USE OF SYNTHETIC TITANIUM PRODUCTS FOR PROTECTION OF THE HEARTH OF ROGESA BLAST FURNACES[1]

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Abstract
The company Roheisengesellschaft Saar (ROGESA) is a joint venture of the AG of Dillinger Huettenwerke, the major European heavy plate producer, and Saarstahl AG, one of the most important manufacturer of long products in the world. In order to cope with increasing demand of the hot metal from both steel shops on one hand, and simultaneously increasing pressure on hot metal cost reduction, on the other hand, ROGESA had decided to enlarge No. 5 blast furnace during the relining in 1997. Its inner volume was increased to 3,067 m³ and its hearth diameter up to 12 m. Due to the geometric change, the hearth lining and the cooling system had to be newly designed. After around 8 years in operation, serious wear was detected in the hearth lining and a part of the shaft cooling. Consequently, an interim repair was necessary and carried out in the period of Dec 05/Jan 06. This paper describes the wear conditions of No. 5 blast furnace after its enlargement with focus on experiences by applying adequate measures against short-term temperature increase, especially use of titanium bearing materials. The here presented paper is a common report from Rogesa, Sachtleben Chemie GmbH (Duisburg) and the GSR (Moers).
Key words: Blast furnace; Titanium dioxide; Hearth protection; Repair.

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1 BLAST FURNACE CAMPAIGN RESULTS

1.1 No. 5 Blast furnace campaigns before and after its enlargement

In Table 1, the results of the last two campaigns of No. 5 blast furnace are summarized, including some construction features and operation data. The first campaign started on Dec. 17th, 1985, after its new erection on the green field. After the successful operation of 11.4 years and a total production of 20.4 Mt hot metal, the furnace was relined and simultaneously enlarged in May 1997. In order to limit the invest expense of the enlargement, it was decided to maximize possible furnace volume on one hand, and to use as much as possible the existing peripheral facilities on the other hand. Consequently, the hearth diameter was enhanced from 11m up to 12m and the inner volume from 2,631 m³ to 3,067 m³. [1]

The second campaign started on Aug. 19th, 1997. Due to the furnace enlargement, a new hearth design concept was applied with the target to achieve a campaign life of 12 up to 15 years. However, investigations carried out in 2004 and in early 2005 indicated that the hearth wall had shown already serious wear. Some wear profiles with "elephant foot" were suspected. Nevertheless, the remained bottom layers seemed to be still in good conditions. Following these findings, it was decided to carry out an interim repair in December 2005. The scheduled repair work included mainly relining of the carbon blocks at the hearth wall and replacing a row of cast iron staves by copper staves at the bosh area. The interim repair started Dec. 15th, 2005 and was completed after 46 days on Jan. 30th, 2006.

Table 1 Construction data and performances of the No. 5 blast furnace

		BF 5 old	BF 5 enlarged	changes
Start of campaign		17.12.1985	29.08.1997	
End of campaign		16.05.1997	(12.12.2005)	
Reason of revamping		BF relining	interim repair	
Campaign life	years	11.4	8.3	
Total HM production	Mio. t	20.4	18.9	
Productiion	t/m³ w.v.	9175	7318	
Hearth diameter	m	11	12	+9%
Hearth area	m^2	95	113.1	**+19%**
Working height	m	24.7		
Working volume	m^3	2222	2581	+16%
Inner volume	m^3	2631	3067	**+17%**
Number of tuyeres		30	32	
Daily production (average)	t/24h	5215	6645	**+27%**
Productivity	t/m² 24h	54.9	58.8	+7%
Productivity (w. v.)	t/m³ 24h	2.35	2.57	+9%
Burden: Sinter	kg/tHM	1266	1182	-84
Pellets	kg/tHM	224	216	-8
Lump ores	kg/tHM	133	208	75
Reduction agents (total)	kg/tHM	467	475	+2%
Coke	kg/tHM	367	346	-21
included small coke	kg/tHM	0	24	
Coal injection rate (PCI)	kg/tHM	100	129	+29

Comparing the second campaign just till the interim repair with the first one, the average daily production of the hot metal could be increased from 5,215 t/d up to 6,645 t/d by around +27%.

1.2 Hearth Temperature Monitoring

No. 5 blast furnace was equipped with numerous double thermocouples at the hearth side wall and at the bottom in 6 different sections for monitoring the hearth wear progress. Figure 1 gives an example of the evolution of temperatures measured at the side wall of the section 1 in the vicinity of No.1 tap hole. The thermocouples Bola 5 and Bola 6 were installed in two upper bottom layers near to the furnace shell, the thermocouples Gela 1 to Gela 3 were located at three side wall layers counted upwards. The four periods are marked in the figure for orientation.

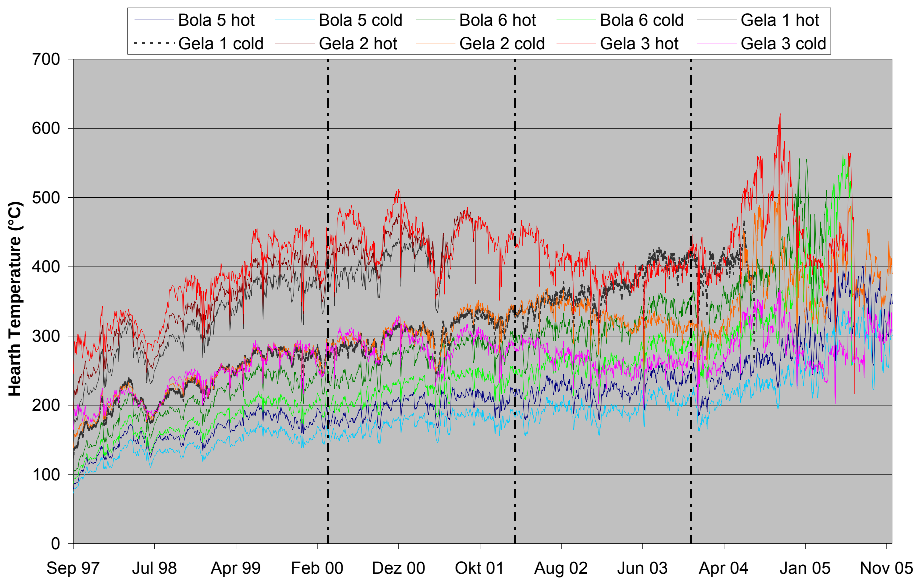

Figure 1 Evolution of temperatures measured at the hearth side wall

For the first period, the temperatures went up almost continuously and indicated steady wear in the course of the operation. During the second and third period, some temperatures maintained at nearly constant levels, especially at the upper side wall; the other temperatures showed still increasing tendency, but with a smaller slope. However, all temperatures increased drastically, with some delay after use of the cokes with bad quality at the fourth period. Especially at the time from the end of 2004 to the beginning of 2005, a lot of the thermocouples located at the side wall failed. In order to obtain the necessary information, some new thermocouples were inserted additionally at different sections of the hearth. The most measured results indicated serious wear conditions in the hearth, especially at the transition areas between side wall and bottom. The formation of the so called "elephant foot" was suspected. Consequently, it was decided to perform the interim repair at the end of 2005. In order to maintain the safe furnace operation until the scheduled repair, a series of various conservative measures had to be carried out including productivity reduction, plugging of selected tuyeres and TiO_2 bearing materials addition with the burden and via tuyere injection.

2 FURNACE DESIGN AND WEAR CONDITIONS

2.1 Hearth Designs and Wear Conditions

Figure 2 gives a comparison of the hearth designs and the wear conditions of No. 5 blast furnace before and after its enlargement. The design type shown in Figure 2a was the traditional standard concept for the blast furnaces of ROGESA in the past. The bottom cooling was situated below the bottom plate. Above the bottom plate, there were two layers of high alumina chamotte bricks (Resistal S65 H) with a very low heat conductivity. Above these layers, three bottom layers of standard carbon blocks (Carbural R) were used. The side wall was constructed also with standard the carbon blocks with a thickness of max. 1,000 mm. The hearth shell was cooled by cast iron staves. This concept is characterized by a low initial sump depth and a thick bottom layer with the low heat conductivity. Thanks to consciously use of two chamotte bricks bottom layers, it was expected the bottom wear rate would be faster than that of hearth side walls. Subsequently, the hot metal could dig deep to create a natural bowl sump shape and depth during the furnace campaign progress. The wear profile was determined during the relining in 1997, after a campaign life of 11.4 years. The wear profile showed the nearly ideal type, since there was not any locally accelerated wear in the lower hearth area, such as formation of an elephant foot.[2]

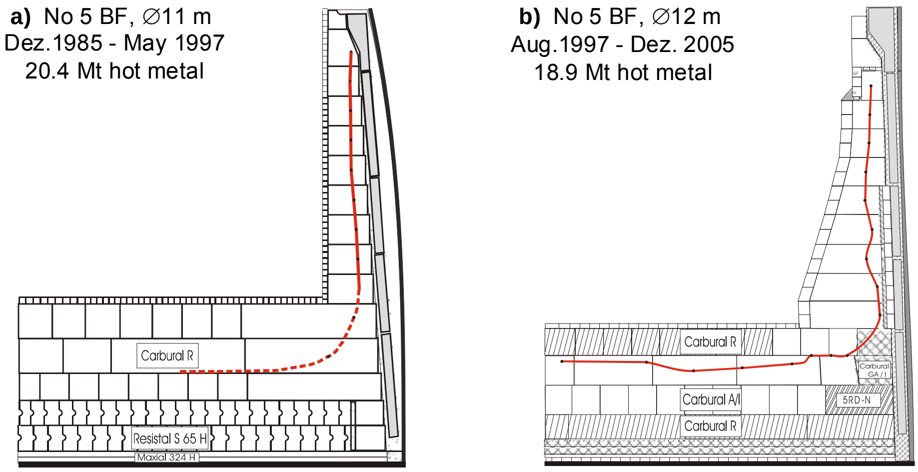

Figure 2 Hearth designs and wear conditions of No. 5 blast furnace before and after its enlargement

Figure 2b gives also an example of the wear profiles determined during demolishing the hearth. In spite of the precautions described above, the most serious wear was observed at the first carbon block above the bottom layer (G1). Figure 3 shows the cross section at the block G1. It is obvious that the wear conditions were very unsymmetrical and the heaviest wear was in the areas under tuyere 8/9 and tuyere 21/22. The residual carbon blocks showed only a thickness of around 100 mm, from an initial thickness of 1500 mm (after only 8.3 years in operation). This result was never expected by initially choosing the hearth design. The causes of such results are considered to be multiplex and were discussed in a previous paper.[3,4]

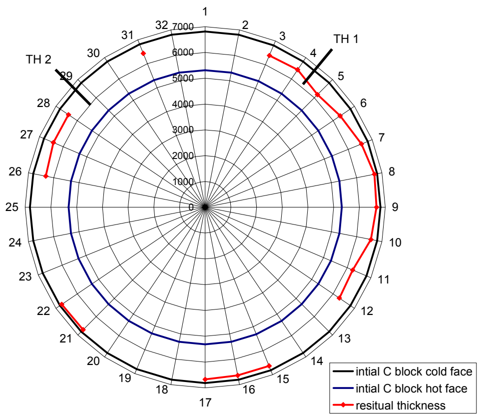

Figure 3 Cross wear profiles of the first carbon block of the side wall (G1-level)

2.2 Conservative measures against short-term temperature increase

As mentioned above, an advanced hearth wear of No. 5 blast furnace had been indicated according to calculation results of the hearth monitoring model in 2004. Since a lot of the initially installed thermocouples failed during the furnace campaign, it was difficult to obtain some reliable information. Subsequently, it was decided to insert additional thermocouples in 2004/2005. In several hot spots, higher temperatures were measured and correspondingly thin residual carbon thickness was estimated. In order to operate the blast furnace properly until the scheduled date of the interim repair, following measures were consequently taken into action:

- Charging lump Ilmenite (32%TiO_2) with burden into the furnace,
- Injecting “Rutilit F” (50%TiO_2) via several tuyeres,
- Plugging selectively tuyeres above the concerned hot spots for a short period,
- Grouting of the ramming joints between staves and carbon blocks,
- Finally reducing the hot metal productivity and the coal injection rate.

3 USE OF TiO_2 SOURCES FOR BLAST FURNACE MAINTENANCE

Sources of TiO_2 are fed into the BF via the furnace top with the burden either in the form of lump Ilmenite.[5,6] Distribution and movement thus takes place throughout the entire BF shaft, with consequences which include delayed times of action, high necessary input quantities, impairment of slag quality and occasional depositions in the shaft.

The increase in [Ti] content in the hot metal achieved, for example, by raising the rate of Ilmenite input, thus results in greater (TiO_2) contents in the slag (Figure 4). TiO_2 content in the slag is, however, a significant quality criterion for processing and sale of the granulated slag as an additive for cement. High TiO_2 contents (> 0.8 to 1 %) in the slag have a negative effect on the cement products’ setting performance.

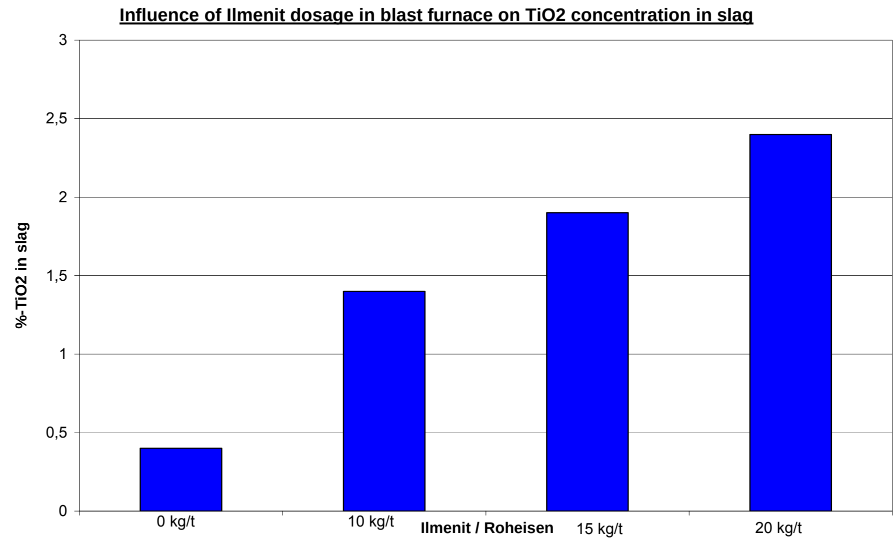

Figure 4 Ilmenite / hot metal

For this reason, changes in Ilmenite, and therefore in TiO_2 quantities, have effects on the entire chemistry of the BF.

The injection of fine-particled TiO_2 sources via the tuyeres directly in the vicinity of the hearth zone is a more effective method of importing TiO_2 into the BF[6,7]. This technique offers a whole series of advantages:

- Injection occurs in the immediate vicinity of the endangered areas of the masonry. This means that best possible results can be achieved systematically and with low input quantities.
- The delay period before the reparative action occurs is shorter, even in case of "hot spots" in the furnace wall.
- There is no accumulation of TiO_2-containing materials in the blast-furnace shaft.
- The TiO_2-containing materials are conveyed directly to the reaction site at tuyere level and in the hearth, where they are able to directly influence the interactions of the gas, metal and slag phases, irrespective of the reactions occurring in the shaft and in the cohesive zone [7,8].
- Lower input rates and higher efficiency of conversion to Ti(C, N) compounds result in improved slag quality, thanks to lower TiO_2 contents in the slag, and therefore easier marketing of the ultimate blast furnace sand product.

Sachtleben Chemie GmbH, Duisburg (Germany) has developed its "Rutilit" range of products specifically for large-scale industrial use.

The particle geometry and low average particle size of around 20 µm of these synthetic TiO_2 sources make them particularly suitable for continuous injection via the tuyeres. They possess good rheological (flow) properties, favouring pneumatic conveyance, combined with low abrasive action on conveying and injection systems.

The Rutilit products consist primarily of TiO_2 and Fe oxides. Like lump Ilmenite, they form Ti(C, N) protective layers in damaged hearth zones and are therefore suitable for blast-furnace maintenance purposes. They also possess specific metallurgical benefits for the BF process.[7,9]

Laboratory tests[9] conducted during preparation for industrial application also indicated further Rutilit product benefits:

a) The reactivity of Rutilit products is significantly greater, since the TiO_2, Fe_2O_3 and Fe_3O_4 constituents are present primarily in mineralogically and, therefore, thermodynamically more favourable oxide phases adjacent to one another. In

Ilmenite, on the other hand, the iron titanate ($FeTiO_3$) firstly needs to be broken down in the blast furnace into FeO and TiO_2 by means of input of energy (82,300 KJ/t Ilmenite) before the generation of Ti(C, N) compounds can occur.

b) The rate of formation of Ti(C, N) compounds is significantly greater, and therefore more efficient, since the sources of Ti and Fe are present in Rutilit products in extremely finely dispersed form, thus offering a much greater specific surface area for reactions.

c) In addition, simultaneous reaction of the Fe oxides also occurs in the Rutilit products, the metallic iron thus generated causing a catalytic action in formation of the Ti(C, N) compounds. The finely dispersed iron exhibits high efficiency in this context, thanks to its large surface area.

Table 2 Three Rutilit products are available for these applications

	TiO_2 %	Fe_2O_3 %	SiO_2 %	Al_2O_3 %	CaO,MgO %
Rutilit AT	25-30	35-45	max. 15	max. 5	max. 10
Rutilit F	45-55	max. 40	max. 20	max. 6	max. 6
Rutilit F85	80-85	max. 15	max. 15	max. 3	max. 6

Due to their differing TiO_2 contents, the various Rutilit products are suitable for a range of different uses, varying from preventative application up to and including high-speed reactions to "hot spots".
An injection system is necessary for the use of Rutilit products.

4 CONDITIONS OF TRIAL

There was used a combination of the input of natural Ilmenit via the burden and an injection of synthetical fine Titan- bearing powders (Rutilit F) via the tuyeres.
1. Period: Ilmenite 9 Kg/t HM from June 4th to July 1th 2005
2. Period: Ilmenite 5 Kg/t HM and Injektion Rutilit F 3Kg/t HM from July 1th to October 7th 2005 Injektion of Rutilit F via 3 lance
3. Period: Ilmenite 5 Kg/t HM from October 8th to November 5th 2005

5 RESULT OF THE USE OF TITANIUM BEARING PRODUCTS AT ROGESA NO.5 BLAST FURNACE

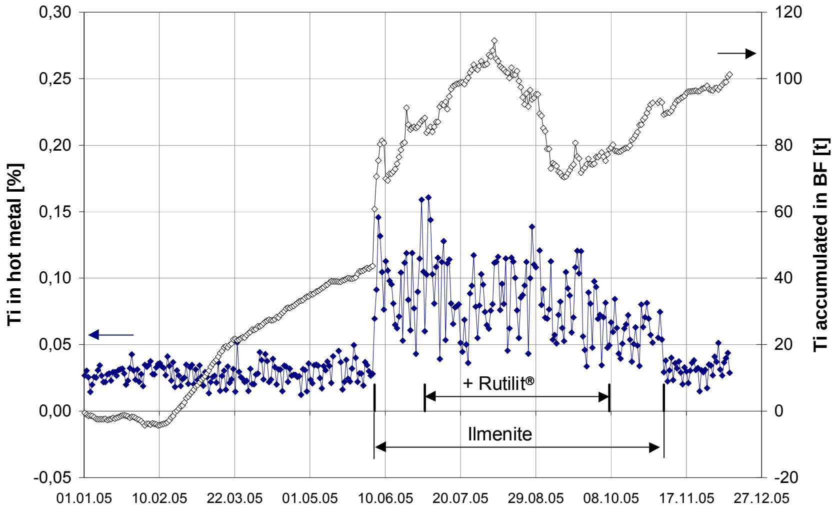

Figure 5 Ti content in hot metal and the titanium balance

Figure 5 shows the evolution of titanium content in the hot metal in 2005. Due to the Ilmenite and Rutilit F addition, the titanium content increased from around 0.03% [Ti] to a range between 0.05% [Ti] and 0.15% [Ti] with a big variation. After stopping to charge the Ilmenite, the titanium content came back again to a level of around 0.03% [Ti]. The balance of titanium during this time was calculated and also illustrated in Figure 6. The first increase from February 2005 was due to change of the burden composition. Just after adding the titanium bearing materials, the balance calculation shows a significant accumulation of titanium in the furnace.

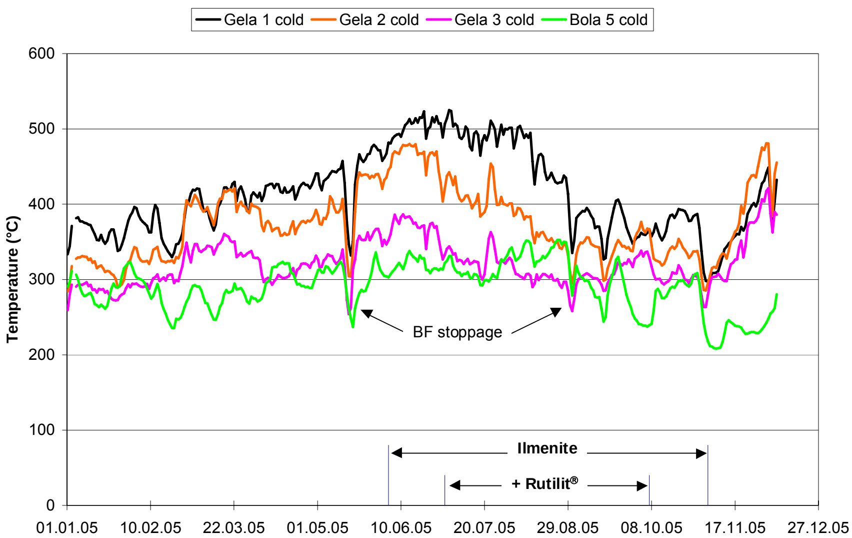

Figure 6 Effects of TiO_2 addition on the hearth temperatures

As an example, Figure 6 shows the evolution of temperatures measured by some residual double thermocouples situated mainly at the cold face, because the thermocouples at the hot face were already damaged. All of these thermocouples were located at the same section, only their heights were different. The Ilmenite charging started on June 4th, 2005. At the first period, it did not show any effects. The Rutilit F

injection was then put into operation up from July 1st via 3 tuyeres at the same time. The productivity was reduced from the middle of June, simultaneously, some tuyeres over the hot spots were selectively plugged for a short time. These joint measures resulted finally in stop of the temperature increase, furthermore, the temperatures began to decrease. Several sharp drops of the temperatures shown in the figure were effects of the scheduled BF stoppages. First BF stoppage caused only a short temperature drop, afterwards, the temperature came back to the same level and continued to increase. This is the normal phenomena which could be observed at all blast furnaces. However, after the second BF stoppage during the TiO_2 addition, the temperatures remained at a lower level and did not increase again. This indicated some built ups in the hearth. In order to prepare the salamander tapping before the interim repair, the Rutilit F injection was taken out of operation on October 7th and the Ilmenite charging was stopped on November 5th. The temperatures at the side wall started again to increase, whilst the temperature at the bottom went up only slowly.
During the demolition of the hearth refractory, massive skull formation was found at the area where there were the thinnest residual carbon blocks and probably the strongest cooling efficiency (under Tuyere No. 7/8 and No. 21/22, see Figure 3). Above the bottom, there was a mixture layer of coke, slag and solidified iron which could hardly be removed. In some areas the massive iron blocks were found. Several core drilling samples were taken and their chemical composition was analyzed.
Table 3 gives the analysis measured along a core drilling iron sample with a height of 210 mm (shown in Figure 7). On the surface of the cross section of the iron sample, no differences are obviously visible. However, the analysis shows clearly the sample consists of, at least, 2 iron layers whose chemical compositions are different of each other.

Table 3 Chemical analysis of a core drilling iron sample

No	Height	C	Si	Mn	P	S	N	Cu	Mo	Ni	Cr	V	Ti
	mm	%	%	%	%	%	%	%	%	%	%	%	%
1	30	4,153	2,101	0,634	0,110	0,020	0,0021	0,009	0,005	0,022	0,059	0,041	0,062
2	50	3,260	2,290	0,647	0,145	0,018	0,0019	0,010	0,007	0,025	0,061	0,051	0,070
3	70	2,665	2,323	0,595	0,089	0,020	0,0018	0,011	0,006	0,024	0,050	0,037	0,053
4	85	3,202	1,817	0,582	0,125	0,021	0,0022	0,009	0,004	0,022	0,057	0,040	0,057
5	105	4,016	1,913	0,573	0,132	0,023	0,0146	0,010	0,006	0,021	0,059	0,042	0,073
6	125	3,789	0,683	0,364	0,226	0,050	0,0082	0,007	0,006	0,020	0,060	0,040	0,024
7	145	4,054	0,759	0,441	0,155	0,054	0,0090	0,009	0,007	0,023	0,049	0,032	0,022
8	165	4,667	0,770	0,409	0,104	0,052	0,0082	0,011	0,007	0,022	0,044	0,031	0,023
9	185	4,424	0,695	0,360	0,132	0,063	0,0073	0,009	0,006	0,021	0,044	0,035	0,016

Figure 7 shows significant changes of C, Si, S, N and Ti content from the bottom to the hearth. The silicon content is only 0.7 % Si in the upper part and around 2 % Si in the lower part. This is considered due to reduction of silica in the slag phase near the dead man bottom.[7].Correspondingly, the sulfur content of 0.02 % S in the lower part is much lesser than 0.05 % S in the upper part. Compared with the Ti content in Figure 6, the iron of the lower part with 0.053 %-0.073 % Ti has the almost same level of the titanium content as the hot metal at the period with the Ilmenite and Rutilit F addition. This iron layer was unequivocally solidified at this period. The upper layer is the ordinary salamander iron remained in the hearth and solidified during the furnace quench. These findings deliver the necessary evidence that charging Ti bearing materials contributed to the formation of protective skulls at the critical locations in hearth.

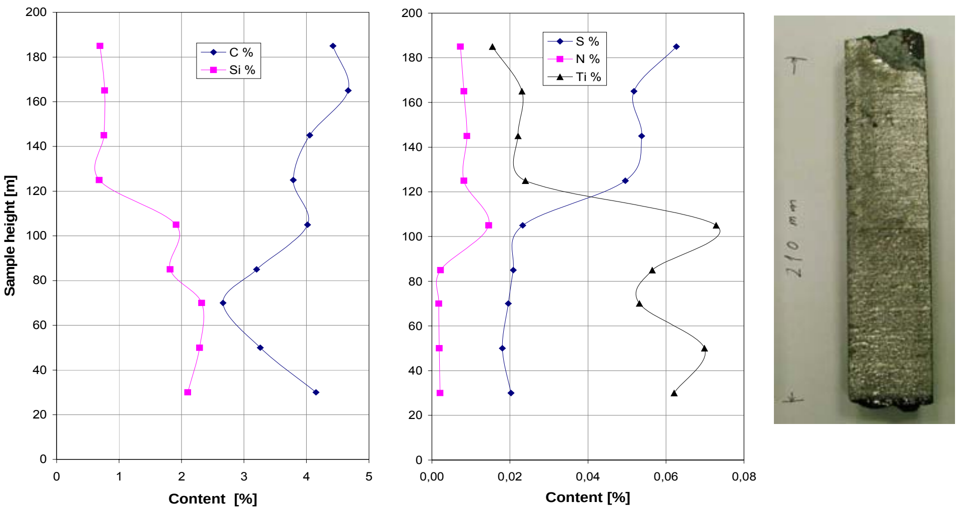

Figure 7 Evolution of some element contents along the core drilling iron sample

6 CONCLUSION

Addition of TiO_2 bearing materials, such as Ilmenite charging or/and Rutilit injection, is based on suggestion of the formation of titanium carbonitrides Ti(C,N) which can promote some protective layers built up in the hearth. Many blast furnace plants reported about similar positive experiences with such technique, whilst some plants could only observe few effects. According to our own investigations, it could be concluded the TiO_2 addition can only be effective, if following conditions are fulfilled:

- The reactivity of TiO_2 – particles due to better thermodynamical and kinetical conditions have to be improved as done in synthetic systems like Rutilit via tuyere injection technology
- Exceeding the minimum Ti concentration required for Ti(C,N) formation,
- Reducing liquid flow rate for Ti(C,N) deposition (e.g. by tuyere plugging, production reduction or BF stoppages)
- Existing sufficient cooling capacity, especially on the cold face of refractory lining.

Furthermore, the titanium balance is a useful additional tool to control the effectiveness of TiO_2 additions.

7 SUMMARY

A campaign life of the blast furnace is predominantly determined by hearth refractory lining and shaft cooling wear. Problems with the shaft cooling can be managed by using copper staves from the bosh to the lower shaft where critical temperatures prevail. The hearth refractory wear remains a serious concern for most blast furnace operators. So here is the important legitimacy for Rutilit. It has proven to be capable to cover rapidly a “hot spot” without exceeding quality limitations of the BF `products like iron and / or slag.

This trial here was made to balance a relationship between input and output of TiO_2 under taking into account as well natural lump Ilmenite and synthetic Rutilit.

The synthetic Rutilit- System is much more effective as well in technical conditions as well in economical conditions.

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