MICROSTRUCTURAL AND CHEMICAL ANALYSIS OF STEEL SLAG FOR INDUSTRIAL REUSE

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Abstract. Steel slag, as an industrial by-product of steel production, contains valuable elements such as manganese (Mn), calcium (Ca) and iron (Fe), which are valuable for its industrial processing and reuse. This paper deals with the chemical and microstructural analysis of steel slag with high manganese content from Navoi Engineering Plant using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The study determines Mn and Si contents in the range of 2% to 3%, showing potential for further processing to extract manganese for other applications or concentrate it for reuse in steelmaking using electric arc furnaces (EAFs). In addition, the high calcium content shows the potential to utilise steel slag in cement production, road construction and soil treatment. However, problems such as chemical heterogeneity and environmental issues of heavy metal leaching need to be addressed to optimise its industrial application. This study contributes to the sustainable utilisation of steel slag by promoting circular economy and reducing industrial waste.
Key words: steelmaking slag, manganese, SEM analysis, EAF, recycling, environmental sustainability.

Annotatsiya. Po‘lat shlaklari po‘lat ishlab chiqarishning sanoat chiqindisi sifatida marganes (Mn), kalsiy (Ca) va temir (Fe) kabi qimmatli elementlarni o‘z ichiga oladi, ular uni sanoatda qayta ishlash va qayta ishlatish uchun qimmatlidir. Ushbu ish Navoiy muhandislik zavodining yuqori marganes tarkibli po‘lat shlakini skanerlovchi elektron mikroskopiya (SEM) va energiya dispersion spektroskopiya (EDS) yordamida kimyoviy va mikrostrukturaviy tahlil qilish bilan shug‘ullanadi. Tadqiqotda Mn va Si ning 2% dan 3% gacha bo‘lgan tarkibi aniqlandi, bu esa marganesni boshqa maqsadlarda ajratib olish yoki uni elektr yoyli pechlar (EAF) yordamida po‘lat eritishda qayta ishlatish uchun konsentrlash uchun keyingi qayta ishlash imkoniyatlarini ko‘rsatadi. Bundan tashqari, kalsiyning yuqori miqdori po‘lat shlaklarini sement ishlab chiqarishda, yo‘l qurilishi va tuproqqa ishlov berishda qo‘llash imkoniyatini ko‘rsatadi. Biroq, og‘ir metallarni tanlab eritishning kimyoviy geterogenligi va ekologik muammolari uning sanoatda qo‘llanilishini optimallashtirish uchun hal qilinishi kerak. Ushbu tadqiqot aylanma iqtisodiyotni rivojlantirish va sanoat chiqindilarini kamaytirish orqali po‘lat shlakdan barqaror foydalanishga hissa qo‘shadi.
Kalit so‘zlar: po‘lat eritish shlaki, marganes, SEM tahlili, EAF, qayta ishlash, ekologik barqarorlik.

Аннотация. Стальной шлак, как промышленный побочный продукт производства стали, содержит ценные элементы, такие как марганец (Mn), кальций (Ca) и железо (Fe), которые ценны для его промышленной переработки и повторного использования. В данной работе рассматриваются химический и микроструктурный анализ высокомарганцевого стального шлака Навоийского машиностроительного завода с использованием сканирующей электронной микроскопии (СЭМ) и энергодисперсионной спектроскопии (ЭДС). В ходе исследования было определено содержание Mn и Si в диапазоне от 2% до 3%, что свидетельствует о потенциале дальнейшей переработки для извлечения марганца для других целей или его концентрации для повторного использования в сталелитейной промышленности с использованием электродуговых печей (ЭДП). Кроме того, высокое содержание кальция указывает на потенциал использования стального шлака в производстве цемента, дорожном строительстве и обработке почвы. Однако такие проблемы, как химическая неоднородность и экологические проблемы выщелачивания тяжелых металлов, необходимо решить для оптимизации их промышленного применения. Это исследование способствует устойчивому использованию стального шлака путем содействия циркулярной экономике и сокращения промышленных отходов.

Ключевые слова: сталеплавильный шлак, марганец, SEM-анализ, EAF, переработка, экологическая устойчивость.

Introduction

High manganese steel slag is a by-product of steelmaking processes that utilise manganese ores and alloys. It has a high manganese content, typically between 11% and 14%, which helps in improving the mechanical properties of steel such as strength and hardness [1]. With the increasing demand for high quality steel in various industries, high manganese steel slag is now a vital material which, apart from being useful in steel production, is used in many other areas for infrastructure development, construction and mining [2]. High manganese steel slag consists mainly of calcium aluminosilicate with other valuable oxides [3], whose distinctive characteristics are high wear resistance and strength [4]. Such distinctive characteristics make slag preferred in many industries such as construction, where it is used as an aggregate for concrete and asphalt, and in railways for the production of track components [5]. The ability to recycle high manganese steel slag also contributes to global sustainability efforts by conserving industrial waste and promoting the circular economy of steel production [6]. In addition to the benefits, the utilisation of high manganese steel slag has some limitations. These include additional material costs for processing and the unavailability of certain grades of manganese, which complicates supply chains and increases project costs [7]. In addition, the unique chemical properties of high manganese content slag can be difficult to handle during welding processes, requiring innovation in standard approaches to ensure structural integrity [8]. Overcoming such challenges is critical to maximising the use of high manganese steel slag and maximising its contribution to sustainable industrial processes. Research on high manganese steel slag is ongoing to strengthen its application and application potential. New processing technologies and characterisation studies aim to increase the recovery of manganese and other valuable elements, thereby making steel production more environmentally friendly and less toxic [7].

Steelmaking slag is a waste product of the steel industry, mainly consisting of various oxides that are produced during the production of steel. The main components of steelmaking slag include calcium oxide (CaO), silica (SiO_2) and iron oxides (FeO, Fe_2O_3) in combination with other components such as manganese oxide (MnO), magnesium oxide (MgO), alumina (Al_2O_3) and phosphorus pentoxide (P_2O_5). The chemical composition of steelmaking slag varies greatly depending on, for example, the type of furnace, the grades of steel produced and the pretreatment methods used. Physical properties The density of steelmaking slag is typically between 3.2 and 3.6 grams per cubic centimetre (g/cm^3), and the bulk density is about 1.6 to 1.9 tonnes per cubic metre (t/m^3). It is a loose aggregate that is hard and resistant to abrasion due to its high iron content [9].

The permeability of slag is very significant, high even at relatively high water flow rates, although it decreases as the slag is crushed or compacted into fine powders. Treated steelmaking slag is characterised by excellent mechanical strength and is therefore used in many applications, particularly as an aggregate. Its mechanical characteristics include good abrasion resistance, strength characteristics and high load bearing capacity, which contributes to its optimum performance in infrastructure and construction works. Mineral phases. Steelmaking slag contains many important mineral phases that are responsible for its nature and applications. The most prominent mineral phases include dicalcium silicate (C_2S), tricalcium silicate (C_3S) and the RO phase which is a solid solution of CaO, FeO, MnO and MgO. Tetracalcium alumoferrite (C_4AF), olivine [$(Mg, Fe)_2SiO_4$], mervinite [$Ca_3Mg(SiO_4)_2$] and free CaO are other mineral phases in varying amounts.

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The multiplicity in mineralogy is important because it affects the cement nature of the slag along with its mechanical behaviour [9].

Hadfield manganese austenitic steel.

High manganese steel known as Hadfield steel was widely developed in the early twentieth century because of its high abrasion resistance, good castability and high hardening factors during machining [10], [11]. Although substitute modern materials are still available for this steel, manganese austenitic steels are independent due to the fact that they contain a balanced mixture of hardness and toughness, abrasion resistance and flexibility. Due to properties such as high strength, good abrasion resistance and a favourable work hardening coefficient, they have been recognised as an extremely valuable structural material.
An induction furnace can be used to melt Hadfield manganese austenitic steel. Iron scrap containing ferroalloy material such as ferromanganese and carbon can be used as a feed furnace for casting this steel. The melting point of this steel is particularly important [12][13]. The flowability of Hadfield manganese austenitic steel is higher than that of carbon steel.
The dehydration of austenite of Hadfield manganese austenitic steel that has been produced in an induction furnace is one of the most important points. If scrap melting is used only for casting, the nitrogen content of the steel is much higher than that of steel produced in an arc furnace, and if aluminium is used for deoxidation, there may be a possibility of intergranular cracking caused by aluminium nitride (AlN). Therefore, it is more appropriate to minimise the amount of aluminium used for deoxygenation and reduce the oxygen level of others such as silicon, calcium or zirconium [13], [14].
Depending on the feed material, one of the following processes is used to produce Hadfield manganese austenitic steel:
(a) Oxidation reduction process for melting.
(b) Reduction process during melting.
They use alternative methods which are currently practised and each of these firms uses one method which, in the opinion of the structural engineers, is the casting method which is considered to be the most suitable. The Hadfield manganese austenitic steel firms make little use of some common melting procedures. It should be noted that the melting process in any form is the most important problem in preventing oxidative melting of manganese by formation of reducing slag [12], [13]. It has been shown experimentally that if the manganese oxide in the slag is greater than the nominal amount of manganese steel outside the range of 10-14 per cent, i.e. the percentage of manganese in the slag is greater than the true manganese, the manganese oxide in the melt will dissolve. Subsequent separation and further recovery of this oxide is difficult.

Chemical Composition of Hadfield steel.

Navoi Machine Building Plant melts steel in electric arc furnaces (EAF) to produce Hadfield steel. A sample was taken from the resulting slag and examined using a scanning electron microscope (Apreo 2 SEM) to study the chemical composition of steel slag. Slag formation is directly dependent on the steelmaking process, and the correct appearance of the slag formed at each stage is represented in Figure 1.

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Fig. 1. Hadfield Steel slag particle from Navoi Machine Building Plant.

Intitially, the steel slag was crushed and formed as a powder to identidy chemical compostion of the steel slag. The powder of steel slag is presented using SEM in the Fig. 2. The image shows powdered steel slag, a fine-grained product of steelmaking operations, usually produced in electric arc furnaces (EAF). The powder consists of irregularly shaped particles with varied morphology and surface texture, indicating rapid solidification and subsequent machining. The porosity and particle size distribution of slag powder significantly affect its reactivity and application value, such as its use in cementitious materials, road construction and metallurgical processing. SEM-EDS analysis display the fine surface topography, phase structure and chemical composition.

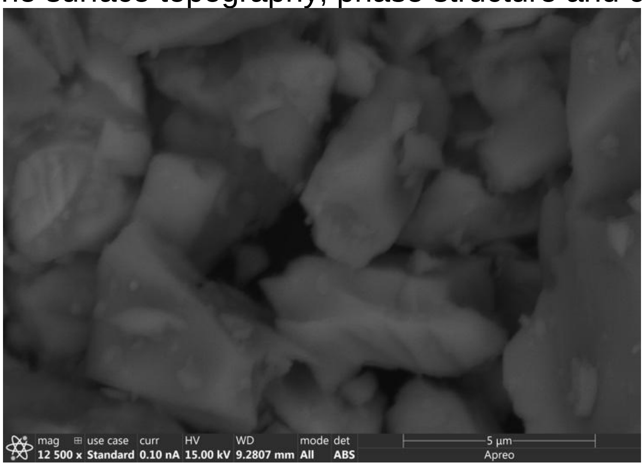

Fig. 2. Microstructural and SEM-EDS analysis of powdered Steel Slag.

The powdered steel slag was also analysed by scanning electron microscopy (SEM) and the chemical composition is shown in Table 1. The result shows that calcium (Ca) and iron (Fe) are the major components of the sample. The manganese (Mn) and silicon (Si) contents range from 2% to 3%, suggesting that further processing to remove manganese for other purposes or concentrate it for use as an alloying agent in steel making is possible. The enrichment of manganese may make it more valuable as a secondary material in electric arc furnaces (EAFs), further research contributes to improved steel making processes.

Table 1.

Element	Wt%	Atomic %	Name
C	4.42	9.28	C
O	15.64	24.67	SiO_2
F	23.56	31.30	CaF_2
Mg	0.75	0.78	MgO

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Al	0.22	0.20	Al_2O_3
Si	3.15	2.83	SiO2
K	0.22	0.14	KBr
Ca	46.38	29.21	Wollastonite
Mn	2.03	0.93	Mn
Fe	0.40	0.18	Fe
Yb	2.61	0.38	YB (v)
W	0.61	0.08	W
Total	100.00	100.00	

The chemical analysis provided indicates a high content of calcium, silicon, and fluorine compounds, which are significant for various industrial applications. Such as an aggregate in road construction and concrete production. Its high calcium content makes it suitable for use as a cement ingredient and concrete aggregate, providing both economic and ecological benefit [15]. It has also environment application which the slag's ability to adsorb pollutants makes it a potential low-cost adsorbent for water treatment and pollutant removal. Its porous nature and specific surface area enhance its effectiveness in these applications [16]. One more option is soil amendment that Steel slag can be used as a soil amendment to improve soil properties and reduce heavy metal leachate potential. It also contributes essential nutrients for agricultural use, promoting environmental remediation [17].
However, there are challenges and considerations on this topic follows: The fisrt one is chemical variability: The variable chemical composition of steel slag can pose challenges in its application, particularly in construction, where expansion issues and fresh property deterioration can occur [18]. The second one is environmental concerns: The leaching behavior of steel slag, especially concerning heavy metals, requires careful management to prevent environmental contamination [19].

Conclusion

The study emphasises the economic sustainability of steel slag as a basic industrial material. Based on an aggressive microstructural and chemical study, it was found that steel slag contains significant amounts of calcium (Ca), manganese (Mn) and iron (Fe) and can be used in certain industrial applications such as cement production, motorway construction and steel production. The results indicate that steel slag can be further processed to extract manganese and thus utilised as an efficient secondary material for electric arc furnaces (EAF).
Despite its potential, problems such as chemical heterogeneity and the environmental issue of heavy metal leaching need to be addressed. Future research should focus on improving slag processing methods to improve slag utilisation without affecting environmental sustainability. By focusing on circular economy and industrial waste reduction, this research promotes sustainable resource utilisation as well as innovation in green manufacturing processes.

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