The Research Progress on the Steel-slag Resource Recovery Utilization

Canhua Li[1,2,a], Lixin Jiao[1,b],Xiaodong Xiang[2,c], Si Liu[1,d]

[1]Research Center of Metal Resource Ltd., Company of WISCO, Wuhan, 43008, China

[2]Hubei Key Laboratory for Efficient Utilization and Agglomeration of Metallurgic Mineral Resources, Wuhan University of Science and Technology, Wuhan, 430081, China

[a] 15827551838@163.com (corresponding author) [b]xinrui@126.com, [c]drxxd@163.com, [d]crystal850607@163.com

Abstract. Steel-slag is a by-product in steel making and was abandoned in the long term.The resource recovery utilization for steel-slag can bring huge economic, environmental and society benefits, and it is one of the important items in circular economy. In the article, we analyze the physical & chemical performances and expensive mechanism, and review the actuality and progress; we conclude that the steel-slag has a great potential in China.

Keywords: Steel-slag; resource recovery utilization; progress

1. Introduction

The product rate of steel-slag is 10 times than rough steel. As an abandoned waste, steel-slag will occupy the fields and pollute the environment. In order to adapt the development of steel industry, the problems of steel-slag utilization is put up to schedule and reached obvious achievements and clear up the damages caused by steel-slag.

2. The basic appearances of steel-slag

2.1 The physical appearance of steel-slag.

Steel-slag looks like the caking cement with black outlook and high hardness and some steel particles inside, the density is 1.7-2.2 g/cm3. The steel-slag is composed with the oxide from melted iron and Al,Si,Mn and other elements from wasted steel; the materials with sand, and slag forming such as calcareousness and fluorite; oxidants or coolant such as iron ore, sinter and iron oxide scale; the corroded materials of liner materials; the alloy used for deoxidation and desulfation can also be the resource of steel-slag.

2.2 The chemical appearance of steel-slag.

The main chemical components are: CaO, SiO_2, FeO, Al_2O_3, MgO and others, and the components are basically stability. The main mine components are FeO·SiO_2, 2CaO·SiO_2, 3CaO·SiO_2, 2CaO·Fe_2O_3 and f-CaO.

3. The steel-slag expansive mechanism

Steel-slag has an aging process, and it is the key process in steel-slag treatment and application. In the late stage it appears to be expansive and powering.

The hydration of free calcium oxide is the main reason for steel-slag expansion and it is admitted in the public. There is too much calcium oxide in steel-slag and it can be created calcium hydroxide which makes the volume expansive. But Feng T. considered that not only the creation from free calcium oxide but also the calcium hydroxide itself makes the steel-slag expansion. In the initial stage, it will create non-shaping or minor lenses calcium hydroxide and then grow up which makes the whole volume expended [1].

For converter, the steel-slag contents too much f-CaO with low alkalinity. RO is a phase with matrix of FeO.MgO is mainly contained in monticellite and merwinite.FeO in steel-slag will be expanded because of oxidation and hydration.Some documents thought Fe^{2+} effected the hydration

activity a lot[2]. Tang M.S. considered that the RO phase will not expanded and it will not effect the hydration in high temperature[3]. The research causes widely issues and Ye G.X. thought RO can be divided into two parts depended on Km=MgO/(FeO+ MnO)[4]. Km>1 will cause expansion while Km<1 will not.Kondo Renichi considered when MnO in RO reached up to some extent can inhibit the expansion[5].

4. The progress of steel-slag application

Steel-slag resource recovery utilization is an extremely complex problem and refers to widely area. There are 7%-10% steel in steel-slag and 90% of this can be recycled and it is only recycled before. Now, as a second resource it is widely used in road project, building materials, agricultural fertilize and chemical materials.

4.1 Reuse in metallurgy.

Reuse of steel-slag in metallurgy includes agglomeration, blast furnace and steel-making. The easiest way of steel-slag reuse is to be a material in steel-making in steel company.The big countries of steel-making insist on steel-slag to be flux and which takes a high proportion. The efficiency is 56% in USA,24% in Germany and 19% in Japan.The method can recycle residual steel,Fe_2O_3,CaO,MgO,MnO and other beneficial components.It can improve the quality and quantity.But in the process, we should pay attention to the problem of P.The application of steel-slag reuse in BISCO started in 1996 and now it stays in the high level of 150 thousand t/a. in the converter, every ton of steel will use 25kg steel-slag.

4.2 Used in the cement production.

Because the steel slag, similar with the cement, contains some active minerals such as C_3S, C_2S and calcium ferrite, is the waterhard gelatinous, therefore it may be the raw material used to produce the non-clinker cement or the few clinker cement, also it may be the mixture of the cement. The steel slag being used in the cement production can reduce the energy consumption effectively and the greenhouse gas effect. China started to develop and product the steel slag cement in the 20th century 60's. China has drawn up the corresponding national standard and the profession standard. The steel slag cement not only has same physics mechanics performance as the iron slag cement, but also has many fine performance such as low hydration heat, wear-resisting, anti- frozen, anti-corrosive, high intensity and so on. Zhu G.L. put forward the study on high marking steel slag cement， the steel slag fine powder and the iron slag fine powder used as a kind of blending material for cement in 1999[6]. When we use the steel slag as the blending material of the cement, we generally mix the gypsumor or other alkalinities stimulation into the cement. According to the research,it is obvious to enhance the steel slag cement early strength when using gypsumor as stimulation[7].When the steel slag's surface area achieve to 400 m^2/kg,it has very high activeness, and may be used as one high activeness mixing material. When the cement mixed with the thinner steel slag, the compressive strength t of his cement will be bigger, because the bigger relative surface speed the hydrating speed. The concrete mixed with the steel slag fine powder have the good later period stability[8].When the steel slag powder degraded to some fineness , the free CaO and MgO are activated, take part in the early time hydration response of the cement, so the concrete mixed with the steel slag fine powder cannot be destructed [9].

4.3 Application in the road engineering.

Application in the road engineering is one main comprehensive utilization way for the steel slag. The European countries and American have approximately 60% of the steel slag used in the road engineering. The degree of hardness and the grain shape of the steel slag crushed stone suit to the path material the request very much. The steel slag may use in the path basic unit, the breaker strip and the surface layer.

4.3.1 The lime-fly ash steel slag road basic layer.

The lime-fly ash steel slag road basic layer may completely not use the cement, because of the steel slag's gelatine,thus it can reduce sub-grade treatment expense, also may enhance the intensity of basic layer, reduce the roadbed thickness. It's an innovation in the road engineering construction. The

lime-fly ash steel slag road basic layer has good board character, the water stability, high mechanics intensity. Chosen the best proportion and the optimum water content of the lime-fly ash steel slag road basic layer, its 7d limits compressive strength without the side can possibly achieve 1.42Mpa,CBR 80%-110%,the snapping back module (2122-2299)MPa,the inflation 1%, completely satisfies the request of the standard.

4.3.2 Wear-resisting material for road surface.

Under the wheel repeatedly abrasion, the non-skid property of the concrete pavement gradually expires, thus the road surface become the hidden security danger. In order to have the road surface to be the certain anti-slippery performance, we can use the steel slag as the concrete pavement aggregate, or prepare the concrete mortar using the steel slag.

4.3.3 Asphalt concrete aggregate.

The domestic and foreign research indicated that, some steel slag mechanics performance are better than the crushed stone's: not only wear-resisting, grain shape and natural gradation good, but also good adherency with the asphalt.The steel slag covered with the bitumen does not inflate,its calorific value high,is suitable very much for the bituminous mixture used to lay the road surface. After all, the steel slag must adsorb more asphalt compared to the crushed stone.Ding Q.J. conduct some application study on the steel slag used as the asphalt concrete aggregate[10]. His research showed that the steel slag was one kind of good aggregate used in the first-class highway, because its each performance index could achieve the standard request. Having good volume stability and high mechanics performance, it is supposed to be used in the first-class highway surface layer, its best oil mass is 5.24%.

4.4 Used in backfilling the ground and reinforcing the soft soil ground.

Using the steel slag in backfilling the ground,We must primarily control inflation performance of steel slag in the ground.It is long-term for the steel slag to inflate, mainly concerns with its physical & chemical properties.Majority of the steel slag may already complete the expansion process, when them piled up a year above.The steel slag of below 200mm, was allowed to use as the backfill material,after 8 months it become stable.The ground sinks generally very much in the backfill project.but it is advantageous to the project for reducing the ground sinking,when using the steel slag. Avoiding the ground the non-uniformity sinking,we must pay attention to the uniformity of laying down the steel slag.

In recent years the domestic steel slag has already large-scale applied as the backfill material. Composite foundation of steel-ash pile is a new type method of ground improvement.On the basis of testing mechanics special property of steel-ash, the values of shear strength and compressive strength as well as single axial compressive strength were obtained. Action mechanism of steel-ash composite foundation were studied before and after self-coagulating.It is concluded that composite foundation of steel ash pile is similar to gravel pile composite foundation and deep mixing method of cement soil, and is effective in the improvement of soft foundation.The above technology once was used in the third issue construction project of the Baoshan Steel Corporation and the Shanghai Pudong international airport construction.

4.5 Agriculture application.

The converter slag contains massive element beneficial to the plant growing such as Si,Ca,Mg,P,moreover,the content of the majority harmful elements of steel slag conforms to the related agriculture standard request, thus it is suitable for the steel slag used to produce the agricultural fertilizer.The steel slag have different applications according to the content of the different element.The agricultural application of the steel slag began at the end of 50's of the 20th century or the beginning of the 60's in china.

4.5.1 Used as soil ameliorations.

The converter steel slag may be used as the acid soil ameliorations, because it contains high calcium,the magnesium. Regarding the acid soil,the long-term employment lime can cause calcium,magnesium,potassium and other elements unbalanced,reduce the activity of magnesium and the validity of the fertilizer.The steel slag used as ameliorations for acid soil may take better effect than the lime, because it contains a quota of soluble magnesium and phosphorus.

4.5.2 Used as phosphate fertilizer.

When steel-making with the high phosphorus molten iron, we can prepare the steel slag phosphate fertilizer with the converter steel slag obtained from the slag-making not adding the fluorspar.The phosphorus in the steel slag does not nearly dissolve to the water, but has a better citrate solubility, may be absorbed by the plant when dissolved under the plant root's weak acid environment.The steel slag phosphate fertilizer is one kind of citrate-soluble fertilizer.The steel slag phosphate fertilizer not only employs the good effect in the acid soil, but also in the soil lacks the phosphorus, and also in the paddy field and the dry farmland.

4.5.3 Used as silicon fertilizer.

The silicon is the necessary element for the paddy rice growing, and may sharpen its anti- disease and anti-insect's ability. The converter slag, in which SiO_2 surpass 15%, can be used as the silicon fertilizer for the paddy field when degraded in size below to 60 item. the silicon in the converter slag is citrate-soluble, the citrate-soluble rate of it may achieve above 80%. According to the result of the related cultivation test, the paddy rice production employed the steel slag silicon fertilizer can enhance 12.5%-15.5%.

4.5.4 Used as silicon potassium fertilizer.

Production slowing release silicon potassium fertilizer with the steel slag,was one kind of emerging technology of the steel slag resource utilization in the recent years.Its production craft is:When kill off silicon processing for the molten iron,put the potassium carbonate continuously into the molten iron package, and melts it into the slag in the nitrogen, the slag escapes silicon processing after cooling and pulverizing become the silicon potassium fertilizer[11].The percentage of K_2O in the synthetic inorganic silicon potassium fertilizer may achieve above 20%.The fertilizer is in the glass condition and the crystal condition,the crystalline state matter mainly is $K_2Ca_2Si_2O_7$.This kind of fertilizer is difficult to dissolve in water,but may dissolve in like weak acid such as citric acid,is one kind of the slow release fertilizer.

4.5.5 Used as the trace element fertilizer.

With the chemical fertilizer employment technology developing, the restrictive factors for the crops growing have already transfers from the nitrogen phosphorus potassium to the zinc,the manganese,the iron,the boron,the molybdenum and other trace elements,we realize the importance of employing the trace element fertilizer gradually.There are many iron,manganese and other trace elements beneficial to the crops in the steel slag.The steel slag, added the zinc, boron,molybdenum and other mineral fine powder into the melted slag in the high temperature,formed into the slow releasing compound trace element fertilizer.

4.6 Application in waste water processing.

The waste water pollution is an extremely serious environment problem.the waste water and the waste residues are harm seriously to humanity's survival and the healthy in mind and body,through the water,the soil,the air,in particular the food chain.In recent years,some people process the waste water with the steel slag,achieved"to waste governed waste"the goal.Li C.H.[12] prepared flocculation PFSS with the steel slag and the iron slag, the product had some merits:little the purifying agent,the non-toxic side effect, good coagulation effect,high rate for Removing the turbidity,widely used in purifying the waste water from the iron and steel enterprise and the papermaking,the printing equipollent pollution production waste water as well as the sanitary sewage.

The adsorption processing method, as one important chemical& physical method, had applied in waste water processing.Chinese scholars separately studied the steel slag’s adsorption behavior used as absorbent processing nickel[13], lead[14], copper[15], chromium[16], arsenic[17], phosphorus[18] and so on in the intermediate stages of 1990s.The research indicated, the removing rate of steel slag absorbent to heavy metal is all above 98%, but we must strictly control response temperature, pH, degree of fineness of steel slag,and reaction time.Moreover,the steel slag absorbent industrialization still had to conduct thorough research at the steel slag containing ferrous and non-uniform granularity.

4.7 Chemical application.

The haul distance may affect the application in the construction or the road engineering,therefore more and more experts now put in their attentions the steel slag utilization in chemistry domain. At present someone develop white carbon black,silica gel with the steel slag,because of the steel slag richly containing the silicon.someone develop kinds of plumping agents including the expanding cement, because the steel slag contains f-CaO which have a small inflation in the later period.

4.8 Application in decoration project.

Because the steel slag concrete has great intensity and certain colors, therefore some factories developed steel slag artificial stone and the man-made antiquity building material.They are used in the decorates wall,the man-made sculpture,the man-made inorganic chair in large-scale park outside. According to the physical &chemical characteristic of the different steel slags, BISCO had many emerging architectural engineering examples using the wear-resisting grounds and so on.Someone prepared the calcium, the magnalium, the silica glass ceramics using the steel slag as the raw material with and adding modifiers.The glass ceramics can serve as the wall material, the building ceramics, pipeline, the vessel, the material trough, the shell and other components replacing the cast iron. It has high intensity, light weight, good thermo stability, is advantageous to the environmental protection [19].

It is completely feasible that we prepared steel slag ceramic material with the thermal state steel slag resources technology directly.It may save the massive energy and the expense of the raw material, reduce the production cost greatly.The performance of the steel slag glass ceramic material greatly enhances because we may get the micro-crystalline structure. The application prospect for the steel slag resources technology is broad[20].

4.10 Application in wall material and road face brick.

Study on the wall artificial brick preparation using the steel slag as the raw material, mixing into the fly ash, the lime and other chemical additives is the very much hot recently.Some results of this research have already been applied to the production.The technology mainly solved too big density and bad stability in the later period, mainly depended on adding additive. We found that it will take some effects when suitably mixing into some iron slag fine powder.

The steel slags used in the road bricks is mainly substitutes in the yellow sands of the traditional formula.In practice, we found that the bricks appeared the phenomenon of partial inflation dehiscence, partial flakes and the dehiscence allover, lost the bearing capacity partially or completely, when the steel slag road bricks laid for a period of time.In order to solve the above problem, we suggested the steel slag must be pressured to steam before using, and added the fly ash,the iron slag powder,the pearlite as well as the water-repellent and so on to it when designing formula.

5. Conclusion

The steel slag is a good "Second resource",the resources utilization steel slag is one important job of circulation economy.Through the long-term application practice,the steel slag comprehensive utilization technology has made progress much.It brings the direct economic efficiency for the enterprise in this domain,also protects the environment,has the very big social efficiency.Through the steel slag comprehensive utilization,we gradually realize that the steel slag is no longer the pure wastage, but the precious resources. Because of steel-making equipment, craft arrangement, slag-making system, multiplicity of the physical &chemical characteristic of the steel slag and its application many kinds of ways,it has decided in the diversification processing craft for the steel slag.According to the ways of the steel slag utilization,the steel-making craft characteristic, as well as the way advantageous to enhance steel-making productivity,the developed industry country choose the processing craft of the steel slag,thus guarantee enhancing the steel slag comprehensive utilization.In brief,the steel slag comprehensive utilization prospect is broad.

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