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EVALUATION OF CARBON DEPOSITION IN THE STRUCTURE OF A HYBRID PLUG USED IN A STEEL LADLE FOR GAS STIRRING

Paula R. Dutra.[1], Marcos P. M. Cunha[1], José L. Zamagno[1], Aloyso O. F. Junior[1]
[1] Magnesita Refractories, Contagem-MG, Brazil
paula.dutra@magnesita.com

ABSTRACT

Several wear mechanisms of gas purging plugs have already been studied and reported in the literature but little has been said about the decrease in gas permeability due to carbon deposition in the porous structure of the plug. Through a post mortem analysis and laboratory tests, comparative measurements of total carbon deposition and permeability have been performed in some used and new hybrid plug. According to this study it was confirmed that during the life of the plug, when it is submitted to the gas flame test, hydrocarbon gas can be cracked and cause carbon deposition in the porous plug structure, which can decrease the efficiency and as a consequence the life of the plug.

Keywords: Plug; Permeability; Performance

INTRODUCTION

Porous plugs are used in secondary metallurgy for the production of high purity steels. The porous plug is usually assembled in a metal can that is connected to a gas inlet pipe. Then this porous plug is fitted in the bottom of the ladle and through it nitrogen or argon is blown into the molten metal bath.
The purpose of inert gas bubbling (especially argon) is: 1-Uniformity of molten steel temperature in the ladle, 2-Homogenization of molten steel components, 3-Removal of non metallic inclusions (purification of molten steel) and 4-Improvement of refining effects.[1] The performance of gas purging plugs greatly influences productivity and quality of steel in the steel making process.[2]
To ensure a good performance of the stirring system, the plugs are tested for leakage and outflow behavior. Nitrogen can be used to test the leak-proofness of the stirring system on the ladle.[3] A hydrocarbon gas like LGP (liquefied petroleum gas), propane or natural gas can be used to check the flame pattern of the porous plug.
According to Tassot P.(2006), the use of natural gas for testing the efficiency of the plug is not recommended as the natural gas can 'crack' in the pores of the permeable element inducing carbon black or graphitization, and resultant blocking of the channels. Besides that, it is known that other hydrocarbon gases, especially those with large carbon chains such as butane present in the LPG, can also be cracked, being a risk to the plug's performance.
In this study it was performed a post mortem analysis and two laboratory tests to confirm the carbon deposition in the structure of the plug and its influence on the permeability of the porous element.

MATERIALS AND METHODS

This study was developed through two steps: post mortem analysis of a hybrid plug used in a ladle of a steel plant and experimental tests in the laboratory with new hybrid plugs.
The post mortem analysis was performed on a hybrid plug, used under the following conditions: the plug was removed from operation after 16 heats, because the flame test showed no more gas flow through the plug; the total flame test was 15 minutes (recommended time for each flame test = 40s); the gas back pressure for the flame test was between 2 and 3 bar; the LGP was used for the flame test.[5]
The plug was removed from the ladle and sent to the laboratory for a post-mortem analysis. The characterization of the plug was performed along its height, by using chemical analysis, optical microscopy, density, porosity, permeability (ASTM C 577) and total carbon.
The quality control parameters of the plug have been checked to make sure it was produced according to the specification.
The laboratory tests were performed with brand new plugs, coming directly from the production process. The goal was to simulate the flame test performed at the steel plant. The test assembly is shown schematically in Figure 1 and described in the steps below:

- The test conditions were chosen to approximate the conditions of the steel plant.
- The plug was placed inside an electric furnace and heated for 1 h at 800 ° C. This temperature was maintained throughout the test.
- After heating for one hour a LGP was injected through the plug and burned at the exit of the furnace door, according to Figure 1.
- LGP was used, with pressure of 1.5 to 1.8 bar.
- Two tests were performed: Test 1 - 30 min. duration and Test 2 – 60 min. duration.
- After the flame tests were carried out in the laboratory, the plugs were tested for Total Carbon and Permeability, as well as ceramography analysis.

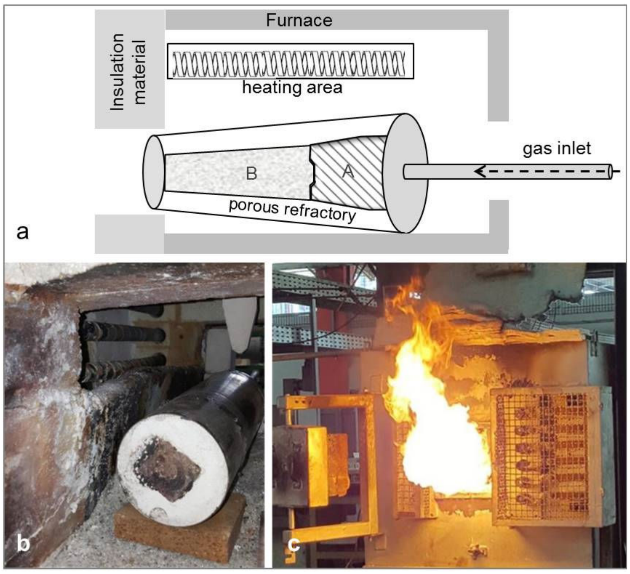

Fig. 1: The assembly of the flame test with LGP in the laboratory; a-the assembly scheme; b- the plug positioned inside the electric furnace ; c-the view of the furnace during the flame test.

RESULTS AND DISCUSSION

The post-mortem analysis of a plug used in a steel plant was performed to determine the failure mechanism. Usually the flame test in this plant is carried out for 40s after every heat. However in this case the test was done in an excessive time of 15min. The plug had to be replaced due to the failure of the gas flow which impaired the stirring system.

Characterization tests were performed and the results showed that the plug presented chemical and physical properties according to the specification. To better understand the failure mechanism, it was decided to evaluate the carbon deposition in the porous refractory. Comparative tests of TC (total carbon) and permeability along the plug were performed; Figure 2 shows the sampling regions for the tests.

The test results showed a carbon deposition throughout the entire extension of the plug. It is possible to observe in the graph of Figure 3 that there is a direct correlation between carbon deposition and permeability decrease. The greater the carbon deposition, the lower the permeability of the plug. The deposited carbon came from the cracking of LPG used for the flame test of the plug.

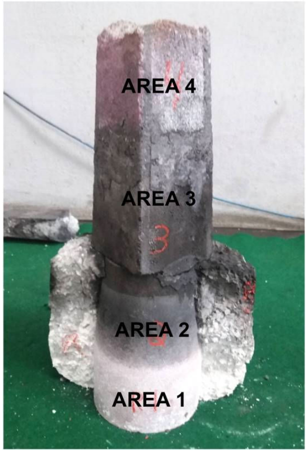

Fig. 2: Received plug for post mortem analysis with indication of sampling regions.

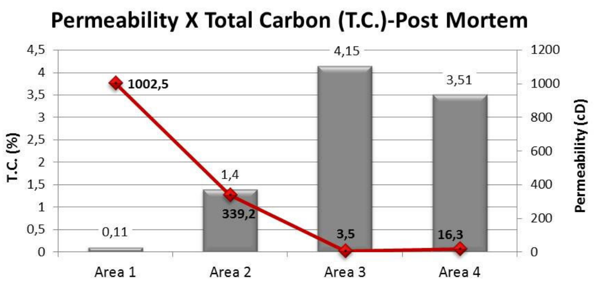

Fig. 3: Comparative analysis between permeability and total carbon.

The laboratory test was carried out trying to simulate the conditions observed at the steel plant. The goal was to confirm the carbon deposition mechanism observed in the post-mortem analysis. Considering that the conditions of the flame test at steel plant are much more severe than what could be simulated in the laboratory, the tests were performed with 30 min. and 60 min.

The graphs of Figures 4 and 5 shows the values of TC and permeability corresponding to Test 1 and 2, measured in regions A and B which are represented in Figure 1 and Figure 6.

It can be clearly seen that the increase of carbon deposition results in the decrease of the permeability of the refractory.

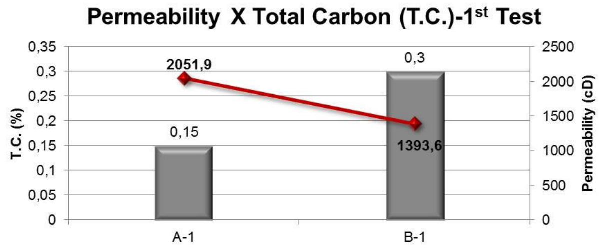

Fig. 4: Comparative analysis between permeability and total carbon. Test 1: 30 min. gas flow.

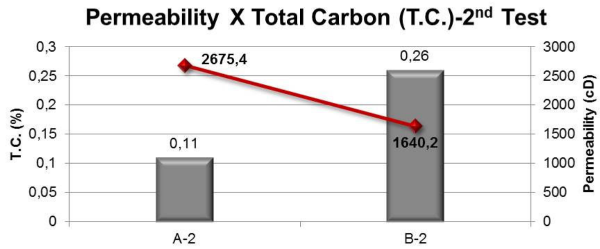

Fig. 5: Comparative analysis between permeability and total carbon. Test 2- 60 min. gas flow.

The carbon deposition found in Test 1 and Test 2 is much lower than that found in the post mortem analysis. Nevertheless the laboratory test proved that the carbon deposition occurs during the flame test and that it is responsible for the decrease of the permeability of the plug.

Samples used in the analysis were drawn from the regions indicated in Figure 6. The lower region of the plug, refractory "A", had a lower percentage of carbon deposition. The permeability of this region is close to the permeability of the unused refractory, which has a typical permeability value of approximately 2000 cD. It is possible to observe that the carbon deposition in the region "B" was more intense and more uniform than in region "A".

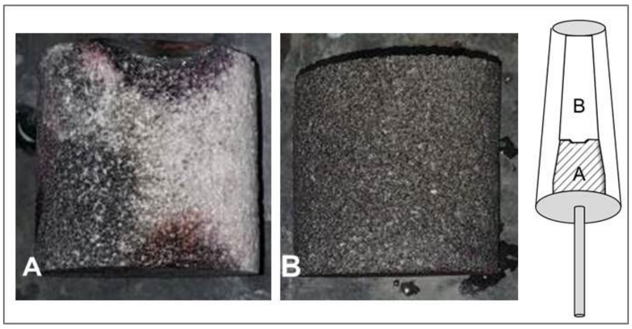

Fig. 6: Carbon deposition in the lower and upper regions of the plug.

In order to better understand the mechanism of permeability reduction in relation to the percentage of deposited TC, a ceramography analysis in the upper region of the plugs submitted to Tests 1 and 2 (Region B. Figure 6) was performed. Although it was not possible to observe significant differences between the TC values of the two tests in the graphs of Figure 4 and Figure 5, in the ceramography analysis this difference can be clearly observed.

It can be seen in Figure 7 and Figure 8 that the carbon originated from the gas cracking (light gray layer) is deposited in the ceramic structure of the refractory. The plug that was submitted to Test 1 (30 min. of gas flow) had a lower carbon deposition than the plug that was submitted to Test 2 (60 min. of gas flow). The carbon began to deposit on the walls of the ceramic structure and as the deposition evolved, a carbon structure was formed which in some cases caused obstruction of the gas passageways. This explains the decrease in permeability observed in post mortem analysis and laboratory tests.

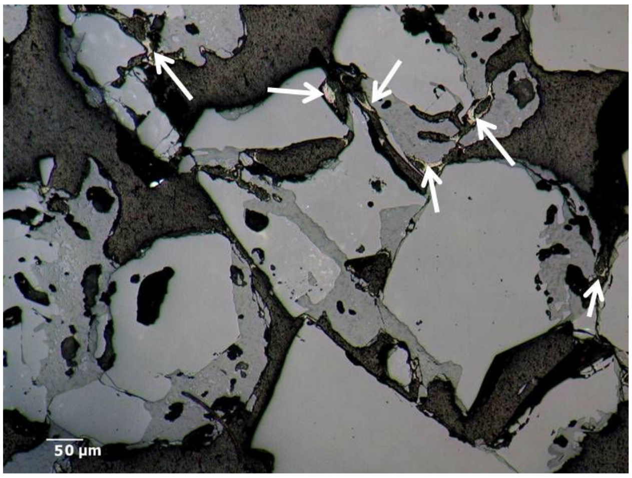

Fig. 7: Ceramography analysis performed in the upper region of the plug. Test 1: 30 min. gas flow. Arrows show the carbon deposition.

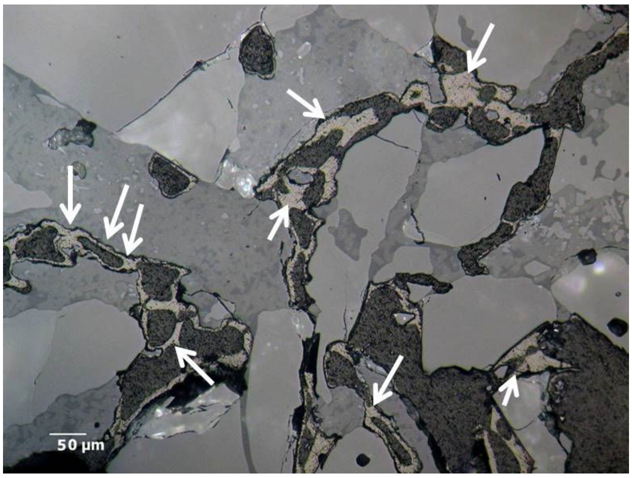

Fig. 8: Ceramography analysis performed in the upper region of the plug. Test 2: 60 min. gas flow. Arrows show the carbon deposition.

CONCLUSION

The use of hydrocarbon gas for the flame test pattern of plugs causes the carbon deposition in the structure of the plugs.

The carbon deposition comes from the cracking of the hydrocarbon gas, when it comes in contact with the structure of the plug, at high temperature.

The use of hydrocarbon gas for the flame test is not recommended, but if it is extremely necessary, the flame test time should be reduced as much as possible.

According to the results, the carbon deposition directly influences the plug performance by reducing its permeability and therefore decreasing the gas injection efficiency.

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