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Optimization of Process Parameter for Smelting and Reduction of Ferrochrome

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***Abstract*— The increasing costs of electric energy and continuous depletion of quality raw material such as Chromite ore and coke for production of high grade Ferro-chrome imposed a big challenge for the Ferro- alloys industries. In order to sustain in the globalized market, an attempt have been made in the present investigation for production of high grade Ferro-chrome utilizing lean grade raw materials. Chromite ore having different Cr/Fe ratio were smelted in a 100 KVA submerge arc furnace (SAF) with low grade nut coke. The Cr/Fe ratio of the Chromite ore pellets were optimized with respect to the slag basicity and power consumption to yield high grade Ferro-chrome. The basicity of the slag and Cr/Fe ratio of the ore were optimized to produce high grade Ferro-chrome (Cr > 60%) with low power consumption. It was observed that high grade Ferro-chrome can be produced utilizing low grade Chromite ore having Cr/Fe ratio 2.4 at the slag basicity of 1.**

***Index Terms*—Chromite ore, pellet, coke and Ferro-chrome**

I. INTRODUCTION

More than 80% of the world production of ferrochromium is used in stainless steel making. As ferrochrome is the main alloying materials for production of stainless steel, the rapid growth of the world stainless steel industry in last two decades posts a high demand on the production of ferrochrome. Submerged-arc furnaces (SAF) are used to smelt Chromite ores to produce ferrochrome by using a carbonaceous material such as coke, nut coke or char as a reductant [1]. The electrical energy consumption for production of ferrochrome is relatively high and it varies between 2000 kWh/t alloys with pre-reduction to 4000 kWh/t alloy without pre-reduction and feed preheating. Depending on the furnace size, the energy consumption and production rates are different [2]. Smelting process in the submerged arc furnaces is highly energy intensive and hence a large portion of the total production costs is goes for energy consumption. The consumption of energy depends up on the quality of the raw materials used, slag chemistry, furnace cooling system, bed porosity, electrical conductivity of the charge and the slag etc. According to Schei et al. [1998], about 32% of the energy consumed in the process remains as chemical energy in the product. Some of the remaining 68% is captured by the water cooling system of the furnace, but the largest fraction of the energy is in the form of SiO and CO off-gas escaping over the furnace top [3].

Due to high energy consumption and continuous depletion of quality raw materials (chromite ore, coke) for production of Ferro-chrome imposed the new challenges for the Ferro-chrome industries to deal with [2]. Therefore, an attempt have been made in the present investigation to optimize the process parameters for production of high grade Ferro-chrome utilizing lean grade chromite ore having different Cr/Fe ratio[4].

II. DETAILS EXPERIMENTAL

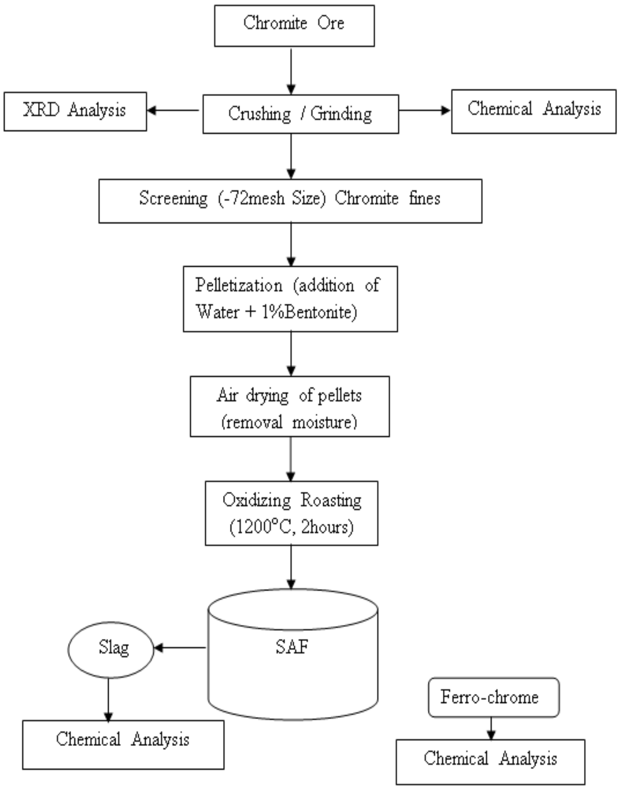

Figure 2.1 Process flow chart for execution of investigation

Based on the literature review process flow chart have been prepared to accomplish the above objectives is given in figure 2.1.

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III. RESULTS & DISCUSSION

Various grade of the chromite ore pellets, smelting reduction of the indurated pellets were carried out in a 100 KVA SAF. The details of the smelting, alloys and slag produced were given in the following section.

3.1 Smelting of chromite ore pellets having Cr/ Fe ratio 2.4

Based on the calculation made for the charge mix, smelting reduction of chromite ore pellets containing Cr/ Fe ratio 2.4 were carried out in 100 KVA SAF as shown in **figure 3.1.** Initially furnace was preheated for 2-3 hours using nut coke to bring the furnace temperature around 1400 -1500^{0}C.

Figure 3.1 100 KVA SAF in Operation

After preheating the charge mix prepared for the 2.4 Cr/Fe ratio charge, were charged in the furnace and arcing was done to smelt the charge mix. All the charge mix was charged and smelting the SAF by charging the charge mix in a batch of 4-5 kg in a interval of 15 minutes. After completion of smelting of reduction of the charge, tape hole of the furnace was open with the help of oxygen lancing and metal were poured on the sand mould. After cooling the furnace, slag were removed from the furnace and total weight of the slag produces were recorded for further investigation. Slag sample were chemically analysed for their chemical composition. Similarly after cooling of the hoot metal in sand mould, weight of the alloys produced was recorded and Ferro-chrome sample were chemically analysed for elements presents in the Ferro-chrome. The charge composition and calculated theoretical as well as experimental metal and slag produced are given in **table 3.1**.

Table 3.2 Chemical analysis of Ferro-chrome (Cr / Fe = 2.4)

Radical	Fe	C	Mn	S	Si	Cr	Ti
%	25.78	7.8	0.35	0.03	0.83	60.01	0.14

For smelting reduction of the indurated chromite ore pellets, SAF is first pre-heated with the nut coke for 3 to 4 hours. After heating preheating of the furnace, charge mix was properly mixed and fed in to the SAF. The charge mix prepared is shown in **figure 3.2**.

Figure 3.2 Charge mix for production of ferro-chrome

Charge mix was fed in the furnace in a 2 to 3 kg batch to ensure the proper smelting and reduction of the pellets. After complete smelting of the charge, furnace was arced for 30 minute more to provide the super heat to the furnace. Thereafter, bottom tape hole of the furnace was opened with the help of the oxygen torch and hot metal was taped on the sand mould. After taping the hot metal, alloys were allowed to cool in the sand mould. Cooled ferro-chrome sample were taken for the chemical analysis to find out the yield of the smelting and extent of the chromium in the Ferro-chrome. Slag sample were taken out from the furnace after cooling the furnace and sent for the chemical analysis to analyse the oxides present in the slag. The alloy and slag sample collected after smelting is shown in **figure 3.3**. From the chemical analysis of the Ferro-chrome sample it is observed that up to 60 % chromium have been recovered in the alloys. The smelting reduction of the chromite ore having Cr/Fe ratio 2.4 gives approximate the same value of the Ferro-chrome when the smelting reduction was carried at the basicity level of 1. Carbon pick up in the produced Ferro-chrome was more than 7 % which indicates that the Ferro-chrome produced is the high carbon Ferro-chrome as shown in **table 3.2**.

Table 3.1

Calculated charge mix, theoretical metal and slag weight and experimental metal and slag weight

Cr/Fe Grade (Heat No.1)	Charge Mix	Theoretical metal and slag Weight (kg)	Experimental metal and slag Weight (Kg)
2.4	Pellets : 40 Nut Coke: 11.5 Lime Stone : 1.0 Quartzite : 2.2	Metal: 15.0 Slag: 11.05	Metal: 14.0 Slag : 9.5.0

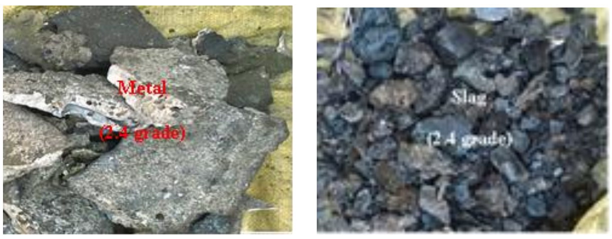

Figure 3.3 Alloy and slag sample collected after smelting

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The chemical analysis of the slag sample indicates that almost all the iron oxide and chromite ore have been reduced to their respective metal and form the alloys. The presence of alumina in the slag is more than 25% whereas the presence of silica is around 22% which makes the slag more liquids leading to the complete separation of the slag metal during taping of the alloys. The details of chemical analysis of the slag sample is given in the table 3.3

Table 3.3 Chemical analysis of slag (Cr / Fe = 2.4)

Radical	Fe(T)	CaO	SiO_2	MgO	Al_2O_3	TiO_2	Cr_2O_3
%	0.84	5.13	22.06	18.65	25.85		4.8

3.2 Smelting of chromite ore pellets having Cr/ Fe ratio 2.6

The chromite ore pellets having Cr /Fe ratio 2.6 were calculated to prepare the charge mix for the production of the Ferro-chrome from the chromite ore pellets having Cr/Fe ratio 2.6. Calculation of the charge mix for the Cr/Fe ratio 2.6 indicate that for smelting reduction of 40 kg pellets 14.4 kg of the nut coke will required for the complete smelting reduction of the chromite ore pellets. To maintain the 1.0 basicity of the slag, it required approximate 1 kg lime stone and 1.74 kg quartzite. The quantity of charge mix, theoretical and experimental metal and slag weight obtained were given in the table 3.4

Table 3.4 Calculated charge mix, theoretical and experimental metal and slag weight

Cr/Fe Grade (Heat No.2)	Charge Mix	Theoretical metal and slag Weight (kg)	Experimental metal and slag Weight (Kg)
2.6	Pellets : 40 Nut Coke: 14.4 Lime Stone : 1.02 Quartzite : 1.74	Metal: 19.0 Slag: 11.05	Metal: 13.0 Slag : 28.0

The metal and slag produced after smelting reduction are given in the figure 3.4

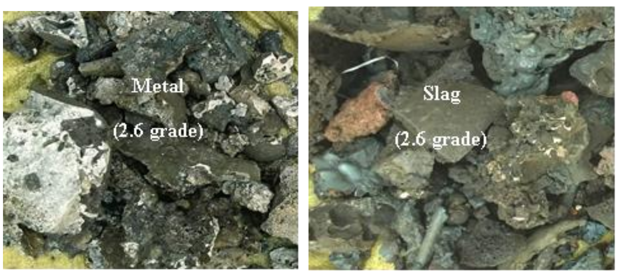

Figure 3.4 Alloy and slag sample collected after smelting of 2.6 grade ferro-chrome

After smelting reduction of 2.6 grade of chromite ore, the alloys and the slag produced was analysed for their chemical. The chemical analysis of the sample is shown in the table 3.5.

Table 3.5 Chemical composition of Ferro-chrome having Cr/Fe ratio 2.6

Radical	Fe	C	Mn	S	Si	Cr	Ti
%	31.6	7.89	0.18	0.06	0.1	59.0	0.04

The chemical analysis of the ferro-chrome sample reveal that almost all the iron was recovered and around 60% chromium was extracted during smelting reduction. The extent of the chromium recovery was little poor compare to the Cr/Fe ratio of 2.4. This may be due poor super heat or poor chromium partition. The slag composition of the alloys indicates that alumina and silica was more or less equal as basicity was same as in the case of 2.4 grade ferro-chrome. However the slag contains little more amount of the chromites in the slag as shown in table 3.6.

Table 3.6 Chemical analysis of slag (Cr / Fe = 2.6)

Radical	Fe(T)	CaO	SiO_2	MgO	Al_2O_3	Cr_2O_3
%	0.71	6.99	27.86	24.02	25.92	9.8

3.3 Smelting of Chromite ore pellets having Cr/ Fe ratio 2.8

Smelting reduction of Chromite ore pellets containing Cr/Fe ratio 2.8 was carried out in a 100 KVA SAF. Furnace was pre-heated and charged with the charge mix which contains 40 kg of Chromite ore pellets and 13 kg of the nut coke for reduction of the Chromite ore pellets and 1.4 kg of the lime stone and 2.7 kg of the quartzite to maintain the slag basicity of 1. The calculated charge composition for the smelting reduction of Chromite ore containing Cr/Fe ratio 2.8, theoretical metal and slag weight and experimental metal and slag weight is given in table 3.7.

Table 3.9 Chemical analysis of slag (Cr / Fe = 2.8)

Radical	Fe(T)	CaO	SiO_2	P	MgO	MnO	Al_2O_3	TiO_2	Cr_2O_3
%	1.14	8.89	0.01	0.017	21.17	0.0	41.95	0.54	9.98

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Table 3.7 Calculated charge mix, theoretical and experimental metal and slag weight			
Cr/Fe Ratio	Charge Mix	Theoretical metal and slag Weight (kg)	Experimental metal and slag Weight (Kg)
3.0	Pellets : 40 Nut Coke: 13.0 Lime Stone : 1.4 Quartzite : 2.7	Metal: 19.42 Slag: 11.92	Metal: 19.0 Slag : 13.1

From the table 3.7, it is observed that all the oxides present in the Chromite ore pellets has been reduced to their respective metal. The alloys produced during smelting reduction yielded more than 97% recovery of the Ferro-chrome. However, the experimental weight of the slag is little higher than the theoretical calculated slag weight. This may be due to the carry over slag of the furnace from the previous heat. From the chemical composition of the Ferro-chrome, it is observed that more than 57 % from is there in the alloys as shown in table 3.8. The Cr/Fe ratio in the alloys is more than 1.9 with more than 8 % carbon.

The slag chemistry of the ferrochrome produced having 10% Chromite with as high as 41 % alumina as shown in table 3.9. The presence of the high alumina in the slag makes the slag viscous leading to poor separation of the alloys and slag. However, the recovery of the chromium can be enhanced by the addition of quartzite.

The Ferro-chrome and slag produced by smelting of the Chromite ore having Cr/Fe ratio 2.8 is given in the figure 3.5. The produced Ferro-chrome sample reveals very good the metallic lustre of the industrial grade Ferro-chrome. The slag produce have very alumina with very quantity of phosphorous with lime which can be used as a feed for cement industries for production of cement.

Figure 3.5 Alloy and slag sample collected after smelting of 2.8 grades Ferro-chrome

3.4 Discussion

The smelting reductions of the different grade of the Ferro-chrome in a 100 KVA lab scale SAF reveal that almost all the chromium and present in the Chromite ore has been reduced to their respective metal. The carbon pickup in the Ferro-chrome produced is around 8 % in the alloys. It is clear from the graph (figure 3.6) that at 2.4 Cr/Fe ratio, the recovery of the chromium is maximum along with optimum recovery of silicon and carbon in the Ferro-chrome as shown in the figure 3.6.

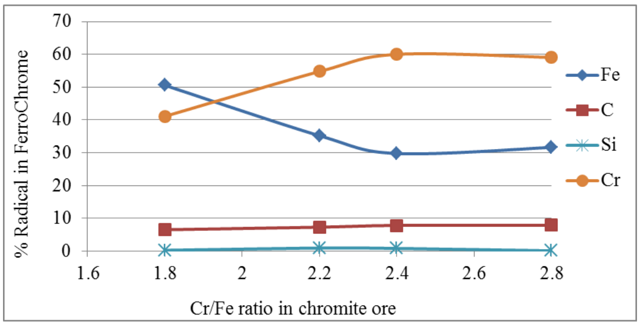

Figure 3.6 Recovery of Cr, Fe, C, and Si in the different ratio of the Cr/Fe in the chromite ore

The basicity level of 1.0 in the slag during smelting reduction yielded up to 60 % recovery of the chromium with low grade Chromite ore having Cr/Fe ratio of 2.4. This indicates that the basicity of the slag at lower level of the Cr/Fe ratio gives rise to the optimum recovery of the chromium. Further, the 2.4 Cr/Fe ratio in the Chromite ore resulted around 2.0 Cr/Fe ratio in the Ferro-alloys at the basicity of 1.0. in the slag as shown in figure 3.7. Therefore, 1.0 basicity in the smelting reduction of Chromite ore is optimum basicity for the production of high grade Ferro-chrome from lean grade Chromite ore.

Table 3.8 Chemical composition of Ferro-chrome having Cr/Fe ratio 2.8						
Radical	%C	%S	%P	%Si	%Fe	%Cr
%	8.7	0.02	0.066	2.35	30.05	57.814

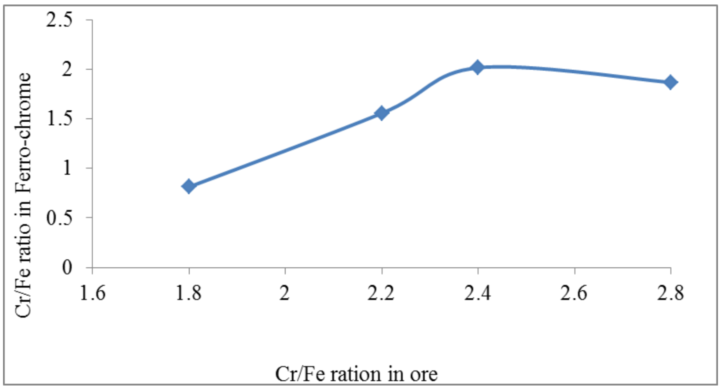

Figure 3.7 Cr/Fe in the Ferro-chrome against the Cr/Fe ration in the Chromite ore

4.1 CONCLUSION

From this study we conclude that:

- The XRD result indicated the size of the nanoparticles between 42.6nm to 52.5nm.

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Vol. 5 Issue 10, October-2016

- The overall weight loss was continuously decreased with the temperature change obtained by the Thermo-gravimetric analysis.
- The Mechanical testing conducted so far indicate the addition of the CMC polymer 2.5gm to 1.5gm has greatly improved the compressive strength of the composite.
- The compressive strength in the elastic range was increased from 1.12MPa to 10MPa which is very near the compressive strength of the trabecular bone

5. REFERENCE

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