EAF STAINLESS STEEL FOAMING SLAG NEW TECHNIQUE, HIGH EFFICIENT TECHNOLOGY[1]

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Abstract

Electric arc furnace technology's economy is strongly dependent on efficiency of electrical energy introduction into the melt. Slag foaming practice for carbon steel grades is normal daily application but for stainless steels not yet. Arc activity stabilization improves thermal efficiency and operation conditions and lowers Production cost. Consequently, refractory and electrode consumption as well as noise level is significant decreased. The patented SMS Demag AG technology developed with AGH-University in Cracow /Pl and tested by Acesita S.A./ Brazil assures all these effects also for stainless steel production. This technology distinguishes in comparison with all known applied and trialled technologies working with injection procedures. Special briquettes are used as reacting agent on the slag and metal phase boundary forming the carbon monoxide necessary for foaming effect. High foaming level covering complete the electric arc allows highest transformer taps resulting in longer electric arcs/ high temperature gradient.

Key words: EAF-stainless steel; Foamy slag; Briquettes; Foaming control.

ESCÓRIA ESPUMANTE EM FEA'S PARA A PRODUÇÃO DE INOX – NOVA TECNOLOGIA

Resumo

FEA's economia operacional depende da eficiência da introdução da energia no banho metálico. A prática de escória espumante para aços carbono já tem a sua aplicação diária porém ainda não se obteve isto para aços inoxidáveis. A redução do custo de produção é obtido através da melhoria da eficiência térmica e das condições de operação através da estabilização das atividades do arco. Conseqüentemente o consumo de material refratário e de eletrodos bem como o nível de ruído é reduzido em muito. Os mesmos efeitos podem ser obtidos agora na produção de aços inoxidáveis com a nova tecnologia patenteada da SMS Demag AG/ Alem., desenvolvida em conjunto com a Universidade AGH de Cracau/ Pol. e testada pela ACESITA S.A. /Brasil. Esta tecnologia destaca-se em comparação com todas as tecnologias já conhecidas e tentadas que se baseiam em procedimentos de injeção. Briquetes especiais estão sendo utilizados como agente reativo junto à interface escória/ banho metálico formando monóxido de carbono necessário para o efeito de formação de escória espumante. Escória espumante cobrindo o arco elétrico por completo permite o uso dos taps mais altos do transformador resultando em arcos mais longos ou elevados gradientes de temperatura, respectivamente.

Palavras-chave: Produção de aço inox em FEA; Escória espumante; Briquetes; Controle de escória espumante

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1 INTRODUCTION

Since many years the foaming slag practice in the EAF is well established in low alloyed steel production. It improves thermal efficiency of the melting, lowers refractory and electrode consumptions, and provides a stable electric arc activity at lower noise level. Good foaming effect is attainable by suitable slag viscosity strong affected by high iron oxide content in the slag as well as permanent iron oxidation and iron oxide reduction by injected oxygen and carbon into the slag and steel, respectively. In case of high alloyed steels with high chromium content the preconditions for slag foaming effect are diametrical different. Oxygen injected into the steel produces mainly chromium oxide with totally different properties in comparison with iron oxide, it changes the slag viscosity significantly. The solubility of chromium oxide in the slag is considerable weaker in comparison with that of iron oxide at the same thermal and basicity conditions. Also the reduction of chromium oxide by carbon does not attain such intensity as the reduction of iron oxide. The gas generation is poor. The oxygen/carbon injection technique in the high chromium alloyed steel production is due to the chemical and physical conditions evidently hazardous and difficult in operation. The risk of uncontrolled oxidation of chromium is pronounced, resulting in high chromium losses and poor foaming.
In common development of the SMS Demag AG / Germany, Acesita S.A. / Brazil and the AGH-University of Science and Technology / Cracow, Poland a new sophisticated technology of foaming slag has been invented and laboratory as well as industrial successful tested.
The novel technology distinguishes principal from the conventional one, which uses injection of oxygen and carbon via manipulator lances. The new technique bases on the reduction of iron and chromium oxide by carbon as well as on the thermal dissociation of lime stone contained in a small dimensioned briquette. Specific density of briquettes is assorted to have value between slag and metal. Their introduction into the melt causes placing exactly on the slag and metal boundary, optimal place for the requested gas generated reaction.
The aim of this project was to establish adequate forms and chemical compositions of materials for effective slag foaming with high chromium oxide content as well as to define optimal slag conditions. The supposed materials contain iron oxide scales, carbon carriers, and high-carbon alloys typical for stainless steel production. As ballast, for the purpose of briquette density control, iron alloys as well as possible calcium carbonate or fluorite combined with some binding agents were taken in consideration. Besides of these features different sizes between briquettes or pellets were considered.

2 SOPHISTICATED IDEA OF SLAG FOAMING FORMATION

Two issues define the foamy slag formation: the foaming material with the corresponding reacting components, which produce gaseous products, and the slag viscosity dependent on the chemistry and temperature. A liquid slag is for the foam formation a prerequisite.
The principal reaction that creates gas bubbles in the slag is the reduction of iron and chromium oxides are given by the following stoichiometry:

$$FeO_{solid\ or\ liquid} + C_{solid\ or\ liquid} = Fe_{liquid} + CO_{gas} \quad (1)$$

$$Cr_2O_3\ _{liquid} + 3C_{solid\ or\ liquid} = 2Cr_{liquid} + 3CO_{gas} \quad (2)$$

The reaction (1) in carbon steelmaking is the principle and iron oxide is the major component in the slag. When the slag viscosity is suitable for sustaining foam, then the simple carbon injection into the slag causes the foaming effect. Other situation is in case of stainless steel slag. The major components are CaO, SiO_2 and Cr_2O_3. The SiO_2 is a fluxing component, while the Cr_2O_3 stiffens the slag. Due to the higher chromium affinity to oxygen the Cr_2O_3 generation takes place preferentially in comparison with FeO. Therefore It is important to control the chromium oxide content and the slag basicity, responsible for the viscosity, which constrains gas bubbles to temporary detainment in the slag layer.
The bubble forming phenomenon is a process of formation new surface area by the mechanical force resolved by reaction gas. In the presented technology this gas is an effect of the reduction reaction of metal oxides by carbon taking place in a briquette or pellet introduced into the metal bath. Buoyancy forces of bubbles crack the slag surface saturating temporary the top layer create the foam. With a sustained gas flow coming from the reacting briquettes the population of the bubble aggregation as foam continues to grow. As a consequence of it, the height of the foam layer increases. Important for such mechanism is the optimal placing of the briquettes to get the maximum foaming effectiveness. It is the boundary between the slag layer and liquid metal. With the control of the briquette density, corresponding to the range between that of slag and metal (3-7t/m^3) such placing is always reachable. The foam height increases with the increase of the gas flow rate; it is directly proportional to the foaming material rate.

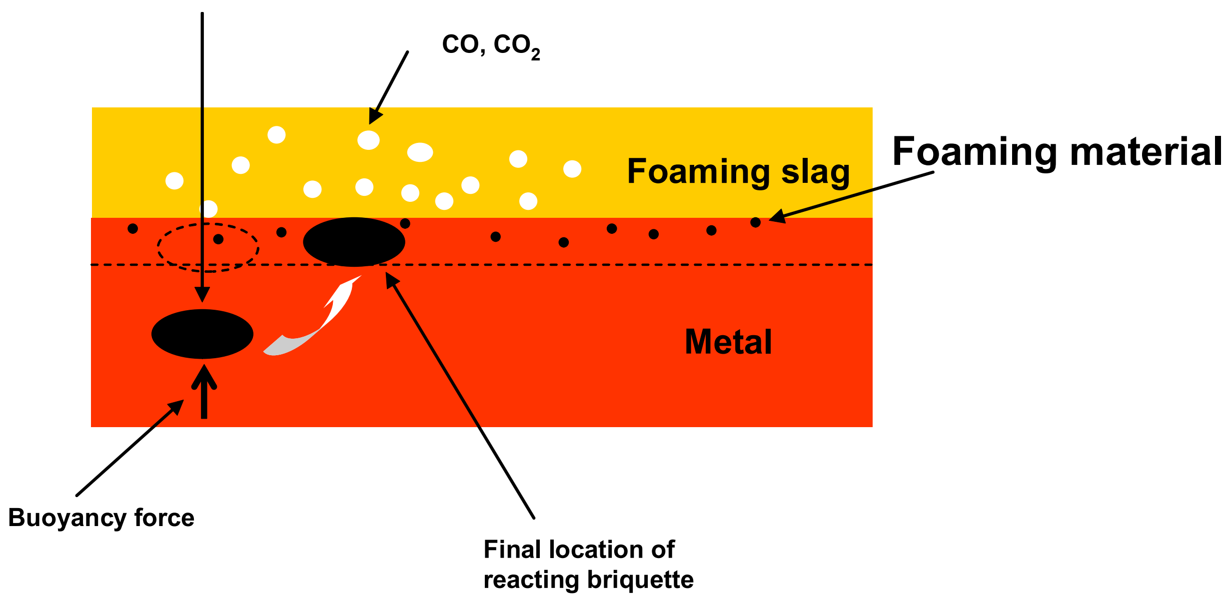


Figure 1. Principle of foaming slag formation by briquette

Figure 1 illustrates the principle of the slag foaming.

3 THEORETICAL CONSIDERATIONS. LABORATORY TEST. RESULTS

The aim of this laboratory experiment was to establish adequate forms and chemical compositions of the materials for effective foaming of high chromium oxide slag. The materials were supposed to contain iron oxide scales, carbon carriers, and high-carbon ferrochromium as weighting agent as well as possibly calcium carbonate as additional producer of gas for foaming process. As to the form of the foaming materials either briquettes or pellets of different sizes were considered. Furthermore, the research study was to be carried out by making laboratory heats, sampling metal and slag phases for chemical analysis in order to optimize the foam ability.
In the first stage of the work, the most promising materials for foaming were selected based on theoretical considerations. A model for computation of the specific densities of the foaming mixtures was applied.
In the second stage of the work, the foaming mixtures were prepared in forms of briquettes and pellets of different sizes. A number of 40 heats were performed in a laboratory arc furnace to investigate the impact of various parameters on the height and stability of the generated foams.
In the third stage, the obtained experimentally results were analysed and the final conclusions and technological recommendations as to the optimal conditions for the slag foaming were established.
Figure 2 illustrates the test stand consisting of a single-electrode EAF with conductive bottom. The furnace was powered by a transformer, 75 kVA rated power, supplied by a voltage of 380V. The total melt capacity was 5kg. Tested metal was prepared from about 1.5 kg of AISI 304 scrap. After the scrap melting, an industrial slag of defined composition and weight, approx. 3 kg, was added and melted accompanied by samplings for metal and slag chemistry, s. Table 1. The temperature was controlled closed to 1600°C, the initial height of the slag recorded and the foaming material in small batches added into the furnace;

Figure 2. Laboratory EAF - Test stand

Since the foaming initiation until the cease of the foam, the slag height and the foaming duration were being measured. The measurement was done by immersion of a tungsten bar until it got the crucible bottom. After taking out the bar, the height of the solidified slag was read out; the reading was supposed to be equal to the foamed slag height.

Table 1. Chemical composition of the slag

Chemical composition, %						
CaO	**SiO_2**	**FeO**	**MnO**	**MgO**	**Al_2O_3**	**Cr_2O_3**
40.33	30.21	5.11	5.44	7.80	8.42	11.86

The total duration time of the foaming process after slag melting was within 7 to 14 minutes range. When the foaming process was over, sampling of the slag was done again and the metal with slag was tapped into a mould. After their solidification the metal as well as slag was weighed.

Two forms of foaming material were applied: briquettes and pellets. The briquettes were made by compression of a powdered charge material by means of a specially designed press device. The diameter of this way produced briquettes was 30 mm, the height was within 15 – 17 mm range. They weighed within 50 – 70 g range. The pellets were made in a drum by pelletizing powdered materials with added molasses as binding agent. Two kinds of the pellets (2 – 5 mm and 8 – 10 mm) were sorted and applied in tests.

The investigations were carried out for the foaming additions as mixture of stoichiometric amounts of Fe_2O_3 and C-graphite. Specific densities of material components and the briquettes are presented in the Tables 2 and 3.

The specific densities of the foaming material components used for the calculations and the calculated specific densities are presented in the Tables 2 and 3.

Table 2. Specific densities of the pure, monolithic foaming material components used for the test

Component	**Fe**	**Cr**	**Fe_2O_3**	**C**	**$CaCO_3$**	**CaF_2**	**FeCr***
Specific density, [g/cm^3]	7.86	7.2	5.3	2.25	2.7	3.18	7.09

**) 54%Cr-35%Fe-8%C-3%Si*

Table 3. Calculated specific densities of foaming materials.

Foaming material	**Material 1**	**Material 2**
Foaming material composition	18.37%C-81.63% Fe_2O_3	27%C-73% Fe_2O_3
Specific density, [g/cm^3]	4.74	4.47

The results of the slag foamability dependent on the kind of used material are illustrated in diagram, Figure 3.

Results indicate that the highest foamability one gets for the pellets of a 8-10 mm diameter, while the lowest one for those of a 2-5 mm diameter. The effect is due to the fact that small pellets do not sink trough the slag layer down but float up to the slag surface. The phenomenon is caused by the interfacial tension forces at the pellet/liquid slag boundary. While floating on the slag surface, the bubbles formed in the pellets do not go into the slag layer but go into the ambient atmosphere. For pellets, the foaming time was lower than this for briquettes. It can be explained by the kind of their structure. Briquettes, are compressed materials, have lower porosity. Decreased contact surface with liquid slag causes slower heat transfer slower reduction of the iron oxides in the briquettes and in consequence lower gas rate. Only briquettes were selected for industrial examination.

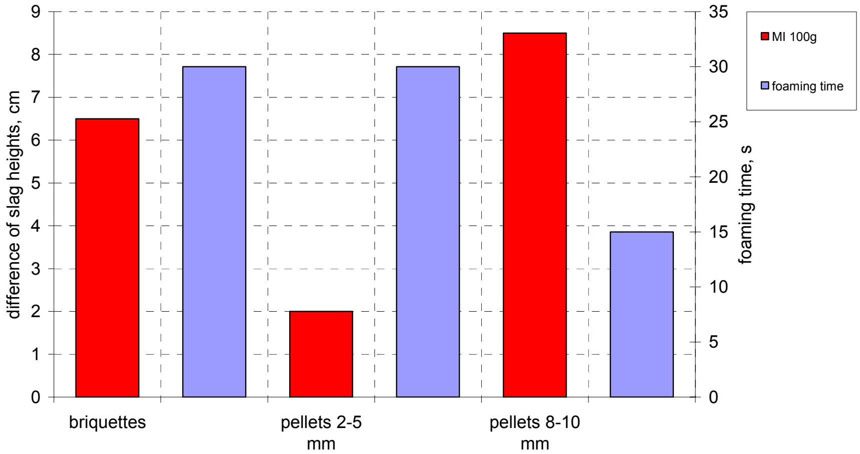


Figure 3. Differences of slag heights for different forms of foaming material

4 Industrial test by Acesita S.A. Procedure. Results

On the base of the above described laboratory test ACESITA S.A. and SMS Demag AG have agreed a common industrial test of foamy slag at high Cr-oxide in an EAF to prove its industrial functionality as well as viability. The test was carried out in the EAF #3 in the steel plant in Timoteo / Brazil. The EAF-AC with the capacity between 34t and transformer of 20/24 MVA is designed for pre-metal production of austenitic and ferritic steel grades in common operation with the down stream operating 80t AOD-L and MRP-L converters.
The test, integrated into the current production consisted of 48 austenitic and 12 ferritic heats. 40 heats were tested corresponding to the technological variant 1, s. Figure 4. The variant 1 distinguishes from the normal operation, variant 2, where oxygen is blown during the whole super heating period. The reason of such procedure was to separate the oxygen effect on the carbon and metal oxidation, additional generation of CO bubbles, as well as impact effect of the gas stream. The residual heats were tested under normal operational conditions by variant 2.

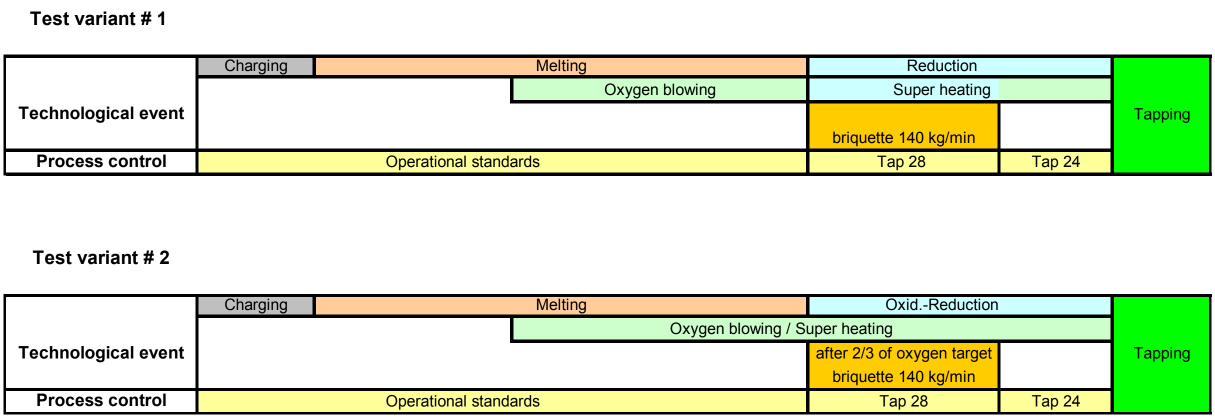


Figure 4. Scheme of test variants

The EAF #3 works with a power divided into 9 taps. The tap 28 with arc length between 16.5 -21.5 cm allows work with the maximal power and is used general in the first melting stage only. Because intensive energy radiation on the furnace walls during the super heating period, where metal bath is flat, a protected operation is requested e.g. short electric arcs. In operational standards the lowest taps between 21 and 24 with the arc length of 11.1 – 17.4 cm are applied. High level of foaming slag, above the electrode tips, allows operations with higher taps shorting the tap to tap time. The real temperature gradient was estimated at approx. 13 - 14 K/min at the tap 28 against 6-7 K/min at the tap 24.
As foaming material briquettes with changed composition in comparison with the lab.-test were used. The ballast function of FeCrHC was substituted by fine shredded ferritic scrap. The briquettes were made from mixtures consisting materials shown in Table 4 while its size is shown in Figure 5.

Table 4. Briquette compounds

Material
Scall CCM **Coke** **Limestone** **Fine scrap** **Binder**
Real density 3.8 - 4.2 t/m3

Figure 5. Briquette size

Briquettes were added into the furnace via 5th hole with controlled addition speed. Each test heat were recorded by video camera and documented by metal and slag analysis before briquette additions and at the tapping. Simultaneously to the metal sampling the temperature were measured. For the purpose of noise measurement developed during the foaming period and comparison with standard operations some heats were recorded continuously by a portable sonic measuring device. Besides these measuring each heat was recorded by signals like voltage, current, energy consumption, power, cos φ and by the tap number. Figure 6 illustrates the observation stand in the front of the EAF # 3.

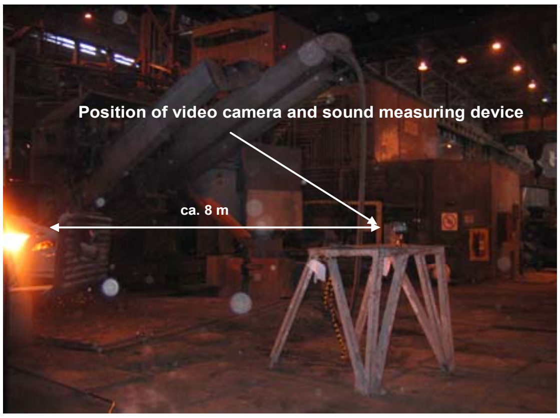


Figure 6. Test observation stand

As the test results show, the foaming of a Cr_2O_3 rich EAF slag is a difficult but under controlled slag conditions possible task. Results of this industrial test confirm the correct recipe of the foaming material and the optimal reacting place of the briquettes. Further experiences of the test show also dependences between the initial slag amount and its foamability.
Intensive gas development in combination with the slag mass and the desired low viscosity allows slag generations with sufficient height for complete cover of the electric arcs. The optimal initial slag amount fluctuates in the range 68-72 kg/t_{steel}

Figure 7 illustrates areas of slag composition after briquette additions. It can be seen, that the most slags were good reduced. The average residual Cr_2O_3 in the slag was indicated by 4,2%. Also the basicity in the range 1,3-1,35 established as optimal. This part of the slag system must be considered to be the optimum area. The viscosity is in this part low, however, partly undissolved lime and higher Cr_2O_3 content the viscosity increases. Figure 8 illustrates a typical slag height development of a AISI 304 heat. For the purpose of slag heights measurement the diameter of electrodes were used.

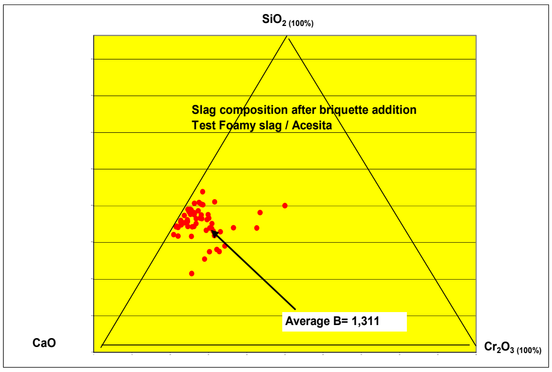


Figure 7. Standardized slag diagram

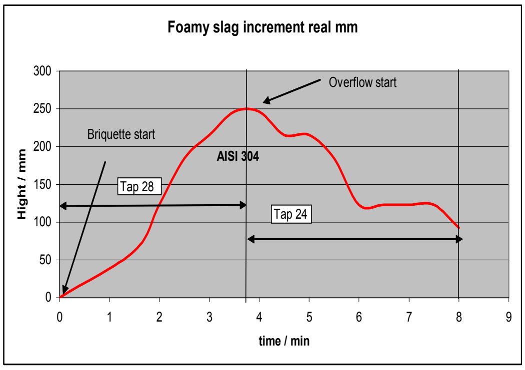


Figure 8. Slag height course

As the curve shows, after approx. 2 minutes the slag reached the adequate height suitable for the electric arc cover. During the next 4 minutes this level was established, leaving the required range after 4-5 minutes. It should be mentioned, that since the 3,5 minutes an overflow of the slag through the furnace door was

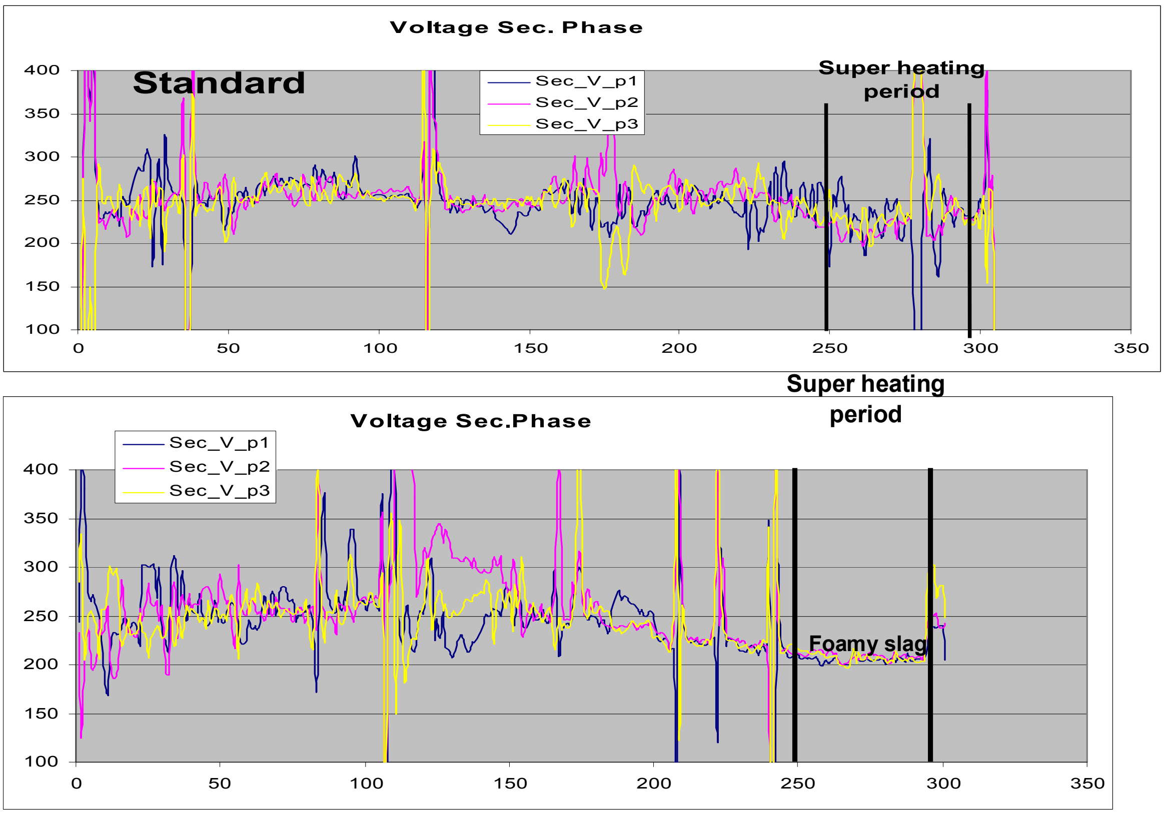
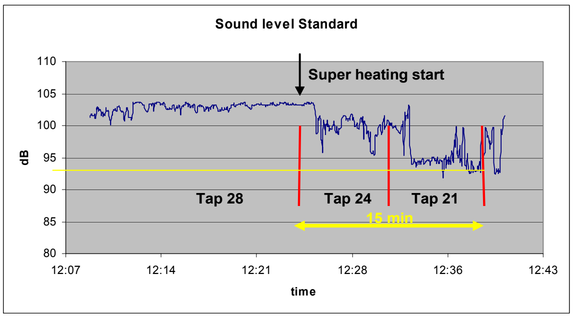


Figure 9. Dynamic of electric arc in standard and foamy slag presence

observed. The slag mass was relating to this continuously reduced untill a stable level was reached. It was observed in other tests with oxygen blowing, that the oxygen stream support in the receipt of the foaming layer. In view on the electrode consumption the foamy slag has an undisputed significance. Figure 9 illustrates by secondary voltage the electric arc behaviour in a standard operation and in the presence of foaming slag operation. Small signal fluctuations, low level of amplitudes lowers mechanical and thermal electrical tensions. In consequence of such courses the level of noise generation is also significant lowerd. Figure 10 shows a comparison of the noise development in case of a standard and with foamy slag treated heat. It can be seen, that the standard heat is operated in the super heating period with a decided lower transformer tap 24 and 21 and generates a noise level between 100 and 95 dB accordingly. Test heats show an exactly correlation between the foamy slag development, means covering of the electric arcs by foam, and the noise level. The impact of the foam damping can be seen explicit in the final period, where the noise level decreases from the approx. 95 to 90 dB at a transformer tap 24, Fig.10 below.



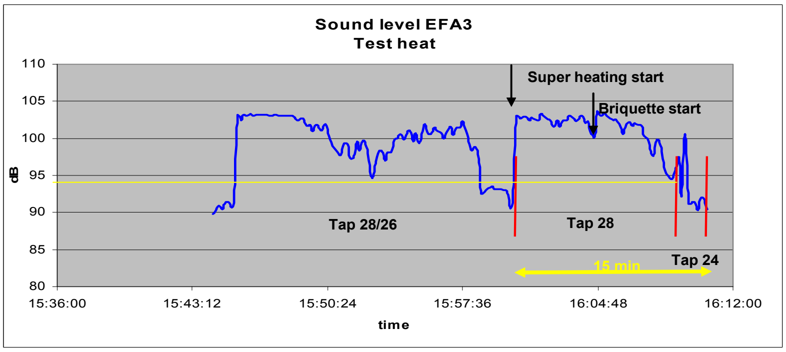


Figure 10. Sound development during super heating

Tested heats were general observed in view on the briquette components, their density, addition speed control, slag conditions and technology. Evaluations of metallurgical parameters show improvement trend in almost all aspects. In scope of charge materials, chromium, manganese and metal yield the improvement is approx. 2 %. The shortening of the super heating period by operation with higher transformer taps has a high potential in increasing of the plant production. However, due to the relative low number of test heats (60) a final comparison will be made after longer campaign in term. Especially long impact effects like electrode consumption, refractory life, electrical maintenance of switch transformer contacts and dust emission present high significance in the process economy.

5 CONCLUSIONS

Both tests demonstrate that the new foaming slag technology for stainless EAF´s carried out by foaming materials containing scale, carbon and ballast materials, introduced into the furnace in briquettes form with a special defined density and in combination with a controlled slag viscosity implicates sufficient foaming quality and its height. The slag height is controllable by intensity and duration of additions. In details it can be concloud, that:

-Briquettes with FeCrHC or ferritic scrap fulfil requirements of density
-Limestone improves the gas formation
-Briquettes with density higher than 3.5 t/m^3 assures the placing directly under the slag
-Good slag foaming is dependent on the slag viscosity controlled by the temperature and basicity. Lower temperatures (1500-1550°C) corresponds lower basicity (lime not completely liquid) , higher temperatures (1600-1650°C) corresponds higher basicity (lime completely solved). Both factors work contrary.
-High foaming effect requires a sufficient level of original slag
-High foaming slag stabilizes thermal and mechanical conditions on the operating electrodes tips
-Covering of the electric arcs by foaming slag causes lowering of noise level

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