THE USE OF DOLOMITE BRICKS AND THE EFFECT OF SLAG FORMATION ON BASIC LININGS IN MODERN STEELMAKING PRACTICE

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INTRODUCTION

The demands made upon the properties of steel with regard to higher cleanness and lower contents of sulphur and oxygen increase continuously. This has to be taken into consideration by all metallurgical treatments. The modern technology of "Secondary Steelmaking" transferred metallurgical processes out of the primary melting facilities into subsequent "secondary" units. Consequently, these units must also be lined with refractories compatible with these metallurgical requirements (1-4).

For such a specialized metallurgy, basic slags and linings are thermodynamic conditions. As shown in Table 1, dolomite has taken a central position in this respect, which is economically confirmed by the European price relation dolomite: magnesite = 1/2.5 to 1/3. (2)

Table 1. Oxygen-content and sulphur partition (Slag: FeO_n)

Crucible	Temperature: 1 600 °	
	[% O]	(% S)/[% S]
Lime	0,009	10,7
Dolomite	0,12	7,9
Magnesite	0,23	3,8

For this reason modern steelmaking is no longer imaginable without dolomite. Its whole range of application is shown in Table 2.

It is no longer the question, if dolomite or magnesite will be the right solution. Today one knows exactly that the refractory lining has not only to withstand the attack

Table 2: Use of Dolomite Products

field of application			type of product								appr. consumption	
			raw dolomite	soft burnt dolomite	mixes from burnt dolomite	pitch bonded dolomite bricks	pitch bonded magnesite enriched dolomite bricks	pitch bonded magnesite bricks	direct bonded burnt dolomite bricks	direct bonded magnesite enriched dolomite bricks	kg/t	DM/t
iron/hot metal production		sintering plant	●								30	0,6
		blast furnace	●								25	0,3
		hot metal ladle			●	●					2-3	1-2
		torpedo type hot metal ladle				●			●		0,8-1,2	0,4-0,6
		hot metal mixer				●			●		< 1,0	< 0,5
steel production	primary	top blown oxygen furnace		●	●	●	●	●	●	●	3-7	2,5-5.0
		bottom blown oxygen furnace		●	●	●		●	●		3-7	2,5-5.0
		open-hearth furnace			●				●		20-30	4,0-6.0
		electric arc furnace			●			●	●		10-30	10-20
	secondary	steel ladle			●	●	●		●	●	4-6	3-5
		AOD furnace			●	●			●		15-30	10-20

in the different areas of the vessel but also to meet the actual metallurgical requirements. Furthermore, in modern refractories technology it is possible to adjust every requested CaO/MgO ratio in manufacturing basic bricks. This can be done in producing a so-called synthetic Co-Clinker or later at brick manufacturing by blending dolomite and magnesia. So it is possible without any difficulties to meet the request to line the different areas of the vessel using the correct CaO/MgO ratio following the technical as well as the economical points of view. (2).

BASIC OXYGEN FURNACE

The lining technique of the BOF's followed different trends in different countries (3). In Austria, where the LD process was invented, it was common to use magnesite or high lime and dicalcium ferrite bonded "Magnit" for lack of dolomite. Other European countries having tradition in making Thomas-steel (Basic Bessemer) used logically dolomite. Whereas in the USA, Japan and Australia, based on their own open hearth experience, they again took magnesite to line the vessels. The trend in most European countries was different from the USA and Japan. In Europe there was a change from originally only dolomite to magnesite enriched dolomite up to 100% magnesite linings where excessive wear requires this. But meanwhile this trend starts to be converted back: in all places where it is possible by the availability of the vessels or where by changed techniques the wear is reduced one starts again to use dolomite.

A reduction of wear can be realised by use of the so-called bottom stirring and a sublance to reduce the FeO-content of the slag.

The situation in America is characterized by the fact that the costs for mining and sintering of natural dolomite are extremely high. There the prices of a pitch-bonded dolomite brick is about 80% of a pitch-bonded magnesite brick compared to only 35% in Europe. Therefore, American dolomite would be hardly an economic advantage in the BOF.

For the lack of good natural resources or because of the difficult processing in Japan, the raw materials are manufactured synthetically. Doing this, it is possible to obtain any CaO/Mg ratio requested. The production of synthetic sinter is the cheapest with the lowest MgO-content.

Assuming these prerequisites one can observe two different trends to meet a zoned wear adjusted lining. One way is to use pitch-bonded magnesite bricks having high MgO-contents up to 99%. The other is the renewed application of dolomite also in hitherto severely attacked converters in which, during the past years, more magnesite has been used.

Independent of this is the lining technique itself (3, 4). It does not matter whether ring or spiral lining, if attached removable bottoms are used. The preheating procedure when using dolomite bricks is less problematic and independent of the size of the vessel. Normally it needs no more than 2-3 hrs (3). With regard to preheating, the hot strength is of great importance. But mostly, the decisive criterion is not the record of performance but the most economical number of heats and the highest rate of availability of the vessels. Of course one tries to get a most uniform wear and a low amount of reclaimed bricks. But this cannot be realized only by thicker linings. There is already set a limit by the necessary reaction volume and also by problems with the torque. Practical experience showed that this aim can be reached better by zonal lining using different types of refractories. Normally this means an increase of the costs per set of lining. But this doesn't mean an increase of the specific refractory costs simultaneously, because e.g. you can get more heats, a uniform wear and a higher yield of the lining. A lining efficiency of 100%, i.e. reclaim = 0, would be the optimum but cannot be realized. In practice an efficiency of 70% is a good and usual result.

Lining efficiency is defined as ratio of the difference of (installed weight - reclaimed weight) to the installed weight given in %.

An example for such an optimized lining is given in Fig. 1. This example is so far of special interest because in this plant European lining technique is compared to Japanese technique. When lined completely with pitch-bonded dolomite bricks following the German model, 570 heats were obtained. The specific consumption of refractories was 3.64 kg/t steel at costs of 0.814 US $/t of steel. By a zonal installation of higher grade bricks the number of heats could be increased to 930 and brick consumption and costs were reduced to 2.1 kg/t steel resp. 0.72 US $/t steel.

This result was reached by installation of dolomite-magnesite bricks having higher MgO-content in areas of excess wear, 100% magnesite bricks in the trunnion section and burnt dolomite bricks on the charging side. But the high grade bricks cover only 25% of the whole lining and of this are 16% magnesite enriched pitch-bonded dolomite bricks and 9% pitch-bonded magnesite bricks. The resting 75% of a lining exist still out of pure pitch-bonded dolomite bricks. It is to be mentioned that simultaneously the lining thickness could be reduced by 50 mm. The properties of the used types of bricks are shown in Table 3.

In the same BOF one reached no better result in using pure magnesite bricks of non-European origin (790 to 1018

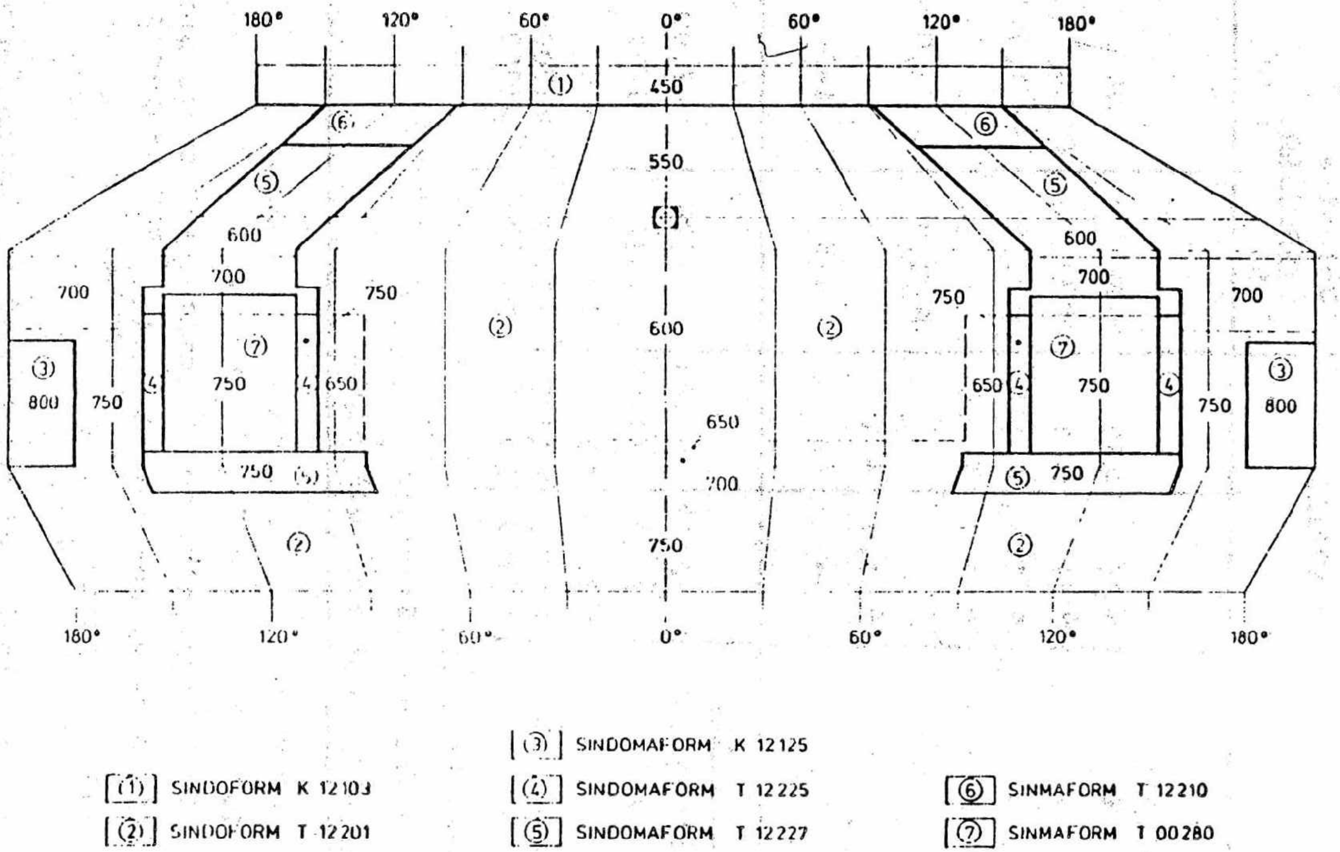


Fig. 1 : A Lining of a 150 t BOF vessel zoned by Material and Thickness

Table 3: PROPERTIES OF SOME SPECIAL BASIC BRICKS FOR THE LININGS OF LD-VESSELS

	Dolomite		Dolomite Magnesite		Magn.
	T	K	T 50	T 70	T 100
Chem. Analysis					
MgO %	> 36	> 36	~66	77	> 94
CaO %	< 61	< 61	~31	~ 20	< 3,0
SiO_2 %	< 1,5	< 1,5	< 1,5	< 1,5	< 2,0
Al_2O_3 %	< 1,0	< 1,0			
+ Mn_3O_4			< 1,0	< 1,0	< 1,0
Fe_2O_3	< 1,0	< 1,0			
pitch cont.%	4-5	ca. 5	4-5	4-5	> 4
physical. Propts.					
bulk density g/cm^3	2,89	2,81	2,96	2,99	3,09
Ptot. %	8-12	10-13	7-12	7-12	6-10
CCS N/mm^3	> 30	> 30	>30	>30	>30
DFB: ta °C	> 1700	> 1700	>1700	>1700	>1700
te °C	> 1900	> 1900	>1900	>1900	>1900

Ptot = total Porosity
CCS = Cold Crushing Strength
DFB = hot load test acc. DIN 51064

Legend:

T 100 = 100 % Magnesite
T 70 = 70 % Magn. enriched Dolomite } all types pitchbonded and tempered
T 50 = 50 % Magn. enriched Dolomite
T = 100 % Dolomite

K = 100 % Dolomite direct bonded and pitch impregnated

heats), but higher brick consumption and costs; 2.4 to 3.0 kg/t steel resp. 1.02 to 1.32 US $/t steel.

This comparison includes already the higher sea freight of the German dolomite bricks compared to magnesite bricks of different origin.

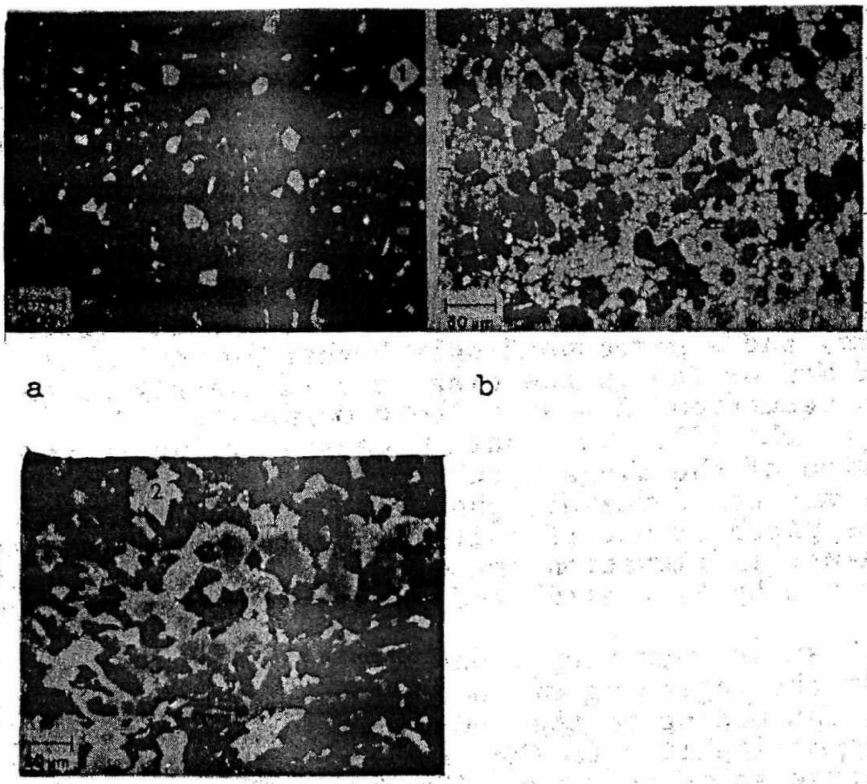
If from the USA and Japan better performances are reported with extremes up to 10,000 heats(5-7), it doesn't mean a better economy at all. This depends on the situation in every country, i.e. the ratio of costs from bricks to mixes and corresponding labour. It has to be checked and calculated for each country.

One way to influence the lining life is the selection of a suitable slag formation. Adding active CaO (soft burnt lime) and a correspondingly higher content of dissolved MgO or CaO in the slag at a very early stage enables a reduction of wear of both magnesite and dolomite bricks (8). The wear is caused by infiltration and reaction of the slags with the refractory oxides periclase and calciumoxide, whereas the carbon originated out of the pitch or out of solid additions is some resistance against infiltration and oxidation. These mechanisms are described by Barthel(9) and Herron & Runk(10) in detail.

Fig.2 shows microscopic photos of a slag sequence in a BOF. At the beginning of the blowing mainly Si is oxidized. According to the CaO-ratio it is transferred into ferromonticellite Ca (Mg, Fe) SiO_4 or olivine and some wuestite solid solutions (Fe.Mn)O. These slags, having low viscosity, penetrate into pores and grain boundaries mainly in bricks based on magnesia. Due to the lack of CaO in the bricks to stop SiO_2, periclase is dissolved. For this reason nowadays one adds at an early stage dolomitic lime to reduce the solubility of such slags for refractory MgO. In the following, more and more lime enriched compounds of the Merwenit-type ($3CaO.MgO.2SiO_2$) and dicalcium silicate (C_2S) are formed until at the end tricalcium silicate (C_3S), magnesiowuestite (Mg, Fe) O, lime wuestite (Ca, Fe)/ and dicalcium ferrite ($2CaOFe_2O_3$) are dominant. Such type of slag attacks mainly dolomite based bricks. Adding MgO at this stage, it is possible to counteract the attack. But it is better to use modern technology to reduce the content of iron oxide in the slag, this assists to reduce wear.

AOD FURNACE

When the AOD process was introduced in the United States, the furnace has always been lined with magnesia-chrome, or chrome-magnesia bricks, because of the fact that magnesia bricks did not provide a satisfactory lining(10-12) life. Krupp in the Federal Republic of Germany had sufficient experience with dolomite when one of the top blown oxygen furnaces had been converted for AOD-operation. As a result of this, better results were obtained with dolomite than with chrome-magnesia bricks, and this immediately from the beginning(13,12). Because the chromium oxide in the slag is reduced in the AOD converter during the reduction period, other existing



a b

c

Fig. 2

Microstructure of BOF Slags

a - 1.7 min: early slag CaO/Si/$_2$ = 1,2
1 = wuestite (FeO)
2 = ferromonticellite (CMS -CFS)

b - 6.1 min: middle slag CaO/SiO$_2$ = 1,5
1 = mervinite (C_3MS_2)
2 = wuestite (FeO)

c -14.5 min: finishing slag CaO/SiO$_2$ = 3,5
1 =(Ca, Mg, Fe)O
2 = alite C_3S
3 = dicalciumferrite (C_2F)

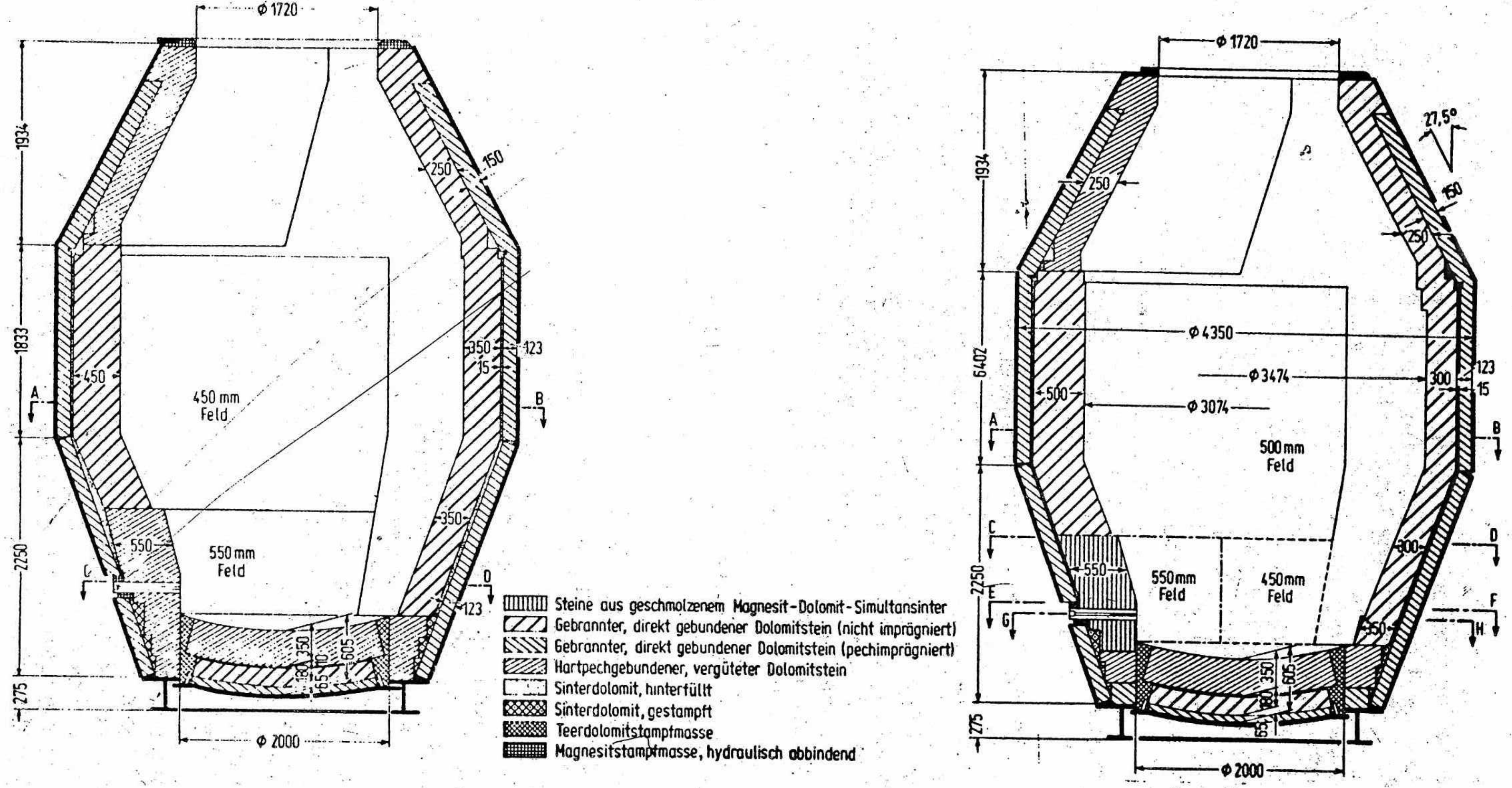
chromium oxides - for example in bricks with a chromium oxide content - will also be reduced.

That means also a destruction of the chrome spinel in the brick which is susceptible against the basic slags of the desulphurisation period. Cr-yields of more than 100% are therefore normal for AOD converters with magnesite chrome bricks. Therefore, dolomite bricks, which are free of chromium oxides, perform very well in AOD converters. In addition to this, under reducing conditions, partial oxygen pressures prevail during the AOD process, which permit a reduction of the MgO. Especially the acid silicate slags of the early blowing period will attack the magnesia. This also explains the failure of pure magnesite linings. With dolomite, the periclase lies within a CaO matrix. CaO cannot be reduced by the prevailing partial oxygen pressures. Because dolomite permits a faster preheating time than a vessel with a magnesite lining, in view of the expected performance and the reasonable costs, almost all European AOD steel works, and more and more in the USA(3), lined with dolomite. With very few exceptions, these are non-impregnated, that is carbon free - burned dolomite bricks, with which ELC qualities can also be produced. It has recently been shown that the AOD process with dolomite linings has been applied to the production of low Cr or Cr-free steels or alloys.

The lining life of AOD converters can be improved with similar methods common with BOF vessels. The number of heats can be considerably increased and consumption of refractories and costs evidently reduced installing thicker linings or higher grade bricks in the areas of excessive wear. Sometimes the best effect can be obtained through a combination of both. But different from BOF, the use of more MgO is restricted. A particular critical section is the tuyere area. The excess wear around and above the tuyeres takes place by erosion which is caused mainly by the turbulence in the melt(15). This excessive wear has to be counteracted using a wear adapted lining. An example is the 80 t AOD converter of Thyssen Edelstahlwerke, Krefeld.

Fig.3 shows the lining design of this AOD vessel a) at the end of 1977 and b) since November 1979. The differences are remarkable. On the tuyere side the lining thickness of the cylindrical part was increased from 450 to 500 mm. The tuyere area in the lower cone is now lined with bricks made out of fused magnesia-dolomite clinker grain resp. pitch-bonded magnesite enriched dolomite bricks instead of pitch-bonded dolomite bricks. At the same time the lining thickness opposite the tuyeres has been reduced by 50 mm. This wear adapted lining doubled the number of heats from 50 to 70 to more than 100 and up to maximum 106 heats after an intermediate repair between 50 and 65 heats. The actual residence time reached a total of 150 hrs. The brick consumption was reduced from 16.3 kg/t of steel to below 10 kg/t steel. Best figures were 8.3 and 8.4 kg/t steel (Fig.4)(16).

The tuyere bricks are usually made of pitch impregnated burnt, magnesite enriched dolomite bricks. One will take advantage of the slag refusing property of the pitch impregnated bricks. To obtain an excellent life of the tuyere, it is essential to place the tuyere tube absolutely concentric into the brick and that there is a good connec-



up to late 1977

since November 1979

Figure 3. Lining of the AOD converters of Thyssen Edelstahlwerke AG in the works Krefeld

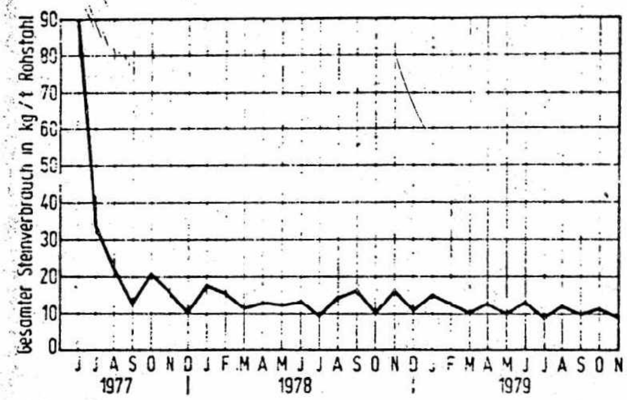


Figure 4. Specific brick consumption of the AOD converters of Thyssen Edelstahlwerke AG. works Krefeld

tion between tube and brick. Also important are smooth brick surfaces so that the whole tuyere block works like a monolithe avoiding excessive, wear in the joints. Furthermore, it is of influence to the tuyere performance to obtain the proper formation of knurdles at the tip of the tuyeres(15).

As explained, wear adapted lining designs have been developed giving satisfying lining performances of 100 heats and more. This is possible by the use of direct bonded high fired bricks having low porosity, high heat resistance, good accuracy in dimensions and low shrinkage during use.

These properties give the best resistance against hot-erosion, penetration and joint-attack. It is reported from Japan that records in performance were reached by means of multiple intermediate repairs and reinstallation of relaimed bricks in areas of less wear. But there is no report of the cost of such a manipulation.

Of course it is possible to counteract the wear with an appropriate slag formation(17). According to the required metallurgical treatment, different slags influence the lining; their composition and basicity CaO/SiO_2 is relevant to the wear mechanism(8). The transfer slag is relatively acid (basicity about 1) and consists of chrome spinel in silicate of melilithic and diopsidic composition. The chromium bearing slags have basicities of 1.3 to 2.0 and show in their early stage chrome spinel/metal-intergrowth surrounded by mervinite. In their later stage they show lath like Ca-chromite and dicalcium-silicate. The reducing slag (basicity 1.5) contains hardly any iron and chromium oxide but mervinite and the desulphurisation slag having high values of basicity (about 2), alite (C_3S) CaO and fluorspar.

These very distinct slags react fairly different to the refractory lining based on dolomite or magnesia-chrome.

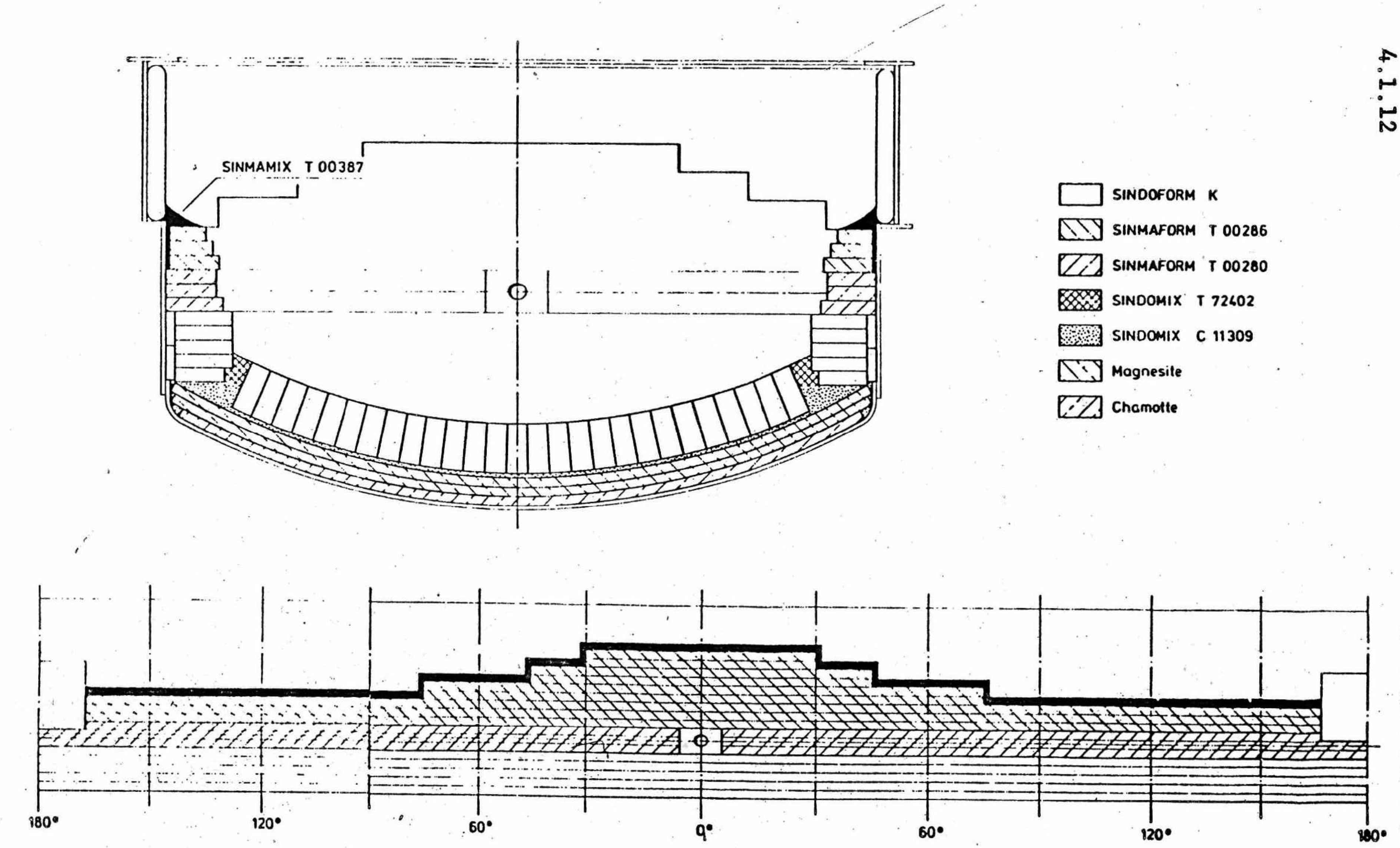


Fig.5: Lining of an Electric Arc Furnace Zoned by Material

So the most aggressive phase to the dolomite is the blowing period having a low basicity, to the magnesia chrome brick the phase of reduction and of desulphurisation having high basicities, because the chrome is reduced and attacked by excess CaO.

The rapidly moving steel/gas emulsion causes an extremely hard hot erosion around the tuyere area. This causes trough like erosions. Furthermore, in this area is the slag attack by iron- and chromium-oxide prevailing, as it can be identified by the new formation of dicalcium ferrite and Ca-chromite.

Wear is reduced if the acid slags will be saturated at the beginning of blowing by an early lime addition. This can be achieved using active and fine-grained soft lime resp. adding of dolomitic lime or by injection of powdered lime(17).

ELECTRIC ARC FURNACE

The development of the HP and UHP furnaces during the last decade has changed completely the lining of the arc furnaces. The previously very common dolo blocks can still be used in ordinary furnaces with normal transformer and melt capacity. But they are not able to withstand the requirements of modern UHP furnaces. Walls and slag lines of these furnaces are lined with magnesite bricks. More and more furnaces use water-cooled panels, developed in Japan (18). Also water-cooled roofs are already in use.

However, the area between hearth and water panels, i.e. the slag line and the area between slag line and cooling panels remains to be lined with bricks. Well proven in these parts of the furnaces are the recently developed graph-mag or mag-carbon bricks. These are graphite enriched pitch-bonded or resin-bonded tempered magnesite bricks. 300 heats in the slag line are not unusual. Manchester Steel (U.K.) got in their 55t 28 MVA UHP furnace 300 heats without an intermediate repair. A slightly modified type installed above the slag line gave 225 heats after an intermediate repair at 105 heats. The hearth of this furnace was lined, as previously common, with burnt direet bonded dolomite bricks (Fig.5).

For reasons of physical strength and to prevent the warpage of the bottom, the bricks should have at least a length of 350 mm. The vertical joints have to be sealed carefully using a special mortar. The performance of a bottom like this is usually 500 to several 1,000 heats.

LADLES

Another drastic change in lining technique during the past decade happened with ladles. Following the rapid development of the secondary steelmaking techniques, the ladles were transformed from a simple transporting vessel to a reaction unit. The refractories had to meet the new requirements. The acid type fire bricks or monolithic compounds used for decades are replaced by basic linings. Only these cover the chemical prerequisites caused by the new processes and are able to withstand the increased attack and to show satisfying results.

The transfer of metallurgical processes from the EAF to the ladle shortens the tap-to-tap time remarkably. But the basically lined ladle is the prerequisite to get an optimized ladle metallurgy with regards to desulphurisation, homogenisation and low oxygen contents (19). Furthermore, for an electric arc furnace plant the hot cycling of basic teeming ladles with a lid and the after treatment of steel, i.e. the TN-Process, are of importance. These are the prerequisites to operate a ladle metallurgy in which the electric arc furnaces are freed from metallurgical work and permit a more economical operation as a melting unit only (20).

With the perfection of vacuum treatment, more and more important metallurgical processes which hitherto took place only in the furnace, were transferred to the ladle(21). These are deoxidation and alloying, desulphurisation, degasification, treatment with purge gas, deoxidation after the gas phase and oxygen refining. The primary melting units were therefore relieved of their metallurgical duties in order to enable them to operate simply as high output melting units.

In the most excellent manner dolomite meets the metallurgical requirements to a ladle lining in connection with the highest economy as can be seen from figures 6 to 10 (48).

Fig.6 shows the oxygen content of iron in equilibrium with slags of various compositions and iron oxide levels, related to temperature (21-34). According to this, the oxygen content of saturated iron oxide slags at steel bath temperatures for a lime and silica sand lining, is about equal. For a dolomite lining, it is on average 0.03% by weight [O] higher, whilst the magnesite and aluminous linings exhibit values which are clearly twice as high.

If the reactions with carbon and manganese in the steel are also taken into account, the silica lining is eliminated and the lining of the ladle with dolomite or lime becomes essential in order to obtain a low oxygen content and high oxidic purity.

An analysis of desulphurisation, Fig.7 (7,8,15), produces the same result. With sintered lime linings in

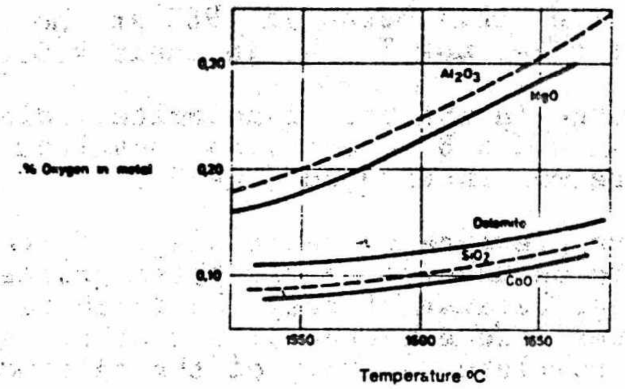


Fig. 6: *Oxygen Content Under Various FeO_n-slags*

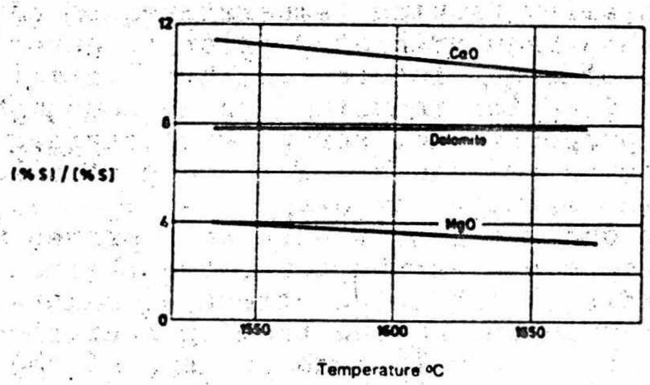


Fig. 7: *Sulphur Partition Under Various FeO_n-slags*

equilibrium, three times the sulphur distribution can be achieved compared to magnesite linings; and dolomite, on account of its chemical composition with approx. 60% CaO and 37% MgO, is closer to lime.

Siliceous and aluminous linings react strongly with desulphurizing slags, frequently resulting in desulphurization as they supply the bath with oxygen.

- In order to achieve levels of 2×10^{-4}% of hydrogen in the steel, it is sufficient to dry the ladles and degassify them in a vacuum unit before putting them to use. The deoxidation is a more complicated matter. In case of acid linings, the crucible reaction (35-39) runs parallel to deoxidation. The former is considerably slower than deoxidation, but has the continuous effect that the supply of oxygen and silicon from the refractory lining hinders the completion of the deoxidation process and the purity level of the steel is therefore diminished by SiO_2 inclusions.

Since the crucible reaction is intensified by the vacuum, the introduction of the vacuum refining process initiated the first step towards basic linings of steel ladles in Germany, i.e. this began in 1962 at the Edelstahlwerke Witten AG, now T.E.W. in their V.O.D. Unit.

The second surge in the use of dolomite ladles took place when the T.N. or C.A.B. process for desulphurization with calcium carbide was introduced (40-45).

Because of the presence of basic slags, fireclay linings are found to be unsuitable for these processes, but dolomite linings, because of their basic character, not only have greater life expectancy, but at the same time permit a more complete recovery of the calcium carbide introduced.

The ~~higher~~ thermal capacity of ladles lined with dolomite, which allow tapping temperatures to be reduced once the ladle has been preheated prior to entering circulation, is of great interest. This thermal improvement can be utilised for reducing energy consumption, for increasing the proportion of scrap metal charged for increasing alloying additions. The yield of alloying elements with an affinity for oxygen is improved, and relatively high quality steels with an improved purity level can be produced. Furthermore, the thermal capacity of the dolomite ladle also has the effect of maintaining a constant temperature during the teeming operation. Temperatures at the beginning and the end of the teeming process differ only minutely from each other. Pouring stoppages as they occur frequently toward the end of the pour, are reduced or eliminated.

For a well preheated 120 ton ladle, a temperature drop of only 5°C is observed during the teeming. Thus the formation of bottom skulls is virtually eliminated (46).

It is of particular relevance that ladles with thermodynamically stable refractory linings, such as dolomite, produce lower levels of oxygen activity than can be achieved from fireclay lined ladles.

A summary (35) of the results obtained from many and various practices is shown in Figs. 8 & 9.

The low oxygen activity results in a high oxidic purity in the steel. An advantage of this fact is found in the elimintion of teeming problems.

The dolomite ladle allows all structural and tool steels - even high aluminium nitriding steel - to be teemed without the need to interrupt the process for cleaning. For continuous casting, it is particularly important to note that the high degree of purity of the steels treated in dolomite ladles allow casting to take place at lower temperatures (45).

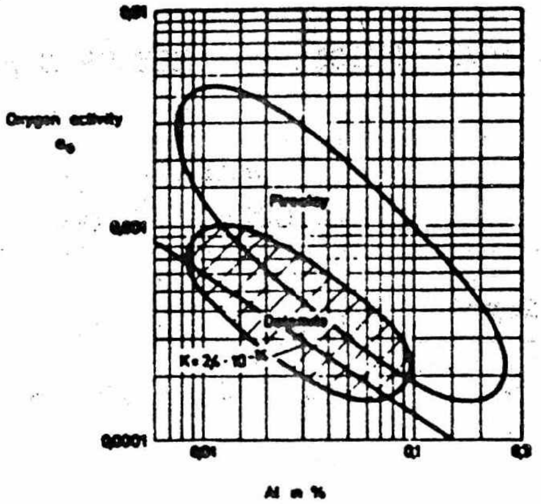


Fig. 8 *Oxygen Activity in Different Ladle Linings*

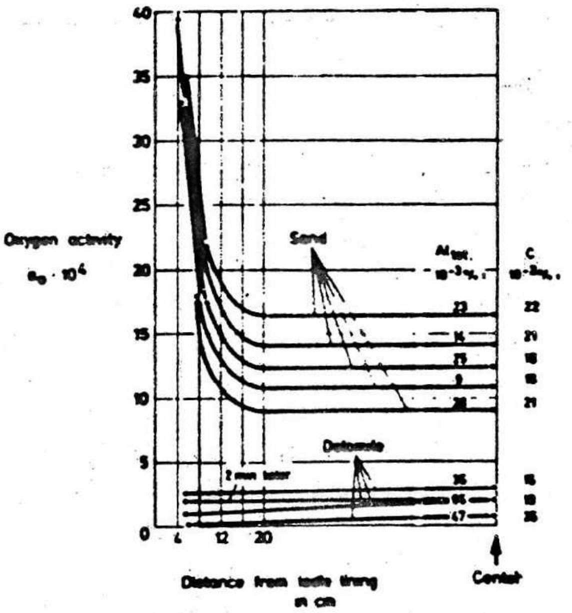


Fig. 9 *Oxygen Activity After Air Stirring*

Frequently with slide gate units in conjunction with acid-lined ladles, after about 50% of the teeming time has elapsed, the nozzle often becomes clogged. After changing over to dolomite ladles, such build-ups are completely eliminated.

Besides the degree of oxidic purity, the sulphidic purity deserves some attention. A prerequisite for a low level of sulphidic purity is effective desulphurization, since the extent of desulphurization depends, among other factors, on the basicity of the slag.

Table 4: BASIC BRICKS FOR ELECTRIC ARC FURNACE LININGS

	GRAPH - MAG T 00286	 T 00280	DOLOMITE K 12.103
Chem. Analysis			
MgO % %	>94,5	>96,5	>36
CaO % %			<61
Others % %			<3,5
Ign.Loss %	7	5	
Rest-C %	6,5	4,5	
K-D gC/cm^3	0,9	0,7	
Physical.Propts			
bulk density g/cm^3	3,05	3,10	2,81
Porosity %			10-13
CCS N/mm^2	>30	>40	> 30
HCS N/mm^2	>10	>10	13 at 1200°C

GRAPH - MAG = Carbon enriched, pitchbonded & tempered MAGNESITE bricks

DOLOMITE K 12103 = direct bonded fired DOLOMITE bricks, pitch impregnated

CCS = cold crushing strength

HCS = hot crushing strength at 300°C

K-D = residual carbon per porosity

The desulphurization in the dolomite ladle is clearly superior, i.e. with the same initial sulphur content and with the addition of the same amount of desulphurizing agent, lower sulphur levels were obtained in the dolomite ladle, or, starting with the same initial sulphur content less desulphurizing agent is required to obtain the same end sulphur level. (Fig.10)

For certain steel grades with very low carbon contents no recarburization from the lining can be

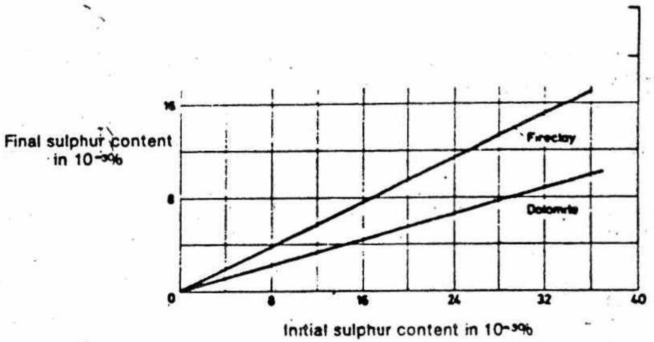


Fig 10

Sulphur Content Reduction by Blowing in of Calcium Carbide for Different Casting Ladle Linings.

tolerated. Therefore fired tar-free dolomite bricks are best suited for this application. This also applies to the production of low-chrome steels (e.g. Silicon Steels) since dolomite contains no chromic oxide.

Last but not least, the dolomitic lined ladle shows the advantage to produce more heats in most cases. The fact obviously indicates a reduction of the specific consumption of refractories and the costs per ton of molten steel.

Usually the performance of dolomitic ladle linings is a multiple of firebrick linings. Of course, there are considerable differences from plant to plant according to the different operating conditions. Thus, performances from 20 to 134 heats have been reported.

The same applies to costs. But even if compared to a sand slingered 100 tons ladle 10% of the costs (51) could be safed. In another plant savings of 1.03 DM/t of steel have been reported in comparison to a firebrick ladle, not taken into account all the other metallurgical benefits like higher yield of alloys (47). An increase of the performance three times that of firebrick is not seldom (49).

In other instances Bauxite lined ladles have already been introduced due to an increase of the metallurgical load, and in this event the cost advantage of dolomite is even more significant, if the overall costs including the savings with regard to the metallurgical advantage as shown in Table 5 (48) are taken into consideration.

The installation technique using dolomite bricks is different from the lining with firebrick (48). Logically one has to consider the specific properties of dolomite. An example is shown in Fig.11.

One has to pay attention in particular to the backing and perhaps to the insulation. Often the impact area and/or slag line are reinforced. The bottom can be placed

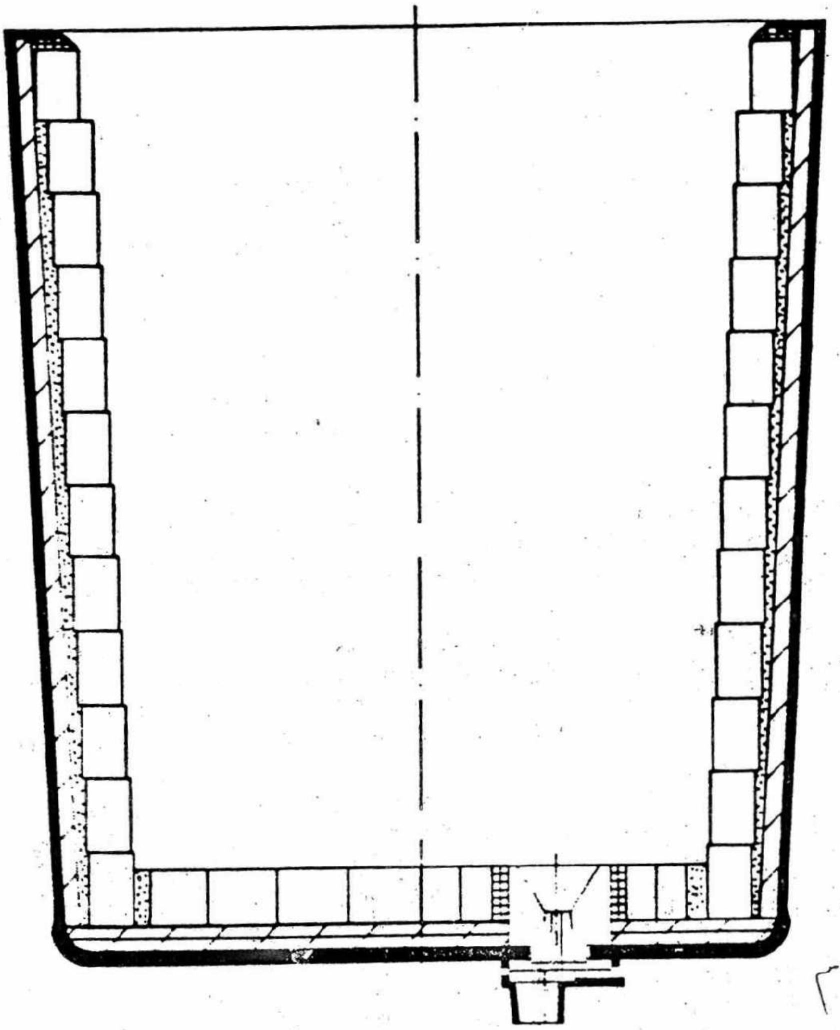


Fig.11: Typical Dolomite Lining of a Ladle

Table 5

	0 Type	1 Refractories	2 Heating	3 Yield of alloys	4 Σ 1 - 3	5 Internal fault	6 Lining life wall/bottom		7 Σ 4 + 5
a)	Fireclay								
	rammed	1	-	0	1	100	78	10	
	bricked	1,19	-	0	1,19	100	28	10	
	Bauxite								
	rammed	1,30	0,14	- 0,35 1) - 1,48 2)	1,09 1) - 0,04 2)	50	80	40	
	bricked						120	60	
	Dolomite								
	bricked	2,21	0,15	- 0,35 1) - 1,48 2)	2,01 1) 0,88 2)	50	27	27	
b)	Dolomite								
	bricked	1,27	0,15	- 0,35 1) - 1,48 2)	1,07 1) - 0,06 2)	0,26	54	27	1,33 1) 0,20 2)
	Fireclay								
	bricked	1,85	-	0	1,85	0,80	18	10	2,65
	Bauxite								
	bricked	2,60	0,14	- 0,35 1) - 1,48 2)	2,39 1) 1,26 2)	0,26	60	30	2,65 1) 1,52 2)

1) St 52 *2) T: micro-alloyed*

Cost Comparison of Differently Lined Steel Ladles

under the sidewall or between them in cases where one campaign demands two sets of bottoms. Sometimes magnesite-chrome bricks are used in the bottom to get equal number of heats of wall and bottom. If the design is optimized and if the porous block and well block are well fitted, the ladle can be used continuously without intermediate preheating (50).

Installations together with magnesite chrome or alumina based materials are common. Contact reactions between dolomite and bauxitic or corundum refractories are effectively eliminated by the use of a specially developed magnesite mortar.

Each of the various processes in secondary steelmaking has its own particularly aggressive mechanical and chemical wear mechanisms, so that besides the differences in insulation and lining thicknesses already mentioned, there is also merit in zoning various qualities of dolomite ladle bricks depending upon the duty to which they are subjected. The grades shown in Table 6 are available. With regard to the bonding method, the differences must be noted between pitch-bonded, and direct-bonded dolomite bricks, tar-free or tar-impregnated.

In spite of all the advantages offered by transferring the refining process into the ladle, there are two important considerations which must be taken into account when comparing dolomite which fireclay linings, the first one being the thermal conductivity difference.

Secondly, despite their thermoplasticity, dolomite bricks are more susceptible to sudden changes in temperature which can lead to spalling. They also exhibit a further unfavourable characteristic. When a cooled-down dolomite lining is reheated, because of the slight shrinkage, the joints do not always close tight, so that there is a risk of steel penetration.

Therefore, the prerequisites for a successful dolomite lining practice are:

1. Slide gate system
2. Ladle preheating equipment for initial burn - in and for maintaining temperature during use. However, infrequent cooling down periods, to permit bottom changes, can be tolerated.

The large number of variations of basic ladle lining configurations - and for cost reasons mostly dolomitic lining - bears witness to the fact that there is no standard lining because there is no such thing as a standard operating condition. Similarly, there are no standard wear patterns of the ladle linings. However, by statistical

Table 6: Dolomite bricks for ladle linings

		pitch-bonded	direkt bonded	
		tempered	tar impregnated	tar-free
binder	%	4.5	2 - 5	-
volatiles	%	2.5	1.2 - 3	-
Physical Propts.				
bulk density	g/cm^3	2.89	2.93	2.85
Porosity	%	8-12	> -10	14-18
CCS	N/mm^2	> 30	> 40	> 40
DFB ta	°C	> 1700	> 1700	> 1700
te	°C	> 1900	> 1900	> 1900
THSR				< 50

chemical analysis of all types:

MgO	36	%
CaO	61	%
SiO_2	1.5	%
$Al_2O_3 + Mn_3O_4$	1.0	%
Fe_2O_3	1.0	%

all test according DIN

CCS = cold crushing strength

DFB = Druckfeuerbeständigkei

THSR = Thermal shock resistan

analysis of a large number of basic practices, a wide variety of wear mechanisms are known to affect the lining of ladles:

1. Corrosive slags containing oxides of iron, chromium, magnesium, calcium, silicon and aluminium.
2. Hot erosion by bath movements during purging, induction stirring or oxygen blowing.
3. High temperatures attained during refining and temperature variations during teeming.
4. Method and duration of refining.

In the same manner as vessels for LD and AOD processes ladle lining wear can also be minimized by equating the chemistry of the ladle slag as far as practicable with the refractory material, whereby the CaO/SiO_2 basicity generally plays an important role.

The wear reducing measures have to be adapted to the individual wear mechanisms occurring in the different steel treatment processes. Not only the choice of the right type of refractories is important but also the neutralization of the oxidizing slag at an early stage by means of a more rapid solution of the added lime or by adding dolomitic lime. Wear can be reduced also using ladle covering compound with a higher basicity. An increase in the MgO content in the bricks doesn't mean a wear reduction at all (53).

CONCLUSION

Basic linings of the vessels are essential in modern steelmaking technologies. In particular, dolomite bricks show decisive advantages as far as metallurgical and economical reasons are concerned. To get best performances at lowest costs, a zonal wear adapted lining is necessary. This can be met by graduation of lining thicknesses as well as by graduation of brick types with regard to their MgO-content resp. their CaO/MgO ratio. Last but not least, a suitable slag formation reduces wear.

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