Physical and Chemical Properties of Steel Slag and Utilization Technology of Steel Slag at Home and Abroad

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Abstract: Steel slag is a large discharge of industrial waste slag. Chinese effective utilization rate of steel slag is only 20%, causing great harm to the environment and economy. Based on the introduction of the element, composition and characteristics of steel slag, this paper expounds the application of steel slag in sintering and blast furnace production, steel slag cement, road engineering, agricultural fertilizer and environmental protection at home and abroad.

1. Introduction

China is the world's largest producer of steel. For every 1t of crude steel produced, 8%~15% of steel slag will be produced. With the continuous increase of crude steel output in China, the output of steel slag also increases year by year. At present, China's steel slag accumulates about 1 billion ton[1]. However, China's steel slag utilization rate is only about 20 percent. If these steel slags can not be used reasonably, it will occupy a lot of land resources and cause environmental pollution and waste of resources. Therefore, it is necessary to study the comprehensive utilization of steel slag, which conforms to the trend of developing circular economy and realizes sustainable development of iron and steel enterprises.

2. Composition and characteristics of steel slag

2.1. chemical composition and mineral composition of steel slag

The main chemical components of steel slag are CaO, SiO₂, Fe₂O₃, Al₂O₃, MgO, MnO, FeO, fCaO, etc. With the difference of raw material, smelting technology and steel type, the composition of steel slag also changes. The chemical composition of converter slag in some Chinese steel mills is shown in table 1.

| Chemical component | CaO  | SiO₂  | Fe₂O₃  | Al₂O₃  | MgO  | MnO  | FeO  | P₂O₅ |
|--------------------|------|-------|--------|--------|------|------|------|------|
| Slag in Tangshan Steel | 40.30 | 15.38 | 12.73  | 2.54   | 9.05 | 1.88 | 14.06 | 1.01 |
| Slag in Angang Steel | 45.37 | 8.84  | 8.79   | 3.29   | 7.98 | 2.31 | 21.38 | 0.72 |
| Slag in Baoshan Steel | 41.42 | 8.74  | 7.66   | 1.04   | 10.29| 3.03 | 21.58 | 1.66 |

The main mineral components of steel slag are tricalcium silicate, dicalcium silicate, dicalcium ferrite, calcium-magnesium peridotite, calcium-magnesium rose-pyroxene, RO phase (solid solution
formed by MgO, FeO and MnO) and free lime. The mineral composition of steel slag is different, and the influencing factors are the chemical composition of steel slag, especially the basicity of steel slag. Su\[3\] believed that olivine, rosaceous pyroxene and RO phase were the main minerals of low-basicity slag, dicalcium silicate and tricalcium silicate were the main minerals of medium-basicity slag and tricalcium silicate were the main minerals of high-basicity slag.

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2.2. Characteristics of steel slag
With the increase of basicity, the color of the cooled steel slag changes from gray and brown gray to gray and white. The bulk density of steel slag is about 3.1~3.6g/cm³, with water content of 3%~8%, and it has good compression resistance. In addition, steel slag has three characteristics: the first characteristic is the gelling activity, the mineral composition of steel slag silicate, ferroaluminate, aluminate determines the gelling performance of steel slag; the second characteristic is stability. The steel slag contains CaO and MgO, which are easy to produce volume expansion after hydration, and this is the main factor affecting the stability of steel slag. The third characteristic is the wear resistance, the wear resistance of steel slag and its own structure and mineral composition. Experimental studies have shown that\[4\], after grinding and screening of steel slag, chemical analysis is carried out on the sieve residue, and the screened substance is basically iron metal. Therefore, the poor wear resistance of steel slag is mainly due to the inclusion of metal iron rather than the mineral itself.

3. Overview of steel slag utilization abroad
In the early 20th century, foreign industrial developed countries began to study the comprehensive utilization technology of steel slag. Especially after the 1970s, industrial developed countries are faced with the dilemma of serious shortage of resources. In addition, many foreign countries have detailed laws and regulations on the control of industrial waste disposal, which further develops the utilization technology of steel slag and rapidly improves the comprehensive utilization rate of steel slag.

The utilization rate of steel slag in the United States is more than 98%, among which, the proportion of sintering and blast furnace reuse can reach more than 56%, and the usage of road construction can reach 38%. Steel slag is used as track slag in 8 major railways in the United States. The utilization rate of steel slag in Japan and Germany is more than 95%, and its main utilization direction is sintering, blast furnace reuse, agricultural fertilizer and civil engineering. At present, many Japanese steel mills treat steel slag with steam aging method, and the treated steel slag is used as upper subgrade material. The proportion of this material is 75% converter slag, 20% blast furnace slow cooling slag, and 5% blast furnace water slag\[5\]. Germany has used converter slag to reinforce the Rhine ports and muz Banks.

4. General situation of domestic steel slag utilization
4.1. Recycling of scrap metal
Generally, the content of metal Fe in steel slag is about 10%. For large steel mills, the first process is using crushing magnetic separation screening process to recover the metal iron contained in steel slag, and then smelting. For example, the amount of steel scrap in steel slag recovered by dielectric self-grinding and magnetic separation in Anshan reaches 8.0%\[6\]. In addition to metal iron, Mn, Cr, V and other metals can be recovered from steel slag. Yang\[7\] smelted vanadium containing steel slag in a mineral hot furnace, which reduced the content of V₂O₅ in steel slag from 3.94% to 0.51%.
4.2. As the flux of iron and steel smelting
Steel slag contains calcium oxide, iron oxide, magnesium oxide and iron metal and other beneficial components, and it can be used in sintering. Since Ca and Mg in steel slag exist in the form of oxides, if they are used to replace the flux for sintering, and this can reduce the consumption of flux (limestone, dolomite), reduce the heat absorption of carbonate decomposition in the sintering process, and save the amount of sintering fuel. Steel slag can also be used as iron smelting flux, which can not only recover iron in steel slag, but also CaO and MgO in steel slag can be used as flux, saving the amount of iron smelting flux and reducing the cost.

4.3. Road engineering or backfilling materials
Steel slag has the characteristics of rough surface, heavy ratio, good abrasion resistance and firm combination with asphalt, which can be widely used in road engineering, reclamation and other aspects. As a roadbed filling material, steel slag mainly has stability problems. Generally, f-CaO and f-MgO can be dissolved and their stability can be improved by adding active materials or pretreatment. In China, a large amount of steel slag is used in the construction of traffic roads, seaports and wharves[8]. In the construction of the national stadium project, steel slag is tried to be used as the backfilling material, and all the backfilled steel slag comes from the waste steelmaking slag of Shougang. After treatment, the steel slag, cement and other auxiliary materials are prepared in accordance with the test ratio, and the density and other technical indicators meet the requirements of the national norms.

4.4. Steel slag cement
Steel slag is known as "overburned Portland cement clinker". This is mainly because the steel slag contains the active substances such as calcium silicate tricalcium silicate, calcium silicate dicalcium silicate which is similar to cement, has very good hydraulicity. Therefore, steel slag can be used as raw material or cement admixture of no clinker cement and little clinker cement[9]. There are several factors that influence the development of steel slag cement: 1) the composition and physicochemical properties of steel slag in different steel mills fluctuate widely. 2) the early strength of steel slag cement is low, and the presence of f-CaO and f-MgO in steel slag has a certain impact on the stability and later strength of cement. Guan[10] found that the comprehensive performance of steel slag cement reached the best when the proportion of steel slag fly ash was 21:9.

4.5. Used for preparing bricks, blocks and other concrete materials
Due to the hydraulic properties of steel, the ground steel slag can be directly used to prepare bricks, blocks or as an admixture of concrete when mixed with other raw materials. The three-storey building built by wisco with steel slag bricks developed by water quenching steel slag has been used for 25 years, which has proved that steel slag bricks are reliable in quality, high in strength and stable in performance[11]. Li linlin et al. prepared cementing materials in accordance with the ratio of 79:15:5:1 ore slag, steel tailings, desulphurized gypsum and cement clinker to replace cement, and used the steel tailings stabilized by thermal titration as aggregate to prepare high-strength artificial reef concrete[12].

4.6. Fertilizers and soil improvers
Steel slag contains silicon, calcium, phosphorus and other elements, which are necessary for the growth of crops. As steel slag is calcined at high temperature during smelting, its solubility increases and it is easily absorbed and utilized by plants. At present, phosphate fertilizer, silicon fertilizer and microelement fertilizer can be produced from steel slag. It has been proved by practice that steel slag phosphate fertilizer is not only suitable for acidic soil and phosphorus-deficient alkaline soil, but also can be applied in paddy fields and dry fields to obtain better fertilizer effect[13]. Because steel slag contains high calcium and magnesium, it can be used as an acid soil improver. Deng[14] studied the improvement effect of steel slag on polymetallic contaminated soil, and the experiment showed that the steel slag used had fine grain size and the heavy metal content in crops was reduced.
4.7. Environmental protection applications
The pulverized steel slag has the characteristics of high density, large specific surface area and fast settling speed in water, so it can be treated by chemical precipitation and adsorption. In addition, the alkaline substances in steel slag have a certain effect on the removal of heavy metal ions in sewage. Zhang\cite{15} used steel slag to remove \( \text{pb}^{2+} \) from wastewater. Under the optimal conditions, the removal rate of \( \text{pb}^{2+} \) could reach 99.81%.

Steel slag is rich in alkaline substances such as calcium oxide, which can react with acidic gases such as \( \text{CO}_2 \) and \( \text{SO}_2 \) in the exhaust gas to achieve the purpose of gas purification. Liu\cite{16} found that the desulphurization effect can be achieved by the desulphurization agent prepared by mixing steel slag with fly ash and gypsum in a certain proportion.

4.8. Preparation of ceramic products such as glass-ceramics
The basic chemical composition of steel slag is silicate. Taking steel slag and fly ash as raw materials, Zhang\cite{17} prepared glass-ceramics with diopside as the main crystalline phase after sintering. The main components of steel slag are \( \text{CaO} \), \( \text{Al}_2\text{O}_3 \), \( \text{SiO}_2 \) and \( \text{MgO} \), which can be used as raw materials for preparing ceramics. Wang\cite{18} studied the influence of steel slag addition amount on the performance of ceramic floor tiles. Using steel slag to prepare ceramic materials is a kind of high value-added utilization technology, which has been studied by more and more scholars.

5. Conclusion
Under the current situation of lack of resources, pressure of environmental protection and sustainable development, comprehensive utilization of steel slag can not only solve environmental protection problems, but also become a new growth point of enterprise economy, realizing sustainable development.

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