VALUE ENHANCEMENT THROUGH ENGINEERED ALUMINA PRODUCTS FOR MONOLITHIC AND BRICK APPLICATIONS

Andreas Buhr, Almatis GmbH, Germany

Abstract

The German steel institute VDEh organises international seminars "steel ladle lining", where European steel companies present their steel ladle lining concepts and projects. During the last one in 2014, the steel engineers listed their requirements on refractories for the ladle lining. This paper discusses examples how engineered high alumina products contribute to solutions fulfilling the requirements of the steel companies.

Introduction

Steel engineers in charge for the refractory lining of steel ladles in European steel works have listed requirements for modern steel ladle lining during a VDEh seminar in July 2014 [1]. They can be briefly summarised as follows.

Inert refractories which are not negatively interacting with the steel and enabling clean steel production, for example no re-oxidation and no carbon pick up in ultra-low carbon steels. Here, also the flexibility of a lining concept for producing different grades of steel and the required performance reserves of the refractories shall be included as was discussed in a previous paper [2].

High wear resistance enabling thinner and lower weight linings in order to increase the ladle capacity and the productivity of the steel works: first extend the ladle volume limit, secondly reduce the refractory weight for staying within crane weight limit. Of course, refractory linings must be safe and break outs must be rare exceptions. "Self-healing" refractory linings would be desirable.

Reduction of energy losses resp. energy consumption and CO_2 emissions: This aspect is getting much more in focus over the recent years not only due to political measures for reducing CO_2 emissions, but also because the processing cost of higher tapping temperatures or reheating of steel in the ladle are significant. The cost of raising the steel temperature by 1 Kelvin are between 3 and 5 [3] or even up to 10 [4] € cent per ton of steel according to different sources.

High availability of the ladle fleet through long and predictable lining life and short times for installation and heating up.

Reduction of material consumption and environmental friendly lining material, e.g. no hazardous fumes during first heating up or problems with disposal of used material. Option for recycling of used ladle refractories.

Now the contribution of modern alumina refractories for solving these different requirements on steel ladle refractories from the steel producers will be discussed.

Tab. 1: Typical data of high alumina raw materials for refractories

		Andalusite	Mulcoa 60	Mulcoa 70	Bauxite	Brown Fused Alumina	BSA 96	White Fused Alumina	Tabular Alumina	Sinter Spinels AR78/AR90	BoniteLD (dense CA6)
Al_2O_3	%	56-59	60	70	85 - 90	94 - 97	97	99.5	99.6	> 99 (Al_2O_3+MgO)	91
SiO_2	%	38-40	35.8	25.6	5 - 10	0.8 - 1.5	0.5	0.02	0.01	0.08	0.7
TiO_2	%	0.2-0.5	2.4	3	3 - 4	1.5 - 2.5	1.5	0.01	0	0	0
Fe_2O_3	%	0.8-1.5	1.2	1.2	1 - 2	0.15 - 0.5	0.15	0.08	0.04	0.1	0.1
Alkaline Earths	%	0.1-0.3	0.2	0.2	0.4 - 0.8	0.4 - 0.6	0.1	0.03	0.02	0.2 (CaO)	7.7
Alkalies	%	0.2-0.8	0.2	0.15	0.2 - 0.8	0.2 - 0.4	0.3	0.3	0.33	0.12	0.15
Bulk Density	g/cm³	3.1	2.78	2.89	3.1 - 3.4	3.8 - 3.9	3.5	3.5-3.9	3.55	3.3/3.4	2.8
Apparent Porosity	%		5.7	6.2	10-15%	1.5	4.5	0 - 9	1.5	1.8	24
Water Absorption	%				3-5%	0.4	1.3	0 - 3	0.5	0.5	8.5

Inert and flexible alumina linings

For the production of clean steel higher purity alumina raw materials have replaced natural materials such as andalusite, mulcoa, or bauxite because of much lower silica content (**tab. 1**) [5]. Silica in ladle refractories is critical for Al-killed steel due to the following reaction, which produces fine alumina particles degrading oxide cleanliness of the steel: $3\ SiO_2 + 4\ [Al] \rightarrow 2\ Al_2O_3 + 3\ [Si]$. Refractories based on synthetic alumina materials are equivalent to basic linings in steel ladles for achieving the demanding requirements in clean steel production.

Tab. 2: Typical data of ladle lining refractories

	MgO/C bricks	AMC bricks		AM	AM
		BFA	BSA 96	Fired bricks	Castables
C [%]	10-15	6-8		-	-
Thermal Conductivity [W/mK]	10	6.8	4.8	3.5	3.5
Bulk Density [g/cm³]	2.9	3.25	3.08	3.0-3.2	2.9-3.0

Ultra-low carbon steels, which are used e.g. for automotive steel sheets, are susceptible for carbon pick up from the refractory lining, if the refractories contain carbon and especially graphite. Such steel grades have specifications of max. 10-20 ppm carbon, so even few ppm carbon pick up are considered critical these days. Different to magnesia refractories, alumina refractories don´t require carbon/graphite in their formulation for achieving the desired thermo-mechanical flexibility and thermal shock resistance. Even carbon bonded AluMagCarbon (AMC) bricks contain significantly less graphite when compared to MagCarbon bricks (**tab. 2**). Lachmund reports about clear differences in carbon pick up of steel from refractories when comparing just carbon bonded bricks with refractories containing a higher amount of graphite. With a high amount of graphite in the refractory the carbon pick up stays at a high level for subsequent heats, where with just a carbon bond, it is clearly lower for subsequent heats [6].

Alumina-spinel castables or fired bricks are carbon free, and are successfully used in ladle side walls for both, Al- and Si-killed steel grades. Alumina-spinel refractories provide high flexibility for producing various steel grades except for alloyed stainless steel. However, in slag lines of steel ladles MagCarbon bricks are often the best choice due to even higher slag resistance vs. alumina refractories.

Wear resistant thin alumina linings

For a steel ladle with 200 tons steel capacity, 2.5 tons additional capacity can be gained by reducing the lining thickness by 10 mm. Except of input material cost, other processing cost remain the same so these additional tons can considerably improve the economic result of the steel works [7]. Consequently, the refractory lining thickness was reduced in many European steel works. **Tab. 3** gives examples for extreme cases where high performance alumina-spinel materials enable wear lining thickness of only 110 to 140 mm for new installed linings and still achieving ladle campaigns of 114 to 140 heats.

Tab. 3: European examples for low lining thickness in steel ladles

	voestalpine Stahl GmbH Linz, Austria	TATA Steel IJmuiden, Netherlands
Ladle size [tons]	180	332
Side wall wear lining	Alumina-spinel forming castable	Fired spinel bricks
Thickness [mm]	110-136	140
Ladle campaign [heats]	114	140

Such capacity increases are possible until the maximum crane weight becomes the limiting factor. In such cases, a focus is also given on the weight of the refractory lining. Alumina refractories based on sintered aggregates typically have a lower bulk density than those with fused aggregates due to the inherent closed porosity in sintered aggregates. An example is given in **tab. 2** for AMC bricks with the new sintered aggregate BSA 96 vs. brown fused alumina [8].

Referring to the request for “self-healing” refractories, in-situ spinel forming refractories at least party fulfil such function. Due to the thermal cycling of the ladle thermomechanical stresses in the lining can lead to joint opening in both, bricked and monolithic linings. Such joints may cause a pre-vailing wear unless they are closed by expansion of the material at the hot face. The spinel formation in AMC bricks and magnesia containing castables leads to a macroscopic expansion at the hot face, capable of closing such joints. Klewski et al. [8] have shown, that the sintered alumina aggregate BSA 96 shows a much more homogeneous and earlier spinel formation when compared to brown fused alumina (**fig. 1**).

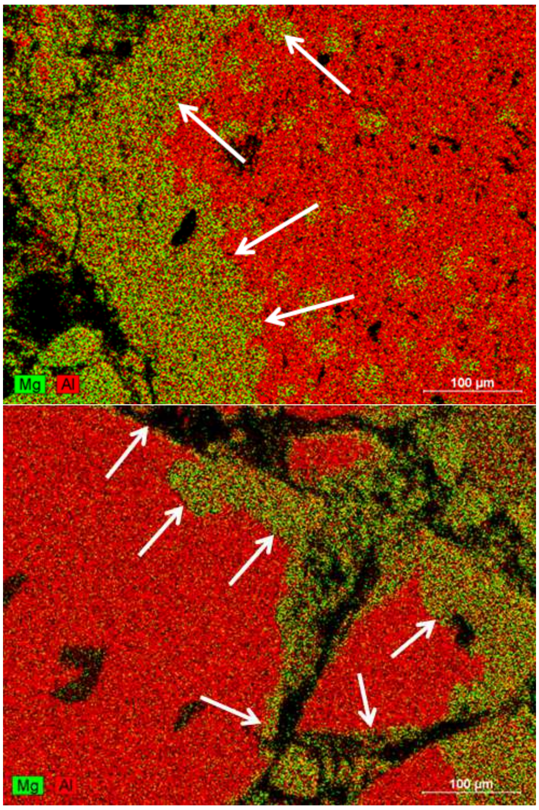

Fig. 1 Spinel formation in AMC bricks with BSA 96 (up) and BFA (down) after firing at 1600°C / 5h in reducing conditions; EDX, arrows indicating the spinel layer [8]

SSAB Raahe, Finland, and voestalpine Stahl GmbH Linz, Austria, apply monolithic lining including relining concepts since many years and report very low specific refractory consumption figures (0.8 resp. 0.6 kg per ton of steel) for both, side wall and bottom wear lining. Applying that concept, in general the complete wear lining needs to be renewed only once per year, and for the intermediate relinings only 50-60% of a complete new lining is needed. Tata Steel IJmuiden, Netherlands is recycling spent fired spinel bricks in AluMagCarbon bricks for the bottom lining [1].

Reduction of energy losses

During treatment and transport of steel in the ladle, it is cooling by typically around 1 K per minute. Heat losses can be reduced by covering the ladle, but this is resp. often cannot be applied in steelworks. The refractory lining is contributing to temperature losses in two ways. First, there is heat transport through the lining to the steel shell, which can be reduced e.g. by better insulation or lower thermal conductivity materials in the wear lining. This heat transfer achieves a kind of steady state situation once the lining is completely warmed up, typically after the first 3-4 heats.

Another heat loss comes from the thermal cycling of the ladle, where the hot face is cooling down during the empty phases from about 1550 to about 800 °C. It depends on the heat capacity and the thermal conductivity of the wear lining how much heat gets lost during the empty period. This aspect has recently been discussed by Ogata et al. (**fig. 2**).

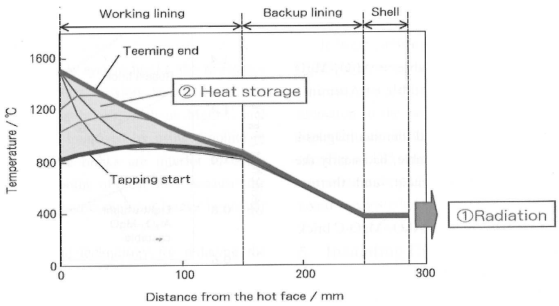

Fig. 2 Calculated temperature change in the refractory lining of a steel ladle during operation [9]

Fig. 3 shows the temperature loss in a 180 ton steel ladle with spinel forming castable in comparison to MgO/C bricks in the ladle side wall. Due to the higher thermal conductivity of MgO/C (**tab. 2**) the temperature loss with MgO/C is 10-15 K higher in spite of an additional insulation layer in the permanent lining. Taking into account that 1 K temperature loss costs between 5 and 10 € cent per ton of steel, a 15 K higher temperature loss means cost of 0.75 to 1.5 € per ton of steel. In general, ladle refractory cost – without the sliding gate system – are in the range of 1.5 to 2 € per ton of steel. So the cost of heat loss can be more than 50% of the ladle refractory cost!

Alumina refractories with lower or no carbon content provide a clear advantage over basic refractories with higher carbon contents due to their lower thermal conductivity, and such aspects should be included in the economic evaluation of ladle lining concepts. It is interesting, that AMC bricks with the sintered aggregate BSA 96 show lower thermal conductivity (4.8 W/mK at 1200°C) when compared to bricks with brown fused alumina aggregate (6.8 W/mK at 1200°C) in spite of an identical matrix formulation of the bricks in that specific case (**tab. 2**) [8]. This is currently further investigated.

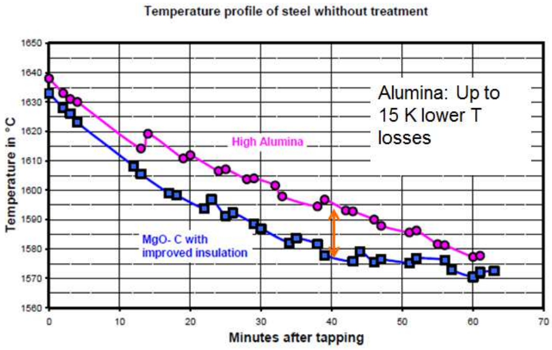

Fig. 3 Steel temperature development in a 180 tonnes steel ladle with different lining concepts: alumina monolithic vs. MgO/C bricks [10]

Another example for innovative alumina refractories are calcium hexa-aluminate (CA_6) materials which provide a combination of safety and reduced thermal losses for the permanent linings in steel ladles. Schnabel et al. [11] reported about the high slag resistance against calcium aluminate slag and the low thermal conductivity (**fig. 4**) of dense CA_6 material bonite, which makes it an interesting solution for steel ladle safety lining.

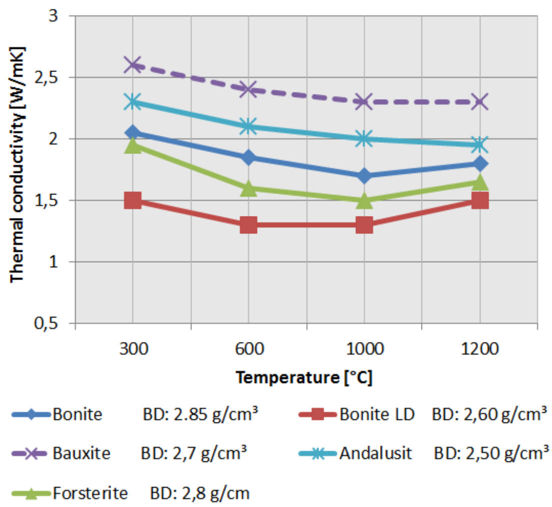

Fig. 4 Thermal conductivity of steel ladle permanent lining materials [11]

The newly developed bonite LD (low density) provides even more energy savings and projects with bonite LD bricks [12] in steel ladle permanent linings are ongoing in Europe. An important aspect in these projects is the replacement of a dual layer system (one for safety, one with lower thermal conductivity in order to reduce the contact temperature for the microporous insulation board) by one layer of bonite LD bricks fulfilling both functions and providing increased mechanical stability of the permanent lining (**fig. 5**).

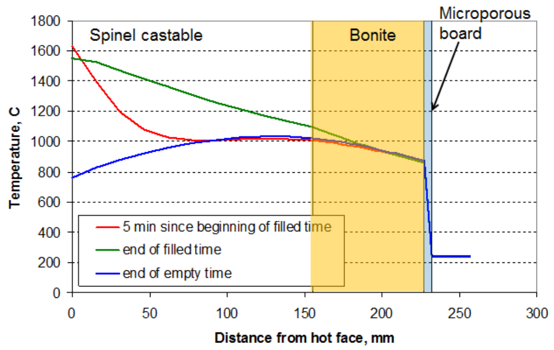

Fig. 5 Replacement of two layers in the permanent lining by one layer of bonite material

Conclusion

The examples of modern high alumina refractories briefly discussed in this paper demonstrate how these materials provide solutions for the requirements on steel ladle linings. High purity alumina aggregates are suitable for clean steel production. Carbon free or low carbon alumina refractories avoid resp. reduce the carbon pick up of ultra-low carbon steel. Alumina spinel refractories have high wear resistance and enable extraordinary thin wear linings, still providing the required safety and achieving low specific material consumption. Spinel forming refractories such as alumina-magnesia castables and AMC bricks have a “self-healing property” by closing joints in the refractory lining.

The low thermal conductivity of alumina refractories when compared to carbon and graphite containing basic materials leads to significantly lower heat losses in steel ladles. The cost for such heat losses can be more than 50% of the ladle refractory cost. This aspect should always be included in the economic evaluation of refractory lining concepts.

Sintered alumina aggregates show advantages over fused aggregates such as lower weight and lower thermal conductivity, caused by the higher amount of closed internal porosity in the sintered aggregates. Further investigations of the influence of the aggregate on the thermal conductivity are ongoing.

The examples given in this paper demonstrate what impact the ladle refractories can have on the economic results of the steel work and are supporting what Siebring [7] stated in the refractory seminar of the Steel Academy: "Refractory is a tool to produce steel."

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