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Refractory Linings of Pig Iron Transfer Ladles

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Abstract

The paper gives a review of refractory lining designs and materials to be used in pig iron transfer ladles according to experience from different shops. Particular attention is given to the effects of incorporation of the ladle desulphurisation process on a service life of the ladles. The article presents specific physical properties (resistance to corrosion, penetration) of iron ladle lining. The obtained results are compared with the field service durability of ladle linings.
Keywords: Refractory lining, Ladle, Pig Iron, Desulphurisation

WYŁOŻENIE OGNIOTRWAŁE KADZI DO TRANSPORTU SURÓWKI

W artykule dokonano przeglądu konstrukcji wyłożeń ogniotrwałych oraz materiałów, które zgodnie z doświadczeniami innych zakładów powinny być stosowane w kadziach do transportu surówki. Szczególną uwagę poświęcono wpływowi, jaki wprowadzenie procesu odsiarczania w kadzi wywiera na jej trwałość. Artykuł przedstawia konkretne własności fizyczne (odporność na korozję, przenikanie) wyłożenia kadzi surówkowej. Uzyskane wyniki weryfikowane są w próbach przemysłowych w zakresie trwałości wyłożenia kadzi.
Słowa kluczowe: wyłożenie ogniotrwałe, kadź surówkowa, surówka, odsiarczanie

1. Introduction

70–90 % of sulphur gets into a blast furnace from a coke charge. In coke, we can find sulphur in three different modifications: organic, sulphide and sulphate. Rather significant amount of sulphur originates from alternative fuels as well, including dust coal.

In steels, sulphur causes red shortness as a consequence of impairing plastic properties. Sulphur also lowers corrosion resistance, notch toughness and electro technical properties of steel. Deterioration in deep-drawing properties brings about significant scrap occurrence while stamping hollow convex details.

Measures for sulphur removal from steel are exercised not only at the stage of charge preparations or in the process of blast furnace melting, but particularly by means of pig iron desulphurization in iron ladles.

For the reduction of sulphur content in steel, two fundamental ways are possible: the production of pig iron with low sulphur content in the blast furnace or desulphurization of pig iron outside the blast furnace.

The desulphurization process, *i.e.* reduction of sulphur content, is from technological point of view much more favourable to carry on in pig iron than in steel, therefore the desulphurization is carried out before casting pig iron into steel vessels. Desulphurization is the process in which the content of sulphur in pig iron is cut down by implementing powdered CaC_2 or CaO in combination with magnesium. This is carried out by means of blowing inert gas as a carrier of the above-mentioned powders through monolithic lance into the bath of pig iron. Within desulphurization many factors are being changed, such as service conditions, slag properties, slag behaviour, chemical reactions between slag, pig iron and lining.

From the technological point of view, as mentioned above, it is of advantage to carry out the desulphurization processes before further modification of pig iron in steel units. Therefore the desulphurization process was transferred to vessels, which originally served only as transport vessels, *i.e.* to torpedo cars or iron ladles. In the past, iron ladles were designed just for transportation of pig iron from blast furnace to the steel vessels, *e.g.* BOF convertors. Subsequent processes of pig iron modification proceeded in the steel vessels. By introduction of desulphurization process in pig iron transfer ladles, both lining designs and the quality of refractory materials used, had to be adjusted or changed.

2. Review of lining patterns of pig iron transfer ladles

Iron ladle is a steel vessel of a truncated cone shape, which is bricked-up with refractory material. In the Třinec Ironworks conditions, it is a vessel of 4 m height, 3.5 m in diameter, with capacity of ca. 175 t. Ladle lining itself consists of insulating, safety and working layers. The shape of the ladle in question is determined by steel casing shell. First layer, to be put upon the wall casing, is insulation. The ladle bottom is concave and this is cast with refractory castable in order to level the bottom surface. Next layer to be put upon both the cast concrete floor and the walls is safety lining made of fireclay bricks of ca. 35 % Al_2O_3.

In the past, when transport ladles served only for the transport of pig iron, the working lining of the bottom and walls was made of fireclay bricks of different thicknesses with the content of Al_2O_3 higher than 40 %, the ladle spout was made of refractory concrete with application temperature of up to 1400°C. Average service life of these working linings was about 450 heats. In the course of this service life, *i.e.* one campaign between major repairs of working linings, the bottom lining had to be replaced twice. The main reason was that in most of the cases the impact area of the cast hot metal was on the bottom.

For reason of increasing service life of the ladles, thus improving specific costs of their linings, the effort was made to increase service life of the bottom, in order to level it with the wall service lives. Hence, the elimination of one bottom repair during the course of a campaign was necessary. For increasing the service life of ladle bottom-lining a field test was carried out by installing alumina spinel based refractory castable on the bottom. Monolithic bottom was horizontal with the inserted impact block precast of the same type of refractory castable (Fig. 1). Fireclay bricks remained on walls and slag zone. Transport ladle with such combination of lining did not bring any improvement, the number of heats reached 450. Since this way of bottom modification did not bring expected results, the next step was the design change of the bottom, *i.e.* from horizontal to spherical. At the same time, bottom bricks of fireclay were replaced by andalusite based bricks. Again, fireclay bricks remained on walls and slag zone. The service life of ladles bricked-up in this way reached 438 heats without any repair of the bottom. Eventually this lining concept was implemented to other ladles.

With the implementation of desulphurization process, the service live of iron ladles dropped drastically. This could be attributed to the altered conditions such as physical and chemical. There are two major factors that bring additional stress to transport ladle lining. Partly, it is a matter of wear by virtue of chemical reactions between refractory material and slag-desulphurizing agents (CaC_2, CaO, Mg, eventually alkali), partly a matter of build-up formation caused by the change of slag composition at relatively low temperatures. Subsequently the secondary problem is a mechanical damage of the brickwork while removing these build-ups.

A.P. Schmidt [1] and his team describes experience with the development of linings of iron ladles in Corus Strip Products Ijmuiden in the Netherlands. The Author is focusing on the development of linings of transport ladles in connection with the transfer of desulphurization process from torpedo cars to transport ladles. In described steel works, they originally used CaC_2 as a desulphurizing agent. This was replaced by CaO mainly for the reasons of its environmental impact. Before implementation of the desulphurization process into the transport ladles, the service life of their linings was about 650 heats. Working ladle lining consisted of andalusite bricks with thickness of 230 mm in the bottom, 152 mm lower part of the wall, 114 mm top part of the wall lining. Moreover, two purging plugs were installed in the bottom of the ladle for better slag separation of iron before pouring into convertor. After implementation of desulphurization by means of CaC_2, the service life declined to 470 heats. It was believed, that there were two major life restricting factors, *i.e.* those increasing the wear of ladle linings. Partly, it was a matter of wear by virtue of chemical reactions between refractory material and slag - desulphurizing agents (CaC_2, CaO, Mg, eventually alkali), partly a matter of build-ups formation caused by the change of slag composition at relatively low temperatures. Subsequently, the secondary problem was a mechanical damage of the brickwork while these build-ups were removed. Low lining temperatures resulting from local conditions in ladles cycling was another factor, which at that time declined the service life. This caused deeper penetration of corrosive media into the linings [1]. With implementation of desulphurization in the Třinec Ironworks similar conclusions were drawn.

Fig. 1. Monolithic bottom of the transport ladle with inserted impact block.

In further steps attempting to increase service life of the whole lining after implementation of desulphurization, the solution to the decreased service life of the fireclay slag zone was to be found. The decreased service life of the fireclay slag zone was at that time only 320 heats. This was attributed to considerable changes in the slag chemistry. That is why the new lining concept was introduced: spherical bottom and slag zone of andalusite bricks, walls remained bricked-up with fireclay shapes (Fig. 2). These ladles reached average service life of 628 heats.

Since linings of transport ladles of competitive materials reached longer service lives, it was decided to make a trial lining entirely based on bauxite bricks. The expectation was to compare results of the same material in iron ladles with those of torpedo cars in Třinec. Bauxite bricks were produced according to current technological documentation. As mentioned above, the bottom, walls and slag zones were lined with bauxite bricks. For the spout lining of transport ladle, the drycreting castable was applied. It was andalusite based castable with the application temperature of up to 1500°C.

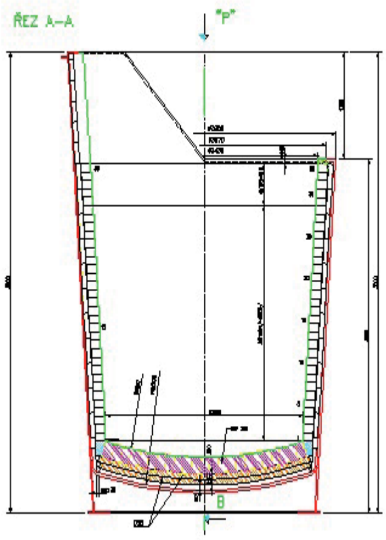

Fig. 2. Cross section of the iron ladle lining.
Rys. 2. Przekrój wyłożenia kadzi surówkowej.

3. Laboratory tests results of grades used for lining of transport ladles

Before field tests in iron ladles started, the cup tests had been carried out to determine corrosion resistance of fireclay, andalusite and bauxite bricks to slag and hot metal. The cups for testing were cut out of the bricks commercially produced, the grade names being fireclay - ST40, andalusite - AT60A, and bauxite - AT80B.

Corrosion resistance test procedure was performed according to the standard ČSN P CEN/TS 15418 in the laboratory of Refrasil. As a corrosive medium the slag from transport ladle before initiation of desulphurization and after the process was taken. The same procedure was applied for hot metal. Table 1 gives chemistry of these corrosive media.

Out of each three grades, the cube-shaped samples with dimensions of 60 x 60 x 60 mm were prepared with bored hole of 18 mm diameter and of 20 mm depth. The cups were filled with corrosive medium in quantity of 15 g, and burnt at the temperature of 1350°C for 4 hours. After the corrosion tests, the samples were cut and the obtained cross sections were studied. In Fig. 3, the appearance of the samples after cup testing is shown. The aim of the tests was to determine the influence of corrosive media, *i.e.* pig iron and slag from transport ladles before the field-test itself.

Table 1. Chemistry of slag and hot metal before and after desulphurization [wt%].

	BF slag before desulphurization process	BF slag after desulphurization process	Pig iron
Al_2O_3	6.4	6.7	
SiO_2	48.7	46.2	
P_2O_5	0.168	0.03	
MgO	4.7	10.7	
MnO	8.8	3.19	
Cr			0.07
S	0.12	1.96	0.035
P			0.097
Si			0.58
Ti			0.02
C			4.577
Mn			0.36

Table 2 gives physical and chemical parameters of the tested refractory brick grades. Individual test procedures were performed according to standardized techniques, *i.e.* apparent porosity according to the ČSN 725010 standard, cold crushing strength according to the ČSN EN993-5 standard, refractoriness under load according to the ČSN EN ISO 1893 standard.

Table. 2. Physical and chemical parameters of the tested refractory brick grades.

		Fireclay ST40	Andalusite AT60A	Bauxite AT80
Chemical analyses of shaped material [wt%]	Al_2O_3	40.4	60	80.2
	Fe_2O_3	2.1	1.5	1.86
	Na_2O+K_2O	1.23	0.52	0.43
	TiO_2	1.4	0.75	3.41
	SiO_2	53	35.8	11.5
Bulk density [g·cm^{-3}]		2.13	2.56	2.86
Apparent porosity [%]		16.6	13.9	17.7
Crushing strenght [MPa]		46.6	69.3	104
Refractoriness under load [°C]		1425	1600	1437

No unambiguous conclusion can be drawn from the above mentioned testing's. Nevertheless, based on the original idea and partly on the achieved results, the working lining of the bottom, walls and slag zone of a test ladle was bricked up by bauxite based bricks of the AT80B grade. Operating results of the tested pig iron transfer ladle in Třinec were not available while writing this paper, as the ladle in question was still in operation. Thus, the final conclusions will be presented during my talk in the conference.

4. Conclusions

Sulphur deteriorates steel properties, thus, it is priority to decrease its quantity to a minimum value. Since sulphur removal is easier from pig iron than from steel, the desulphurization is carried out before casting pig iron into steel vessels. Thus, there are two ways of how to get low sulphur content in steel: (i) production of pig iron with low sulphur content in blast furnace, (ii) out-of-the-furnace desulphurization of pig iron in either torpedo car or in hot metal transfer ladles. Desulphurization is the process in which the content of sulphur in pig iron is cut down by implementing powdered CaC_2 or CaO in combination with magnesium. This is done by blowing these powders by inert gas through monolithic lance into the iron bath in ladles.

The implementation of desulphurization process, however, brings about decreased service life of linings. It is believed, that there are two major life restricting factors, *i.e.* these increasing the wear of ladle linings. Partly, it is a matter of wear by virtue of chemical reactions between refractory

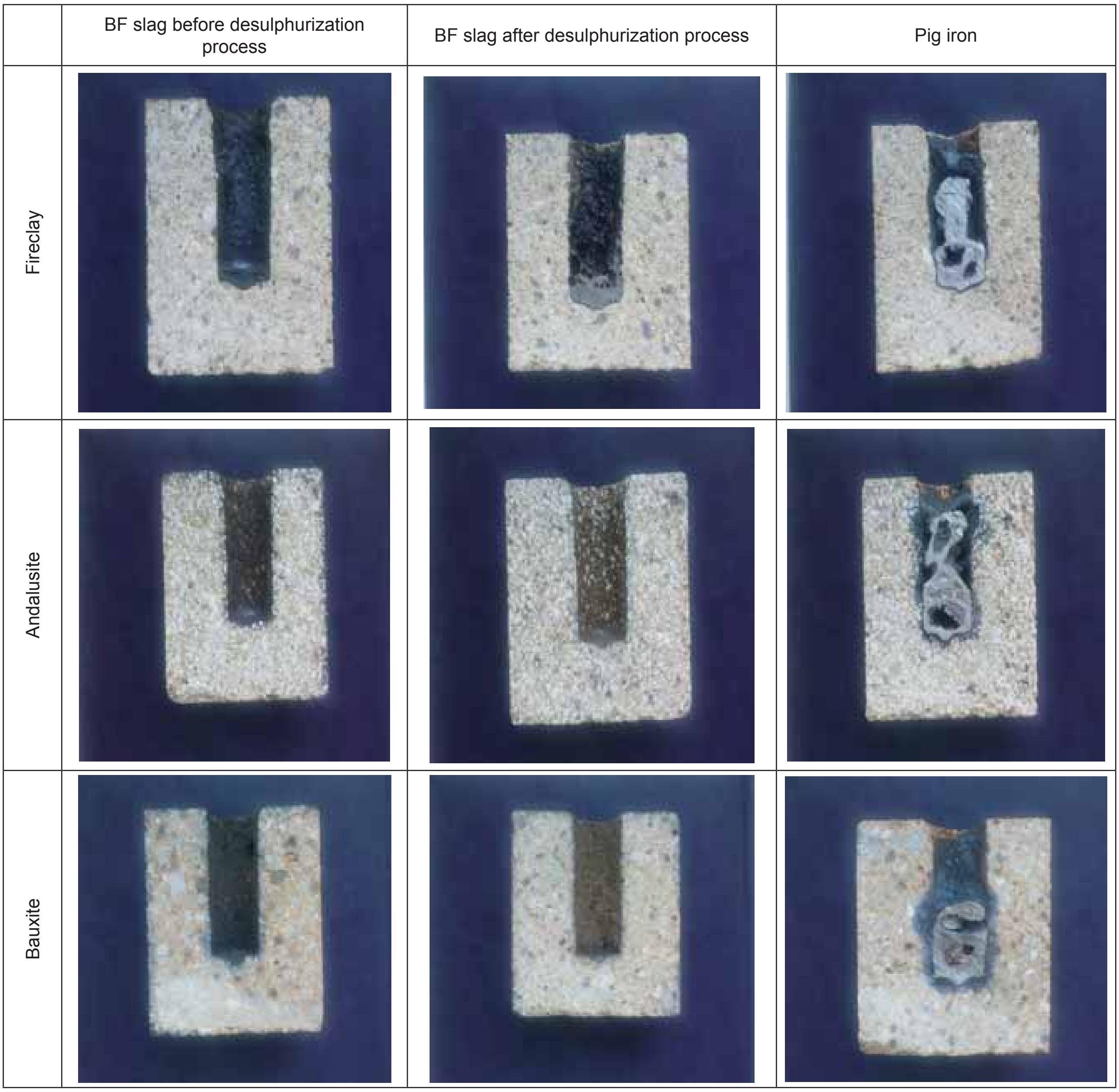

Fig. 3. Appearance of crucibles after static corrosion testing.

material and slag-desulphurizing agents (CaC_2, CaO, Mg, eventually alkali), partly a matter of build-ups formation caused by the change of slag composition at relatively low temperatures. Subsequently the secondary problem is a mechanical damage of the brickwork while these build-ups are removed. With implementation of desulphurization in the Třinec Ironworks similar conclusions were drawn. The field tests in the Třinec Ironworks are still under way, as the tested iron ladle with the entire working lining of bauxite bricks is still in operation. Thus, the final conclusions will be presented during my talk in the conference.

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