BREAKAGES OF SØDERBERG ELECTRODES DURING SUBMERGED ARC FURNACES START-UP

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Abstract

This article presents a technological issue related to the operation of self-baking electrodes in six-electrodes submerged arc furnaces during the process of smelting high-grade silicon alloys with iron and other elements by carbothermal reduction, carried out in Re Alloys ferroalloys plant. Particular attention is paid to technological problems related to the use of Søderberg electrodes during start-ups of electric furnaces after shutdowns. The impact of furnace shutdowns and starts-ups on thermal conditions disturbance of electrode sintering process, formation of microcracks, and thus deterioration of mechanical strength of the electrode leading to increased risk of breaking, is presented. Actual examples of electrode breaking during SAF start-up, causes of breaking, and possible ways to avoid them are described in the article.

Keywords: Metallurgy, self-baking electrode, submerged arc furnaces, ferrosilicon

1. INTRODUCTION

The self-baking electrode is one of the basic components of submerged arc furnaces (SAF). The main function of the Søderberg electrode is to serve as an electric conductor so that the current can be brought from the transformer down to the smelting zone [1]. An abrupt change of current load during shutdowns and start-ups of electric furnaces influences on thermal conditions disturbance of electrode baking process, formation of micro-cracks, and thus deterioration of mechanical strength of the electrode leading to increased risk of breaking.

2. PROBLEM TO SOLVE

The Søderberg electrode consists of an outer steel casing with fines, which acts as a form for carbon paste. The carbon paste is baked to a solid electrode by a combination of conductivity from the SAF and electrical resistance heating from the current flowing in the electrode [2]. Baking of the electrode is an important and difficult part of the smelting of high-grade silicon alloys with iron and other elements by the carbothermal reduction process. Slow heating of the electrode mass takes place along the entire length of the electrode column, from its top to the contact clamps. In the zone where a temperature of 80-100 °C is reached, electrode mass melts and it is already fluid enough to fill the entire cross-section of the electrode. When the temperature exceeds 400-500 °C, the binder boils and the electrode mass is sintered into a monolithic carbon electrode. The gases released during sintering escape through the liquid mass to the top of the electrode jacket. The intensive sintering process continues until the temperature of 900°C is reached when the electrode material has its maximum mechanical strength. The electrode reaches a temperature of 900°C at the height of the lower edge of the contact clamps. Below the contact clamps, the steel casing is completely destroyed by the action of high temperature and aggressive gases. From this point, the mechanical strength of the electrode depends only on the properties of the sintered mass.

When certain right methods were developed operating self-baking electrodes does not cause problems. However, in some cases, e.g. start-up of the SAF, failures do occur. The worst consequences of such failures are breakages of the Søderberg electrode. There are two types of breakages: soft and hard. The main reason for soft breakages during SAF start-up is an anomalous electrode slipping when the current does not recover and critical 500 °C isotherm goes under the lower edge of contact clamps [3]. Unbaked liquid electrode mass goes out of steel casing, what in **Figure 1** is presented.

Figure 1 Stages of self-baking electrode soft-breakage

Hard breakages are provoked by thermal stresses in the electrodes caused by dynamic temperature changes during the shutdown and start-up of SAF [4]. In **Figure 2** the way leads to hard breakage during SAF start-up is presented.

Figure 2 Stages of self-baking electrode hard-breakage

3. RESULTS

To understand more the process of baking of electrodes in six-electrodes open SAF without a low hood, temperatures with K-type thermocouples placed in a fixed position at the beginning and at the end of the fins during the FeSi75 process were measured. The measurements of temperature allowed to make thermal profiles of the Søderberg electrode during the FeSi75 production process. The isotherms of the electrode are shown in **Figure 3**.

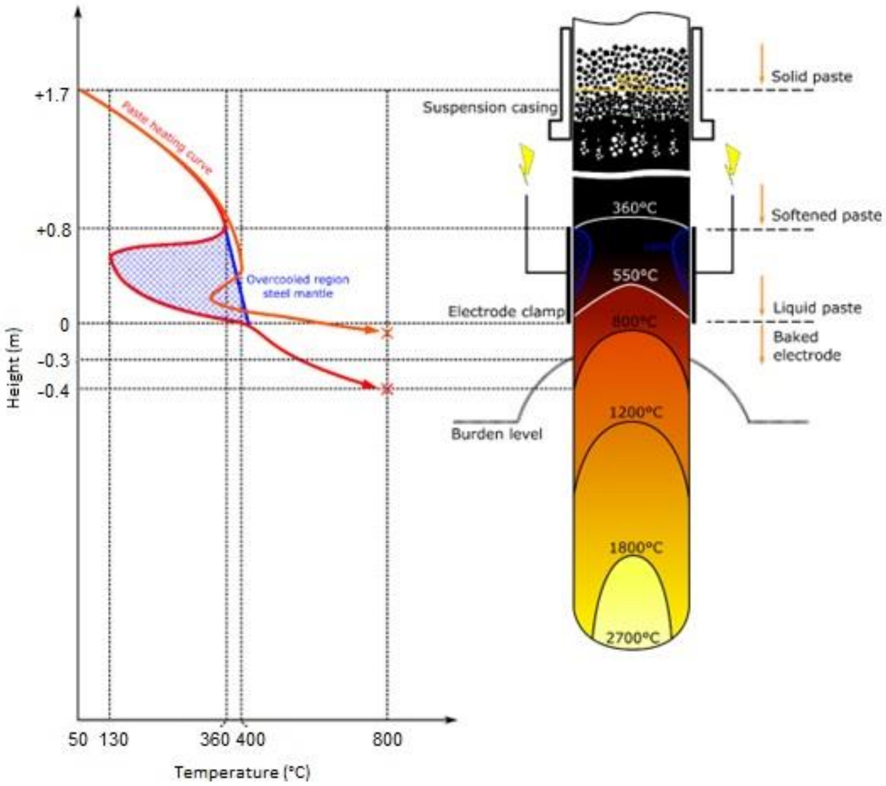

Figure 3 Temperature profiles of self-baking electrode

As we can see, in the upper zone of the electrode the paste is slowly heated up and baked by the heat from the SAF. The Søderberg paste is softening, turning into liquid, and then at 500-550 °C solidification process takes place. However, the baking process could be disturbed by the heat losses via cooled contact clamps. In the center of the electrode, the fall of temperature is lower than beside of casing, because of heat transfer from the furnace. In the fracture of the hard-broke electrode, which is presented in **Figure 4**, a well-baked paste in the center of the electrode in opposition to the outer zone could be observed. The measurement due to technical issues was stopped near 950 °C and further data was approximated.

Figure 4 Fracture of self-baking electrode hard-breakage

4. DISCUSSION

In the period from 2014 to 2022 at ferroalloys plant Re Alloys LTD 136 numbers of electrodes breakage occurred. 75 of them happened during SAF start-ups, therefore a decrease in breakage is one of the main problems to be solved by R&D staff as part of the program of technological progress in ferroalloys [5]. As a supplement to the applicable guidelines for the operation of self-bonding electrodes, which consist in determining and observing the conditions of softening and melting of the electrode mass, the permissible current load of the electrode, and the electrode wear, the relationship between the duration of the furnace start-up and the standstill time was determined on the basis of previous experience. The implementation of new guidelines for the preparation for the shutdown and the next start-up of the furnaces made it possible to avoid breakage of the self-baking electrodes after a three-month standstill in 2023 and a lot of short and medium shot-downs during the first half of 2023. Based on experience, calculations, and estimations technologists working in R&D have divided the time of shout-downs into three groups: short (up to 4 hours), medium (from 6 to 12 hours), and long (over 12 hours). Depending on the duration of the shutdown, the parameters of reducing the current load before the planned shutdown, the initial current load after switching on the furnace, and the duration of the start-up are determined. After a short shot-down, the electric furnace can be turned on at the rated electric current without having to plan a start-up. Before a medium stop, a reduction of the current to 80% of the nominal value 2 hours earlier is suggested. The furnace should be started at 50% of the nominal amperage. At least four hours before a long stop, a gradual reduction of the current to 60% of the nominal value is advised. After that, starting the furnace should be with 20% of the nominal current. The duration of the start-up depends on the duration of the shot-down and is determined in accordance with the developed by R&D department diagram presented in **Figure 5**.

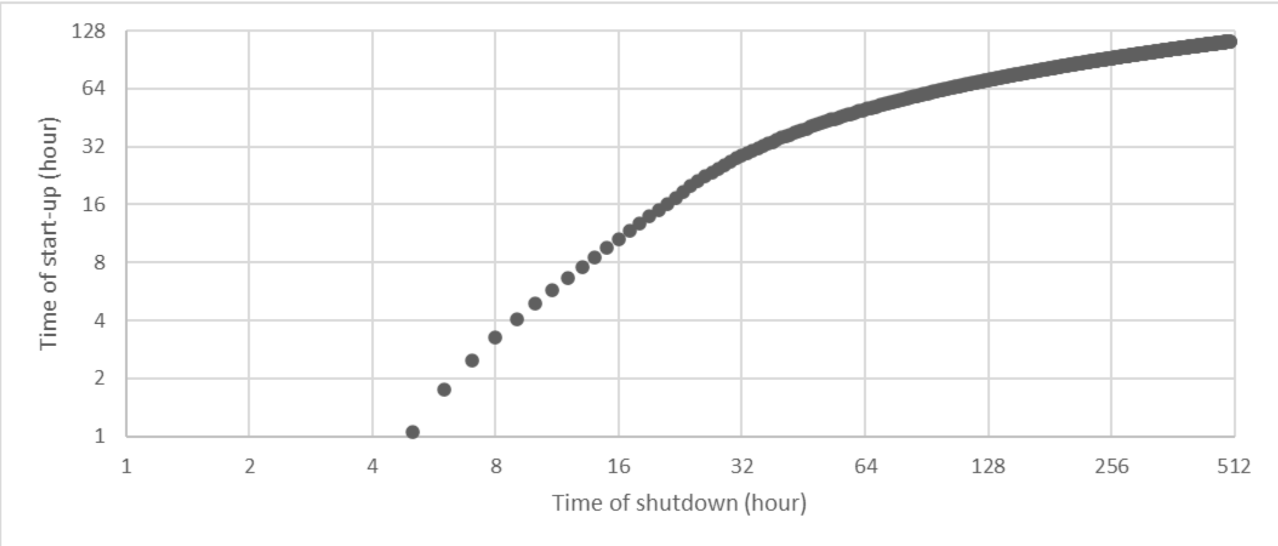

Figure 5 The relationship between the start-up duration and the shutdown duration

5. CONCLUSION

The results from this research show the reasons of soft and hard breakages of self-baking electrodes during SAF start-ups and implemented solutions to avoid them. Breakages mostly were caused by disobeying procedures of properly preparing electrodes for the SAF shut-down, overload electrodes during the SAF start-up, incompatible between current and slipping, and too short start-up causing too fast increase of current density in the cross-section of the electrode. Most of these reasons could be minimized by improving the technical equipment of electrodes, systematically providing training for SAF operators, and continuously collaborating with electrode paste manufacturers. The most important factor in minimizing the risk of electrode breakage is the development of appropriate technological procedures based on previous experience.

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REFERENCES

[1] ASPHAUG B., INNVÆR R. *Introduction to the Søderberg electrode*. Kristiansand: Elkem, 1997.

[2] SCHEI A., TUSEK J.K., TVEIT H. *Production of High Silicon Alloys*. Trondheim: TAPIR, 1997.

[3] ANDERSEN G., INNVÆR R., LARSEN B. Operation of Søderberg electrodes. Methods to avoid and solve electrode failures. In: *The IX International Ferroalloys Congress INFACON*. Quebec City, 2001, pp. 494-500.

[4] LARSEN B., FELDBORG H., HALVORSEN S.A. Minimizing thermal stress during shutdown of Søderberg electrode. In: *The XIII International Ferroalloys Congress INFACON*. Almaty, 2013, pp. 453-466.

[5] KOZŁOWSKI S., BANASIK Ł. Innowacyjne rozwiązania w elektrometalurgii żelazostopów na przykładzie projektów realizowanych przez Re Alloys sp. z o.o. *Hutnik-WH*. 2021, vol. 88, no. 1, pp. 14−21.