spheres. This test will determine the quality of the aggregate. Some aggregates such as steel slag tend to have high LA abrasion loss but perform adequately in the field. In this study, two grades of aggregates are used: Grade B (passing = 12.5 mm ; retained = 9.5 mm) and Grade C (passing = 9.5 mm ; retained = 4.75 mm). Figure 2 shows the results of LA abrasion value. For sample with 100% natural aggregates (Sample Code: A1), it does not meet the specifications of less than 25% where the LA abrasion for A1 for Grade B and Grade C are 40.7% and 37.56%, respectively. For 100% of steel slag used (Sample Code: A6), the LA abrasion for Grade B and Grade C are 23.25% and 21.1%, respectively. For the replacement of natural aggregates with steel slag, it was found that the sample with 30% of gravel and 70% of steel slag (Sample Code: A5) has meet the specifications needed where LA abrasion value for Grade B and Grade C are 24.9% and 22.12%, respectively. These results are acceptable. Lower the LA abrasion value, the resistant of the aggregate becomes stronger.

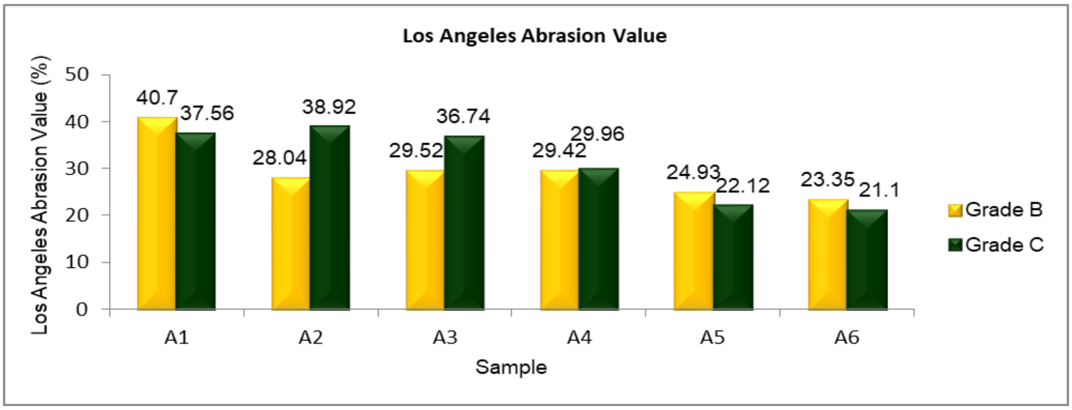

Figure 2: Result of LA Abrasion Value

3.6. Aggregate Crushing Value

Aggregate crushing value (ACV) are carried out to determine the crushing value of the coarse aggregate and to assess suitability of coarse aggregates for use in different types of road. The ratio of weight of fines formed to the weight of total sample in each test shall be expressed as a percentage. Results have shown that the A5 sample has the highest ACV which is 8.15% compared to the other samples: A1, A6 and the other mixes of gravel and steel slag (A2, A3 and A4). Even though A5 has the highest ACV, it still met the requirements of JKR/SPJ/2005 which is below than 30%. The higher the ACV, the greater the crushability of the aggregates.

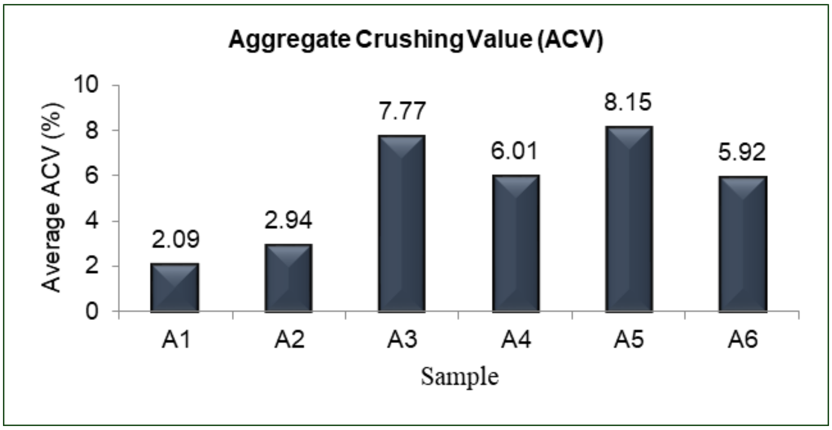

Figure 3: Aggregate Crushing Value

4. CONCLUSION

The main objective of this study was to identify the physical and mechanical properties of steel slag as the replacement of the natural aggregates for the road base. From the test results, the following conclusions are drawn:

i. In terms of specific gravity, the steel slag has higher value than the conventional aggregates which results the better stability and resistance against rutting as well.
ii. For absorption, steel slag has much higher value than the natural aggregates where it indicates of non-durable aggregates.
iii. Less crushing value and good LA abrasion are obtained from using steel slag in flexible pavement.
iv. Economically, the steel slag may be cheaper if utilized in road construction due to the transportation charges.

The results of this study suggest that the replacement of natural aggregates with 70% of steel slag and 30% of granite in road base can preserve the natural resources, save the environment and ecological systems from being disturbed. It also can reduce the amount of granite application in road construction. There must be a guideline or specification for steel slag to be followed, for the different proportions of steel slag blended with natural aggregates to obtain and adequate mix design. Literature showed that steel slag has enough potential and can be utilized in road base. However, very little research has been performed in this area. With its excellent results in terms of the high resistance abrasion and weathering, good crushing value, it is recommended that steel slag be used as an aggregate replacement for sustainable development in road construction.

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