Microstructure and leaching characteristics of steel slag and CRT glass

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Abstract. In view of the large amount and types of waste materials generated, an extensive suite of environmental tests is carried out to assess the potential of reusing these materials. This study investigates the morphology and leaching characteristics of steel slag and Cathode Ray Tube (CRT) glass. The morphology and elemental composition of the samples are examined using field emission scanning electron microscope (FESEM) and energy dispersive X-Ray (EDX). The result of the leaching test is analysed and compared with the toxicity characteristics leaching procedure (TCLP) limit for hazardous elements. Results of the FESEM tests show that each sample has different morphological characteristics and texture. The surface of steel slag is rough, uneven, irregular and porous compared to the surface of granite and CRT glass. The outcome of the TCLP test shows that none of the identified hazardous elements exceed the standard limits, which indicates these materials may be suitable for use as construction materials.

1. Introduction
In line with the global awareness of the need to preserve and conserve the environment, many studies have been carried out to explore the possibility of reusing by-products (steel slag) and waste products (CRT glass), for instance as a construction material. In addition to preserving and conserving the environment, the use of by-products and waste products will help to reduce the need for large landfills. \cite{1,2}. With respect to the environmental assessment, the aggregate samples used in this study are investigated for their toxic compound concentration due to the concern for the leaching of heavy metals. Galvin \textit{et al.} \cite{3} stated that the potential risk of environmental contamination is due to the leaching of toxic wastes into the soil. The problem with leaching is not due to the amount of contaminants (heavy metal element) but the amount of water that seeps into surface water or subsurface water. Other factors influencing the rate of leaching as noted by Tiruta-Barna and Geankoplis studies in Law and Evans \cite{4} are the volume to surface area ratio. Oluwasola \textit{et al.} \cite{5} studied the potential of utilizing Electric Arc Furnace (EAF) steel slag and copper mine tailing as asphalt paving. Testing was conducted on four different asphalt mixtures using both types of waste. The result of leaching analysis shows that the
utilization of mixes containing either EAF steel slag or copper mine tailing or both did not produce hazardous elements exceeding the standard TCLP limits.

This study investigated morphology and leaching characteristics of waste material by-product; steel slag and waste product. Morphology sample test was examined by using FESEM and EDX. The leaching test was analysed and compared with TCLP procedures.

2. Materials and method
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 EAF. Steel slag is a residual material produced during the manufacture of stainless steel through EAF and BOF (Basic Oxygen Furnace) processing. [6][2]. 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 a laser cutting method, and the glass components were processed by crushing and grading in order to obtain angular glass particles.

The morphology and elemental composition of the aggregate samples, i.e. granite, steel slag and CRT glass, were examined using FESEM (Supra 55vp-ZEISS (Merlin-Zeiss, Germany). The outer surface of the aggregate samples was coated with a thin layer of platinum using the k550 sputter coater before being mounted in the equipment. The samples were then examined at a resolution of 15kV. The same samples were subjected to EDX analysis to determine the elemental distribution on the surface of the aggregate sample.

The TCLP developed by the United States Environmental Protection Agency US EPA (1992) was used in this study to assess the leaching of heavy metals from the aggregates. Leaching test is conducted to analyse the leached hazardous elements when a material is exposed to leaching fluids. The sample is subjected to leaching test before performing any physical and mechanical tests because the tests able to evaluate the environmental safety as a suitable road construction material [8]. The leachate of the aggregate samples (steel slag and CRT glass) were prepared by putting a representative solid portion of the materials in an extraction bottle, and leaching fluid was then added to the bottle. The bottle was sealed tightly and placed on the rotator and rotated at 300 rpm for 18 hours at laboratory ambient temperature of 25 ºC. After 18 hours agitation the leachate was removed from the bottle and filtered through a 0·45 µm membrane filter to remove the suspended solids. The metal contaminants in the leachate solution were characterised by using inductively coupled plasma optical emission spectrometry (ICP-MS). Table 1 show the conditions of leaching test.

| Test conditions                  | TCLP (EPA Test Method 1311) |
|--------------------------------|-----------------------------|
| Leaching solution              | 2.5% acetic acid            |
| Liquid to solid ratio (cm³/g)  | 20:1                        |
| Leaching time (h)              | 18                          |
| pH of leaching solution        | 4.0 +/- 0.1                 |
| Temperature (ºC)               | 19 – 25                     |

Sources : [7][5]

3. Results and discussion

3.1 Microstructure analysis
Figure 1 shows the FESEM micrographs and the result of EDX elemental analysis of the aggregate samples. The FESEM images for each sample shows a different morphology and texture. Unlike the surface of granite and CRT glass, steel slag has a porous, rough, uneven, and irregular surface texture. This result is consistent with those obtained by Oluwasola [5]. Granite has a rougher surface texture.
Kosior-Kazberuk [9] examined the surface of steel slag and granite, and found that the rough surface texture of both materials gives them the ability to improve internal friction, thereby strengthening the bond between the materials in the mixes. The benefits of using steel slag in road construction is that it provides better interlocking and friction, thus resulting in better stability, rutting resistance and skid resistance in comparison to the utilization of natural materials [2]. CRT glass, on the other hand, has a smooth surface texture. In a related work, Ling and Poon [10] and Romero et al. [11] have shown that CRT glass has a smooth surface and an angular grain shape.

EDX spectrum of the aggregate samples were used to compare the elemental composition of the samples. Figure 1 shows that granite and CRT glass have a high weight percentage of silica of 41.3 wt% and 24.2 wt%, respectively. The presence of silica can increase the strength of a material by virtue of its pozzolanic properties [12][13]. The high silica content in CRT glass makes it a suitable substitute for the fine aggregates used in various building material products, such as foam glass, glass ceramic bricks and concrete materials [14][15].

![Figure 1. FESEM micrograph and EDX of sample aggregate.](image)
3.2 Result of TCLP

The leaching test measures the concentrations of seven heavy metals, i.e. Arsenic (As), Barium (Ba), Cadmium (Cd), lead (Pb), silver (Ag), Selenium (Se) and Mercury (Hg), in the steel slag and CRT aggregates, and the results are presented in Table 2. It shows that the heavy metals with the highest concentrations in steel slag and CRT glass are Pb and Ba, respectively. However, the concentrations of all metals did not exceed the regulatory limit of TCLP test. Therefore, the waste aggregates are non-hazardous and do not present toxicological problems.

| Parameter | Steel slag | CRT Glass | TCLP limits |
|-----------|------------|-----------|-------------|
| As        | 0.001      | 0.001     | 5.000       |
| Ba        | 0.033      | 0.628     | 100.000     |
| Cd        | 0.0003     | 0.0005    | 1.000       |
| Pb        | 0.005      | 4.694     | 5.000       |
| Ag        | -0.0002    | 0.0001    | 5.000       |
| Se        | 0.0001     | -0.0004   | 1.000       |
| Hg        | 0.0004     | -0.0003   | 0.200       |

Table 2. Concentration of heavy metals in leachates.

4. Conclusions

The results of this study suggest that among the benefits of utilising steel slag and CRT glass aggregates are safety for leaching problem and preservation of the environment. The following conclusions can be drawn based on the results of this research:

- The microstructure analysis of the granite, steel slag and CRT glass samples showed that steel slag is more porous and rougher than granite and CRT glass. The roughness of steel slag provides better interlocking and friction, thus resulting in better stability, rutting resistance and skid resistance when compare with natural materials.
- The results of TCLP test revealed that the concentrations of the seven heavy metals were below the TCLP regulatory limit for waste material aggregates containing steel slag and CRT glass. This shows that the leaching that occurs when these materials are used in field conditions does not present a threat to the environment.

5. References

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