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Research Article

CHARACTERIZATION AND STUDY OF DIFFERENT ELECTRIC ARC FURNACE STEEL SLAGS FOR USAGE IN WASTEWATER TREATMENT

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Key words: Electric arc furnace slag, Akermanite, Ghelenite, Merwinite, Monticellite, Wastewater treatment.

ABSTRACT

In this study we present the mineralogical, morphological, phase structure and chemical composition of two types of Electric Arc Furnace Slags (EAFS). The slag samples, Electric Arc Furnace Falling Slag (EAFFS) and Electric Arc Furnace Dust Slag (EAFDS) were analysed using instrumental and wet chemical analysis. The result indicated that both types of slag contain the same types of minerals and metals albeit in different percentage. The most common mineral forms were akermanite, ghelenite, merwinite, monticellite, calcite, ferrite and quartz. It was found that EAFDS contains a larger proportion of the readily soluble mineral forms, less concentration of hazardous metals and a larger percentage of alkali (greater than 94% as $CaCO_3$). Hence EAFDS is a better choice for acidic wastewater treatment for neutralisation as well as removal of metals.

INTRODUCTION

Steel is a metal alloy containing iron and carbon with other alloying elements mainly produced by the Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) methods. The EAF method is responsible for over 40% of steel produced globally. Since it uses scrap metal as the raw material it is a more competitive and sustainable process (Penteado, et al., 2019). The EAF, one of the methods of steel production, impacts the environment by generating various pollutants. EAF slags are formed during the melting of scrap metal in the EAF with flux in refractory lined vessels. The silicon and other remaining impurities in the scrap metal as well as in the added flux combine with the injected oxygen to form slag layer on top of the molten steel (Ducman, et al., 2011).

Dust is also generated during the entire operation and contains hazardous metals such as Cr, Ni and Zn. The chemical composition and the amount of the slag as well as the dust can vary extremely based on the batch, the composition of the raw materials used for the production, the melting and refining methods employed; the total duration of the process; the grade and type of the steel produced ranging between and 130–180 Kg/t of steel (Matinde, et al., 2018; Omran, et al., 2019). Large volumes of different types of slags and other wastes are disposed of in landfills especially in developing countries creating long-term environmental challenges (Forsido, et al., 2020). According to World Steel Association, over 400 million tonnes of ferrous slags are produced annually.

To solve this dilemma associated with the huge amount of slag which keeps on increasing annually, it is imperative to find alternative applications and utilization for the by product rather than dump it (Mercado-Borrayo, et al., 2018; Forsido, et al., 2020). For using the slag in any application, it is important to determine its chemical, mineralogical and morphological characteristics as well as phase structures that determine its properties.

EAF slag is used in different techniques for the treatment of wastewater. Manchisi, et al., used it as an adsorbent for the removal of metals from wastewater. Omran, et al. employed EAF slag for selective removal of zinc from industrial effluent. Forsido, et al., developed a method for the neutralisation as well as metal removal from highly acidic metal rich industrial effluent using EAF dust. Penn, et al. applied steel slag for the removal of phosphate from subsurface drainage(Manchisi, et al., 2020; Omran, et al., 2019; Forsido, et al., 2020; Penn, et al., 2020).

Steel slags generated during the production of steel products, have major components of the CaO-SiO_2-Al_2O_3-MgO-FeO system with trace amounts of other

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metals such as Cr, Mn, Ni and Zn (Tan, et al., 2017). However, the chemical composition of EAF slags vary greatly and have been reported to consist about 22–60% CaO, 10–40% FeO, 6–34% SiO_2, 3–14% Al_2O_3, 3–13% MgO in different mineral forms and varying amounts of free CaO and MgO. These minerals in steelmaking slags form complex mixture and solutions of oxides such as akermanite, ghelenite, merwinite and monticellite (Rosales, et al., 2020).

Since physico-chemical properties are the determining factors for the utilisation of steel slag, different studies have been carried out to determine the characteristics of steel slag (Aziz, et al., 2014). Sas, et al. and Rosales, et al., used X-Ray Diffraction (XRD) and Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES) for the determination of different characteristics of steel slags(Sas, et al., 2015; Rosales, et al., 2020).

This study is carried out to determine the common minerals and their phases in two types of EAF slags; the percentage of each mineral; the type and amount of metals in the slag as well as the amount of total alkali using analytical instruments XRD, ICP-OES and wet analysis.

MATERIALS AND METHODS

Two different types of EAF steel slag samples were collected from a steel industry that uses scrap steel as an input to produce new steel products. The two types of slags were falling slag and EAF dust.

All the chemicals used in the study were of analytical grade and used without any further purification.

X-ray Powder Diffraction (XRD), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and wet analytical methods were used to characterize the slag and to reveal the mineralogy, morphology, chemical composition, crystal and phase structure as well as elemental composition of the materials.

RESULTS AND DISCUSSION

To use slags it is imperative to determine its components and the phase they form in the mineral. This helps to devise a better way to utilise in a way it is effective and safe. This was achieved by implementing different analytical techniques on the two types of slags.

Mineralogical and morphological characteristics of the slags

From the XRD analysis of the two slag samples it was observed that both types of slags, the Electric Arc Furnace Falling Slag (EAFFS) and the Electric Arc Furnace Dust Slag (EAFDS) were composed of the same type of minerals; quartz (SiO_2), akermanite-gehlenite solution ($Ca_2MgSi_2O_7$-$Ca_2Al_2SiO_7$), monticellite ($CaMgSiO_4$), merwinite ($Ca_3MgSi_2O_8$), calcite ($CaCO_3$) and magnetite (Fe_3O_4) in different proportions. The percentage of each mineral in the two sample slags determined by using XRD is given in Fig. 1 and Fig. 2 as well as in Table 1.

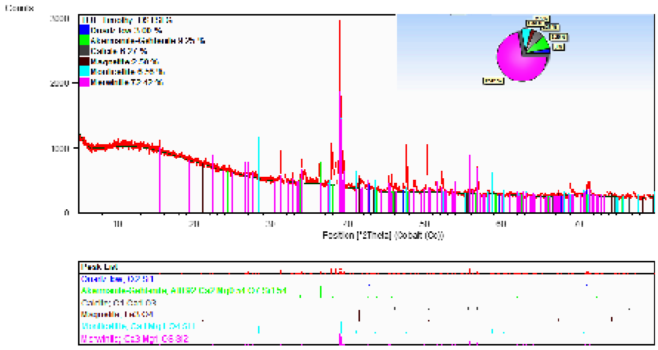

Fig. 1 XRD results for electric arc furnace dust.

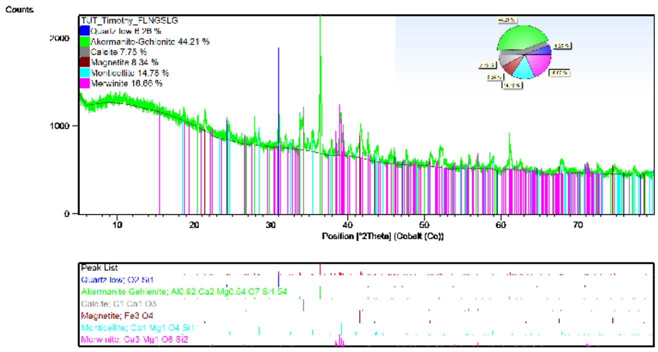

Fig. 2 XRD results for electric arc furnace falling slag.

Table 1. Percentage of minerals in the two slags.

Type of Mineral	Chemical formula	EAFFS (%)	EAFDS (%)
Quartz	SiO_2	6.26	3.00
Aker-manite-Gehlenite	(Ca_2Mg [Si_2O_7]-Ca_2Al[$AlSiO_7$])	44.21	9.25
Calcite	$CaCO_3$	7.75	6.27
Magnetite	Fe_3O_4($Fe^{3+}{}_2Fe^{2+}O_4$)	8.34	2.50
Monticellite	$CaMgSiO_4$	14.78	6.56
Merwinite	$Ca_3MgSi_2O_8$	18.66	72.42

Each mineral that makes up the slags has different rate of solubility. Calcite is the most sluble chemical species among the minerals, while quartz is the least. Engström, et al., synthesized and investigated the rate of solubility of most common minerals found in slags with nitric acid and determined the volume of the acid required to dissolve each mineral completely (Engström, et al., 2013). The results they obtained are given in Table 2.

Table 2. Volume of 0.1 M HNO_3 required to dissolve 50 mg of each mineral.

Mineral	Vol (mL)
Akermanite	11.0
Merwinite	12.2
Gehlenite	18.2

According to the study akermanite is readily soluble when compared to the other melilite gehlenite. Merwinite also is readily soluble in acidic solution. Akermanite is a mineral commonly found in slags from the production of carbon and stainless steel, hence it is a good sign for the slag to be able to be used as a source of alkali for wastewater treatment.

Acid neutralisation capacity of steel slag is determined by the chemical composition, mineral components and the phase structure of the material (Xue, et al., 2013). The solubility and the capacity of neutralisation of the two slags were dependent on the mineralogical structure and composition of each slag. The major component of EAFFS was akermanite-gehlenite solution. The solution phase is formed with ratio of 2:3 ghelenite being the dominant species. Studies by Engström, et al., indicated ghelenite is one of the least soluble form of minerals that make up the slags. The EAFFS also contains a higher percentage of quartz and monticellite compared to the EAFDS, which are the least soluble forms of the minerals.

Whereas, the major component mineral in the dust EAFDS was merwinite. According to the study by Engström, et al., merwinite is readily soluble in acidic media. This can be associated to the presence of a larger proportion of calcium and magnesium oxides in merwinite. The content of quartz, monticellite and ghelenite, the less soluble mineral forms, in the EAFDS is also very low. Hence this property makes EAFDS the material of choice for treatment of wastewater(Engström, et al., 2013).

Metal content in the slags

To determine the amount of metals in the slags study was carried out on both EAFDS and EAFFS using ICP-OES. Again the study indicated that both falling and dust slags contained iron, magnesium, calcium, sodium, potassium, manganese, aluminium, chromium, cobalt, nickel, copper, zinc and barium in different concentrations.

In both slags calcium was the metal with the highest concentration followed by magnesium, iron and aluminium. The mineralogical study indicated that all the mellilites, merwinite, monticellite as well as calcite in the slags were rich in calcium followed by magnesium and aluminium. The dust slag had higher concentrations of basic metals (Ca and Mg) and lowest concentration of trace metals considered hazardous, hence this property also favoured dust slag as a material of choice for the utilisation of it for acidic wastewater treatment. The amount of each metal in each of the slags is given in Table 3.

Table 3. Metal content in EAFFS and EAFDS (mg/g).

Metal	EAFFS	EAFDS
Ca	5520	6990
Mg	806	1070
Fe	539	246
Al	442	102
Mn	320	96.9
Na	83.4	10.5
K	80.5	2.2
Cr	36.1	32.9
Zn	14.7	Nd*
Ni	13.0	3.5
Ba	9.8	6.5
Cu	2.3	0.5
Co	0.2	0.1

Lime content of the slags

Chemical precipitation method of wastewater treatment uses different alkalis as an agent to neutralise acidity, raise pH and remove hazardous metals. Hence the amount of alkali in a material that can react with the acid and the metals in the wastewater is crucial. The amount of total alkali was determined using a wet analytical method. The total alkali content in both slags, that is the percentage of alkali that is available for the reaction, is given in Table 4.

Table 4. Total alkali contents in the two slags.

		Percent (%)	
Parameter	**Sample mass(g)**	**EAFDS**	**EAFFS**
Total alkali	2.50	92.4[a]	59.2[a]

Note: [a]: percentage as $CaCO_3$

CONCLUSION

The study indicated that dust EAFDS has a better characteristics compared to the falling slag. Mineralogically it contains a larger proportion of minerals that are more soluble. It also contains less concentration of hazardous metals. Most importantly it contains more than 94% lime measured as $CaCO_3$, which is the most important property that can be used for neutralisation as well as removal of hazardous metals from industrial wastewater as well as acid mine drainage by raising its pH to a level where they form stable precipitates at a raised pH.

REFERENCES

Penteado CSG, Evangelista BL, Ferreira GCS, Borges PHA and Lintz RCC. 2019. Use of electric arc furnace slag for producing concrete paving blocks. *Ambiente Construído Porto Alegre*. 19:21-32.

Ducman V and Mladenovič A. 2011. The potential use of steel slag in refractory concrete. *Mater Charact*. 62:716–723.

Matinde E, Simate G and Ndlovu S. 2018. Mining and metallurgical wastes: A review of recycling and re-use practices. *J S Afr Inst Min Metall*. 118:825–844.

Omran M, Fabritius T and Heikkinen E. 2019. Selective zinc removal from electric arc furnace dust by using microwave heating. *J Sustain Metall*. 5:331–340.

Forsido T, McCrindle RI, Maree J and Mpenyana-Monyatsi L. 2020. Application of EAFDS/lime integrated system for the removal of Cu and Mn from industrial effluent. *Int J Water Wastewater Treat*. 6: 75-81.

Mercado-Borrayo B, González-Chávez J, Ramírez-Zamora R and Schouwenaars R. 2018. Valorization of metallurgical slag for the treatment of water pollution: An emerging technology for resource conservation and re-utilization. *J Sustain Metall*. 4:50–67.

Manchisi J, Matinde E, Rowson NA, Simmons MJH, Simate GS, Ndlovu S and Mwewa B. 2020. Iron making and steelmaking slags as sustainable adsorbents for industrial effluents and wastewater treatment: A critical review of properties, performance, challenges and opportunities. *Sustain*. 12:2118.

Penn C, Livingston S, Shedekar V, King K and Williams M. 2020. Performance of Field-Scale Phosphorus Removal Structures Utilizing Steel Slag for Treatment of Subsurface Drainage. *Water* . 12:443.

Tan K and Hameed B. 2017. Insight into the adsorption kinetics models for the removal of contaminants from aqueous solutions. *J Taiwan Inst Chem Eng*. 74:25–48.

Rosales J, Agrela F, Entrenas JA and Cabrera M. 2020. Potential of Stainless Steel Slag Waste in Manufacturing Self-Compacting Concrete. *Materials*: 13:2049.

Aziz MR, Hainin H, Yaacob Z, Ali F, Chang L and Adnan AM. 2014. Characterisation and utilisation of steel slag for the construction of roads and highways. *Materials Research Innovations*. 18:255-259.

Sas W, Głuchowski A, Radziemska M, Dzięcioł J and Szymański A. 2015. Environmental and Geotechnical Assessment of the Steel Slags as a Material for Road Structure. *Materials*. 20: 4857-4875.

Engström F, Adolfsson D, Samuelsson C, Sandström A and Björkman B. 2013. A study of the solubility of pure slag minerals. *Minerals Engineering*. 41:46-52.

Xue Y, Wu S and Zhou M. 2013. Adsorption Characterization of Cu (II) from aqueous solution onto basic oxygen furnace slag. *Chem Eng J*. 231:355–364.