HYDROMETALLURGICAL EXTRACTION OF ZINC AND IRON FROM ELECTRIC ARC FURNACE (EAF) DUST WASTE USING HYDROCHLORIC ACID

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ABSTRACT

Electric arc furnace (EAF) dust is a by-product produced from the EAF steelmaking process. About 7.5 million tons of EAF dust are produced annually by the worldwide steelmaking industries. EAF dust is considered as a hazardous waste as it contains heavy metals such as zinc, iron, lead, and cadmium. Zinc and iron, which constitute the greatest composition (8-40wt% and 16-60wt%, respectively) in EAF dust can be recycled and extracted. However, zinc and iron mainly exist in the form of zinc ferrite ($ZnFe_2O_4$) in EAF dust which can impede the zinc and iron extraction. In this project, a hydrometallurgical process using hydrochloric acid (HCl) as a leaching agent was performed to extract zinc and iron from EAF dust. The effects of temperature, dust-to-acid ratio and acid concentration on the extraction of zinc and iron were investigated. Results showed that the increase in temperature and acid concentration increased the amount of zinc and iron extraction. The highest zinc extraction was about 70% using 5M of HCl with dust-to-acid ratio of 3g per 100ml HCl after 15 minutes of leaching at 70°C, while the highest iron extraction under the similar condition was about 60%. The result indicates that both zinc and iron can be extracted from EAF dust through HCl hydrometallurgical process, which will be beneficial for steelmaking industries in future.

Keywords: Electric Arc Furnace (EAF) dust waste; hydrochloric acid leaching; hydrometallurgical process; iron extraction; zinc extraction.

INTRODUCTION

In recent years, global steel production has increased due to high demand on infrastructure development and automotive applications. In 2015, the world crude steel production achieved 1621 million tons [16]. In conjunction with the increase in steel production, zinc and iron which are the essential elements in steelmaking industries have been highly demanded. Conventionally, steels can be produced through basic oxygen furnace (BOF) or electric arc furnace (EAF). In steelmaking industries, BOF process has contributed to approximately 70% of total world steel production [15]. However, due to the depletion of metal ores [10,13] and the emerging technology of EAF steelmaking process, steels can be produced through the recycling of steel scraps [6,7,10]. This EAF steelmaking process is associated with the generation of flue dust known as EAF dust due to the volatilization of metals in extreme melting condition [11]. Approximately 15-20kg of EAF dust has been generated per ton of steel recycled [2,5,10]. EAF dust is considered as a hazardous waste due to its high content of heavy metals such as zinc, iron, lead, cadmium and chromium which will cause environmental pollution when they are left untreated in landfill [2-5]. Nevertheless, owing to the high amount of zinc and iron in EAF dust, they can be considered as secondary raw material in the steelmaking industries for recycling [5]. Generally, zinc and iron exist in the form of zinc ferrite ($ZnFe_2O_4$), zincite (ZnO), hematite (Fe_2O_3) and magnetite (Fe_3O_4) in the EAF dust [5-7]. The content of zinc in EAF dust varies from 8wt% – 40wt%; whereas Fe content varies from 16wt% – 60wt% [3]. The differences of zinc and iron content in EAF dust are due to several factors such as the type of steel scraps fed into the EAF, type of steels to be manufactured, EAF operating condition and the degree of dusts recirculates in the process [5,7,11].

The recovery of zinc and iron from EAF dust can be performed through several processes such as pyrometallurgy and hydrometallurgy. Pyrometallurgical process on EAF dust is usually performed in rotary Waelz kiln. This high temperature reduction process consumes huge amount of energy and requires large quantity of EAF dust for the operation [2,6]. Hydrometallurgical process of treating EAF dust involves the use of leaching agents such as acids and alkalis to selectively extract zinc and other elements. The increase in popularity of hydrometallurgy is due to its low energy consumption, high flexibility, low operating cost and environmental friendliness [3,5,10]. In hydrometallurgical process, the most commonly used leaching agents are sulphuric acid and sodium hydroxide. On the other hand, hydrochloric acid which is an effective lixiviant can also be used in hydrometallurgical process [8,9]. Cl^- ions which are strong activators enable the dissolution of zinc, iron and the removal other toxic elements such as lead in chlorides form [13]. HCl leaching also avoids the formation of jarosite ($KFe^{3+}{}_3(OH)_6(SO_4)_2$) which is harmful to environment [8,9]. In addition, the filtration process for solid-liquid separation using HCl leaching is easier than sulphuric acid leaching [9]. Past studies have shown that HCl leaching is feasible for zinc extraction from EAF dust and zinc ferrite. Atmospheric HCl leaching on EAF dust yielded maximum zinc extraction of about 23wt% using 5M HCl at 50 °C for 48 hours [13]. In the case of pressure leaching (85 bar), about 93wt% of zinc was extracted from synthetic zinc ferrite using 0.3M HCl at 260 °C after 100 minutes of leaching [8]. In a pH-controlled HCl leaching (1-2M), the highest iron extraction from EAF dust was reported about 80wt% at 90 °C after 2 hours of leaching [1]. In this project, HCl was used as leaching agent to extract zinc and iron from EAF dust. The factors that affected the extraction process such as temperature, acid concentration and dust-to-acid ratio were investigated for the extraction of zinc and iron from EAF dust.

EXPERIMENTAL PROCEDURE

The EAF dust was obtained from the local steelmaking industry. Zinc and iron contents of the EAF dust were determined using inductively-coupled plasma optical emission spectroscopy (ICP-OES). On the other hand, the mineralogical compositions of the EAF dust were analyzed using X-ray diffractometer (XRD). Scanning electron microscopy (SEM) was performed on the EAF dust to investigate its morphology. Leaching experiment was conducted using different concentrations of HCl from 1.0M to 5.0M. The temperatures were varied from 25 °C to 90 °C. Leaching time for the experiment was set at 15 minutes. The dust-to-acid ratio was 3g per 100 ml of HCl. Further investigation of dust-to-acid-ratio on the extraction was performed using 1g to 8g of dust per 100ml of HCl. After leaching process, the filtered solution was subjected to ICP-OES analysis and the remaining solid residue was analyzed using XRD and SEM.

RESULTS AND DISCUSSION

Characterization of EAF Dust

ICP-OES analyses showed that the zinc and iron content in EAF dust is ~26wt%, respectively. The XRD diffraction pattern of the EAF dust is showed in Figure 1. The phases of the EAF dust are zinc ferrite ($ZnFe_2O_4$), zincite (ZnO), hematite (Fe_2O_3), magnetite (Fe_3O_4) and silicon oxide (SiO_2). SEM image of the EAF dust is showed in Figure 2. EAF dust consists of spherical particles with different sizes. These particles stick to each other to form agglomerates.

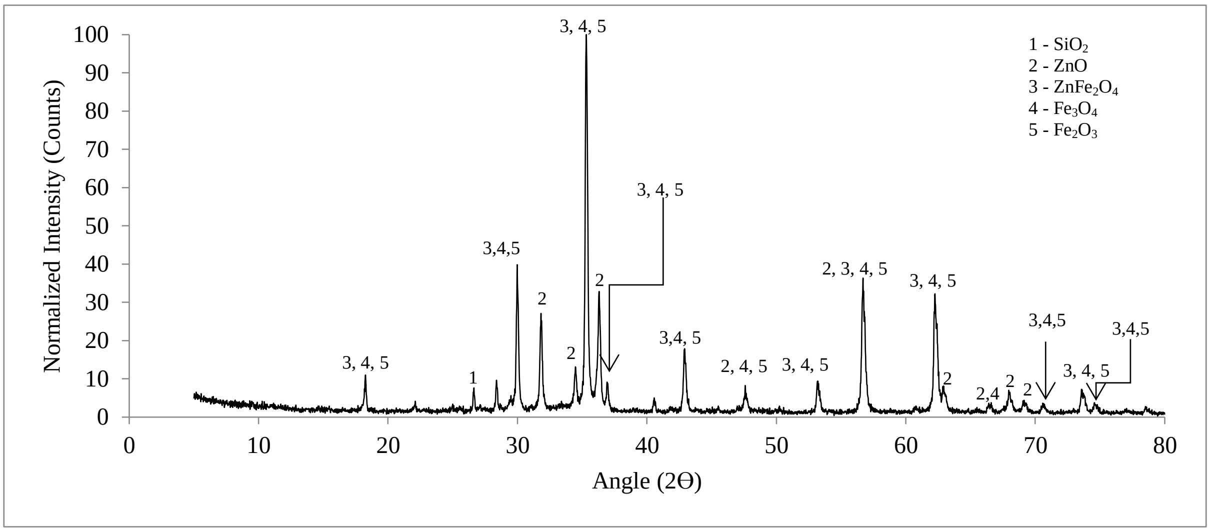

Figure 1. XRD analysis of EAF dust

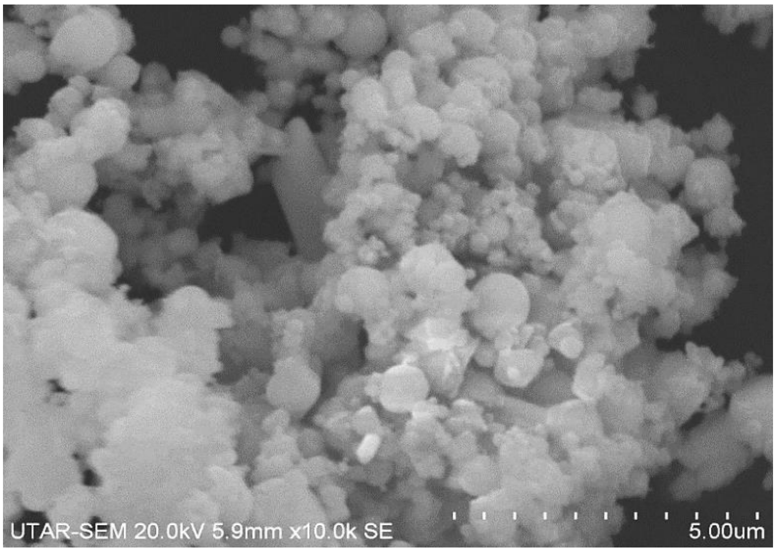

Figure 2. SEM image of EAF dust

Effects of Temperature and Acid Concentration on Zinc and Iron Extraction

The effects of acid concentration and temperature on the extraction of zinc from EAF dust are showed in Figure 3. The amount of zinc extracted from EAF dust increases with the increasing of HCl concentration. This could be due to high acid concentration increases the amount of Cl^- ions which act as strong activators to dissolve the zinc in EAF dust [13]. It also can be observed that the increase in temperature increases the amount of zinc extraction. This possibly due to the elevated leaching temperature accelerates the reaction of EAF dust with HCl. Nevertheless, the increase in zinc extraction from EAF dust with the increasing of temperature did not apply for all samples. Depending on the acid concentration, further increase in temperature after a certain temperature can lead to a decrease in the zinc extraction from EAF dust due to the evaporation of HCl [14]. In addition, high HCl concentration can increase its viscosity. The increase in viscosity of the solution can reduce the diffusion rate of ions and lead to the decrease in effectiveness of extracting zinc from EAF dust [2,10,12]. Current investigation as shown in Figure 3 shows that the increase in zinc extraction with the increase in HCl concentration at high temperatures occurs in HCl leaching process using 1M, 2.5M and 4M. The highest amount of zinc that can be extracted from EAF dust is about 70% using 5M HCl with 3g of dust to 100ml of HCl after 15 minutes of leaching at 70°C. Iron also can be extracted concurrently from the EAF dust during the leaching of zinc from EAF dust. The effects of acid concentration and temperature on the extraction of iron from EAF dust are showed in Figure 4. The results show that when HCl concentration increases, the amount of iron extraction increases. The increase in the leaching temperature also increases the amount of iron extraction. Nevertheless, when high leaching temperatures (80-90°C) were attempted in the leaching process using 5M HCl, it showed a decrease in iron extraction. Under leaching condition of 5M HCl, the highest iron extraction of around 60% can be obtained using 5M HCl with 3g of dust to 100ml of HCl after 15 minutes of leaching at 70°C.

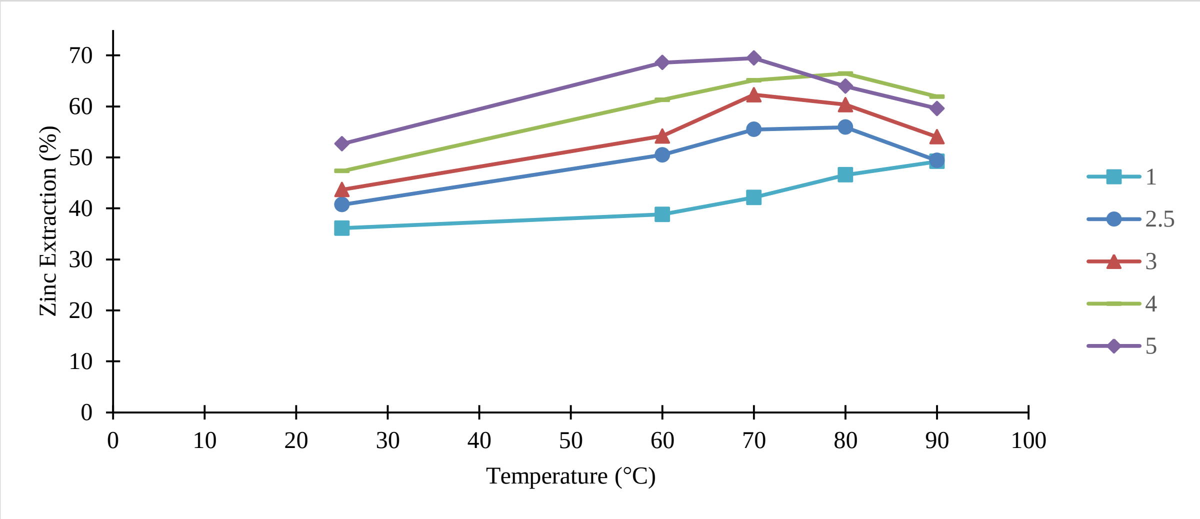

Figure 3. The effects of acid concentration and temperature on zinc extraction

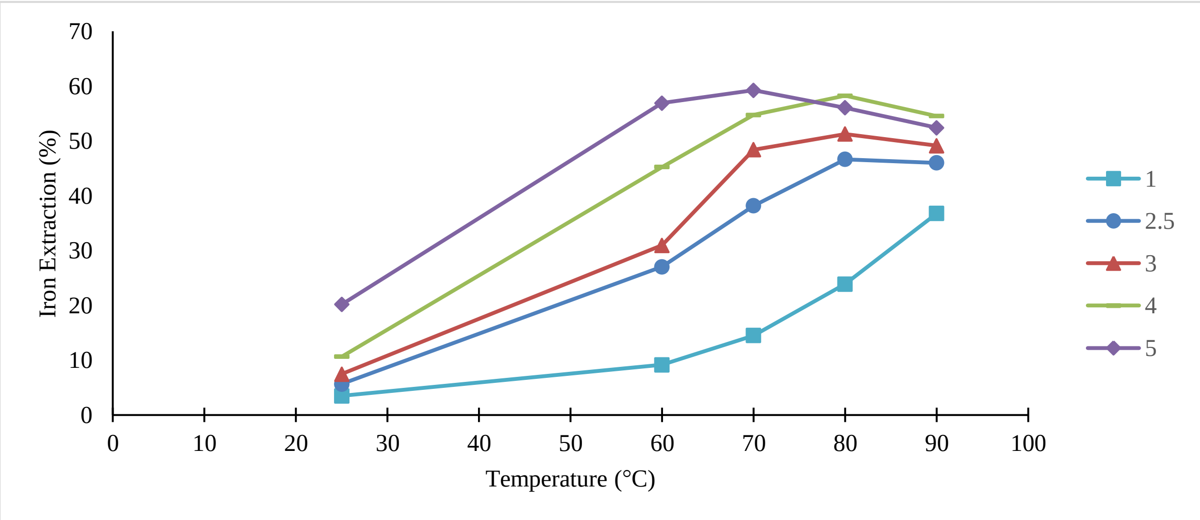

Figure 4. The effects of acid concentration and temperature on iron extraction

Effects of Dust-to-Acid Ratio on Zinc and Iron Extraction

The results of dust-to-acid-ratio on the extraction of zinc and iron are showed in Figure 5 and 6. The investigation was performed based on 1g to 8g of dust per 100ml of HCl at 70°C. The results showed that the highest extraction of zinc and iron occurs at 3g of dust to 100ml of HCl, which is around 70% and 60%, respectively. Further increase in the amount of dust with constant HCl volume reduces the amount of zinc and iron extraction. This could be due to the decrease in HCl solution that is available to extract zinc and iron from the EAF dust [6].

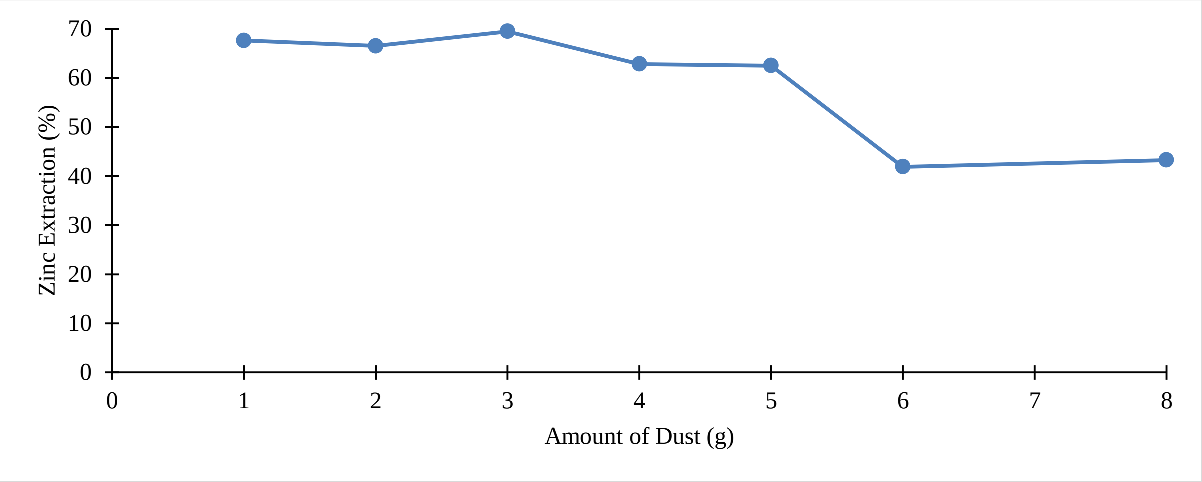

Figure 5. The effect of dust-to-acid ratio on zinc extraction

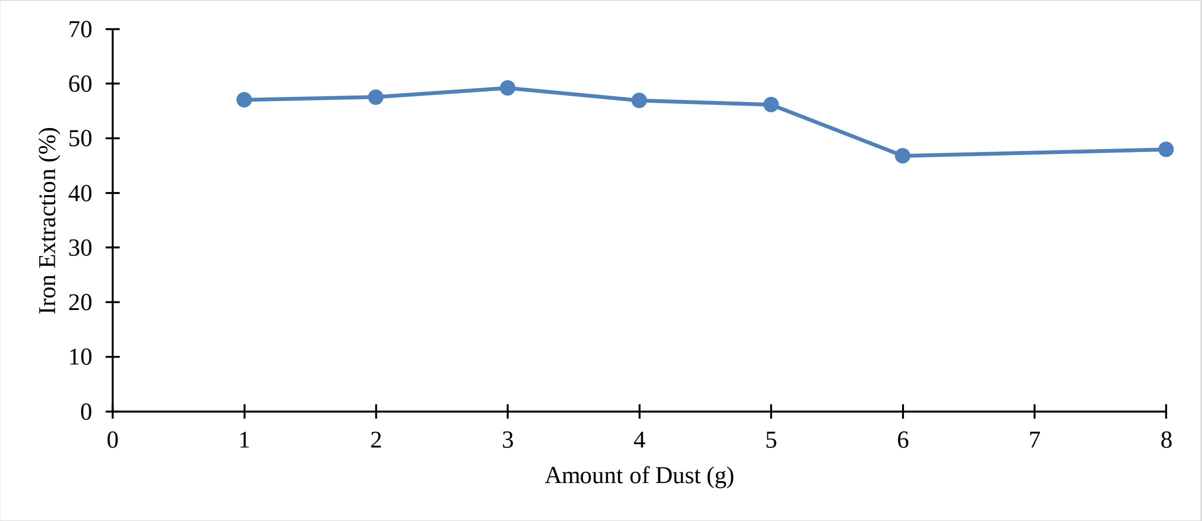

Figure 6. The effects of dust-to-acid ratio on iron extraction

Characterization of Solid Residue after Leaching

The remained solid residue after leaching with 5M of HCl at 70°C was analyzed using XRD. As shown in Figure 7, zinc oxide and iron (III) oxide peaks are not observed after leaching. In addition, the peaks of the zinc ferrite and iron (II, III) oxide in the EAF dust decreases after the leaching process as compared to the raw EAF dust before leaching (Figure 1). These results indicated that both zinc and iron have been leached from the EAF dust during the leaching process. However, the presence of the remaining zinc ferrite and iron (II, III) oxide peaks in the EAF dust after the leaching process can imply that zinc and iron are not completely leached from the EAF dust. SEM image of the solid residue is shown in Figure 8. It can be observed that the shape of EAF dust particles becomes irregular after leaching process. Pores are found among the agglomerates which can indicate that EAF dust particles have been leached by HCl during the leaching process.

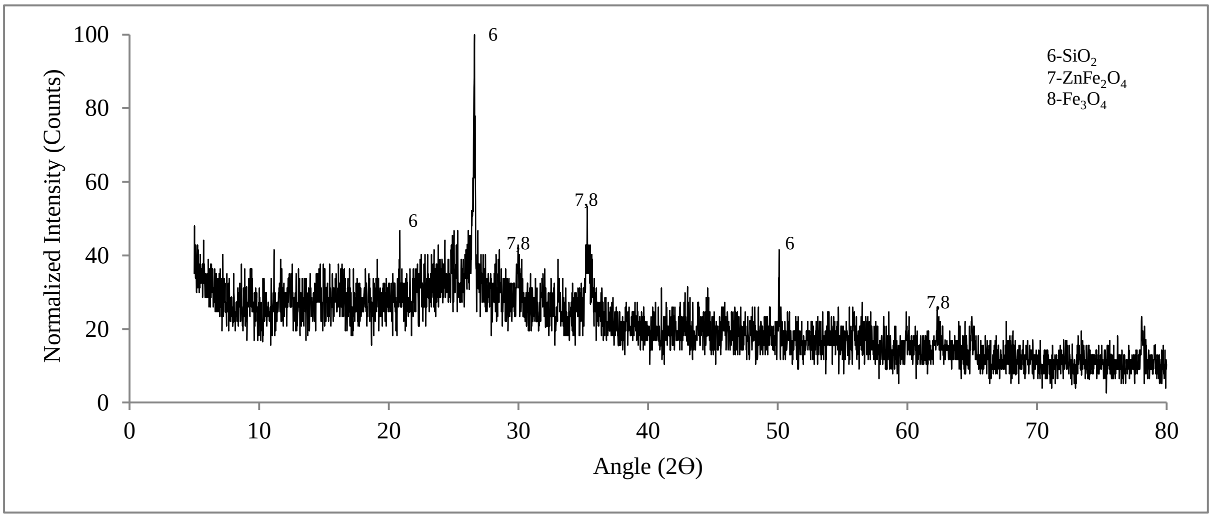

Figure 7. XRD analysis of EAF dust solid residue after leaching using 5M of HCl at 70°C

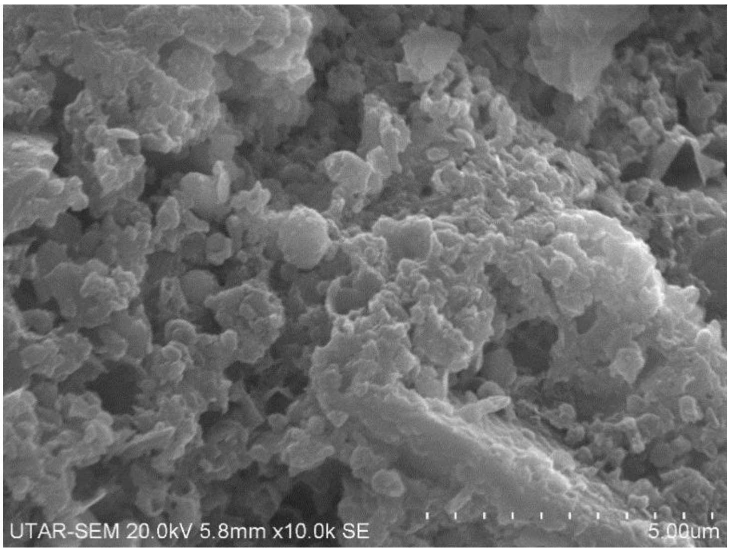

Figure 8. SEM image of EAF dust solid residue after leaching using 5M of HCl at 70°C

CONCLUSION

The effects of acid concentration, dust-to-acid ratio and temperature on the extraction of zinc and iron from EAF dust had been investigated. Both acid concentration and temperature affect the zinc and iron extraction from EAF dust. High acid concentration and high temperature can increase the zinc and iron extraction. Present investigation showed that the highest amount of zinc and iron extraction is around 70% and 60%, respectively under 5M of HCl with dust-to-acid ratio of 3g to100ml after 15 minutes of leaching at 70°C. Further investigation on dust-to-acid ratio in terms of increasing the acid volume and acid molarity can be performed in future to improve the zinc and iron extraction from the EAF dust.

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