OPTIMISATION OF SiMn PRODUCTION AT TRANSALLOYS

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ABSTRACT

Transalloys produces 160 000 tons of SiMn per annum from five AC submerged-arc furnaces. The lime-ore melt from two AC open-arc furnaces is contacted with SiMn to produce 50 000 tons of medium carbon FeMn per annum. Metallics in the slag are reclaimed in a jigging plant, which has been in operation since 1999.

The flow of materials between the jigging plant and furnaces has been optimised. The amount of recycle slag in the feed of the SiMn furnaces has been decreased by more than 30% which still provides satisfactory stability of the furnace operation. The jigging plant has absorbed all the additional slag generated, to recover SiMn metal.

A review of the raw materials used and operating parameters for SiMn production was also undertaken. Slag to metal ratios were decreased by more than 30% by reducing the slag recycle, removing magnesite from the recipe and introducing high-grade ore. Electrode penetration was improved by reducing coke levels and by utilising more reactive coal.

The pitch circle diameter (PCD) was reduced to get a better operating stability on furnace no 5 using the MINSTRAL Control System.

Energy consumption on the furnaces improved by more than 15% while SiMn production increased as a result by more than 18%.

1. INTRODUCTION

Transalloys, a division of Highveld Steel and Vanadium Corporation Limited, located in Witbank, South Africa, produces about 160 000 tons of SiMn per annum from five AC submerged-arc furnaces: two of 21 MVA each, two of 48MVA each and one of 22MVA. An additional 50 000 tons of MC FeMn per annum is produced from two AC open-arc furnaces of 7MVA each, by silicothermic reduction of a lime-ore melt. The silicomanganese metal grade produced, is as follows: min 65% Mn, 15 – 18.5% Si and max 2%C.

Bezemer [1] reported that a high slag to alloy ratio of not less than 2 to 1 has been a feature of SiMn production at Transalloys. Attempts to operate the furnaces at lower slag to metal ratios were not successful and as a consequence no long-term benefits could be achieved, with operating problems developing, mainly related to electrode management and tapping of furnaces. Energy consumption and manganese recovery to the alloy deteriorated to unacceptable levels.

Manganese recovery to the alloy was a focal point in the past. Slags were controlled at high basicity levels and magnesite was added to maintain a level of approximately 17% MgO, which gave improved manganese recoveries[1]. The above strategy led to good manganese recoveries with relatively high energy consumption.

Because of the ever-increasing competition in the market and the decline of the price of steel and the commodities used for its manufacturing, investigations aimed at cost reduction were undertaken. These were carried out in a context where no capital inflow was envisaged but the use of existing equipment and resources in order to improve the efficiency of the operation.

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A jigging plant has been in operation since 1999 to reclaim metallics from slag in order to increase the overall plant recovery of ferromanganese metal and improve the profitability of the overall operation.

2. BACKGROUND

The feed to the furnaces traditionally comprised of low-grade manganese ores, fluxes, recycled metal rich slag and reductants.

Manganese ores are supplied from the Northern Cape region of South Africa.

Quartz is used as raw material for silicon reduction and to adjust the slag basicity to required levels. Coke and coal are used as reductants.

The minimum content of silicon in the silicomanganese alloy (fixed at a level of 16%) makes it necessary to operate at a high ratio of reductants to other non-conducting materials, such as ore and quartz in the input raw materials. Too high reductant densities will lead to a low furnace burden resistance and the inability to get electrode penetration. Recycled slag is employed to reduce the reductant density in the raw material feed and to ensure adequate electrode penetration.

Molten material from the furnaces is tapped into refractory-lined ladles, generally through a single taphole. The supernatant slag layer in the metal ladle overflows into cast steel pots. Once the taphole has been closed, the slag remaining in the metal ladle is skimmed just prior to the metal casting operation. After that, clean metal is cast into ingots using a double strand casting machine. The solidified SiMn metal ingots are crushed and screened to the market size requirement. Fines, less than 3mm, generated during this operation, are used as raw material in the smelting of Medium Carbon FeMn.

A portion of solidified slag is crushed and recycled back to the smelting furnace whilst the balance is being fed to the jigging plant to reclaim metallics. About 60% of the recovered metallics are readily sold in the open market for ferromanganese alloy.

3. ANALYSIS OF POSSIBILE OPERATION IMPROVEMENT

The slag volume has traditionally been kept at a high level, as this was the only way to ensure acceptable electrode penetration. A reduction in the slag volume would lead to an improvement in the energy consumption and production of the SiMn furnaces.

An additional opportunity for the minimisation of the amount of slag was the reduction of metal rich slag recycled to the furnaces. This could free up metal rich slag to be processed at the metal recovery plant, which would improve the profitability of the plant and ultimately improve the total metal production volume between the furnaces and the metal recovery plant. The jigging plant has sufficient capacity and an additional circuit to treat ultrafines was implemented to further increase the recovery of metallics.

The challenge was to reduce the slag to metal ratio while achieving good electrode penetration, which could not be achieved in the past.

4. DISCUSSION

4.1 Reduction of slag to metal ratio

4.1.1 Magnesite removal

Magnesite contributed to the generation of the high slag volume and was, at the same time, an additional raw material input cost. Magnesite was successfully removed in a single step. This did not affect negatively the fluidity of the slag. The results were in agreement with those of Shu Li *et al*[2] who reported that basicity extent does not affect the furnace operation provided that the hearth temperature and the slag fluidity are kept in an appropriate range. It is to be understood in this case, that an adequate hearth temperature is achieved with an adequate electrode penetration. In some cases, MgO was only added in a SiMn smelting furnace when the level of Al_2O_3 in the slag was above 15% [3], that is not the case of Transalloys.

4.1.2 Slag basicity
The slag basicity used was calculated as a tertiary basicity index expressed in mass ratio as:

Basicity Index = (%CaO + %MgO) / (%SiO_2).

The slag basicity has a significant effect on both ore and energy consumption. The ore consumption is defined as the amount of ore smelted to produce one ton of SiMn alloy. Optimisation of the slag basicity was undertaken after the magnetite was removed. A high basicity would favour ore consumption while energy consumption would be optimised at a lower basicity. The options have been to focus on the optimisation of the ore consumption or the energy consumption or a middle of the road strategy.

The MnO level in the slag was reduced to 8-9% when the basicity of the slag was increased above 0.9, by reducing the quartz input. These MnO levels were similar to that obtained with magnesite addition. A successful reduction in the slag to metal ratio resulted in an improvement of the Mn recovery and ore consumption compared to the approach of magnesite addition. The above could only be achieved with the optimisation of other parameters mentioned.

High slag basicity levels led to high levels of fixed carbon input due to the lower activity of SiO_2 in the slag and ultimately to poor energy consumption and lower SiMn production. Carbon input levels have to be increased to maintain the same Si grade in SiMn since the activity of SiO_2 is decreased by the increase in slag basicity. The high carbon input levels increased the risk of the formation of SiC banks in the furnaces.

The above was done to investigate the first option of optimising ore consumption. The second option was to operate at a lower basicity and was achieved by increasing the quartz input.

For the second option, the MnO in the slag increased to approximately 14% but the energy consumption decreased significantly.

The profitability was optimised by setting the basicity at a lower level. This would focus on the optimisation of energy consumption and ultimately the production volume. A lower basicity improved the activity of the SiO_2 and had the positive effect of reducing the fixed carbon requirements, leading to improved electrode penetration

4.1.3 Introduction of high-grade ore
High-grade manganese ore from the Northern Cape deposits was introduced and gradually increased to 50% of the ore input replacing low-grade manganese ore. The increase of the level of high-grade ore had a negative effect on the penetration of electrodes and steps had to be taken to address this effect.

4.1.4 Reduction of recycled slag to furnaces
The amount of slag with a higher metallic content recycled to the furnaces was as high as 40% of ore input to the furnaces. Recycled slag was gradually reduced, while ensuring that adequate electrode penetration was maintained.

4.2 Improved electrode penetration
In the past, electrode lengths used to be short due to the inability to maintain electrode penetration. These resulted in hot burden tops and sometimes open arcing and difficulties in draining furnaces. The high total fixed carbon input was the main contributing factor of poor electrode penetration.

In the carbothermic reduction of ores, heat is just as essential for reduction as carbon is, due to the endothermic reduction reactions and a deficiency of heat may cause incomplete reduction in the same way[4]. Good electrode penetration is therefore essential to have adequate heat to drive the reactions to completion.

The following steps were implemented to improve electrode penetration.

4.2.1 Coke

Furnaces were traditionally operated on a reductant input constituted of a high coke to coal ratio. The coke to coal ratio was reduced to increase the burden resistance in order to improve the penetration of electrodes. This resulted in a reductant cost saving due to the relative high cost of coke compared to coal.

4.2.2 Furnace operating resistance

The operating resistance of the furnace was decreased by operating at the highest practicable currents. The resistance setting of the Minstral controller, which is operating on resistance control, was reduced.

4.2.3 Total fixed carbon input per ton of raw material

In the silicomanganese production, the reductant density must be kept at low levels in order to maintain a proper level of electrode immersion[2]. The total fixed carbon input is normally controlled at 90% to 110% of the stoichiometric requirement.

The total fixed carbon inputs used to increase to levels as high as 145% of the stoichiometric amount. SiC banks were formed as a result and fluorspar was used on some of the furnaces to remove them. The high fixed carbon inputs led to low burden resistance and ultimately to poor electrode penetration.

Reactive coal was introduced in the furnace feed and regular monitoring of the total fixed carbon input with the use of a mass balance was carried out.

Traditional carbon control was simplistic by adjusting the carbon input as a result of high or low silicon and carbon content in the SiMn metal. Carbon control was further improved by incorporating the reading of furnace parameters such as electrode penetration, temperature of furnace tops and slag composition to aid in the decision as to whether the furnace was over or under carbon.

4.3 Electrode pitch circle diameter (PCD) change

Furnace no. 5 had the following operating problems:

- The electrodes moved independently, indicating that they were not arcing towards the star point in the centre of the furnace. One of the electrodes would then frequently lose penetration and operators had to take action to get penetration on those electrodes again. The furnace did not perform well on resistance control due to the above reasons.
- The electrodes smelted open separate craters, while the feed in-between them did not smelt.
- The draining of the furnace was sometimes difficult suggesting a formation of disconnected pools of molten material inside of the furnace.
- The total fixed carbon inputs was much higher than the stoichiometric required amount, to produce on specification material.

The above aspects are indicators of too large pitch circle diameters.

The optimum electrode current flow through a furnace should go via the tips of all three electrodes to the star point in the middle of the furnace. The resistance between the electrodes (delta resistance) must be higher than the resistance between the electrode tips and the star point. This condition can only be fulfilled with a correctly sized PCD. Currents will not flow preferentially to the star point if the PCD is too large. This is in agreement with observations from others[4],[5] and [6]. A heat deficiency (lower heat-distribution factor) in the silicochromium smelting following a decrease in the charge resistance created a difficult control of the carbon balance, with predominantly high carbon balance levels to produce the required alloy specifications. The heat distribution is influenced by the resistance in the crater zone compared to the resistance in the charge; the lower the resistance in the crater zone relative to the resistance in the furnace charge, the more power is generated in the crater zone[4]. It was also mentioned that narrow craters could lead to poor furnace operation since they might decrease the ability of the raw materials to enter the reaction zones[5]. The electrode spacing is affected by materials such as coke and coal in the silicon metal smelting. The use of coke causes low resistance and narrow craters which perform better with closer electrode spacing[6]. For all these cases, furnace performed better with closer electrode spacing.

A reduction of the PCD of Furnace no 5 by 7% relative to the initial measure was undertaken. This change improved the stability of the furnace on resistance control using the Minstral control system. The three electrodes started moving together, indicating that the electrodes were now arcing towards the star point in the centre of the furnace, with improved stability of electrode movement and no single electrode was no longer losing penetration. This resulted in improved energy consumption.

5. RESULTS

5.1 Slag to metal ratio

The slag to metal ratio was successfully reduced from 2.0 to 1.3. The recycle of metal rich slag could be reduced by more than 30% in the process.

5.2 Ore consumption

The MnO in the slag increased from approximately 8% to 14% due to the lower slag basicity resulting in lower MnO activity. The reduction in slag volume did however compensate for MnO losses. The end result was that ore consumption per ton alloy produced stayed on the same level.

Ore cost increased due to the higher price of high-grade ores that was introduced, but the saving on the magnesite that was removed was of similar value. The end result was that the combined cost of magnesite and ores stayed the same.

5.3 Energy consumption

Energy consumption was reduced by more than 15% as can be seen in Figure 1.

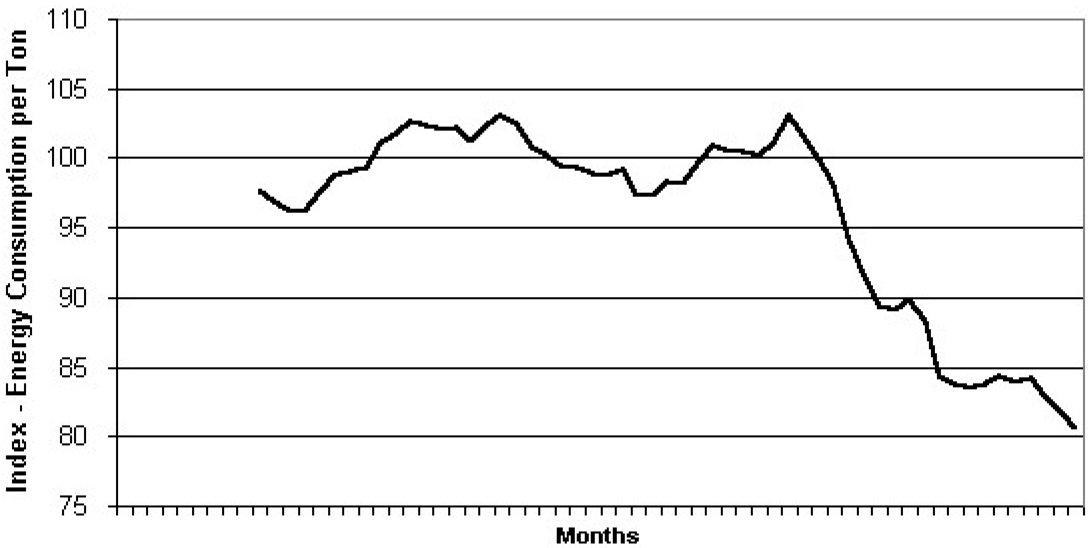

Figure 1. Evolution of energy consumption on one of the SiMn furnaces.

5.4 Production volume

Silicomanganese production volume increased by more than 18% as a result of the improved energy consumption.

5.5 Operation

Good electrode penetration could be sustained with the reduction in slag to metal ratio, while operating problems such as difficulty in draining of the furnaces disappeared.

5.6 Cost saving

The decrease in the energy consumption by more than 15% contributed to a significant reduction in variable costs. Increased production volume of more than 18% as a result of improved energy consumption, resulted in a substantial increase in profit.

6. CONCLUSION

The slag to metal ratio was successfully reduced with the removal of magnesite, reduction in slag recycled and with the introduction of high-grade ores.

Ore consumption could be improved without magnesite, by operating on a high slag basicity and with a reduced slag to metal ratio. Total operational profitability was however improved by rather focusing on energy consumption, while operating on lower slag basicity.

The combined cost of magnesite and ores consumed per ton of alloy stayed the same, while energy consumption improved significantly. Increased production volume as a result of improved energy consumption had a significant effect on profitability.

The reduced PCD of Furnace no 5 led to improved electrode stability and improved furnace energy consumption.

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