The Hybrid-Ladle: A proposition for a cost-conscious steel production referring to the application of refractory linings

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Mag-Carbon bricks as working lining combined with a monolithic or a masonry permanent lining is recently the "state of the art" and the most frequently used refractory lining of steel ladles. The technology of the lining has been established over many years and is undoubtedly a guarantee for the successful metallurgical treatment resulting in prolonged service lives. The excellent corrosion resistance of this refractory lining in the slag zone is particularly noteworthy.
Also known for many years but rarely practiced, is the use of a completely monolithic lining as working lining in combination with bauxite bricks as permanent lining employing vibration or self-flow casting compounds based on alumina or alumina magnesia according to the ***"Endless Lining System"****. This casting method possesses clear advantages in terms of material consumption, flexibility and effectiveness to increase the availability of the ladles and is associated with positive ecological aspects.*
Particularly nowadays, in a time when the market shows a rapid rise of raw material costs, especially for basic materials, cost optimization is mandatory to maintain competitiveness. An expertise of the two lining systems of the steel ladle offers the possibility to combine them and to adjust the desired properties of the lining. Therefore the key of success is the combination of different systems to the so-called ***"HYBRID LADLE"****.*
The result is the best technical and commercial solution for steelmaking in terms of operational safety, the demand of refractory materials as bricks and masses, the service of personnel, the availability of refractory materials and a contribution to environmental protection that should not be underestimated.

KEYWORDS: HYBRID LADLE, MAG-CARBON BRICKS, AMC BRICKS

INTRODUCTION

The refractory lining of a "hybrid ladle" combines in application and use two different technologies to one lining system fitting a steel ladle (Fig. 1). This lining system contains parts which are built of shaped refractory bricks and parts which are casted. Selected materials are used to optimize the properties of the lining within the different zones of the steel ladle. This concerns the permanent as well as the wear lining, for which refractory materials composed of raw materials based on alumina and magnesia are used. The casted parts are lined using the proven "Endless Lining System" and the shaped products are installed under guidance of experienced personnel possessing many years of practical expertise.

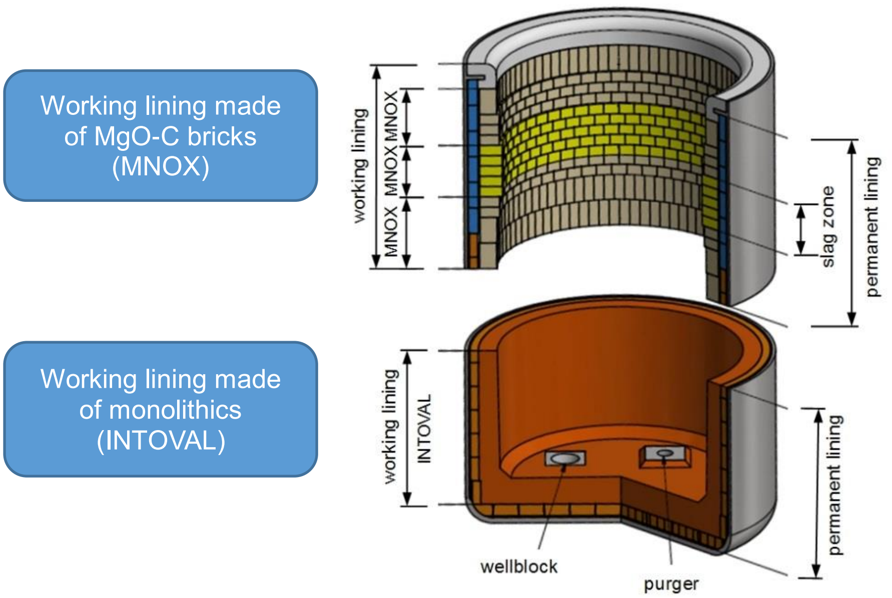

Fig. 1 – Schematic view of the lining of a hybrid ladle

The procedure of the installation of the lining is represented schematically by Fig.2:

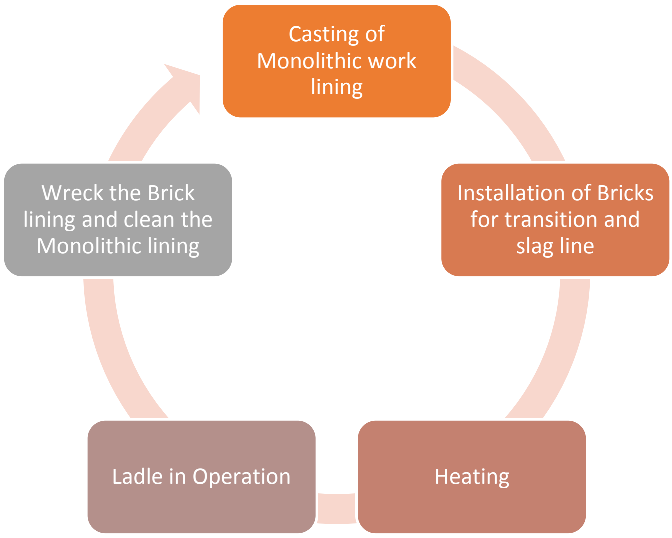

Fig. 2 – Schematic view of producing the linining of a hybrid ladle

The concept to line the ladle unifies the different technical demands on the refractory materials with respect to the desired properties of the resulting steel quality (S, O, Al, Si). The following properties of the refractory materials possess an important influence on the steel quality:

- Chemical attack against the slag and resistance against infiltration
- Thermal shock resistance
- Resistance against mechanical erosion
- Metallurgical treatment processes

Of major importance is also the economic aspect. The application of this concept offers the following advantages:

- Low specific costs because of a low consumption of refractory materials
- Economy of labor time
- The outbreak can be used as slag conditioner

TECHNIQUES USED FOR LINING OF THE LADLE

Ladle lining by bricks

Many steel producers install their ladles in a conventional manner by using MgO-C bricks only. The advantages of such a lining are:

- Fast heating rates
- Low porosity by impregnation
- Thermodynamic stability
- Very good resistance against slag
- Application of the metallurgical treatments
- High availability of the ladle
- No availability of equipment to produce a monolithic lining

The installation is carried out by using either the standard P format or the SU format depending on the type of ladle. The ladle is divided into different working zones for which bricks of different qualities are used. A great influence on the life time of the ladle has the composition of the refractory material in the slag zone.

Here, preferentially, bricks possessing a carbon content of 5-15% derived from a LC (large crystal) periclase as raw material with a MgO content of > 97,8% and a low Si content (C/S > 2) are installed. If an LC periclase is used, the influence of the secondary phase C_2S has a minimal effect on wear. The crystallite size of the periclase of > 1000µm achieved by the crystallization process provides with its small specific surface for a smaller attack surface and thus for a smaller leading wear by erosion of its oxide component by its own contained carbon. The graphite content also has a decisive influence on the properties of the stone, as it counteracts the wettability by the molten metal and the slag. The higher the proportion of graphite, the lower the density and strength, but the thermal shock resistance and thermal conductivity increase. Graphite quality has a decisive influence on corrosion resistance. The lower the proportion of impurities (side oxides), the lower the formation of low-melting silicate side phases increasing the wear. Therefore, only coarse crystalline (> 150 µm) natural graphites with a carbon content of > 98.5% are preferred in high-quality MgO-C bricks. MgO-C stones are either pitch or resin bound. It is not clear which type of bond has a more beneficial effect on corrosion resistance. However, this will certainly also depend on the steel mill's preferred mode of operation (metallurgical process, slag composition).

The impact area of the ladle bottom is subject to the influence of strong abrasion and erosion. AMC bricks (alumina-magnesia-carbon bricks), with a low carbon content (approx. 5%) and with brown corundum as main raw material base proved to be resistant here. The Al_2O_3 content is approx. 90%. A small addition of Al powder reinforces this effect. The bricks have a very good resistance to thermal shock, which prevents spalling compared to a standard MgO-C brick. During use in the ladle, MA spinel is permanently formed. By a continuous crystal growth, cracks in the microstructure are partly filled resulting in a lowering of the porosity. In parallel to the formation of spinel, the content of carbon in the bricks diminishes the wetting and therefore the infiltration of the slag as well.

Numerous investigations on different refractory materials show that the absorption of alumina into steel, which results from a reaction between the steel and the material of the lining, is minimized by the use of MgO-C bricks with a carbon content of 5-15 % or pure Al_2O_3. On the other side, producers of ultra-low carbon (ULC) steels prefer to use a monolithic lining to avoid carbon pick-up from the refractory lining into steel.

Although a lining of the ladle by refractory bricks is associated with many advantages, some intrinsic drawbacks of the system need to be considered:

- Defined format of the bricks with not variable dimensions
- Large demands on required space for storage of the bricks
- To mason the lining is labor-intensive
- High consumption of refractory materials, high costs
- For a relining, parts of the lining have to be removed
- Extra costs for disposal of waste can arise

The average life time for a lining of a ladle built from MgO-C and AMC bricks correspond to about 100 heats. In some steel mills, however, an intermediate repair in the area of the slag zone or on the ladle bottom takes place after about 70 heats. Since the commodity prices for fused magnesite increase recently very fast, the extra costs caused by the lining of the ladle are not negligible.

Monolithic lining of the ladle using the ‘endless lining’ system

By using the ‘endless lining’ system, the complete monolithic wear lining of the ladle is installed during one production step. After service, the infiltrated and brittle parts of the lining are broken out, and the original thickness of the lining is reestablished by relining of the refractory material (Figs. 3, 4) employing a template. This process can theoretically be repeated arbitrarily often [1, 2]. Approximately 40-60% of the wall and base area remain in the ladle. In addition, the wellblock can be dispensed as it can be cast directly into position simply with the aid of a dummy. However, this technology was not able to establish itself because the wear and thus the repair costs in this area were disproportionately high.

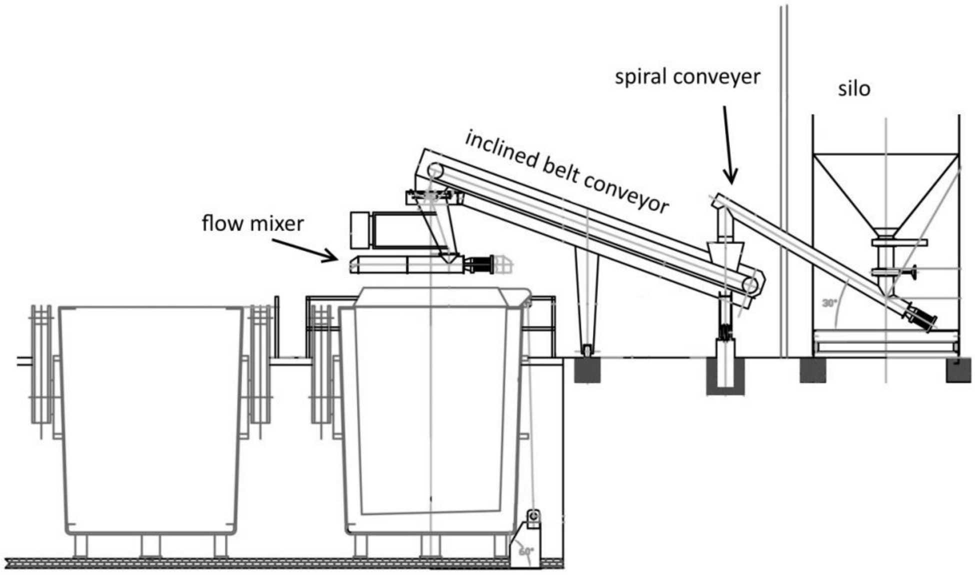

Fig. 3 – Schematic view showing the lining of a steel ladle using the ‘endless lining’ system

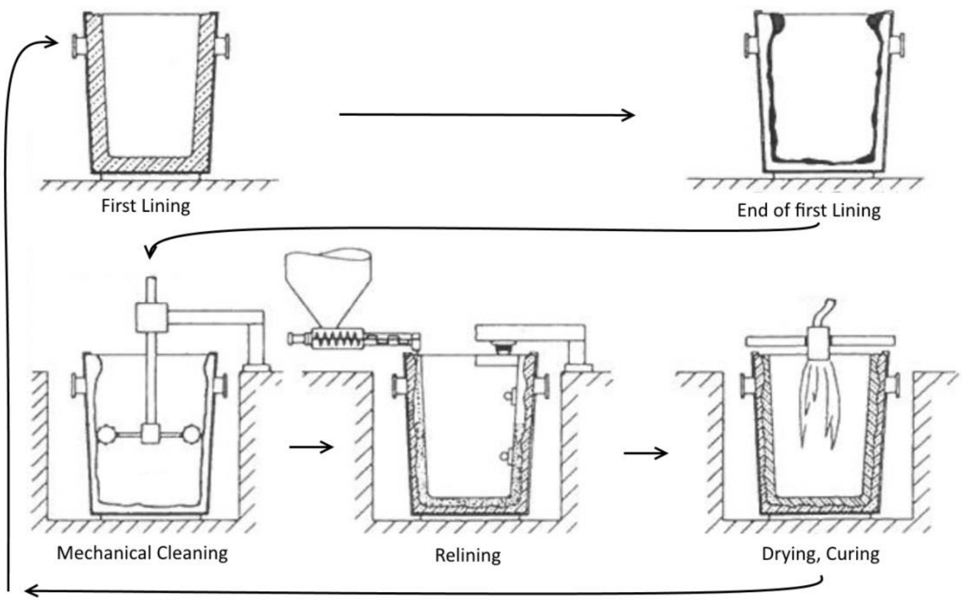

Fig. 4 – Schematic view of the different steps during the relining of a steel ladle, copied from Ref. [2]

The advantages of this lining method are:

- High savings potential in refractory material and costs
- Low costs for disposal of waste
- Lining method is not labor-intensive, low labor costs
- Short time for the installation
- No joints within the lining
- Low use of primary raw material

To line the ladle by this method, some expensive equipment, like e.g. a template, mixer and drying system, needs to be applied. Furthermore, the lining has to be dried carefully before its operation, especially within

the temperature range at about 280°C, to prevent crack formation, spalling or explosions. The heating rate of the drying process depend on the amount of water present in the lining, its distribution as well as the pore size of pores filled with water. To remove the chemically bound water quantitatively, the lining has to be heated to temperatures of about 600°C. A drying of cement-containing refractory materials under optimal conditions can take about 35 hours.
Monolithic linings with thixotropic or self-flow character are produced from low cement, ultra-low cement or no cement castables containing 4.5-6 wt% water. Generally, these castables are produced from pure tabular alumina as raw material and can contain additionally periclase or spinel or both. By heating the lining, the amount of spinel increases, and this in-situ formation of spinel is not only favored because of its low costs. A properly chosen composition of alumina and periclase with advantageous distributions of the grain sizes results into a temperature-dependent growth of the refractory material. By this, pores and cracks within the microstructure are filled and counteract the effects of corrosion.
Statistic crucible tests testify that refractory materials forming in-situ spinel possess both a high infiltration resistivity and a high corrosion resistivity against metal and slag [3]. Refractory materials containing spinel which did not form during heating show a higher degree of infiltration [3].
On the other side, the content of Al_2O_3 dissolved from the refractory material increases with increasing basicity of the slag (C/S > 2) and increase with the time the liquid slag is in contact with the refractory material. The slag zone of the lining is therefore subject to strong corrosive attacks and needs to be regularly reinforced by applying a magnesite gunning mix. For the application of the gunning mix, however, large amounts of material, sometimes about 25 t per month and per ladle, are needed. Because auf the high costs resulting from the repair of the lining this method seems not to be economically efficient.

The ‘hybrid ladle’
Considering the concepts of the two described individual linings, it is useful to combine them to one system which unifies the advantages of the two original systems. Through such a combination the ‘hybrid ladle’ was created. The bottom and the lower part of the ladle are lined monolithically, and the transition from the steel to the slag zone as well as the slag zone are installed by different types of MgO-C bricks. Figure 5 shows required steps to transform an unlined ladle into a ‘hybrid ladle’.

a) employing of the template b) casted parts of base and wall c) masoning of the slag zone d) completed hybrid ladle

Fig.5 – Different steps during the lining of the ‘hybrid ladle’

CONCLUSIONS
From technical, economical and ecological point of view, the hybrid ladle is an alternative approach to a ladle completely lined by bricks or a completely monolithic lining. The following example should demonstrate how costs can be diminished if the lower wall and the base of a lining are casted by a refractory castable and other parts of the lining are installed by bricks. Supposed, for the first lining 10 t of refractory material are required and for the complete relining 60% of the castable. If no repair is carried out during 12 relinings, then

about 80 t of monolithic concrete are needed. To accomplish 12 relinings with bricks, about 120 t of material are needed. Thus, already after the first relining costs can be saved (Fig. 6). For optimal conditions the number of relinings might even be reduced by about 40-50% causing a further saving of refractory material and, of course, an increase of the number of expected heats.
If the costs for raw materials, like e.g. fused magnesite from China, do not stabilize in close future, the expenses which can be saved by the proper choice of the lining system will become an increasingly important factor.

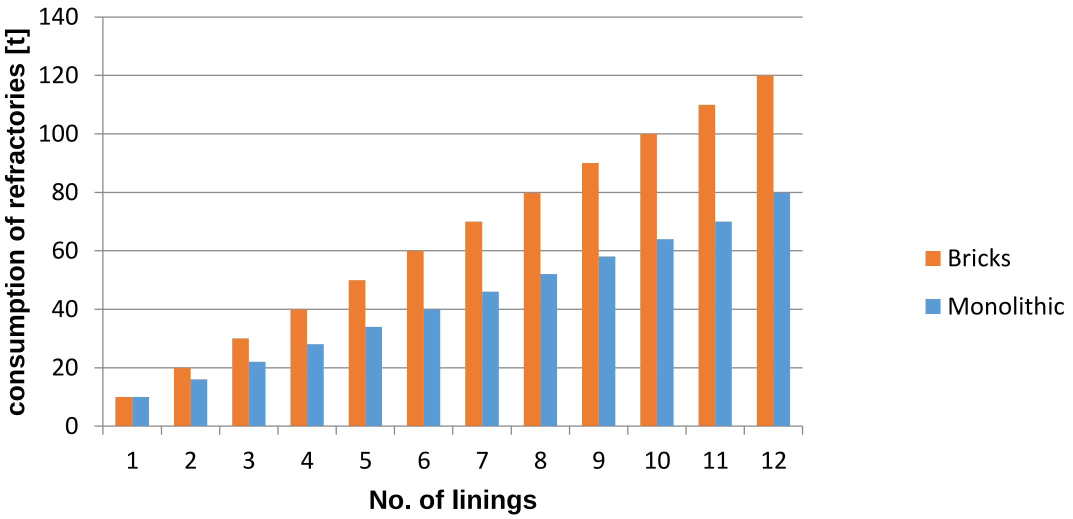

Fig.6 – Consumption of refractory materials

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