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Comprehensive Utilization and Control Measures of Iron and Steel Slag

Xianzhen Wu[1], Jin Xue[2*]

(1. College of Metallurgy and Energy, North China University of Technology;
2. North China University of Technology)

Abstract: With the increase of steel production, the amount of steel slag piled up is on the rise. The article analyzes the current situation of blast furnace slag utilization, elaborates on the current treatment technology of blast furnace slag, and points out that in the future, the utilization of blast furnace slag will develop towards the direction of developing high value-added products, and the sensible heat recovery rate of blast furnace slag is expected to increase. Analyze the current application status and treatment process of converter slag. The comprehensive treatment technology of converter slag is limited by multiple factors, and it is proposed to control converter slag from the production source through "slag recycling".
Keywords: blast furnace slag; converter slag; comprehensive utilization

China is the world's largest producer of steel. According to the latest preliminary statistics from the World Iron and Steel Association, the country's crude steel production in 2019 was 99.6 billion tons, accounting for 53% of global crude steel production 3% [1]. Steel slag mainly refers to the blast furnace slag and converter slag generated during ironmaking and steelmaking processes. With the increase of steel production, the amount of steel slag produced increases synchronously. In 2017, the metallurgical slag production of steel enterprises in China reached 4 More than 400 million tons, including 24.7 billion tons, converter slag 10.01 billion tons. After years of accumulation, the current amount of steel slag in China is about 1 billion tons, which not only occupies land for enterprises, but also pollutes the environment, endangers organisms and human health [2]. In the future, seeking reasonable utilization of metallurgical slag is one of the main tasks faced by steel enterprises.

1 Current situation of steel slag treatment

Developed industrial countries abroad have conducted early research on the utilization of blast furnace slag and converter slag, and have also achieved remarkable results. The utilization rate of blast furnace slag in some European countries, Japan, and the United States has already reached 100%, and the utilization rate of converter slag has also reached a high level.

(1) Application of blast furnace slag. 81% of German blast furnace slag is used as cement raw material, 10% is used as concrete material, and 9% is used for intermediate storage and internal consumption; 72% of Japanese blast furnace slag is used as raw material for cement production, 25% is used in construction and road construction, and the rest is used in agriculture; 35% of the blast furnace slag in the United States is used for roadbed and pavement, about 30% is used as binder, and the rest is mainly used as raw materials for concrete [3].

(2) Application of converter slag. 53% of German converter slag is used in the building materials industry, 9% is used in the agricultural sector, and the smelting and recycling amount is about 13%. The rest is mainly used for landfill treatment; 41% of Japanese converter slag is used in the construction industry, 39% is used as paving materials,

* Corresponding authors.
E-mail addresses: 8974125863@qq.com

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and the rest is mainly used as raw materials for cement and foundation improvement; 66% of converter slag in the United States is used for roadbed and pavement, while the rest is widely used in cement and agriculture fields [4].

Compared to others, the utilization rate of domestic steel slag has always been low, especially converter slag. Although the utilization methods are wide, the comprehensive utilization rate is less than 30%. Among them, about 56% of blast furnace slag is used as slag powder, 23% is used as cement mixture, 3% is used as slow cooling slag crushed stone, and about 18% is not utilized. About 10% of converter slag is used as steel slag powder, 7% is used in the metallurgical field, 5% is used as raw materials for steel slag cement and paving, and about 71% is selected for iron stacking treatment but not utilized.

Overall, there is still a certain gap between the comprehensive utilization level of steel slag in China and advanced industrial countries, especially the low utilization rate of converter slag, which has become the main limiting factor in improving the utilization rate of steel slag.

1. 1 Current status of blast furnace slag utilization

In recent years, the utilization rate of blast furnace slag in China has reached over 80%, and there is still a significant gap compared to the 100% utilization level in developed countries. The chemical composition of blast furnace slag is similar to that of Portland cement and rocks in nature. The typical composition of blast furnace slag is shown in Table 1 [5]. The treatment process of blast furnace slag mainly includes water quenching method and dry method.

(1) Water quenching method. There are mainly two types of water quenching methods in China. One is to directly flush the blast furnace slag with water, and the other is to first mechanically crush the slag and then carry out water quenching treatment [6].

After water quenching of blast furnace slag, according to the different dewatering methods of the slag, the water quenching method can be further divided into: bottom filtration method, Inba method, Tula method, Magang method, Lhasa method, and Mingteke method. The bottom filtration method is mainly used domestically, while the inbar method is commonly used abroad.

After water quenching treatment, blast furnace slag can be used as raw materials for producing cement mixtures, slag powder, slag concrete, slag crushed stone concrete, and expansion beads, but the resource utilization value of blast furnace slag is relatively low. The water quenching process of blast furnace slag requires a large amount of water resources (1 ton of new water/t of slag), and releases harmful gases such as H_2S and SO_2. At the same time, the sensible heat of the slag cannot be utilized [7].

(2) Dry method. Since the 1970s, metallurgical workers have been studying the dry treatment process of blast furnace slag. According to the waste heat recovery method, the dry treatment process of blast furnace slag can be divided into two categories: physical recovery method and chemical recovery method [8].

Physical recovery method: This method mainly absorbs the heat energy of slag through media such as water and molten salt, and achieves the effect of heat recovery through the conversion of medium heat energy. According to the granulation method, it can be further divided into drum method, centrifugal granulation method, and air quenching method. Taking the drum method as an example. The blast furnace slag flows through a rolling drum and exchanges heat with the medium inside the drum during the contact process. The medium inside the drum recovers heat energy and is recycled. The heat recovery efficiency of the drum method is about 40%, and the vitrification rate of blast furnace slag is about 80%. The centrifugal granulation method is to place blast furnace slag into a high-speed rotating cup, where the slag is crushed by centrifugal force and undergoes heat exchange with the water-cooled wall. The wind quenching method utilizes the airflow blown out by a high-pressure fan to exchange heat with the slag, and completes the crushing and granulation of the slag.

Chemical recovery method: The chemical method uses the sensible heat of the slag as a heat source for chemical reactions, and converts the heat into chemical heat for storage and utilization. The recovered heat can be used for power supply and blast furnace hot blast furnaces. This process is accompanied by chemical reactions during the heat recovery process, resulting in lower heat recovery efficiency. At pres-

Table 1 Composition of blast furnace slag

Classification	CaO	SiO_2	Al_2O_3	MgO	MnO	Fe_2O_3	TiO_2	V_2O_5	S	F
Ordinary slag	38～39	26～42	6～17	1～10	0. 1～1	0. 15～2	-	-	0. 1～1. 5	-
High titanium slag	23～46	20～35	9～15	2～10	＜1	-	20～29	0. 1～0. 6	＜1	-
Manganese iron slag	28～47	21～37	11～24	2～8	5～23	0. 1～1. 7	-	-	0. 3～3	-

ent, the use of methane to produce hydrogen, biomass gasification, microcrystalline glass or slag cotton preparation, etc., all belong to the category of chemical recovery methods.

1.2 The current situation of converter slag utilization

Converter slag is a high alkalinity slag composed of oxides such as Ca, Si, Mg, Fe, P, and Mn. The chemical composition of converter slag in some steel plants in China is shown in Table 2 [9].

The presence of harmful elements such as P and S in converter slag limits its application in the metallurgical field. At the same time, free CaO and MgO in the slag react with water to generate Ca $(OH)_2$ and Mg $(OH)_2$, leading to automatic pulverization of the magnesite phase and its adjacent phases after expansion in the slag [10], which limits its large-scale application in other fields.

(1) Converter slag treatment process. At present, the converter slag treatment process mainly adopts a two-step method. The first step is to pretreat converter slag to eliminate its self dissociation phase, achieve slag stabilization, and facilitate slag iron separation; The second step is to select iron for the slag treatment, and the residual slag is utilized as a resource according to demand. The common pre-treatment technologies and characteristics of converter slag are shown in Table 3 [11].

Steel companies have many technologies for treating converter slag, but most of them focus on the recovery of metallic iron. After removing iron, the slag is often stacked, discarded, or reclaimed. Only a portion of the slag is further processed and used as sintering ore additives, synthetic slag raw materials, or building materials.

Table 2 Chemical composition of converter slag from domestic steel mills (mass fraction)%

Steel mill	CaO	SiO_2	Al_2O_3	MgO	FeO	P_2O_5	f—CaO	MnO
Ma-steel	43. 15	15. 55	3. 84	3. 42	19. 22	4. 08	4. 58	2. 31
Tai-steel	52. 35	13. 22	2. 81	6. 29	13. 20	1. 30	5. 53	1. 06
Ben-steel	50. 44	16. 36	2. 56	13. 22	11. 50	0. 56	1. 57	2. 66
An-steel	45. 37	8. 84	3. 29	7. 98	21. 38	0. 72	6. 95	2. 31

(2) Application fields after converter slag treatment. So far, there are many comprehensive utilization pathways for converter slag that have been developed. In the field of steel, converter slag can be used as sintering flux, hot metal pre-treatment flux, or recycled in the converter process; In the field of construction, converter slag can be used as raw material for producing steel slag bricks and blocks after treatment; In terms of wastewater treatment, crushed converter slag can be used to adsorb and digest acid ions in wastewater; In agricultural production, converter slag can be used as a raw

Table 3 Converter slag treatment process and characteristics

Treatment process	Advantage	Disadvantage	Application enterprises
Tank-type hot disintegrating method	Simple process and high slag activity	Large subsequent processing volume and long cycle time	Ansteel, Shougang, Baosteel
Hot splashing method	Easy to mechanization, high productivity	Large footprint and poor environment	Tangshan Iron and Steel, Wuhan Iron and Steel
Plate splashing method	Small footprint and large processing capacity	Complex process and high investment	Nippon Steel and Baosteel
Water quenching method	Simple process with low investment	Easy to explode, uneven slag particle size	Ji-steel
BSSF	Small footprint and low pollution	Complex equipment and high investment	Baosteel Second Steelmaking Plant
Wind quenching method	Small footprint and low pollution	High noise and high raw material requirements	China Steel Group and Chongqing Iron and Steel Corporation
Granulation wheel method	Large processing capacity and low investment	Poor separation of slag and steel, high requirements	Ben Steel, Liu Steel, Sha Steel
Chenhua treatment	As a follow-up process for steel slag treatment	Additional thermal energy, complex equipment	Japan

material for producing phosphate fertilizer and silicon powder; Meanwhile, converter slag can be used to prepare ceramic products such as microcrystalline glass [12].

The comprehensive utilization of converter slag in other fields has alleviated the problems of resource waste, environmental pollution, and land occupation of converter slag. However, the treatment technology of converter slag after being discharged from the furnace is limited in various aspects, such as the enrichment of P element in steel slag, which limits its circular use in blast furnace ironmaking, the self pulverization characteristics of steel slag, which limits its promotion in the construction industry, and the low effective element content of steel slag, which limits its further application in agriculture.

2 Analysis of development trends in steel slag treatment

2.1 Development trend of blast furnace slag treatment

At present, the wet treatment process of blast furnace slag (water quenching process) is widely used, accounting for more than 90% of the total treatment capacity of blast furnace slag. Although there have been many studies on dry treatment processes, due to the poor thermal conductivity of slag, large-scale recovery has not yet been carried out in industrial production. Therefore, for a long period of time in the future, the treatment of high slag will still be mainly based on wet processes.

With the continuous expansion of the application field of blast furnace slag, the utilization of blast furnace slag in the future is no longer limited to being used as raw materials for low value-added products such as cement mixtures and slag. The application of blast furnace slag in high value-added products such as the construction industry (new wall bricks), decorative materials (microcrystalline glass or slag cotton), environmental protection (sewage adsorption materials), and agriculture (silicon fertilizer) will gradually increase. Meanwhile, with the upgrading of blast furnace slag treatment technology, the sensible heat recovery rate of blast furnace slag will correspondingly increase, and the proportion of blast furnace slag dry treatment process is expected to gradually increase.

2. 2 Development trend of converter slag treatment

To improve the utilization efficiency of converter slag, on the one hand, efforts should be made to increase the development of high value-added products of converter slag and seek more suitable application markets; On the other hand, the control of converter slag should be carried out from the source, and the production of converter slag should be truly reduced through process improvement or slag recycling.

2.2.1 Development of high value-added products for converter slag

In recent years, the development of high value-added products from converter slag has become a research hotspot for many scholars. This type of research focuses on the various beneficial elements contained in converter slag. By extracting these elements and producing materials with specific functions, such as using them to make anode materials for lithium batteries and water treatment agents. However, due to the physical limitations of converter slag itself, current treatment technologies cannot endow converter slag with good resource utilization characteristics, and no application reports of such technologies have been found in production or literature. Therefore, there is still a long way to go to improve the utilization value of converter slag through technological innovation.

2.2.2 Converter slag recycling technology

The recycling technology of converter slag is a major direction for converter slag treatment. This technology involves the recycling of liquid high-temperature slag in the converter process, which can effectively reduce the production of new converter slag. At present, processes such as converter dual connection, converter "dual slag+slag retention" operation, and slag retention operation all have such characteristics.

(1) Converter dual process. This process uses two converters for dephosphorization and one converter for decarburization. The slag from the decarburization furnace can be used as the initial slag for the dephosphorization furnace.

The converter dual process is mainly used for the production of low phosphorus steel, and has the process characteristics of slag recycling. The application practice of Shougang Jingtang has shown that compared to traditional single slag converter, the converter dual process saves 10-20kg/t of lime and reduces steel material consumption by 25kg/t [13]. The shortcomings of the converter dual process are the high infrastructure cost and the complexity of the converter inversion process.

(2) The smelting process of "dual slag+residual slag" in the converter. This process divides the smelting tasks of the converter. After the early dephosphorization of the converter is completed, all the dephosphorization slag is poured out of the furnace, and the slag is remade for decarburization. The decarburization slag is left in the converter as the initial slag for the next furnace use.

The application practice of Qian'an Shougang shows that this process can reduce lime consumption by 15-25 kg/t,

dolomite consumption by 5-10 kg/t, and total slag amount by about 30% [14]. But this process is suitable for promotion in large-scale converters, and it is difficult to pour out phosphorus removal slag in the early stage.

(3) Operation process for converter slag retention. This process will leave some or all of the high-temperature slag after splashing in the furnace for recycling in the next furnace. After leaving the slag, the amount of slag making agent used in the next furnace smelting will be significantly reduced. Laigang converter reduces lime consumption by 15% through slag retention operation 27 kg/t, reducing dolomite consumption by 1.60 kg/t reduces steel consumption by 18 kg/t [15]. The slag retention operation in the converter is easy to promote, but both S and P in the slag circulate into the next furnace, so the amount of slag retention should not be too large.

Overall, "slag recycling" provides a new approach for the treatment of converter slag. Although these technologies have some restrictive conditions, with the advancement of technology, the future of converter slag recycling technology is expected to be further promoted in steel enterprises.

3 conclusion

An analysis was conducted on the current application status and future development trends of steel slag, and the following conclusions were drawn:

(1) At present, the comprehensive utilization rate of blast furnace slag in China is over 80%. The treatment of blast furnace slag is dominated by water quenching technology, and the treated slag is mainly used as raw materials for low value-added products such as cement mixtures and slag. In the future, with the upgrading of dry treatment technology for blast furnace slag, blast furnace slag treatment will develop towards the direction of developing high value-added products, and the sensible heat recovery rate of blast furnace slag is expected to increase.

(2) Currently, the comprehensive utilization rate of converter slag is less than 30%. The treatment of converter slag mainly adopts a two-step method, and the focus of enterprises is mostly on the recycling and utilization of Fe. The slag after iron selection is mainly stacked. In the future, there is still a long way to go in the development of high value-added products for converter slag, and "slag recycling" can reduce the output of new converter slag from the production source. With the upgrading of process technology, this technology is expected to be further promoted.

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