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Analysis of Steel Slag Treatment Process and Comprehensive Utilization

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Abstract: As a by-product of steel enterprises, steel slag has a huge output and is rich in valuable minerals, but its comprehensive utilization rate is very low. The article mainly introduces the hot splashing method, hot sealing method, and drum method for the treatment of steel slag outside the furnace, and compares and analyzes the advantages and disadvantages of the production operation process and steel slag treatment process. At the same time, it also introduces the residual slag+double slag process and gasification dephosphorization slag circulation steelmaking technology for steel slag treatment inside the furnace, providing direction for steel enterprises to clean and comprehensively utilize steel slag.

Keywords: drum method; heat splashing method; heat stuffiness method; gasification dephosphorization slag; residue+double residue

China is a major steel country, and the steel industry is a pillar industry in our country. With the increase of steel production in our country, the emission of steel slag continues to grow [1], with a cumulative stock of over 1 billion tons. A large amount of discarded steel slag is piled up into a slag mountain, seriously polluting the environment.

At present, the steel slag treatment process is a major research hotspot. Chen Hua et al. [2] used X-ray diffractometer and spectroscopic analyzer to verify the chemical composition of steel slag, and the results showed that the main chemical components in the slag were calcium oxide and ferrous oxide, which can be recycled and reused through mature steel slag treatment processes. Liu Liexi et al. [3] conducted research on the steel slag hot splashing treatment process at Wuhu Xinxing Casting Plant. After the hot splashing method treatment, the steel slag powder expansion rate reached over 97%, which can better achieve slag iron separation; Li Song [4] conducted practical analysis on the latest optimized drum method steel slag treatment system equipment currently used by Baosteel. The drum method steel slag treatment rate reached over 85%, the treatment process was clean and environmentally friendly, and the treated steel slag had good stability, which can be directly used for product manufacturing; Shu Liping [5] elaborated on the steel slag processing technology of Ningbo Iron and Steel Company's drum method. After treatment, slag with a particle size less than 10mm accounts for more than 90%, and almost all iron and calcium oxides in the slag are recovered and digested.

Due to the wide variety of steel slag types and significant differences in slag conditions, there are problems in steel slag pretreatment and comprehensive utilization. In terms of pretreatment: slag has complexity, and the slag treatment technology is not mature, making it difficult to balance treatment costs and environmental protection; In terms of comprehensive utilization, there are many types of slag and significant performance fluctuations, which cannot be directly applied to product manufacturing. Based on the above difficulties, it directly leads to a low degree of steel slag resource utilization. Therefore, mature steel slag treatment processes and efficient utilization methods are of great

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significance for steel slag resource utilization and environmental improvement.

1 Comparison of steel slag treatment processes

Due to significant differences in process equipment, production level, and steel slag performance among steel enterprises in different regions, steel slag treatment processes are diverse and have their own advantages and disadvantages. At present, the mature and widely used processes for treating steel slag outside the furnace at home and abroad include hot splashing method, hot sealing method, drum method, etc. [6–13].

1.1 External steel slag treatment

(1) Heat splashing method. The hot splashing method is to pour high-temperature hot steel slag into a slag tank, transport it to the slag treatment workshop by a slag tank truck, and then spread the slag in the tank on a fixed slag treatment site. A certain amount of cooling water is sprayed on the surface to achieve rapid cooling. At the same time, under the action of extreme stress generated by a sudden temperature drop, the slag cracks quickly and accelerates crushing. Wait until most of the water evaporates, mix with a forklift, and then spray an appropriate amount of cooling water multiple times. After about 2-3 days, the steel slag will completely solidify, and be transported to the next processing workshop with a forklift for further crushing and magnetic separation. The advantages of hot splashing method are fast slag discharge speed, simple operation, and low requirements for slag fluidity. The disadvantages are obvious: slag treatment occupies a large area, consumes a large amount of water, and the secondary loading and unloading of the forklift during the intermediate process will generate a large amount of dust and steam, resulting in unorganized emissions and serious environmental pollution; Difficulty in separating slag and iron, uneven particle size of hot splashed slag, and easy agglomeration. At present, only a few steel enterprises such as Wuhan Iron and Steel Group and Ansteel apply this process.

The shallow plate method process was developed and developed by Nippon Steel in Japan, and belongs to a type of hot splashing method. Load the high-temperature hot slag into the slag tank, lift it to the metal tray with a crane and pour it onto the slag tray. Spray a large amount of cooling water on the surface of the slag that is starting to solidify, and spray water 3-4 times at intervals. When the steel slag cools to around 450 ℃, flip the slag over and spray water again to cool it to around 200 ℃ before pouring it into the cold water tank. Finally, salvage and magnetic separation are carried out. Compared with the traditional hot splashing method, the shallow plate method cools the metal plate, alleviating the pollution of dust to the environment, and occupying a small area. The processed steel slag has a small and uniform particle size [9]. However, metal slag trays are prone to deformation at high temperatures and the cost of replacement is particularly high; Frequent water cooling can cause severe erosion of equipment and factory buildings. At present, the application of the shallow plate method in China is relatively limited, mainly in Baosteel, and Baosteel is gradually replacing the shallow plate method with the drum method.

(2) Heat sealing method. The hot sealing method is a waste heat self decomposition slag treatment technology developed by the China Metallurgical Construction Research Institute in 1992. The hot slag is poured into a hot sealing pool (or tank) through a slag tank truck or slag tank crane, and then sprayed with water, sealed and hot sealed, repeatedly hot sealed for about 12 hours. A large amount of water vapor is generated in a closed space, with a certain temperature and pressure. Through physical and chemical reactions, saturated water vapor reacts with free metal oxides in the slag to achieve the purpose of crushing and pulverization. After the hot sealing is completed, use an excavator to scoop out the hot sealing slag and perform multi-stage magnetic separation treatment.

The hot sealing method has a simpler operating process and shorter cooling time compared to the hot splashing method. Hot sealed water spraying generates a large amount of water vapor, which can fully dissolve and react the free calcium and magnesium oxides in the slag, making the slag easy to pulverize. Therefore, hot sealed slag has high stability, relatively small steel slag particle size, high slag iron separation rate, and metal recovery rate; In addition, there are no special requirements for the fluidity of slag, and basically any slag system can use the hot sealing method; The hot sealing time is relatively short, and the slag treatment efficiency is high. However, the shortcomings are that the equipment investment is large, and the secondary loading of forklifts during the treatment process pollutes the environment. Steam emissions erode the factory building and affect the visibility of workers. In addition, cooling water and liquid slag can easily form enclosed spaces, and improper heat sealing treatment can easily lead to explosions, which is the biggest drawback of this process. At present, the hot sealing method is widely used in large and medium-sized steel enterprises such as Shougang, Ansteel, Wukuang Yingkou Plate Plant, and Ansteel Bayuquan Steel Plant.

(3) Drum method. The drum method is a new type of steel slag treatment technology developed by Baosteel, based on the reform and innovation of Russian slag treatment technology. The world's first drum method device was built in 1998.

The slag scraper scrapes the high-temperature hot slag from the converter into the slag pouring and tilting device,

and then accurately and stably pours the slag into a rotating closed drum (a 16Mn metal plate inside the drum) for treatment, forming a "three in one" combination of drum device, slag pouring and tilting device, and slag scraper equipment, which greatly improves the efficiency of steel slag treatment. The drum is filled with two media, steel balls and circulating cooling water. Under the combined action of steel ball pressure and cooling water, the high-temperature slag is rapidly cooled to 60-70℃, and then solidified and crushed. Add a bucket elevator at the end of the drum device to transport the processed drum slag to a high-level silo. The transportation vehicle will pick up the material under the silo, ensuring that the slag does not fall to the ground throughout the process, greatly reducing secondary transportation pollution. During the entire operation process, vibrating screens and online magnetic separation equipment are also installed to better recover large pieces of scrap steel and slag steel.

Due to the different shrinkage rates of slag and molten steel, the drum method can completely separate slag and steel, with a metal recovery rate of over 90%; The equipment has a small footprint and low one-time cost, unlike traditional processes for steel slag stacking and graded crushing magnetic separation; The addition of steel balls in the drum can fully granulate the slag, with uniform particle size. At the same time, cooling water can also dissolve free calcium oxide, so the stability of the slag is good, and the product can be directly used. However, the bottom slag of the drum drum tank is not thoroughly treated during the processing, and the process flow should be further improved to achieve full energy utilization and full coverage of steel slag types by the drum method. At present, this process is mainly applied in enterprises such as Baosteel and Ningsteel.

After comprehensive analysis of the steel slag treatment process outside the furnace, it is found that the hot splashing method causes serious environmental pollution, with a high demand for personnel during production and high costs for multi-stage crushing. The traditional and backward open-pit hot splashing process is basically phased out in China; The hot suffocation method can fully dissolve calcium oxides and is widely used in China; The drum method is gradually being promoted and used. Based on the advantages of three processes, a new treatment mode can be achieved by combining hot splashing, hot sealing, and drum method. The slag is scraped into a cold water tank, cooled to a certain temperature, and then loaded into a hot sealing tank. The tank is then sealed for waste heat self decomposition, and the steam in the tank is appropriately discharged to control the pressure inside the tank. The powdered and digested slag enters the drum device for crushing and magnetic separation. The "three in one" technology and "slag not falling to the ground" technology applied by the drum method have greatly improved the stability of slag, equipment processing capacity, and adaptability to converter slag. In addition, during the initial stage of steel slag treatment, a large amount of unorganized water vapor can be recovered for power generation or waste heat heating, which not only protects the environment but also efficiently utilizes resources to achieve zero emissions.

1.2 Steel slag treatment in the furnace

(1) Converter dual slag+residual slag smelting process. The principle of converter dual slag+slag retention smelting process: After tapping, the vast majority of the slag in the converter is left in the furnace, and the remaining slag must be the final slag with high alkalinity and high content of ferrous oxide. After splashing and solidification, scrap steel and molten iron are added. After the first phase of blowing and smelting, all the slag can be poured out as much as possible, and then the next round of slag making operation begins. The dual slag+slag retention process can reduce the consumption of slag (lime), achieve the goals of low slag smelting and hot slag recycling, and efficiently and quickly remove phosphorus at low temperatures, meeting the needs of producing low phosphorus steel. In recent years, the converter dual slag+residual slag smelting process has been widely promoted and applied in China. Li Xiang et al. [14] conducted industrial experiments on residual slag dual slag smelting based on the Fengbao 50t converter in Henan; Lv Kaihui [15] provided a detailed introduction to the double slag operation of slag retention at the San'an Steelmaking Plant in Fujian, providing rich production practice experience for other enterprises; Shougang officially started using the dual slag+slag retention process in 2012. This process has considerable economic benefits in protecting the furnace lining, as well as in low slag smelting and efficient dephosphorization.

(2) Circulating utilization process after gasification and dephosphorization of converter slag. Based on the concept of energy conservation and emission reduction, Wang Shuhuan and others from North China University of Technology proposed the converter final slag gasification and dephosphorization followed by cyclic steelmaking method [16], and obtained relevant patents. This process consists of five stages: the first stage is the slag retention operation in the converter after tapping, adding dephosphorization agents to the final slag, and discharging the phosphorus in the slag in the form of gasification during slag splashing protection; The second stage is to add scrap steel and molten iron into the furnace, use the waste heat of gasification dephosphorization slag to increase the scrap steel ratio, then add slag making materials and lower the gun oxygen blowing; The third stage is the period of oxygen blowing and slag making, which

efficiently removes phosphorus elements from the molten steel at low temperature; The fourth stage is the endpoint of carbon pulling and pouring out high phosphorus slag; The fifth stage is to adjust the endpoint temperature and composition for steelmaking, and proceed to the next round of converter gasification dephosphorization slag circulation dephosphorization steelmaking process operation.

At present, this process technology has been promoted in enterprises such as Shougang and Tangshan Iron and Steel [17], providing valuable experience for steel enterprises in low slag smelting and cyclic steelmaking. The process flow is as follows: 1/2 to 2/3 of the total slag amount is left in the furnace after the converter is steelmaked, and the amount of reducing agent added is calculated using formula [18]. The reducing agent is used up in two parts, half of which is used before the top blowing starts splashing slag, and the other half is used after the lower gun blowing starts. The appropriate splashing gun position is controlled to vaporize and discharge the harmful element phosphorus in the slag, achieving the recycling of steel slag for converter gasification and dephosphorization operation. The adoption of converter gasification dephosphorization slag circulation steelmaking can fundamentally solve the problem of large-scale discharge of steel slag, while also reducing the content of harmful phosphorus elements in slag, which plays a positive role in the comprehensive utilization of steel slag.

Circulating steelmaking after gasification and dephosphorization of converter slag is a good solid waste resource utilization technology, but the disadvantage is that the discharge of gasification phosphorus can pollute the atmospheric environment, so the collection of gasification phosphorus is also important. The gasification of phosphorus undergoes oxidation hydration reaction to prepare phosphate, which can be used as food ingredients and functional additives, agricultural phosphate fertilizers, etc. The comprehensive treatment process of steel slag in the furnace mentioned above is of great significance and scientific research value for the resource utilization of phosphorus containing slag.

2 Outlook on application technology of steel slag treatment process

Steel enterprises should follow the principle of "three-step method" in the treatment of steel slag. The first step is to completely dissolve the calcium and magnesium oxides in the slag, making the slag stable. This is beneficial for the high added value of subsequent products, and this step is the focus of research by scholars; The second step is efficient slag iron separation, enriching iron containing materials and returning them to smelting production, which can reduce production costs, but the composition of the returned raw materials must be strictly controlled; The third step is the resource utilization and direct productization of tailings. At present, most domestic steel enterprises have two problems: first, the treated tailings contain excessive free calcium and magnesium oxides, and second, the steel slag is sold to small processing enterprises or reclaimed land at a cheap price, resulting in low utilization rate. Researchers should do a lot of work in the efficient utilization of steel slag tailings, fully leveraging the excellent characteristics of steel slag to achieve product high-end, such as sponge city technology, micro powder technology, and special molding sand technology.

The steel slag treatment process should adapt to the pace of steelmaking production, while considering economic, social, and environmental benefits. Economic benefits: low equipment cost, high safety performance, stable overall performance of slag, suitable for productization, high-efficiency slag iron separation, etc. Social benefits: The processed steel slag can be maximally utilized in all aspects, achieving product high-end. Environmental benefits: Neither the slag treatment process nor the comprehensive utilization of slag products can cause pollution to the ecological environment. Therefore, through mature slag treatment processes, the slag is efficiently treated, useful components are extracted as production raw materials, and finally the waste slag is comprehensively utilized. Based on the synergistic development of the three benefits mentioned above, the formation of a new circular economy model is of great significance for the resource utilization of bulk social waste in steel enterprises.

3 Conclusion

Steel slag is a type of "secondary energy" that has been well applied in the construction industry, smelting materials, and other fields. It not only solves the problem of abandoned slag in China, but also brings good economic benefits. At present, whether the processed steel slag can be directly utilized is the key to the efficient resource utilization of steel slag. The new drum method steel slag cleaning treatment process can solve environmental pollution problems, and the processed drum slag can be directly used for productization. The application of residual slag dual slag+smelting process and converter gasification dephosphorization slag circulation steelmaking technology can solve the large amount of solid waste steel slag discharge from the root. The combination of the external drum method for treating steel slag, the dual slag smelting process with residual slag in the furnace, and the gasification dephosphorization slag recycling steelmaking technology will definitely be widely promoted in the near future, in order to maximize enterprise benefits.

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