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ANALYSIS OF THE THERMAL PROFILE OF THE ELECTRIC ARC FURNACE OF SINOBRAS S.A

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Abstract. *Due to the high working temperatures of the lower metal housing of the electric arc furnace (EAF), this work has as objective to analyze the thermal profile of the EAF, suggesting an increase in the refractory of work, aiming at the decrease of the lower metal housing of the EAF. Thus, the influence of the thermal cycle of the process was analyzed through thermographic monitoring, analytical calculations and computational simulations using the Finite Element Method. Therefore, the proposed modifications, after being tested and analyzed denoted efficiency in such a way that it resulted in a decrease of approximately 60ºC in the temperature in the lower metal housing of the EAF.*

Keywords: *Electric arc furnace; Computational simulation; Thermic cycle; Finite Element Method.*

1. INTRODUCTION

The Electric Arc Furnace (EAF) used in steelworks for the fusion of scrap metal are undoubtedly the most versatile instrument for steel production and have also become one of the most efficient in recent decades [1].

The high working temperatures of the EAF are constantly analyzed. A thermal monitoring, often by measuring instruments such as pyrometers and thermographic cameras, is of prime importance for the production process. This indicator allows quick and necessary action to avoid possible stops in the process. A typical situation concerns the high temperatures of the lower housing of the EAF, especially at the end of the campaign when the refractory is already very worn, which indicates the need for repair in the region, often through projections of refractory masses. Thus, avoiding greater consequences, such as the drilling of the metal housing causing large process stops for repair and possible serious accidents, due to the leakage of liquid steel.

The high working temperatures in the EAF also cause large deformations in the lower metal housing of the EAF and, as a consequence, such deformations overturn the permanent and working refractories of the EAF, exposing the metallic housing to the high radiations of the graphite electrode. In this way, it is essential to control the thermal cycle during the melting and refining process of the steel to obtain a safe and puncture-free electric furnace.

Thus, the present work aims to analyze, through data collection in the area, analytical calculations and computational simulations, the thermal profile of the lower metal housing of the EAF during the steel production process, suggesting an increase in the refractory of work aiming at reducing the external temperatures of the metal housing of the EAF.

In the radial direction of each graphite electrode in the EAF, there is a sector called "hot spot" where higher radiation and heating occurs [2]. In Sinobras S.A, such a region is called "spot 4" shown in Figure 1. There are other hot spots, however, spot 4 has a history of problems such as reddening and perforations of the sheet metal and thereby will be the focal spot. Reaching the above-mentioned objective should, consequently, improve the performance of this region, lowering its working temperature avoiding reddening and large thermal deformations.

2. MATERIALS AND METHODS

2.1 Determination of the working temperatures of the EAF metal housing

The control of the temperature of the processes in a melt shop is of fundamental importance to reach the quality and productivity requirements currently required. with the thermal imager FLIR - T Series, it was possible to obtain data of the external temperature of the lower metal housing of the EAF at several points. The collected work temperatures were used as boundary conditions for the computational simulations and for the analytical calculations.

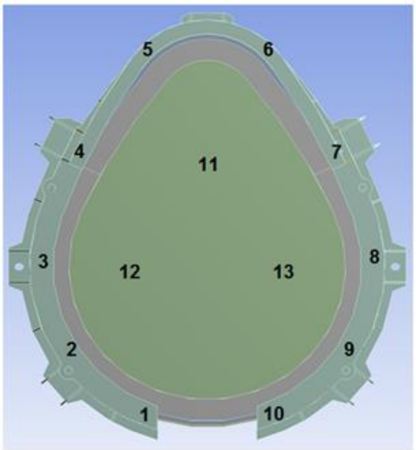

Figure 1. Reference spots in EAF

2.2 Analytical calculations

The energy transfer rates in the form of one-dimensional and steady-state heat were considered, as indicated in Gupta [3]. According to Incropera [4], the equations describing the temperature distribution on the EAF wall are:

One-dimensional heat transfer rate by conduction in composite walls (Equation 1):

$$\dot{q}_{wall} = \frac{T_{hf} - T_{mp}}{\frac{\ln\left(\frac{r_1}{r_i}\right)}{2\pi L k_t} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi L k_p} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi L k_c}} \quad (1)$$

Where T_{hf} corresponds to the temperature in the hot face and T_{mp} the temperature in the metal housing, both in Celsius. r_i is the internal radius of the EAF, r_1 the radius to the cold face of the working brick, r_2 the internal radius of the metal housing and r_3 the outer radius of the metal housing, all in meters. k_t is the thermal conductivity of the working brick, k_p is the thermal conductivity of the permanent brick and k_c is the thermal conductivity of the metallic housing, all given in W/m^2C. L represents the thickness in meters.

The results of the temperature distribution of the refractory lining from the interior of the EAF to the external face of the metal housing are subsequently compared with the results of the computational simulations in permanent regime in order to validate the same.

2.3 Numerical calculations

Due to estimate the heat in the workpiece, two techniques can be considered. The first one depends on analytical mathematical models based in heat equations involving the solution of adapted and simplified partial differential equations, to simulate practical operation. This generally leads to significant simplifications in mathematical models, in general, due to complex part geometries [5]. The second technique is the computational basis for the computer-aided engineering systems and uses Finite Element Analysis, based on some equations, more applied on small and finite simple elements. When they are joined, the part with complex geometries can be evaluated [6]. Such techniques of Finite Elements, Finite Differences and Finite Volumes are widely used for heat transfer problems [7].

For the discretization and computational simulation of the model by the finite element method it is necessary to first develop the three-dimensional geometry. Thus, the EAF lower housing geometry was developed based on the original design made by the German Badische Stahl Enginnering GmbH (BSE). In Figure 2 the original geometry and the proposed geometry can be observed.

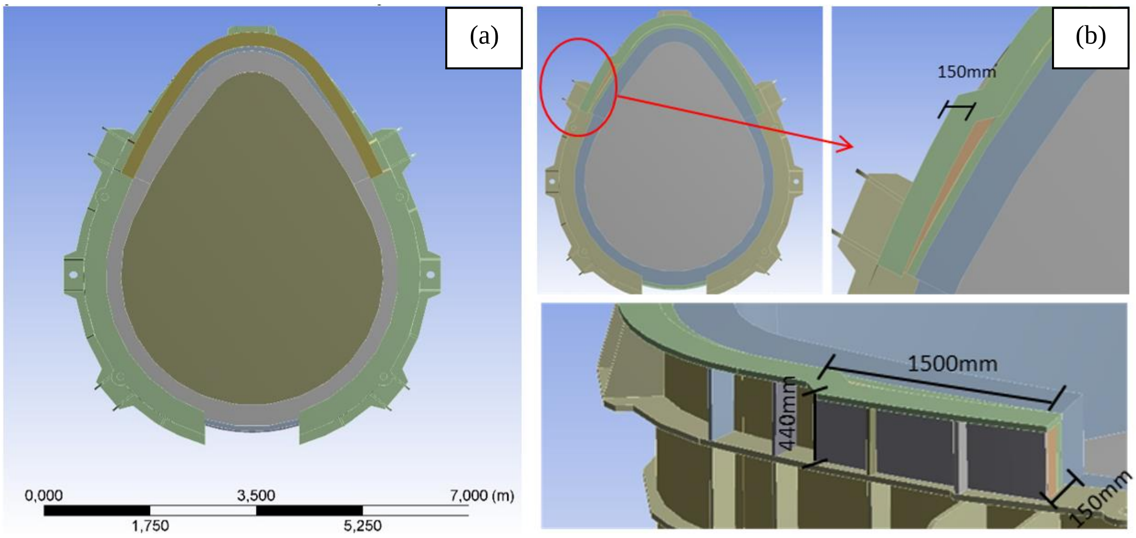

Figure 2. (a) EAF original geometry; (b) proposal geometry.

The ANSYS © software was used for the geometry discretization and simulation of the theoretical model of heat profile being exchanged with the refrigeration fluid by natural convection and radiation. The mesh parameters for the proposed geometry were composed of 200204 nodes and 61648 elements, with refined hexahedral cells, shown in Figure 3. The boundary conditions used for the thermal simulation were:

- Steady state condition;
- Heat conduction by refractories and sheet metal;
- Natural convection and radiation by sheet metal in environment contact;
- Constant environment temperature equal to 50 ºC;
- Liquid steel temperature equal to 1700 °C;
- Working refractory thickness of 180 mm, end of campaign;
- The conductivity thermal coefficient of the working refractory is equal to *4.043W/m.K* and the permanent refractory is equal to *2.983W/m.K*.

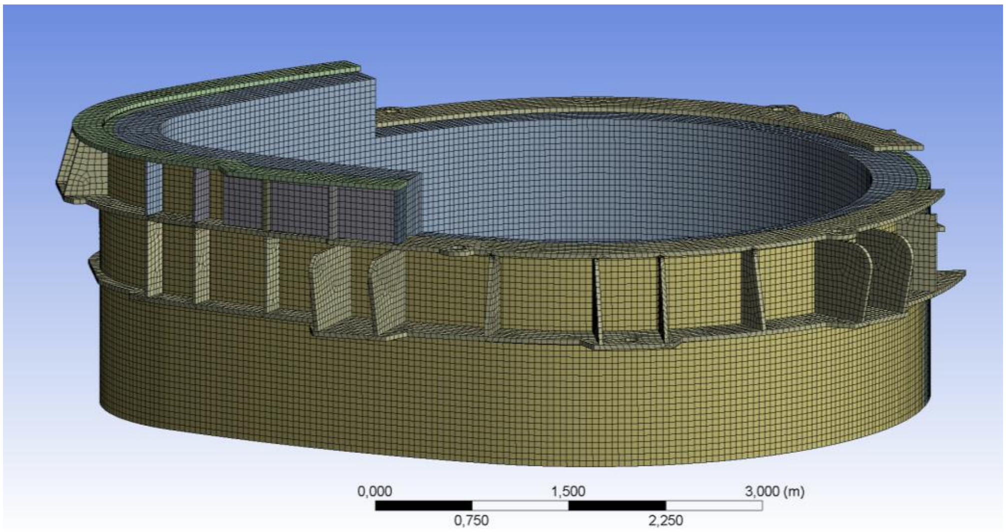

Figure 3. Detailed mesh example of EAF lower housing with working refractory in the end of campaign.

During the simulation, the first element on the inner surface receives heat by conduction simulating the thermal exchange between the liquid and the refractory steel. All other elements in the wall, the surface of the metal housing, exchange heat with the environment using the convection coefficient. After calculating the temperature distribution for the entire domain, the same procedure is applied to the next element. This procedure continues to its permanent state. At the end, the final temperature distribution is obtained.

2.4 Expansion of the working refractory in spot 4

The improvement was applied on May 10, 2017. As shown in Figure 2 the region of spot 4 was increased and therefore the working refractory as well. There was an increase in working refractory of 150mm, left 350mm, previous situation, to 500mm, current situation. Such measurement was taken only in the critical region - spot 4 - about 1500mm in length and 440 in height. Figure 4 shows the enlargement of the region.

Figure 4. Expansion of the working refractory in spot 4.

3. RESULTS AND DISCUSSION

3.1 Analytical results

Equations 1 determined analytically the temperature profile from the working refractory to the external metal housing of the EAF, before and after the expansion of the working refractory, shown in Figure 5.

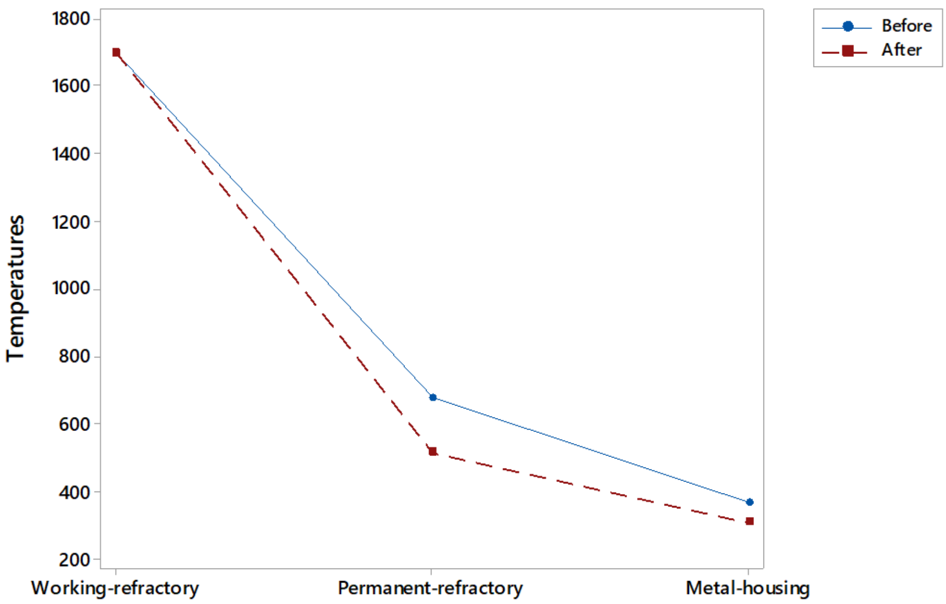

Figure 5. Temperature profile of the EAF

According to the AISE Technical Report No. 9 for EAF with similar characteristics as Sinobras SA, nominal capacity of 40 tons of steel and thickness of the metal wall of one inch, the working temperature limit is 343°C [8]. Therefore, before the change in the lower metal housing its analytically calculated external temperature was approximately 370°C, above the maximum allowed temperature. such work temperatures increased the structural deformation of the region, causing the refractory bricks to work and expose the metal housing directly to the high temperatures of the electric arc, provoking stops of the process. After the change in the lower metal housing its temperature decreased by approximately 60°C, being below the maximum allowed working temperature according to the AISE Technical Report No. 9.

3.2 Numerical results

Figures 6 show the temperature profile from the working refractory to the external metal housing of the EAF, before and after the application of the expansion of the working refractory, both at the end of campaign.

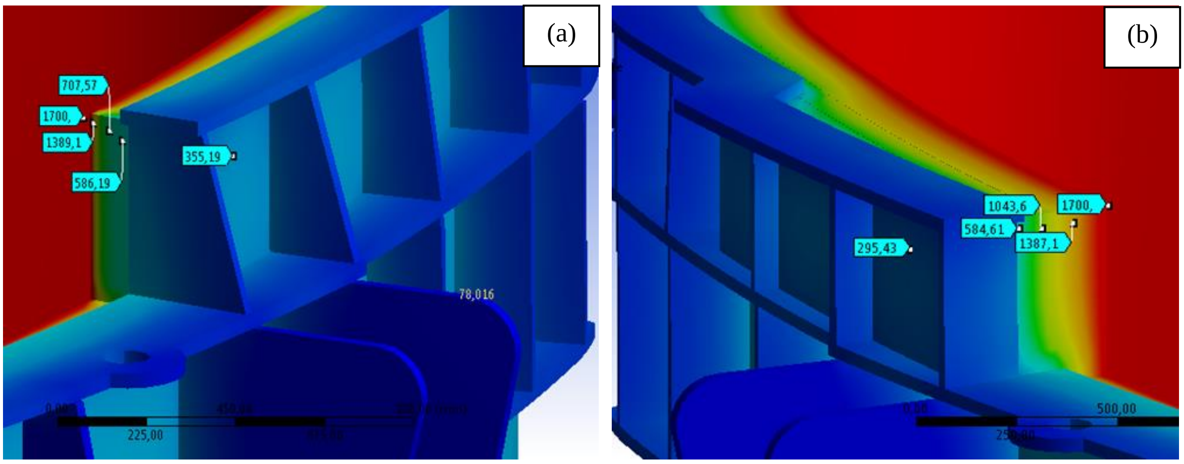

Figure 6. Temperature profile of the EAF, (a) before the expansion of the working refractory end (b) after the expansion of the working refractory, both at the end of campaign.

By comparing the temperature profile curves with the computational simulations, we can see that there is a difference of results that does not compromise the model, due to its small fluctuation value. In addition, the experimental analysis using thermographs shown in Figure 7 shows that the results, both numerical and analytical, are in accordance with the reality of the situation. The analysis shows a temperature reduction of approximately 60 ° C.

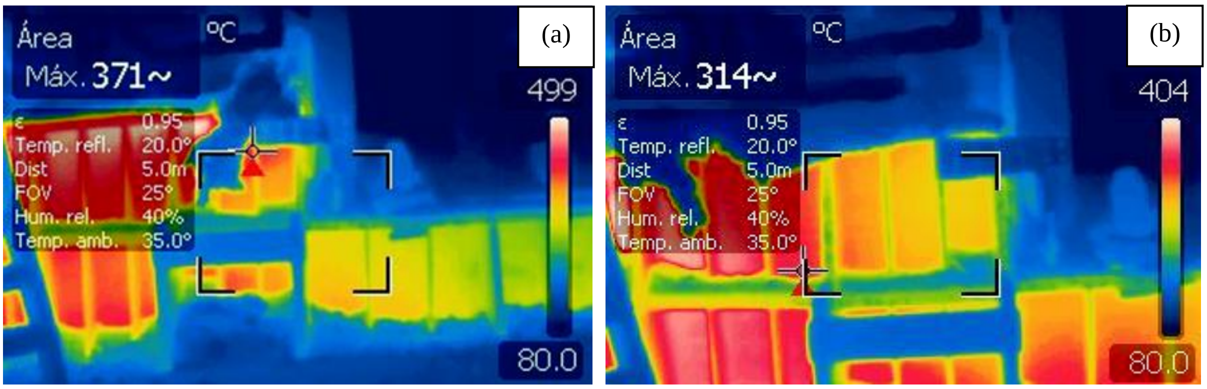

Figure 7. Thermography of the spot 4, (a) before the expansion of the working refractory end (b) after the expansion of the working refractory, both at the end of campaign.

4. CONCLUSION

- The temperature of the lower EAF housing significantly reduced after the expansion of the working refractory, about 60 ° C;
- Due to the project enlarges the region of spot 4, increasing its surface area of contact, it avoided the occurrence of refractory falls in the same, and, thus, reducing the direct exposure of the lower metal housing to the high temperature of the electric arc;
- The decrease in working temperature of the metal housing reduced the preventive stops of the EAF, 70 days of production without stops were achieved;
- There was a drop in the total cost of refractory about 1.7%.

5. ACKNOWLEDGEMENT

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