44. Internationale Colloquium on Refractories
Sept. 26 and 27, 2001 Aachen

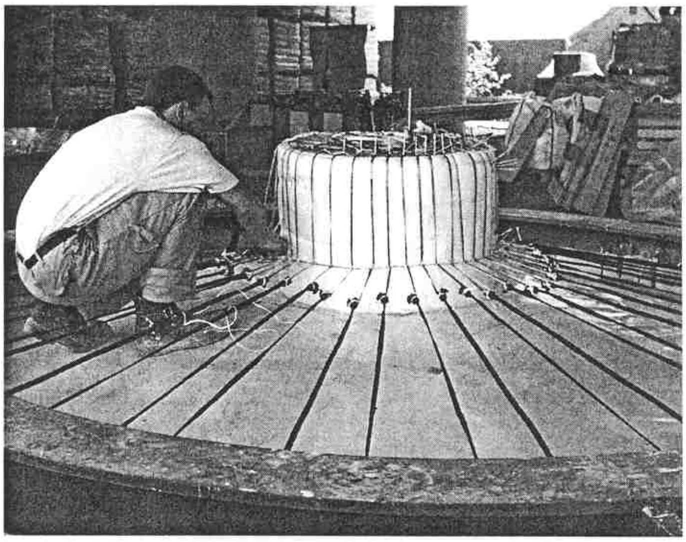

Fig. 3. Carbon fibre heating conductors

without any visible success. Only comprehensive investigations of the worn material made clear that one has to look for major wear in the binding matrix and not in the coarse grained components. Intensive research work in terms of the binding mechanism of CAC cements and the associated problems – in particular when drying LCC and ULCC concrete – made quite clear that the former lining practice did not meet the requirements of the system.

The following standard was introduced:

- Lining is carried out by "in situ personnel"
- The personnel has been instructed in terms of handling CAC binding systems
- High-duty forced mixers with vortex equipment have been used
- In addition, an electronically controlled drying system has been introduced where the carbon fibre heating conductor is also cast in the concrete in the centre of the wall thickness of the cover and then electrical power is applied (Luputherm® drying system) **(Figure 3)**. This drying system can be adapted accurately to the curing conditions of the CAC cement and then it is possible to implement a controlled drying process up to a max. outside temperature of 180 °C of the cover where all the free water and a considerable part of the crystallisation water is eliminated. The drying process is nearly fully automatic and reproducible due to a program control system.

4. Summary

Contrary to quite a number of opinions from the refractory industry, not only the selected specific refractory castables are responsible for the service life and quality of the components when lining monolithic components but also exact processing in an appropriate mixer by qualified personnel, controlled curing of cement and the subsequent drying process are of decisive significance. For the example of the above mentioned VOD cover an average service life of 30 batches could be achieved with intermediate repairs, using the same application of input castables. This means that even under modified and more severe production conditions, the service life of the castables could be increased by 200% as compared with the "old standard" (10 batches) due to an optimum lining and drying technology. The refractory costs developed accordingly in an enjoyable way despite the increased additional expenditure. (F 021)

Innovative ceramic fiber free steel ladle preheaters at CORUS Steelworks IJmuiden

Dipl.-Ing. Theo de Wit – CORUS Staal, IJmuiden, Netherlands
Dipl.-Ing. Wolfgang Lorenz – Mapeko GmbH, Neuwied, Germany
Dipl.-Ing. Dirk Pörzgen; Dipl.-Ing. Michael Specht – Intocast AG, Ratingen, Germany
Dr. rer. nat. Andreas Buhr – Alcoa World Chemicals, Frankfurt/Main, Germany

Abstract

Process changes due to the introduction of the Direct Sheet Plant (new near netshape casting machine) at CORUS Strip IJmuiden required an adjustment of the steel ladle lining and the possibility for heating the empty steel ladles during the ladle cycles. Therefore new ladle preheaters have been installed with a focus on ceramic fiber free refractory linings of the preheater covers. This paper describes the fundamental properties of the new steel ladle preheater technology using a microporous insulating castable after 12–17 months of successful industrial application experiences.

Introduction

CORUS Staal IJmuiden is an integrated steelworks with three 325 t BOF's, two RH-OB degassing units, one ladle treatment station, and one ladle metallurgy furnace. The production capacity of the plant has been increased from 5.3 to 6.5 million tons crude steel per year by the introduction of a Direct Sheet Plant (DSP) for thin slabs besides the two existing slab casting machines in January 2000. The product range covers flat products like hot rolled coil, tinplate beverage cans, coated products, automotive grades, Al-killed, and ultra low carbon steels.

The introduction of the near netshape casting process requires changes of secondary metallurgy processes including a development towards more aggressive slag compositions in the steel ladle. Therefore, the steel ladle lining has been changed from fired Andalusite bricks to Magnesia-Carbon bricks or fired Spinel bricks to withstand the severe slag conditions. In comparison to the Andalusite bricks, the new steel ladle linings have a higher thermal conductivity, thus resulting in higher temperature losses of the lining during periods, when the ladle is empty during transport from the caster, cleaning, etc. This re-

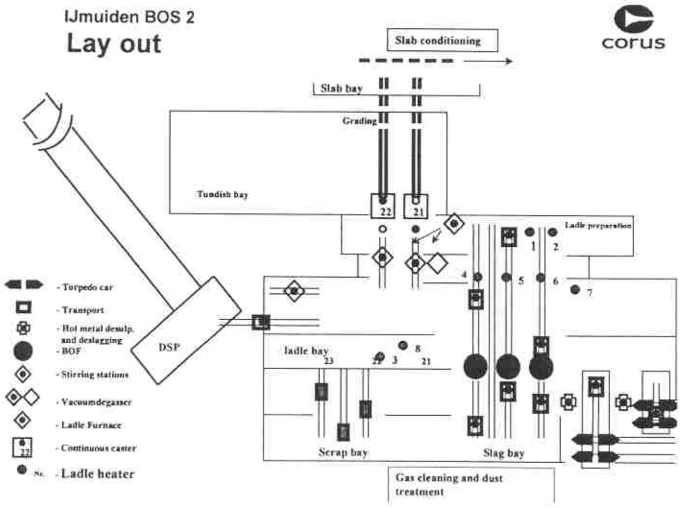

Fig. 1. Layout of CORUS IJmuiden steelmaking department showing the positions of the ladle preheaters. No. 1–3 supplier A lined with a conventional castable, no. 4–8 supplier B with new microporous insulating castable

quires in case of interruptions during hot cycling of the ladles the capability to keep the lining warm using ladle preheaters in order to sustain the overall thermal stability of the steel ladle.

As CORUS Strip IJmuiden did not have preheating stations for empty ladles during ladle cycles, new ladle preheaters had to be installed for this purpose. All together 8 new high performance ladle preheaters have been installed since then. **Figure 1** shows the layout of the IJmuiden steelworks with the ladle preheating stations. The first 3 ladle preheaters from supplier A have been installed during summer 1999 and are lined with a conventional castable. The following 5 ladle preheaters from supplier B, which are discussed in this paper, have been installed since February 2000 and are lined with a new microporous insulating castable. CORUS IJmuiden uses the 3 burner ladle preheaters (no. 4–6 in Figure 1), in front of the BOF's, 20–25 times per day for 15 minutes. The other 5 preheaters are used 8–10 times per day. The temperature for ladle preheating is up to 1200 °C. Between the preheatings the lining of the ladle preheater cover cools down.

The conventional lining for steel ladle or tundish preheaters has been ceramic fiber based because of advantageous properties inherent to fiber refractories. These are low density, high thermal shock resistance, and low thermal conductivity. The first is important because of the resulting low weight of the refractory lining, which is positive for the construction requirements of the preheater cover and mechanics. The latter is important, because ladle preheaters are only periodically used and cool down between heating cycles. However, in December 1997 the European Union classified refractory ceramic fibers (RCF) used for these applications as a category 2 carcinogen [1]. Therefore CORUS Strip IJmuiden decided to set up RCF free ladle preheater linings to overcome health concerns.

Ceramic fiber free ladle preheater linings

The key requirements on ladle preheater refractories are:

- Refractoriness of at least 1400 °C (1200 °C service temperature and in addition 150–200 °C to allow for temperature spots and long term stability),
- Low specific weight to keep preheater steel construction and hydraulic power within reasonable limits,
- Low thermal conductivity to achieve a low lining thickness and thereby low cover weight for above mentioned reasons,
- High thermal shock resistance to withstand numerous cycles between 1200 °C and ambient temperature with rapid, almost immediate heating up and cooling down.

As replacement for refractory ceramic fiber, monolithic preheater linings have been preferred to simplify the lining procedure and to increase the mechanical stability of the preheater cover lining. Conventional insulating refractories, either bricks or castables, have a serious disadvantage over fiber linings (**Table 1**). This is their low thermal shock resistance. It results from a low thermal conductivity, therefore a steep temperature gradient and high thermal expansion stresses within the material during thermal cycling. The low mechanical strength inherent to low density materials is disadvantageous in withstanding these stresses.

Therefore conventional insulating castables (about 1.4 g/cm^3 bulk density) would fail as preheater lining after a short period of time because of damage through thermal shock attack. On the other hand, dense castables (bulk density about 2.4 g/cm^3) have a higher thermal shock resistance and also have a higher thermal conductivity which require a higher lining thickness for insulating reasons. As a result, they would need a much more solid and robust steel construction and a dramatic increase in hydraulic power to lift the preheater cover (**Table 2**). Another disadvantage of dense castable preheater linings is their higher heat capacity which means energy losses for furnaces used only periodically.

Tab. 1. Comparison of selected refractories

	Microporous lightweight castable	Insulating brick ASTM class 28	Conventional dense castable	Refractory ceramic fiber mats/modules
Raw material base	Microporous Calcium-hexaluminate	Mullite	Aluminosilicate	Amorphous 55% Al_2O_3 fiber
Classification temperature [°C]	1500	1540	1500	1430
Bulk density [g/cm^3]	1.10	0.90	2.4	0.25
Thermal conductivity [W/mK] at 800 °C	0.34	0.39	2.2	0.17
Thermal shock resistance [cycles air quenching]	High	Low	Medium-high	High

A new high temperature insulating raw material composed of microporous Calciumhexaluminate provides the key properties required for fiber replacing monolithic preheater linings. An application of this material as a preheater lining has been published first by Duhamel and Verrelle [4]. CORUS Strip IJmuiden installed the first ladle preheater with a microporous lightweight castable in February 2000. The properties of the raw material and the new preheater refractories used at CORUS Strip IJmuiden are described in detail in the following.

Microporous material SLA-92

The name SLA-92 of the newly developed insulating raw material stands for super lightweight aggregate of 92% Al_2O_3.

Tab. 2. Comparison of ladle preheater refractory concepts for 325 t steel ladle, cover diameter 4.5 m

Type	High temperature microporous lightweight castable	Conventional refractory castable	Refractory ceramic fiber
Material density δ [g/cm^3]*	1.1	2.4	0.2
Specific thermal capacity Cp [J/kg·K]*	1250	1080	1060
Volume related specific thermal capacity Cp · δ [J/l·K]*	1375	2700	212
Required thickness for insulation [mm]	150	200	100
Weight of refractory lining [t]	2.6	7.7	0.5
Cp at 1000 °C of refractory lining [kJ·10^3]	3250	8300	530
Required hydraulic power [kW]	18	44	7.5
Thermal shock resistance	High	Medium – high	High
* Data at 1000 °C			

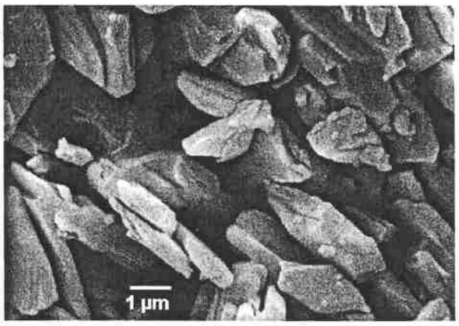

Fig. 2. Scanning electron microscope picture of SLA-92 (broken surface)

The other main component of this material is calcia (7–8% CaO), and the level of total impurities is very low, with SiO_2 and Fe_2O_3 contents max. 0.1%. The base mineral composition is Calciumhexaluminate ($CaO \cdot 6Al_2O_3$ or CA_6). Among minerals in the calcium aluminate system, CA_6 exhibits the best thermal properties with a melting point above 1850 °C. The bulk density of SLA-92 is around 0.75 g/cm^3.

Figure 2 shows the microstructure of SLA-92. Small CA_6 platelets are arranged like a house of cards with micropores between the crystals, which gives a homogeneous structure with a high internal porosity (typically 75%). The pore size distribution of SLA-92 is shown in **Figure 3**. It shows a narrow range of pore size between 1 and 5 µm with an average pore size of 3–4 µm. This structure accounts for the two key properties of SLA-92 described below, which make SLA-92 superior to conventional insulating raw materials.

The microporosity hampers heat transport by radiation, which is the main transport mechanism at high temperatures, resulting in the *low thermal conductivity* of SLA-92 especially at temperatures exceeding 1000 °C [2]. In general, insulating materials are susceptible to spalling caused by thermal shock, because a temperature change creates a steep thermal gradient that causes high thermal stresses. But thermal spalling occurs only if a crack developed by thermal stress propagates through the material. The microporous house of cards structure of SLA-92 hampers crack propagation and contributes to the *high thermal shock resistance*. This, besides the relatively low weight, is an essential property for the new ladle preheater lining.

The properties of SLA-92 including its long term stability at temperatures up to 1500 °C and its chemical resistance against alkalis or when in contact with silica-containing insulating refractories are discussed in detail by van Garsel, et al. [2,5].

Microporous refractory castables

Intoval VL 1000 HT, a newly developed lightweight insulating castable, is based on the microporous raw material SLA-92. The castable is hydraulically bonded using high alumina cement. Intoval VL 1000 HT has been cast under vibration, using 55–60% by weight mixing water into the ladle preheater covers. After hardening, the covers have been tempered at about 800 °C to remove the physically and chemically bonded water from the hydraulic bonding.

The data of Intoval VL 1000 HT are given in **Table 3**. The bulk density, which depends on the prefiring temperature, is between 1.17 and 1.04 g/cm^3. The cold crushing strength is between 8 and 10 MPa, and over the entire pre-firing temperature range, it exceeds the strength (1–3 MPa [3]) of typical insulating fired bricks of ASTM class 23–30. The high thermal shock resistance of refractories based on SLA-92 was proved in a previous investigation [2], and it is also a key property of refractory linings based on Intoval VL 1000 HT.

The thermal conductivity is between 0.34 and 0.46 W/m·K, which is about 6 times lower in comparison to a dense castable with a bulk density of 2.4 g/cm^3. This therefore requires a lower lining thickness of the ladle preheater to achieve a comparable backside steel shell temperature. Compared to fiber linings with a bulk density of about 0.2 g/cm^3 the thermal conductivity of INTOVAL VL 1000 HT is higher at temperatures below 1200 °C, but at higher temperatures the situation changes. In contrast to conventional insulating refractories and even to fibrous materials, refractories based on SLA-92 show no steep rise in thermal conductivity at temperatures exceeding 1200 °C [2]. This is due to the microporous structure which hampers heat transport by radiation.

As INTOVAL VL 1000 HT contains some SiO_2 from bonding additives, its temperature limit for application is 1450 °C. Above this temperature a partial melting occurs which can be expected from the phase diagram $CaO\text{-}Al_2O_3\text{-}SiO_2$ [6] and leads to

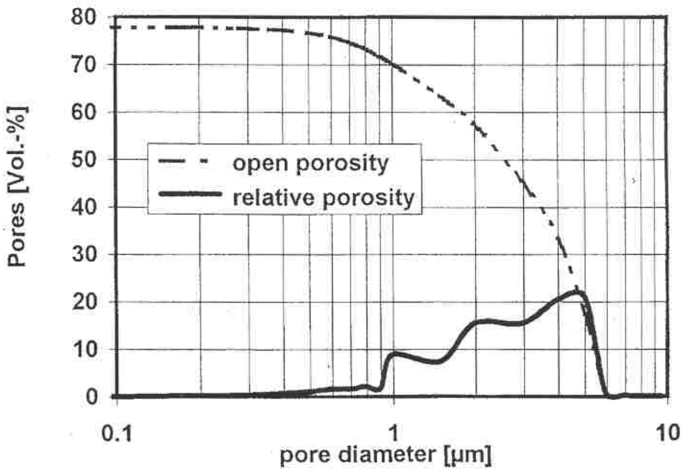

Fig. 3. Micropore size distribution of SLA-92 (Hg-intrusion method)

Tab. 3. Data of microporous lightweight refractory castables

	Intoval VL 1000 HT		Intoval VL 1000 HT/1	
	CAST	GUN	CAST	GUN
Temperature limit of application [°C]	1450	1450	1500	1500
Chemical analysis [mass-%]				
Al_2O_3	86	84	89	89
CaO	10.5	10	10	10
SiO_2	3	4	< 0.2	< 0.2
Fe_2O_3	< 1	< 1.5	< 0.2	< 0.5
Bulk density [g/cm³]				
110 °C	1.17	1.17	1.18	1.25
1000 °C	1.05	1.10	1.10	1.10
1400 °C	1.04	1.18	1.15	1.20
Cold crushing strength [MPa]				
110 °C	7	5	5	6
1000 °C	8	8	3	2
1200 °C			3	3
1400 °C	10	12	5	5
Permanent length change [%]				
110 °C	-0.1	-0.1	-0.1	-0.1
1000 °C	-0.4	-0.4	-0.4	-0.3
1200 °C	-0.5	-0.6	-0.4	-0.2
1400 °C	-1.2	-1.5	-0.5	-0.9
Dilatation 20-1000 °C [%]	0.6	0.6	0.6	0.6
CO – resistance (ASTM) [class]	A-B	B	A	A
Thermal conductivity* [W/m·K]				
at 400 °C	0.37	0.37	0.30	0.30
at 800 °C	0.34	0.34	0.28	0.28
at 1000 °C	0.36	0.36	0.27	0.27
at 1200 °C	0.46	0.46	0.36	0.36

* measured by hot wire method (DIN EN 993-15)

shrinkage of the refractories. Therefore, the silica free version INTOVAL VL 1000 HT/1 has been developed to achieve a refractoriness of 1500 °C.

Furthermore gunning versions for both lightweight castables have been developed and in various applications successfully applied. The gunning of lightweight castables allows an easy repair of insulation linings, especially when only parts of it are damaged, for example mechanically by moving equipment in a furnace. The gunning versions can also be trowelled for smaller repairs. This is another advantage of the new lightweight castable preheater lining over fiber linings. If fiber linings are damaged, it is not easy to repair them and the damage very often increase rapidly, which requires a complete relining of the preheater cover.

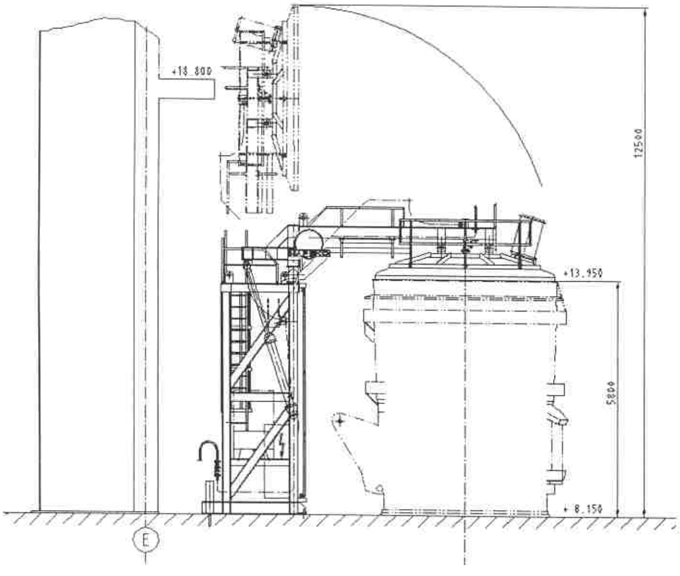

Fig. 4. Ladle preheater general layout

Industrial application

A sketch of the ladle preheater is given in **Figure 4**. In general, a ladle preheater consists of three systems, which are independent from each other:

1. Motion to put the ladle preheater cover on the steel ladle.
2. Burner with automatic control for fuel – air/oxygen ratio to ensure a burning flame over the entire range of application.
3. Temperature control to compare actual status with target temperature and to steer the burner.

Figure 5 shows the refractory lining of the ladle preheater cover. Besides the new microporous insulating castable a high wear resistance dense castable is used for the cover border to avoid mechanical damage by contact with the steel ladle.

The new ladle preheater station at CORUS IJmuiden is shown in **Figure 6**. The first ladle preheater from supplier B with the microporous refractory lining has been put in use in February 2000 (no. 4 in Figure 1). Another 4 have been installed in the following months (no. 5–8 in Figure 1). **Figure 7** shows the new ladle preheater refractory lining after 12 months of regular use. There is no damage of the lightweight castable and no repair was required in the last 17 months. In comparison, the ladle preheaters lined with a conventional castable need a complete relining every 3–4 months because of serious damage of the refractory lining. This shows clearly the advantage of the new microporous and high thermal shock resistant insulating castable.

Besides the advantageous material properties also the specific way of installation and thermal pre-treatment of the preheater cover contribute to the high lining life of the new systems. These technical construction issues cannot be discussed here in detail.

After 12–17 months of successful industrial application, the new ladle preheater refractory technology has been proven to be a technical and economical alternative to refractory ceramic fiber linings.

Outlook

The microporous lightweight castables could also replace fiber linings in existing preheater equipment for steel ladles or tundishes. This may require some adjustments of the overall

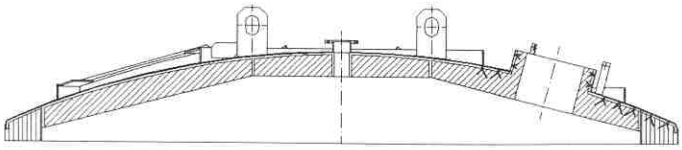

Fig. 5. Ladle preheater cover refractory lining. Inclined hatched area is new microporous insulating castable and vertical hatched area is high wear resistance dense castable at the border of the cover

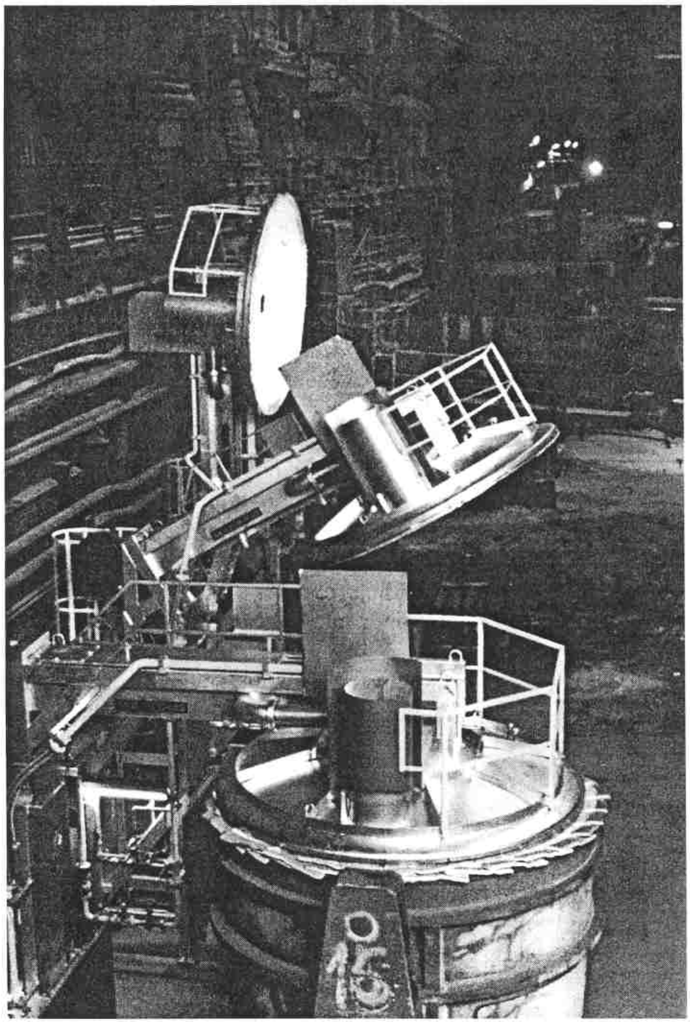

Fig. 6. New ladle preheating station at CORUS Strip IJmuiden

construction, because the older equipment has been constructed only for the very low weight fiber linings.

The new microporous insulating raw material SLA-92 is used also in other innovative refractory applications like replacing fiber materials for subentry nozzle insulation [7] or as kiln car lining in the ceramic industry [8]. Due to its inherent combination of low weight, high refractoriness, low thermal conductivity, and high thermal shock resistance there are a lot of other interesting application areas besides the steel industry or as fiber replacing material. (F 022)

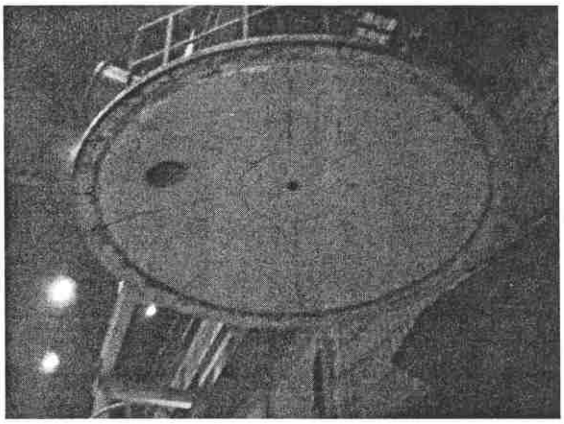

Fig. 7. Ladle preheater refractory lining after 12 month usage without any repair

References

[1] Commission Directive 97/69/EC of 5. 12. 1997 adapting to technical progress for the 23rd time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

[2] Van Garsel, D.; Gnauck, V.; Kriechbaum, G. W.; Stinneßen, I.; Swansinger, T. G.; Routschka, G.: New Insulating Raw Material for High Temperature Applications, Proc. 41. International Colloquium on Refractories Aachen, 122–128.

[3] Routschka, G.: Taschenbuch Feuerfeste Werkstoffe, Vulkan-Verlag Essen, 2. Auflage 1997.

[4] Duhamel, S.; Verrelle, D.: Developments in the Refractory Design of Lids for Ladle Preheating in Dunkirk Steelworks, The Refractories Engineer, March 2000, 29–33.

[5] Van Garsel, D.; Buhr, A.; Gnauck, V.: Long Term High Temperature Stability of Microporous Calcium Hexaluminate Based Insulating Materials, Proc. UNITECR'99, Berlin, 18–33.

[6] Slag atlas, Verlag Stahleisen, 1995, 105.

[7] Gotthelf, D.; Schrick, G.; Buhr, A.: Faserfreie Isolierung von Tauchausgüssen beim Stranggießen, Stahl und Eisen 121 (2001), No. 3, 73–78.

[8] Pörzgen, D.; Heide, W.; Buhr, A.: Innovative Refractory Solutions using a new Microporous Material for Kiln Cars in the Ceramic Industry, CN Special Refractories Vol. 7, No. 2, 2000, 68–70.