The present situation and development in technology of iron and steel slag utilization with high-value addition

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Abstract: Along with the technology innovation and upgrading of iron and steel slag (ISS) processes and utilization technologies, the application of the equipment has been promoted, the comprehensive utilization way and the scale expends continuously. Good economic, social and environmental benefits have been achieved. The basic principle and process of steel slag heat pyrolytic pulverization technology are described in the paper. Steel slag is pulverized because of physical and chemical reactions in the cooling process. It can eliminate the volume instability caused by free-CaO and free-MgO. Dry twin-roll magnetic separation makes the TFe grade more than 85%, which can be directly recycled to converter steelmaking, and the TFe grade more than 60% can be recycled as the sintering burden. The slag powder with specific surface area over 420m^2/kg can equivalently substitute 10%-40% cement to make different strength grades of concrete, so that have improved the performance of concrete.

This paper puts forward that along with the progress of science and technology, 31 items of standards about comprehensive utilization of iron and steel slag have been drafted and revised in recent years in China, and have played an important role to promote the solid wastes “zero emission” for the iron and steel industry.

Keywords: Blast furnace slag, steel slag, high-value utilization, present situation and development

1. Introduction

China is a big country of iron and steel production. 695.5 million tons of crude steel was produced in 2011 and it accounts 45.5% of the total production of the whole world. The production of pig iron was 630 million tons in the same year. Along with the development of iron and steel industry, the amount of slag increases. The production of steel slag and blast furnace slag (BFS) were 90.42 million tons and 214.2 million tons respectively in 2011. Realizing the high-value utilization and “zero emission” are urgent tasks to develop the circular economy, to protect the bio-environment, to save energy and reduce emission, to accelerate the construction of resource-saving and environment-friendly society.

The Chinese government attaches great importance to the comprehensive utilization of resources. It will be a major technical and economic policy and long-term strategic approach of the economic construction. It should be encouraged and vigorously guided to make high-value utilization of the steel slag a great progress. ISS processing technology has been innovated continuously and its technical level has been raised gradually. A batch of new technologies and equipments have been promoted and applied. The utilization ways are clearer. The investment and operation mode have been transferred. A few professional environmental protection companies have been established and professional management has been implemented. In addition, the steel slag management and utilization standard system has been established and implemented. It led to that the comprehensive utilization rate of steel slag raised from 10% in 2008 to

22%.

Ministry of Industry and Information Technology of the People’s Republic of China and National Development and Reform Commission released the bulk of solid waste comprehensive utilization of “12th Five-Year Plan” (year 2011-2015) and implement programs. It requires the comprehensive utilization rate of smelting slag should reach 70%. Steel slag heat pyrolytic pulverization technology should be vigorously developed and the technology of producing steel slag powder and GISS powder should be promoted. A few slag pretreatment and "zero emission" demonstration projects and 10 demonstration projects which produce cement and composite powder by BFS and steel slag will be built. These projects will cost 12 billion yuan and consume 5.475 million tons of steel slag annually. The estimated annual output is 12.5 billion yuan. At present, via the vigorous promotion of government and active implement of enterprises, a primary management model suitable for Chinese ISS comprehensive utilization of the technology has been formed under the relevant state regulations and preferential policies. The successful construction works as a model role, and lays the foundation for the realization of the “12th Five-Year Plan” goals.

2. Comprehensive utilization of iron and steel slag

2. 1 The generation and utilization of iron and steel slag

The output of ISS in 2007 to 2011 is shown in Table 1. The utilization and stockpiling of steel slag in 2007 to 2011 is shown in Table 2.

Table 1 Output of ISS from 2007 to 2011 (Unit: ten thousand tons)

Years / Species	2007	2008	2009	2010	2011
BFS	15000	16000	18500	20067	21420
SS	6500	6510	7950	8147	9042
total	21500	22510	26450	28214	30462

Table 2 Stockpiling of Steel Slag from 2007 to 2011

Species / Years		BFS	Steel slag	Stockpiling in the very year(ten thousand tons)	Stockpiling in total(ten thousand tons)
2007	Utilization Amount (ten thousand tons)	10500	650	10419	59298
	Utilization Rate (%)	70	10		
2008	Utilization Amount (ten thousand tons)	11200	651	10733	70031
	Utilization Rate (%)	70	10		
2009	Utilization Amount (ten thousand tons)	14189	1749	10594	80625
	Utilization Rate (%)	76.7	22		
2010	Utilization Amount (ten thousand tons)	15251	1011	11952	92577

	Utilization Rate (%)	76	21		
2011	Utilization Amount (ten thousand tons)	16708	2261	7053	99630
	Utilization Rate (%)	78	22		

2. 2 The main utilization means and proportions of iron and steel slag

The main utilization means and proportions of ISS are shown in Table 3.

Table 3 Main utilization means and proportions of ISS

Species		Main utilization means	Utilization Amount (ten thousand tons)	The Proportion of Comprehensive Utilization (%)
BFS	Water quenching	Granulated blast furnace slag powder used for cement and Concrete	11954	71.5
		Cement compound material	3926.4	23.5
	Slow-cooled	Crushed slow-cooled BFS	835.4	5.0
Steel slag		Steel slag powder used for cement and concrete	850	42.7
		Steel slag cement and cement burdening	453	22.8
		Steel slag bricks	226	11.4
		Steel slag used for road materials and backfill materials	460	23.1

3. Advanced technology and equipment of steel slag comprehensive utilization

3. 1 Heat pyrolytic pulverization technology of steel slag

Since the eighties of last century, the iron and steel enterprises have adopted hot pouring processing to treat steel slag. Steel slag are abandoned after recycling bulk scrap steel. Because there were too many slag that the normal production of steel was affected, so a number of research institutes, universities and enterprises began the study about processing and comprehensive utilization of steel slag and tailings. Two ways of slag utilization were proposed, be used as sintering burden and be used for cement, building materials and road materials.

The slag as sintering burden to use requires the particle size be less than 8mm. Therefore, granulated blast furnace slag (GBFS) processing technology has been successfully studied (including water quenching, air quenching, and drum process). In the twenty-first century, along with the improvement of smelting technology, of high-grade ore smelting is promoted. Due to the slag iron grade is below 20%, and contain harmful elements such as phosphorus pent oxide etc, the slag return sintering time is longer. The cost of smelting slag is higher. It results the amount of return sintering steel slag decreases greatly. The application of steel slag in producing cement, building materials, road materials become main utilization route.

Because of using hot pouring processing，the free calcium oxide (f-CaO) in the slag cannot be completely dislodged. The slag volume expands 98% when meet with water so that the building materials, building or road cracks would happen. It results in that the steel slag utilization rate is lower than 10%.The present situation of slag’s occupying area, polluting the environment, wasting resource are needed to change urgently. With the development of modern large-scale converter steelmaking, it is necessary to meet the requirements of rapid dishing, safety, clean production and rapidly dislodging the f-CaO in the slag so that the stability of steel slag would be improved. Central Research Institute of Building and Construction took the lead in studying steel slag heat pyrolytic pulverization technology in 1994. After technical innovation, the molten slag, semi-solid slag and solid slag apply since the antipyretic boring technology to meet the fast modern steelmaking slag requirements.

The unstable of slag mainly due to the f-CaO in slag turns into $Ca(OH)_2$ when the slag meets water and the volume expands 98%.The f-CaO content in the slag is generally 3.80% to 7.64% (Table 4).

Table 4 Chemical composition of the slag (in wt %)(Alkalinity=$\frac{CaO}{SiO_2+P_2O_5}$)

Species / Composition	Dephosphorization slag	Convention converter slag	Decarburization converter slag
SiO_2	13.56	15.34	14.78
Al_2O_3	3.17	5.16	3.54
CaO	58.21	43.22 	40.2
MgO	1.59	7.78	8.1
FeO	8.12	8.12	9.21
Fe_2O_3	8.95	9.18	10.11
MnO_2	0.69	0.81	1.11
TiO_2	1.48	1.21	0.98
P_2O_5	2.88	1.8	1.1
f-CaO	4.6	7.64	3.8
Alkalinity	3.54	2.52	2.53

Figure 1 the lime in the steel slag

Because of the time of steelmaking slag formation is shorter, the excessive input of lime, the lime and saturated slag are wrapped. (Figure.1) Dead-burned lime is generated when lime contacts with slag and it generally contains FeO in it. The cement has a compact structure and its activity is very bad， and the rate of hydration is very slow.

The C_3S in slag decomposes at high temperature as $C_3S \rightarrow C_2S+CaO$, and f-CaO is generated. The f-CaO turns into $Ca(OH)_2$ when meets water and the volume expansion results in the unstable of steel slag.

Kinetic theory shows that the hydration can be accelerated under certain temperature and humidity. The gas-solid reaction model of f-CaO and water vapor, the reaction rate and water vapor pressure P_{H2O} have been studied.

The actual P_{H2O} in hot stuffy device is 100% and the P_{H2O} in the air is 3%～4%. Hot stuffy reaction speed is 25 to 30 times to hot pouring processing, so heat pyrolytic treatment time is 8～12h under the condition of saturated vapor. After 8h heat pyrolytic treatment, the f-CaO in the slag is cleared up. The effect equals to 200h-240h hot pouring processing.

Determined by the principle of the heat pyrolytic technology and the test of the relationship of stability and pulverization rate with spraying water amount, the slag temperature, steam pressure, the ratio of slag and water, sprinkler system, Pyrolytic treatment time, the process flow diagram and main parameters (Table 5) can be determined. The process flow diagram of heat pyrolytic production technology (Figure.2) has been proposed to guide the production of application unit.

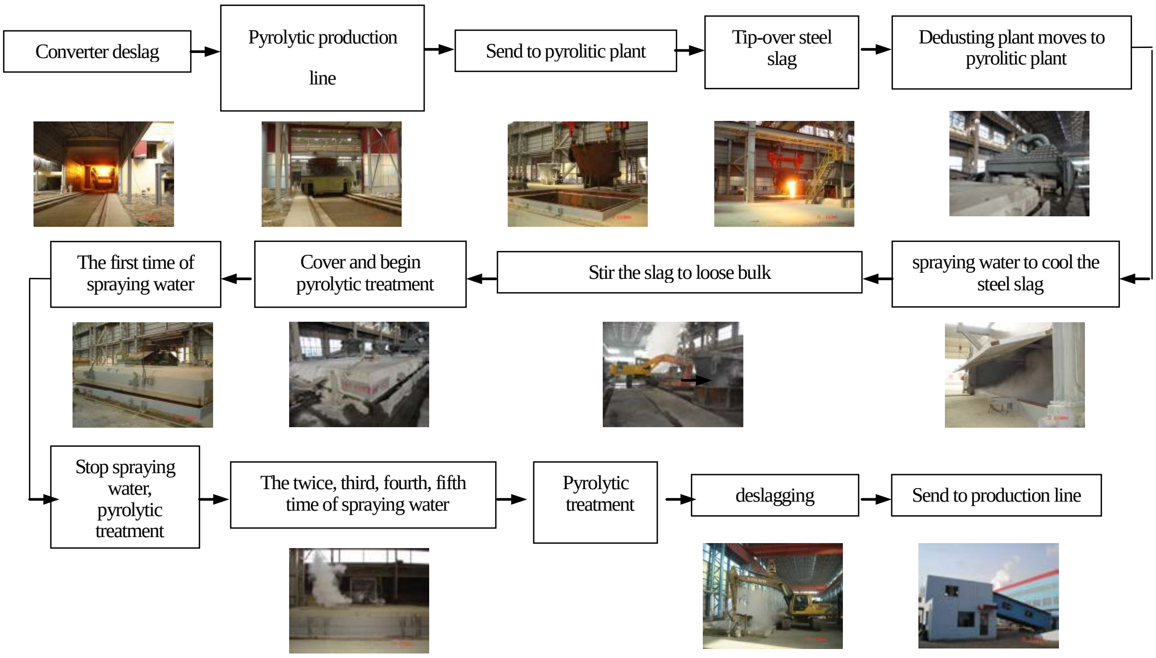

Figure.2 The Process Flow Sheet Diagram of heat pyrolytic pulverization technology of steel slag

Table 5 Main parameters of process

The ratio of slag and water	Pyrolytic treatment pressure (kPa)	Saturated vapor temperature(℃)	Pyrolytic treatment time (h)	Expansion rate after retting (%)	Pulverization rate<20mm (%)	Water content (%)
1：1.3	2.4	105-108	8-12	<1	>60	6-8

The technology enables the f-CaO in slag digests in a short time and becomes stable. Therefore the slag can be 100% resource utilized. It results in a high chalking rate and good separation of slag and steel to improve the metal recovery rate. Clean production is achieved and the slag can be excluded without pollution and waste water. The technology has been promoted to apply in 28 enterprises such as Shougang Jingtang steel, Angang Bayuquan new steelmaking, Benxi Iron and Steel, TISCO etc. Great economic, environmental and social benefits have been achieved.

3.2 The processing, purification, metal recovery technology of steel slag

In the process of steelmaking, slag is on the surface of molten steel. Molten steel could be splashed and then wrapped up together with slag. The slag cannot be fully separated. In order to recover the steel in the slag, many slag enterprises adopt the separation process crushing or magnetic. Though bulk scrap steel can be recycled, it cannot solve the problem of fully separating the steel and slag. The separated slag generally has a low TFe grade of 60%-70%. The magnetic powder with a 40% TFe grade can be directly returned to steelmaking plant. So, the energy consumption is high. The tailings with a high iron content (> 4%) cannot be used and lead to a resource wasting. Although wet grinding and wet separation process allow magnetic powder grade increasing to a level higher than 60%, after the election, more than 90% of the tailings appears a slurry form. It is difficult to handle and comprehensive utilized, resulting in an environmental pollution.

According to the fragmentation theory, the characteristics of the rod mill is the line contact between media and material in the process of grinding, thus it has a certain selective grinding effect. The crushed material has the function of broken and peeling effect. After studying the steel content of different granularity slag and the wrapping status of steel and slag, dedicated dry rod mill is designed and developed. Slag grindability tests have been conducted according to standard Bond grindability test procedure and the indexes have been obtained. The efficiency coefficient in the Bond basic equation was introduced to calculate the power consumption of the grinding unit, gear input power, the transmission efficiency, the motor power, mill diameter and length, granulating rate and steel bar load etc. The material inlet has been designed as hollow shaft inlet with the consideration of the large particle size of slag and iron content. The feed equipment can be inserted into the rod mill and open 4 to 6 discharge ports on the tube wall according to the mill diameter size. After application, the effects of steel slag purification and metal recovery have been achieved.

The slag crushing purified rod mill has the following innovation points:

a. An increased size of the rod mill feed inlet can meet the requirements of different particle size of steel and slag.

b. The surrounding layout has the advantage to control the particle size and purity of steel slag. According to the slag particle size, moisture and handling capacity, the size, quantity and arrangement of discharge port can be determined.

c. The material of rod mill grinding has a moisture-content as high as 12.5%. Thus it will not be adhered to the bar or clog the discharge port.

d. The curvature and angle of the liner have been determined after calculation. The lifting height of steel bars meet the requirements of improving grinding efficiency, reducing the vibration of the rod mill and extending service life.

The steel slag processing, purification and metal recovery processing technology that taking rod mill technology as core has been proposed. The magnetic purification process of steel slag is shown in Figure 3. This technology takes the place of the intrinsic technical of multi-stage crushing, magnetic separation and screening process.

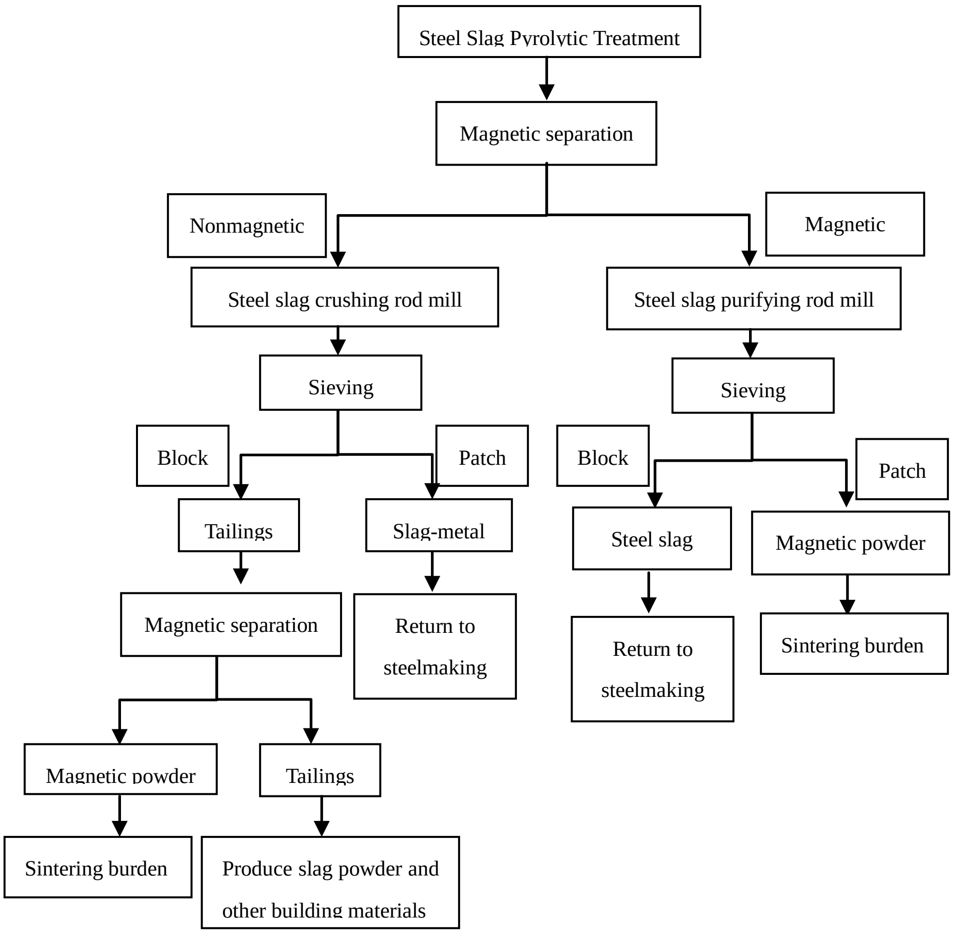

Figure.3 The magnetic purification process of steel slag

The implementation of the technology in more than 30 enterprises has achieved remarkable results. High-grade steel slag (iron grade greater than 85%) and the magnetic powder (Fe grade greater than 60%) can be got and then be returned directly to the steel-making and sintering sectors. It improves the value and rate of resource utilization. The iron content of the tailings is less than 2% and it can be used to produce steel slag powder, slag cement, building materials and road materials. Then the slag resource 100% utilization can be achieved.

3. 3 Steel slag cement

The Portland cement mixed with steel slag powder can be used to produce slag Portland cement, low heat slag cement, slag road cement. This type cement has the advantages of low heat of hydration, good wear resistance, good corrosion resistance, good penetration resistance, and higher later strength.

Electron microscopy, X-ray diffraction and EDS analysis show that the main mineral composition of slag are tricalcium silicate (C_3S), dicalcium silicate (C_2S), olivine (CMS), rose pyroxene (C_3MS_2) and RO-phase (divalent metal Mg^{2+}, Mn^{2+}, Fe^{2+} etc oxides melted in solid). Mineral composition is shown in Table 6.

Table 6 Mineral composition of steel slag

Alkalinity	C_3S	C_2S	CMS	C_3MS_2	RO	Main minerals
2.73	30~35	20~30	5~10	10~20	15~20	C_3S、C_2S、C_3MS_2、RO
2.20	10~15	30~40	15~20	15~20	15~20	C_2S、CMS、C_3MS_2、RO

The steel slag contains cementitious property minerals tricalcium silicate C_3S and dicalcium silicate C_2S. The content is more than 50%. It can be regarded as the Portland cement clinker. The formation temperature of steel slag is 1600℃-1700℃. It is 200℃-300℃ higher than cement clinker. Therefore the steel slag is called "burnt Portland cement clinker". The difference between steel slag and cement clinker is in the features of C_3S and C_2S. The difference between them is that the C_3S and C_2S in the steel slag have compact structure, thick crystal and a few other minerals.

When the alkalinity of the steel slag ($CaO/SiO_2+P_2O_5$) is 0.78-1.8, the main minerals are CMS (forsterite), C_3MS_2 (manganolite). When the alkalinity is 1.8-2.2, the main minerals are C_2S (dicalcium silicate) and RO-phase (Divalent metal oxide solid melt). When it is above 2.2, the main minerals are C_3S (tricalcium silicate), C_2S and RO-phase.

The steel slag was started to use to produce cement in the 1970s in China. It has been used about 50 million tons up to now. Steel slag cement is mainly used in industrial and civil buildings, large reservoirs, airport runways, bridges and other construction works. The application history is more than 40 years. (Figure. 4-7)

Figure.4 The Gangnan Reservoir in Hebei Province built by steel slag cement

Figure.5 the Residential building built by steel slag cement

Figure.6 the whole construction of Handan Steel Rolling Mill was completed by steel slag cement

Figure.7 Wave attenuation frame built by steel slag cement

At present, Taiyuan Shuangliang Cement Company, Xinjiang Tunhe Cement Company, Wuhan Green Building Materials Company all produce steel slag cement.

3.4 The production of steel slag used in concrete construction work

In 1996, on the basis of in-depth study on steel, we could stimulate the activity of the ISS by machine. The steel slag with 400m^2/kg fitness could be used in concrete as a replacement of 10%-30% cement. The steel slag concrete can be used in construction projects. It can improve the late strength of concrete and reduce the heat of hydration of concrete to decrease cracks. The replacement can improve the workability of concrete such as wear resistance, freezing resistance, corrosion resistance, etc. The cost of slag powder is 30% lower than cement. Therefore the project cost can be reduced.

The national standard of “Steel slag powder used for cement and concrete” (GB/T20491) drafted by Central Research Institute of Building and Construction has been implemented. Promoting the production of steel slag and GISS powder has been included in the national "12th Five-Year Plan”. 10 demonstration projects regarding GISS powder will be built. Steel slag powder will be the best high-value utilization pathway of steel slag.

Up to now, Rizhao, Wuhan, Hangzhou, Jiujiang, Xinyu have built production plants for utilization of steel slag powder. Slag powder has been widely used in industrial and civil buildings.

From 2001 to 2002, Shanghai Municipal Engineering Research Institute applied the concrete mixed with steel slag powder in the projects of Matou Bridge, Qihou Bridge and Xiabaishi Bridge in Fujian Province the Funing highway A19 tenders. The total length of Xiabaishi Bridge is 384.6m. The main bridge is 145m+2×260m+145m four-span continuous prestressed structure and the approach is 3×45m+30m continuous T-beam. The slag concrete applied in the projects had a cement amount of 450kg/m^3, a steel slag amount of 55kg/m^3 and a 39% sand rate. Xiabaishi Bridge adopted the construction means of irrigating ready-mixed concrete. The engineering application shows that the 28d compressive strength of concrete mixed with slag powder is 52MPa. It meets the design requirements of C45 concrete.

Figure.8 Xiabaishi Bridge built by steel slag concrete

Figure.9 Nantaizi Lake Bridge built by steel slag concrete

Figure.10 Wuhan Gymnsasium built by steel slag concrete

3. 5 Ground iron and steel slag powder is the best admixture of concrete

Steel slag powder as concrete admixture can improve concrete strength, improve the workability of the concrete mixture and improve the durability of concrete. But due to the BFS powder’s low alkalinity, large dosage will significantly reduce the liquid pH value in concrete phase and destruct the passivation velum of the rebar in the concrete (if pH<12.4, it is easy to damage). It results in the corrosion of the reinforced concrete.

In addition, BFS is a kind of vitreous body with main component of C_2AS and C_2MS_2. It can generate $CaCO_3$ when acts with the CO_2 in the air. It results in worse wear consistence and serious sandy condition on the surface.

The main components of slag are C_3S, C_2S, CRS, C_3RS_2, CFS and RO-phases. Steel slag as concrete admixture has low early strength, but it has the advantages of good wear resistance, good penetration resistance, and higher later strength. The GISS powder is intermodulation and has better performance. It is the best solution for concrete admixture.

3. 5. 1 The improvement of the strength of concrete by ground iron and steel slag powder

Table 7 Relation between content of blast furnace slag powder and steel slag powder and concrete compressive strength

Number	The amount of concrete materials (kg/m^3)			Water reducing agent JG-2(%)	The cement amount replaced by slag powder(%)	The ratio of water and binder	Sand coarse aggregate ratio (%)	Slumps cm	Compression strength (MPa)	
	Cement	Slag powder	Water sand stone						7d	28d
1	480	0	144 764 1012	1.2	0	0.30	43	0	65.4	71.4
2	384	96	144 764 1012	1.2	20	0.30	43	1.0	70.6	82.3
3	360	120	144 764 1012	1.2	25	0.30	43	1.5	69.8	81.5
4	336	144	144 764 1012	1.2	30	0.30	43	1.5	66.4	78.6

We can get the following conclusions from Table 7:

(1) The concrete replaced 20%, 25% and 30% cement by ground iron and steel slag powder have better 7d and 28d strength. C70 concrete can be made up. It is a strength grade higher than C60 concrete at the same mix proportion.

(2) At the same mix proportion, the concrete made up by ground iron and steel slag powder has better 7d and 28d strength to the concrete made up by single BFS powder or steel slag powder.

(3) The slumps of concrete made up by ground iron and steel slag powder increases.

The strength of induration concrete depends on the strength of aggregate，the cement slurry after induration and the interface between cement slurry and aggregate. The strength of the cement slurry after mixing ground iron and steel slag powder depends on the particle accumulation and bonding situation. The differences of particle accumulation form will result in different porosity. One of the reasons of better concrete strength after mixing ground iron and steel slag powder is due to that the steel slag powder fitness is $400m^2/kg$. It has the function of material accumulation and reducing the porosity. Therefore the strength increases.

In addition, the fitness, hydration rate and high hydration degree of BFS powder and steel slag powder are important factors to improve the strength of concrete. If the cement is replaced too much by slag powder, the strength is lower than pure cement concrete. The main reason is that the hydration of slag powder as vitreous body and the main mineral component of steel slag powder is C_2S. Both of their hydration strengths are worse than the C_3S in Portland cement. The strength of ground iron and steel slag powder is higher than only one kind of the powder.

The hydration process of C_3S and C_2S produces more CHS gelatin and $C_5S_6H_5$ (Tobermorite). It has the function of expansion and enables the slurry more compact structure. Therefore the strength of concrete is increased.

3. 5. 2 The good durability of the ground iron and steel slag powder concrete

The main hydration product of slag powder is $C_5S_6H_5$, whose carbonation rate is slower than CSH (B). After carbonization, the strength is increased by 50%.

At the same time, the hydration of C_2S and C_3S in the slag powder releases $Ca(OH)_2$ rather than absorbs $Ca(OH)_2$, the liquid pH value will not become lower or destruct the passive film on the steel surface.

4. The change in the pattern of investment operations of iron and steel slag comprehensive utilization

There were two processing and operating ways in China formerly: built and operated by metallurgical enterprises; built and operated by township metallurgical enterprises, individuals or the private sectors.

The drawbacks of the above two ways are: construction and operation costs were paid by metallurgical enterprises and the management responsibility is unknown. It affected the advancement of enterprises' technology. If built and operated by township metallurgical enterprises, individuals or the private sectors, it is short of talents of environmental protection and resource utilization. It is hard to manage the establishment reasonably and pollute environment seriously.

The effective method is to manage the smelting slag processing and resources by professional environmental operations.

Along with the expansion of production ability of metallurgical enterprises and the constant depth of national energy saving work, the pressure of reasonable solid waste disposal and resource utilization is bigger and bigger. China Metallurgical Group Co., Ltd. began to try a new business mode of making use of advantages of capital and technology to invest metallurgical enterprises of solid waste utilization projects and achieve long-term operation and management. Now preliminary results have been achieved.

Since 2008, Central Research Institute of Building and Construction has generalized steel slag "zero emission" technology by EPC and BOO mode, and signed framework of agreement of investment operations and environmental operations with Xinyu Iron and Steel Company, Ping steel Jiujiang Iron and Steel Company, Tianjin Seamless Steel Tube Company, Guangdong Zhuhai Yueyufeng Iron and Steel Company, Panzhihua Xichang vanadium titanium steel company, Baosteel Zhanjiang steel base. Central Research Institute of Building and Construction has formed professional operating companies with professional and experienced management to guarantee the steel slag "zero emission" and meet the requirements of environmental protection. It is easy to manage and control the environmental protection departments at a higher level. The structural adjustment ensures the utilization of steel slag.

In recent years, the "zero emission" technology has been widely promoted. More than 40 enterprises have built Pyrolytic production line and have treated more than 31 million steel slag in total. More than 6 billion output value has been achieved and 496 thousand tons of iron has been recycled. After treatment, the steel slag with good stability can be used to produce slag powder. The technology leads and formed emerging markets and industrial chain of scrap steel recovery and steel slag products. So that the utilization rate of steel slag in China has increased to 25 percent from 10 percent in three years. It promotes the slag utilization process.

5. The establishment of steel slag comprehensive utilization standard system

Tightly around the steel industry development plan and regarding the standard system as a breakthrough, National Steel Standards Commission promotes the utilization of steel solid waste resource. Since 2005, National Steel Standards Commission has began to organize China metallurgical information and standardization institute and Central Research Institute of Building and Construction to carry through the research of the comprehensive utilization and resources standardization work of iron and steel industry solid waste. They enact the standardization system and revise a series of relevant standards. In addition, they standardize the market speculation of steel solid waste industry and promote its "zero emission". Since then, the standards of steel slag resource comprehensive utilization basically formed series standards (Table 8). In the future, strengthening the basic standards and standardized criteria should be focused on to meet the needs and provide the basis for steel slag resource utilization. Therefore the enterprises can benefit more and stay a virtuous circle for ISS waste resource comprehensive utilization. It will provide technical support for comprehensive utilization.

Table 8 Series of standards of ISS

Species	Serial number	The denomination of standards	Serial number
The standards of product	1	Portland steel slag cement	GB 13590-2006
	2	Steel slag powder used for cement and concrete	GB/T 20491-2006
	3	Low heat Portland steel slag cement	JC/T 1082-2008
	4	Steel slag cement for road	JC/T 1087-2008
	5	Steel slag masonry cement	JC/T 1090-2008
	6	Steel slag cement for road	GB 25029-2010
	7	Low heat steel slag and blast furnace slag cement	To be issued
	8	Ground iron and steel slag powder	To be issued
	9	Steel slag sand for road	YB/T 4187-2009
	10	Granulated blast furnace slag powder used for cement and concrete	GB/T 18046-2008
	11	Crushed air-cooled blast furnace slag for concrete	YB/T 4178-2008
	12	Silicon-manganese slag powder used for cement and concrete	YB/T 4229-2010
	13	Lithium slag powder used for cement and concrete	YB/T 4230—2010
	14	Steel slag used for cement	YB/T 022-2008
	15	Steel slag for engineering backfill	YB/T 801-2008
	16	Steel slag for metallurgical furnaces chargings	YB/T 802-2009

	17	Steel slag for road	GB/T 25824-2010
	18	Steel slag for concrete perforated brick and concrete pavior brick	YB/T 4228-2010
Basic standards	19	Terminology for iron slag, steel slag, treatment and utilization	YB/T 804-2009
Method standards	20	Test method for stability of steel slag	GB/T 24175-2009
	21	Chemical analysis methods of steel slag used for cement	YB/T 140-2009
	22	Test method for the contents of magnetic metallic iron in steel slag	YB/T 4188-2009
	23	Test method for the content of total iron in steel slag	YB/T 148-2009
	24	Test method for grindability of slag	YB/T 4186-2009
	25	Test method for particle size distribution of slag powder - Laser diffraction method	YB/T 4183-2009
	26	Test method for the metal content in stainless steel slag	YB/T 4227-2010
Criterion	27	Technical specification for application of ground iron and steel slag powder concrete	Formulating
	28	Technical specification for application of mineral additive	Formulating
	29	Construction technical specification of steel slag mixture used as road base	YB/T 4184-2009
	30	Technical specification of tailings mortar	YB/T 4185-2009

6. Social and economic benefits of iron and steel slag resource utilization

6. 1 Social benefits

Resource utilization of steel slag firstly carries through slag stabilization treatment to achieve the recovery of most metal iron in the slag and 100% utilization of tailings. Therefore it will occupy less land and save energy and increase the comprehensive utilization rate of steel slag. It is the major technical support to complete the “12th Five-Year Plan”.

To metallurgical enterprises, except the scrap steel recovery, tailings can be used to produce steel slag powder as concrete admixture and other building materials. It can form chain of waste slag resource utilization, new industrial growth point, create more employment and promote regional economic development.

6. 2 Economic benefits

After achieving the goals of “12^{th} Five-Year Plan”, if 70% of steel slag adopts the pyrolytic production and steel slag powder technology, the results described in the following subsections can be concluded.

6. 2. 1 Scrap steel recovery

90.42 million tons of steel slag was produced in 2011. If 70% of slag adopted this technology, 63.29 million tons could be treated. Therefore 1.31 million tons of scrap steel (TFe≥90%), 2.21 million tons of steel slag (TFe≥85%) and

9.81 million tons of magnetic powder (TFe⩾60%) could be recovered.

6. 2. 2 Take up less land and save sewage charges

If heap 10 thousand tons of residues will occupy 0.5 acres, 3165 acres can be saved.

6. 3 Promote energy conservation, low-carbon economic development

The steel slag after stable treatment can be used to produce steel slag powder as cement and concrete admixture by low consumption mill device. The product in accordance with “Steel slag powder used for cement and concrete” (GB/T20491-2006) is promoted to apply. Steel slag powder can replace 20%-30% cement to prepare concrete and it can improve the performance of late strength and wear resistance.

The tailings of 60% steel slag after metal recovery can be used to produce 63.29 million tons of steel slag powder.

6.3. 1 The energy saving by using steel slag powder in cement production

Power consumption of the production of one ton of steel slag powder can save 60KW•h compared to produce cement. Therefore produce 63.29 million tons of steel slag powder can save 38.0 billion KW•h power consumption what equals to 1.53 million tons of coal. Slag powder can save 121kg clinker coal consumption per ton compared to the cement production. 63.29 million tons of slag powder can save 8384 thousand coal.

6. 3. 2 The resource saving in the consumption of resources

Replacing cement by steel slag can save the limestone and clayey used in cement production. It consumes 1.1 tons of limestone and 0.18 tons of clayey to produce one ton of cement. Therefore producing 63.29 million tons of steel slag powder can save 69.61 million tons of limestone resource and 11.39 million tons of clayey resource.

6. 3. 3 The reduction in CO_2 emission

Cement production requires a large consumption. It consumes 0.12 tons of coal and 110 KW•h of power. Huge energy consumption means a vast CO_2 emission. It discharges 0.815 tons of CO_2 to produce one ton of cement.

The production of 63.29 million tons of steel slag can reduce 51.58 million tons of CO_2 emission and contribute to energy saving.

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