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INTRODUCTION OF UNSHAPED REFRACTORIES IN THE WEAR LINING OF STEEL LADLES

UPORABA NEOBLIKOVANEGA OGNJESTALNEGA MATERIALA ZA OBRABNO OBSTOJNO OBZIDAVO JEKLARSKIH PONOVC

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Steel ladles are essential tools in steelmaking. In the past, research was almost entirely centred on converters but nowadays attention has focused on ladles. The determining factor for the choice of a lining is the cost per tonne of steel as well as reliability, security, availability and metal purity. The cost per tonne of steel has now reached a constant level with shaped products and can hardly be improved. The introduction of new technology and radical changes are the only possible means to make improvements in the economic situation. The application of unshaped products to the ladle may provide a solution. Experience in Japan has shown that improvements are possible when techniques utilising monolithics in ladles are adapted. Here we intend to describe the trials carried out by Lafarge Réfractaires Monolithiques and the first significant industrial results with the use of monolithic ladles in European conditions.

Key words: steel ladles, wear lining, monolithic lining, industrial experience

Jeklarske ponovce so bistveno orodje za izdelavo jekla. V preteklosti je bila pozornost usmerjena predvsem v konvertorje, sedaj pa se pozornost usmerja v ponovce. Odločujoči dejavnik pri izbiri obzidave so strošek na tono jekla ter zanesljivost, varnost, razpoložljivost in čistost kovine. Strošek na tono jekla je pri oblikovanih proizvodih sedaj dosegel konstantni nivo in ga bo težko izboljšati. Razvoj nove tehnologije in radikalne spremembe so edina možnost za izboljšanje gospodarskega položaja. Uporaba neoblikovanih proizvodov za ponovce bi lahko bila rešitev. Izkušnje iz Japonske so pokazale, da je mogoč napredek z uporabo monolitov v ponovcah. Tu želimo opisati preizkuse, ki so bili izvršeni pri Lafarge Réfractaires Monolithiques in prve pomembne industrijske rezultate pri uporabi monolitskih ponovc v evropskih pogojih.

Ključne besede: jeklarske ponovce, obrabno obstojna obzidava, monolitska obzidava, industrijske izkušnje

1 EUROPEAN CONDITIONS AND THE LAFARGE CONCEPT

a) LININGS IN EUROPE

In the steelmaking and secondary steelmaking process, the lining is submitted to different thermomechanical stresses. If the evolution of refractories in Europe is taken into account, it is not surprising that a wide range of ladle linings is found on the market.

- Brick linings

- Basic linings: The slag line is often magnesia-carbon bricks, the other areas are magnesia or dolomite. The basicity of the lining may be considered a favourable factor for secondary steelmaking.
- Aluminosilicate linings: only the sidewalls and the bottoms are in such bricks, generally bauxite. Alumina-spinel is rarely used.

- Raw materials

Let us compare the relative costs of the raw materials for the above compositions:

Spinel	100
Tabular alumina	75
Bauxite	15 - 40
Magnesia	15 - 40
Dolomite	5 - 10

Ladle linings have previously been made from less expensive raw materials (bauxite, magnesia, dolomite). In Japan, this was not the case and mostly more expensive materials were used. Therefore, from an economic point of view, the starting point for monolithic design differs in Japan and Europe.

- Metal quality

The steel ladle has become a metallurgical reactor where many operations of secondary steelmaking are carried out. Ladle refractories in contact with steel may influence the steel quality, either directly or through secondary effects. For example, refractories may cause alterations in slag composition, or indirectly affect steel quality as a result of the performance of the refractory involved in the stirring operation.

Consequently refractories play an important role in metal quality. Basic linings, in particular dolomite, have been developed for metallurgical reasons and in addition also offered to European steelmakers a cheap solution. In the past steelmakers where also concerned by the presence of alumina in ladle linings.

b) THE CONCEPT

For technical reasons, basic slag line products will not be considered in this paper. Basic castables with properties competing with basic bricks in this area have not yet been developed to a commercial level. Therefore to date our solutions exclude the slag line and our experiences are concentrated on the monolithic sidewall, prefabicated and the casting of the in-situ bottom. Our designs are based on the following five principles:

1 The various zones of the lining

Alumina-spinel products are not considered necessary for the whole ladle, since the raw material is relatively expensive in Europe. Examples are found where this design proved to be wrong from the economic point of view. It is necessary to have different properties for the different conditions encountered in the ladle, i.e. the best quality/price ratio in each zone of the lining.

2 Deskulling and repairs

The cost of high technology alumina castables is greater than those of alumina or basic brick. However the repair/veneering of the initial lining after cleaning, not only allows the ladle availability to improve, but also reduces the refractory cost of the ladle.

For subsequent repairs/veneers we propose a self flowing castable (MONROX RANGE) which are specifically designed for this type of repair. Their special characteristics give a free flowing product which readily fills the lining profile between the former and residual lining, and has an excellent adhesion to the residual materials.

3 The development of silica-free products

With the exception of the slag line which must remain basic, the sidewall and the bottom of the ladle are lined with alumina materials. Bearing in mind the metal quality, LRM developed silica-free products for monolithic ladles.

4 Appropriate placing

Mixing, vibrating and drying together account for 50% of the achievement of the maximum campaign life. These features are specific to unshaped materials.

5 User and supplier as partners

The key to progress for the user and the supplier is co-operation. Monolithic ladles are a good replacement for shaped linings, but full co-operation is required to optimise the economic factors, a difficult but not impossible task. The following solutions may be proposed.

2 DEVELOPMENT OF SILICA-FREE PRODUCTS

Monolithic materials have vastly improved over the last few years. Highly compact products and increased refractoriness have been obtained through the technology of ultrafine particles and defloculation.

Corrosion resistance can be improved by the addition of fine particles to protect the matrix taking care to avoid possible reactions between the lining and the liquid steel, which may lead to contamination. These fine particles additions can be classified as:

- *Anti-wetting-agents*

These agents impair the penetration of the refractory matrix by oxide slags and therefore limit the corrosion to surface phenomena. They are non-oxide compositions which can only be employed in products working in reducing or moderately oxidizing atmospheres. Their use is made possible by the reduction of the oxidation rate because of the great compactness of these castables.

The most effective are also those which oxidise the most readily such as: pitch, resin, and carbon black used alone or in combination.

- *Agents wich reinforce the dissolution resistance*

These agents work by increasing the viscosity of the diffusion layer and are generally oxydes, such as Cr_2O_3, ZrO_2, MgO and MgO Al_2O_3.

The use of ultra-low cement castables allows us to obtain a matrix with the characteristics close to those of the aggregate materials. Therefore, means limiting the penetration of the corrosive elements using the two methods indicated and employing alumina ultra-fines (no silica) were developed.

Anti-wetting castables

In castables with alumina matrix moderate sintering leaves a very fine capillary structure which is easily and deeply penetrated by the slag.

With the addition of silicon carbide **(table 1- castable A)**, test shows a slight improvement of corrosion resistance while the slag still penetrates deeply. This behaviour is verified by the analysis of a panel used in a ladle wall: after 50 heats, by the total residual thickness 185 mm, the thickness of the impregnated layer is 60 mm.

The transformed area no longer contains silicon carbide as this has been completely oxidised with reaction with the slag, mullite and anorthite have been formed.

Carbon is the key element to avoid penetration **(table 1 - castables B, C, D)**. However, carbon addition weakens mechanical strength since it diminishes the sintering of the alumina matrix. A compromise, as in castable D, through the choice of the carbon type and the content of carbon and silicon carbide is required depending on the anticipated degree of oxidation and silicon carbide content and according to the risk of oxidation.

The principle has been applied to both corundum and bauxite castables.

Alumina-spinel castables

In several Japanese papers the use of spinel as addition to tabular alumina castables to reduce impregnation is described. The mechanism may be explained as follows:

- Spinel magnesia fixes in solid solution iron oxide from slag;
- Slag lime reacts with the alumina of the matrix to form refractory CA6

Table 1: Castables with antiwetting agents

	A	B	C	D
Al_2O_3	72	67	67	73
SiC	10	10	5	5
C	0,9	0,9	0,9	0,6
Water	4	4,2	4,8	4
Density after 1550°C/5 h*	3,30	3,13	2,98	3,18
Compression Mpa 110°C	60	30	30	30
1200°C/5 h*	65	40	25	30
1600°C/5 h*	160	120	50	100
PLC 1500°C	-0,1	+0,1	+0,2	-0,1
Corrosion 1600°C-80 mn Steel XC 38-Synthetic slag	(C/S=2,4) (Fe_3O_4=20) (CaF_2=5)			
Wear (mm)	8,6	8	6,5	7,5
Impregnation (mm)	7	0	0	0

* *reducing atmosphere*

Table 2: Alumina-spinel castables

	E	F	G
Alumina	82	59	62
Electro-fused spinel	-	20	-
Sintered spinel	-	-	20
Magnesia	-	3	1,4
Lime	1,4	1,4	1,4
Mixing water	4,3	4,4	4,9
Apparent density	3,07	2,92	2,93
Compression Mpa			
100°C	85	55	50
1200°C/5 hr*	90	90	80
1500°C/ hr*	140	100	90
PLC 1600°C/5 hr	+0,3	+0,9	+0,7
Corrosion 1600°C-30mn Steel XC 38-Synthetic slag	(C/S=2,4) (Fe_2O_3=20) (CaF_2=5)		
Wear(mm)	not detectable	8	9
Impregnation	completely	12	12

* *reducing atmosphere*

- Silica concentration in slag increases and consequently its viscosity increases also
- Reaction with alumina induces precipitation of C_2AS (gehlenit)

These results have been verified in a tabular alumina castable with alumina bond. Addition of 10 to 20% of spinel strongly reduces slag penetration. The introduction of silica in the system promotes the dissolution and in this case undesirable monticellite is formed.

In **table 2** the evolution of tabular alumina-spinel products is presented. Recent developments have been made considering the following parameters:

The nature of the spinel: Laboratory corrosion tests had originally shown a deeper penetration at the slag-metal interface in over-stoichiometric than in stoichiometric spinel similar crystal size.

Facility of installation: Due to their alumina bond, the castables may need care during placement.

Improvements are being made in workability and rheology to achieve a high degree of mobility. This is essential for the future.

3 INDUSTRIAL RESULTS

Many trials have been undertaken and are either still in progress in laboratory and industrial stage. Today we have a good background of industrial experiences throughout Europe, each site presenting a different scenario:

- Integrated and electric steel plants manufacturing flat products, IFS, long products, steel for roll bearings or stainless steel;
- Ladle capacities from 50 to 310 tonnes,
- Equipement for secondary steel making including RH, DH degassers, desulphurisation lances, ladle furnaces, CAS-OB...
- And the different work cultures within the European community.

Precast wear linings for Ladle Bottoms

The development of high performance castables allows competitive solutions to be put forward in order to obtain a balanced ladle life. This is currently been demonstrated by the use of pre-cast blocks in steel ladle bottoms.

The pre-cast wear lining of ladle bottom is a solution which offers a competitive and simple alternative with many advantages, including:

- quick and easy installation,
- controlled off site casting,
- pre-drying, under controlled conditions,
- design flexibility, and
- enhanced performance.

The concept uses different castables for various pieces and joints, depending on the characteristics and constraints encountered (impact area, porous plug as well as tap-hole number and position).

a- SITE 1 - Steel Teeming Ladle-Precast bottom blocks

This site is an intregrated steel plant operation with 3 No. BOF's producing approximatively 2,3 Mt/year of strip product and supplying high quality low and ultra low carbon steel to the motor industry. Ladle availability is fundamental to this plant and improved ladle bottom performances were required. The standard brick lining gave a typical campaign of 30 heats with failure occurring in the impact pad. Our objectives were to achieve 60 heats and provide a ladle with an uniform sidewalls and bottom life. The proposals for a complete precast bottom were based on:

- improvement of the impact area with introduction of a precast pad in alumina-spinel quality;
- providing an economicaly viable balanced bottom lining exhibiting an even wear. This was achieved by introducing bauxite based products in the none impact area of the bottom;
- an intregral joint in a self flowing version of our alumina-spinel castables, which are designed for this type of installation. Their special characteristics give a free flowing product which readily fills the lining profile between the precast blocks and has an excellent user friendly nature;
- elimination of additional drying time usually associated with the use of monolithics. The drying schedule is the same as that used for the bricks.

All the objectives were achieved in performance. A typical campaign of 60 heats has been attained with a stop at mid campaign to change the wellblock. In **table 3** some technical and economic benefits acquired are listed.

Table 3: Economical and technical benefits on site 1

	Actual situation	Solution: prefabicated bottom
Material cost	100	105
Manpower cost	100	28
Client profit directs costs		-6,5% on the cost ratio
Maintenance standstill	42h	26h
Duration of a ladle campaign including installation maintenance and production duration	15 days	15 days
Client profit		-38% on the maintenance time
Indirect costs		+4,5% on ladle availability

Currentely trials are ongoing to extend the wellblock life and eliminate the stop at mid campaign and further improve ladle availability. In late 1995, this site decided to convert all their teeming ladle fleet to precast bottoms.

b- SITE 2 - Steel Teeming Ladle-Cast in-situ bottom

This 2 x 300t BOF plant is similar to other large integrated plants in that there is a desire to diminish the refractory costs in ladles. The general feeling is that the cost per tonne of steel has now reached a constant level using bricks. However, the introduction of monolithic technology was felt to be a solution that could offer significant improvements. In **table 4** the clients final gains after adoption of the monolithic concept are listed.

Our alumina-spinel products were used, the cast vibration version for the initial installation, and repairs with self-flow product. The performance of these products allowed the customer's objectives to be achieved. The fleet of ladles on this site is sufficient to allow planned campaigns when the monolothic concept is adopted the clients final gain is:

Table 4: gains on site 2

	Actual situation	Solution:cast in-situ bottom
The campaign	90 heats life with one stop to repair the impact area	360 heats with 3 small repairs of the impact area
Material cost	100	92
Manpower cost	100	29
Client profit:direct cost		-14% on the ratio
Maintenance standstill/length	336 h(4 campaigns)	208 h(4 notations)
Duration of a ladle campaign	15 days	15 days
Client profit		-38% on maintenance time
Indirect cost		+3,5% on ladle availability

The next step at this plant is to improve the ladle sidewall.

c- Monolithic sidewall and bottom lining: our references

Monolithic products either as precast shapes or insitu casting increase the ladle life. The campaign length is the main parameter which allows the decrease of costs per tonne. Numerous trials carried out since 1989 show a favourable evolution in maintenance costs. Some benefits are in **table 5**.

Table 5: Benefits obtained at different sites

	SITE A	SITE B	SITE C	SITE D
Process	2x310t BOF Cas-OB/CC Slag	1x70t BOF DH/LF/Lances Bloom/ Billet	1x80t EAF RH/LF/CCR Bloom/Billet	1x85t EAF LF/CCR Tube/Pipe
Initial lining	80% Al_2O_3 bricks	Dolomite bricks	MgO-C bricks	Dolomite bricks
Initial life	80 heats	60 heats	50 heats	70 heats
Monolithic concept	Al_2O_3 spinel product	Al_2O_3 spinel and bauxite product	Al_2O_3 spinel products for metal quality	Al_2O_3 spinel products for metal quality
Life	400 heats with 1 relining at 240 heats	300 heats with 4 relinings every 60 heats	120 heats with one relining	420 heats with 3 relinings
Achiefed production costs	10% material and manpower	20% material and availability	10% material and manpower	10% material and manpower

4 CONCLUSION

The trend towards the use of monolithic refractories in ladle applications has been initiated by changes in steelmaking technology and associated product technology.

However, products development has to continue to further reduce wear of the steel ladle refractories and to decrease refractory costs.

Lafarge Réfractaires Monolithiques have considered the metal quality in the development of new products for secondary steelmaking. The new silica-free bond products behave very satisfactorily in industrial service and confirm the results predicted on the base of laboratory corrosion tests. The improvement of the installation techniques will have a significant effect on the use of monolithic refractories since such techniques lend themselves to automation. When the suitability of the product has been established, the required investment in installation equipment will bring increased benefits. Recent innovations have shown that there is a place within the ladle environment for monolithic refractories and that they can meet the most competitive challenges.

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