Deqing Zhu, Xianlin Zhou*, Yanhong Luo, Jian Pan and Bing Bai

Reduction Smelting Low Ferronickel from Pre-concentrated Nickel-Iron Ore of Nickel Laterite

DOI 10.1515/htmp-2015-0025
Received March 18, 2015; accepted November 16, 2015

Abstract: The research of smelting low ferronickel from pre-concentrate nickel-iron ore with 2.76% Ni and 38.00% Fe total was carried out to find an effective way for stainless steel enterprises to use the low-nickel laterite ore reasonable. The results show that Ni and Fe both have a certain degree of enrichment, and impurities and harm elements have different degrees of reduction after pre-concentration of nickel-iron ore. Most valuable metal did not compound with impurities which greatly accelerated the speed and extent of melt separation reduction. Good alloy of 6.58% Ni with the overall recoveries of 93.38% and 89.95% Fe total with the overall recoveries of 89.57% was manufactured under the following conditions: 10% coke, 1.0 binary basicity, 18% MgO and 3% Al2O3 in slag, melting at 1,550 °C for 10 min. The product can be used for the feed of producing stainless steel.

Keywords: nickel laterite ore, pre-concentration, reducing smelting, low ferronickel

Introduction

According to the statistical data of Stainless Steel Council of China Special Steel Enterprises Association, the crude stainless steel’s production was 21.692 million tons in 2014 in China, with an increase of 14.27% compared to 2013. The rapid development of Chinese stainless steel industry caused the shortage of nickel demand in the world. Meanwhile, there are few laterite nickel ores reserved in China, so it is with great important to utilize nickel laterite ore. Recent researches were both focused on hydrometallurgical [1–5] and pyrometallurgical [6–11] process. Hydrometallurgical process is suitable for limonite laterite, which has the problems of complex process, huge consumption of acid, high production cost and needs high-level equipment. In contrast, pyrometallurgical process is with the advantages of mature technology, high productivity and low equipment investment. In this research, a pre-concentrated ore from an imported nickel laterite was used to make low ferronickel, in order for the domestic steel enterprises to use foreign low-nickel laterite ore resources rationally. The process has the competitiveness of low-smelting temperature for short time with high recovery of valuable metal. The production of the process can be used to make stainless steel, nickel-iron alloy steel and alloy cast iron; in particular, it can afford the increasing requirements of the 200# stainless steel.

Experimental

Raw materials

There are three types of raw materials used in the research, containing one pre-concentrated nickel-iron ore, one reductant and one flux ore.

The pre-concentrated nickel-iron ore is made from a nickel laterite ore imported abroad under the conditions as follows: pre-reducing at 1,100 °C for 80 min by 2% coal-bearing with a total carbon to iron mass ratio of 1.5, then grinding the pre-reduced pellets up to 91.80% passing 0.043 mm, and magnetically separating the ground product in Davis Tube at 0.17 T magnetic field intensity. 79.50% of productivity, 94.28% and 91.09% of nickel and iron recoveries were achieved, respectively. The chemical compositions (Table 1) indicate that the nickel laterite ore has low Ni and high Fe, and around 20% of impurities were discarded during pre-concentration process, which releases the burden of smelting process and reduces the fuel consumption of electric furnace. X-ray diffraction analysis (Figure 1) shows that the main minerals of pre-concentrated ore are metallic iron, metallic nickel and forsterite. Most of valuable metals are reduced and not combine with impurities; it can increase the smelting-separating speed during reduction smelting.

During research some analytical reagents were added to adjust to the right component of slag, such as MgO...
(From Xilong Chemical Co., Ltd., China, 98.50 % purity) and Al₂O₃ (From Sinopharm Chemical Reagent Co., Ltd., China, 98 % purity). Coke is a good reductant which contains 80.76 % of fixed carbon and only 0.34 % of sulfur. Limestone is used as a flux ore to change the basicity of the slag, which also has low P and S.

**Experimental procedure**

Firstly, nickel-iron concentrate, coke, limestone and other additives were mixed at a given ratio. Then smelt the mixture in the electrical furnace at a given temperature, the mixture was putted in a plumbago pot. After melting N₂ gas was bubbled through the plumbago pot to protect the melt from oxidation. Finally depart the slag and alloy when the metal was cool down. And analyze the chemical components respectively.

In mixture calculation, the ratio of reducer is amounted to m_coke divided by m_concentrate. The basicity of slag is binary basicity which calculated by %CaO divided by %SiO₂.

The main indexes of evaluating melting products include:

1. Ni grade and Fe grade of ferronickel: Ni_{alloy} and Fe_{alloy},
2. Productivity of ferronickel = 100 %*m_{alloy}/m_{mixture},
3. Coefficient of recovery of Ni (or Fe) = 100 %* (m_{alloy}*Ni_{alloy} (or Fe_{alloy}))/m_{concentrate}*Ni_{concentrate} (or Fe_{concentrate}),
4. Contents of P and S of ferronickel. m_coke means the mass of coke, other subscripts have the same means.

**Results and discussion**

**Optimization of reducing smelting process**

**Smelting temperature**

The effects of smelting temperature on Ni and Fe grade and recovery of product are shown in Figure 2. Smelting temperature has a great impact on product, recoveries of Ni and Fe both increase significantly. When the smelting temperature was elevated from 1,490 °C to 1,550 °C, Ni recovery raised from 56.03 % to 95.43 %, while iron from 58.46 % to 95.30 %. The viscosity of slag was too high to promote the separation of ferronickel when the temperature was low. While the temperature was increasing, on the one hand it improves energy transmission.
which is good for smelting, on the other hand it decreases the viscosity of slag and metals melt and drip well under low resistance, and most alloys can be recovered.

**Smelting duration**

To fitting the smelting duration, series of tests have been designed. Results in Figure 3 show that when smelting time increased from 5 to 10 min, Ni and iron recoveries improved significantly, and they keep stable while continue to extend the time.

Element Ni was mostly reduced during pre-concentrate process, so that it could enter melt alloy quickly and separated with slag along with smelting process. But there was part of combined iron which was reduced by remain carbon in the slag in the beginning of smelting process, so smelting time was set to 10 min.

**Coke ratio**

During the smelting process, coke was used to reducing Ni and iron which were not reduced in pretreatment process, and kept reducing atmospheres during smelting. The effects of coke ratio on smelting process were shown in Figure 4. It can be seen that grade and recovery of Ni and iron are both low when there was no coke added in the mixture. While coke ratio increased from 5.0 % to 10.0 %, each index of ferronickel improved dramatically. If coke dosage was too low, it couldn’t provide a sufficient reducing atmosphere and the results were not good enough. But when coke ratio was up to 12.5 %, both Ni, iron contents and recoveries decreased. It could be seen that after smelting and cooling the separation of slag from hot metal was incomplete, and there were some particles of alloy that attached to the slag surface. Because the melting points of coke ash and remain carbon were too high to have a slag with low-melting point
and low viscosity, so that the hot metal couldn’t drip smoothly. Meanwhile increasing coke ratio will increase the mass of slag and smelting costs, so adding 10.0 % of coke would be the best.

Effect of component of slag on smelting

Base on the components and content of gangue minerals, quaternary slag system of Al$_2$O$_3$-CaO-MgO-SiO$_2$ was used in this research [12]. Different binary basicity, MgO contents and Al$_2$O$_3$ contents were used to examine the impacts on the smelting process.

Effect of binary basicity

From Figure 5 it can be seen that smelting results become better and better when the binary basicity of slag raises from 0.80 to 1.00, and they become worse if the basicity continues to increase. According to the slag phase diagram [12], in the test range of slag component, slag basicity had a great effect on slag melting temperature while other minerals were fixed. When the basicity was between 0.9 and 1.1, slag had lowest melting temperature, and if the basicity was more than 1.1, the temperature increased with the increasing basicity, it increased also with the decreasing basicity when the basicity was less than 0.9. Meanwhile, the best slag composition was within the initial crystalline region of melilite (2CaO · MgO · 2SiO$_2$) which the melting point and viscosity of slag would be low. If the basicity was changed, the phase point would move up and down, the composition leaved away from the region and the melting temperature increased which leaded to a low viscosity of smelting slag. So that it was the best to set the basicity to 1.0 during smelting.
Effect of MgO content

Figure 6 shows the effects of MgO content on smelting process. Ni grade and iron grade had a trend of first increased and then decreased with the increased MgO content from 10% to 22%, so as the recoveries. Increasing MgO in slag can avoid forming $2\text{CaO} \cdot \text{SiO}_2$ which has high melting temperature. And it also can bring in more $\text{O}^2-$ that will reduce the degree of polymerization of anion groups of Si-O and Al-O, break their network structure and form a simple single and double tetrahedral structure [13–14], which can improve the fluidity of slag.

Effect of Al$_2$O$_3$ content

From the results (refer Figure 7) of smelting on different Al$_2$O$_3$ content, it showed that the increasing Al$_2$O$_3$ within limit had a good impact on smelting. Because of the similarity between this research’s slag composition and blast furnace’s, a consistent result can be achieved compared to the research of blast furnace slag [15]. In general condition, the slag stability would become worse if Al$_2$O$_3$ content was lower than 6% to 7% and the basicity was in normal range (between 1.05 and 1.20). It means that slag viscosity may increase dramatically when basicity or other composition of slag have a little change. And when Al$_2$O$_3$ content are between 7% and 15%, the result would be good. So that the Al$_2$O$_3$ content of blast furnace slag must be kept in a certain degree, so as in this research.

Tables 2 and 3 present the grades, recoveries and the chemical compositions of alloy produced by the whole flow test, the smelting conditions were: smelting at 1,550 °C for 10 min with 10.0% coke, the slag binary basicity was 1.0 and MgO content was 18% while Al$_2$O$_3$

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ni grade</th>
<th>Ni recovery</th>
<th>Iron grade</th>
<th>Iron recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferronickel</td>
<td>6.58</td>
<td>93.38</td>
<td>89.95</td>
<td>89.57</td>
</tr>
</tbody>
</table>

Table 2: Grades and recoveries of Ni and iron of ferronickel compared to raw mineral (mass%).
was 3%. The process of using pre-concentrate nickel-iron ore to make low ferronickel has a higher recovery of Ni of 93.38% than normal smelting process recovery of 90%. And the impurities of P and S are low in the product. It can be used to produce 200# stainless steel.

Conclusions

(1) Nickel laterite ore used has low Ni and high Fe, and part of impurities have different degree of reduction after pretreatment, which can reduce the fuel consumption of electric furnace. Most of valuable metals are reduced and not combine with impurities; it can increase the smelting-separating speed during reduction smelting.

(2) A ferronickel assaying 6.58% of Ni and 89.95% of Fe was manufactured under the smelting conditions of smelting at 1,550 °C for 10 min with 10.0% coke, the slag binary basicity was 1.0 and MgO content was 18% while Al₂O₃ was 3%.

(3) The process of using pre-concentrated nickel-iron ore to make low ferronickel has a higher recovery of Ni than normal smelting process recovery of 90%. The product of the process can be used to smelting 200# stainless steel. And it provides a new method to use nickel laterite effectively.

Funding: The research presented this paper was supported by National Natural Science Foundation of China (Grant No. 50974135).

References