MONOLITHIC PERMANENT LINING BASED ON SINTERED MAGENSIA

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ABSTRACT
In this paper the devolvement progress of a monolithic permanent lining concept based on sintered magnesia for the application in the electric arc furnace (EAF), converter (BOF) and the steel ladle will be presented. The approach of the new mix concept is to focus on a water free, ready-for-use application or at least significantly reduce the water content, to minimize the potential for hydration. The individual requirements for EAF, BOF, and steel ladles such as binding strengths at room temperature, limitation of smoke and dust release during preheating/application, binding strength development with temperature etc. are significantly different. Therefore individual mixes for each vessel have been developed to fulfill these requirements.
For the permanent lining of the EAF and BOF either a ready-for-use water free mix or a chemically bonded mix (setting with small water addition) have shown the best results. For the steel ladle a dry lining similar to dry setting tundishes mixes showed the most promising results. Furthermore the slag resistance of different binder concepts in comparison with a standard basic permanent lining brick were investigated through an induction furnace test.

Key words: basic mix, EAF, BOF, ladle, permanent lining

INTRODUCTION
Essentially, the refractory lining concept of a vessel consists of a working and a permanent lining layer which have to be relined after a certain period of time due to refractory wear. This relining duration is dictated by the complexity, number of shapes and brands, shift model layouts, skills, and logistic systems. A short relining period that considers steel plant utilization, the continuously increasing safety regulations, and aims for the highest vessel productivity and availability levels is essential. Focusing on the permanent lining, the state-of-the- art installation technology in the BOF, EAF, and ladle is currently the use of bricks. In the BOF, mixes with shotcrete/shotcast and gunning applications are rarely used, whereas in the ladle occasionally casting solutions are applied. The main influencing factors in the selection of the permanent lining are the handling, relining duration limits, safety demands, lifetime, and emergency properties. The installation of bricks requires the manipulation of brick pallets, observing weight limits, and logistic systems for handling. An additional issue is the deformed vessel steel shell, deformations have to be counterbalanced using back filling mixes between the wear and permanent lining to guarantee a proper relining. Commonly used mix applications such as shotcrete/shotcast, gunning, and casting contain considerable water content which can affect the vessel brickwork properties through hydration effects during the preheating and in the initial stage of the campaign. Furthermore, an additional effort in terms of machinery, steam holes, welded anchors on the vessel steel shell have to be considered for the handling itself.

In this work a new permanent lining approach based on a basic mix which provides minimal or negligible water content will be introduced. As a result, the possible hydration attack on the basic brickwork in the vessel through the use of such a monolithic mix will be minimized to an insignificant value. Sufficient emergency running function and mechanical strength are ensured for each vessel specifically. The related handling concept during relining is based on an acceleration of the process, bypassing additional cost intensive and time consuming processes. Ideally, existing disadvantages of brick, shotcrete/shotcast, gunning, and casting applications as permanent lining layout will be minimized.

Each vessel (EAF, BOF, steel ladle) is characterized by different requirements for the installation of a permanent lining. A single common solution, or one binder concept, for BOF, EAF and ladle is not suitable. That is why an individual binder concept had to be developed to fulfill the vessel specific needs. On the one hand the permanent lining for the EAF and BOF typically requires a certain mechanical strength after the relining. This ensures that the MgO-C brickwork (wear lining) is stabilized in position to the cold face and a rotation of the vessel can proceed. On the other hand strength of the mix directly after lining is not necessarily required for ladles. The densified mix, fixed behind closed wear lining rings, provides enough stability for the ladle preheating procedure (preheating in vertical position without tilting). However, health and safety concerns in terms of smoke and gas emissions are an issue for ladle lining materials since ladles are usually preheated without a gas exhaust system.

Due to the different permanent lining requirements three types of binder system with individual advantages have been developed, which are illustrated in Fig. 1.

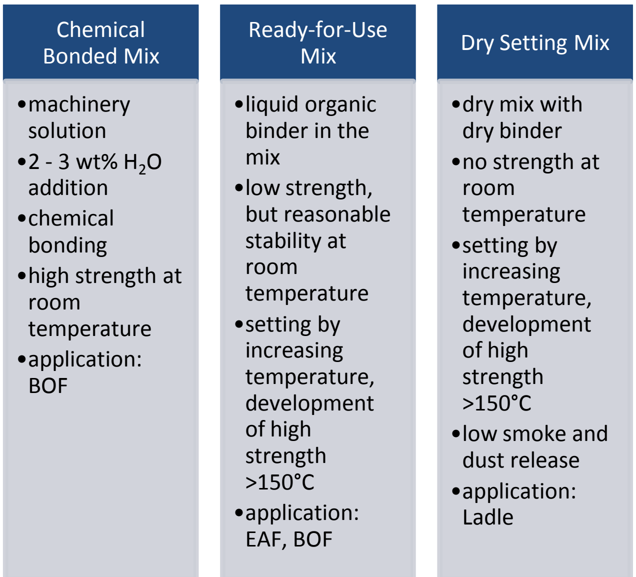

Fig. 1: Overview of mixes for permanent lining application.

For each of the mentioned mixes different tests and trials were performed in the laboratory and in service laboratory tests to determine the physical properties, the behavior in application and the refractoriness.

RAW MATERIAL CONCEPTS
As the desired raw material dead burned sintered magnesia type 96% MgO with a typical composition as illustrated in Tab. 1 was used. The maximum grain size of the mix was limited to 5 mm. The raw material concept was maintained for all trials to ensure comparable results between the different binding systems.

Tab. 1: Chemical composition of DBM96 used in all trials.

MgO [%]	CaO [%]	SiO_2 [%]	Fe_2O_3 [%]	Al_2O_3 [%]
96.2	2.3	0.8	0.3	0.1

This high quality raw material concept was chosen to reduce potential negative effects from the raw material and to concentrate on binder effects. As this mix should be used as the permanent lining without permanent steel and slag contact, alternative raw materials (e.g., alpine sinter with higher Fe_2O_3 levels, addition of olivine, etc.) may be sufficient but have to be discussed separately. Referring to Fig. 1 the investigated mixes have been clustered in three groups:

CHEMICAL BONDED MIX

If a machine supported installation (continuous mixer) is available, chemical bonded basic mixes with a low amount of water addition will provide the best strength after lining conditions. The setting of the used mix is based on the addition of 2-3 wt% of fresh water. Laboratory trials with different binder combinations were carried out. The setting time can adjusted by the addition of an accelerator. Fig. 2 shows the development of the cold crushing strength (CCS) over time for different additions of the accelerator (0 wt%, 0.5 wt% and 1 wt%) and a suitable binder system. Samples were prepared in the laboratory mixer with the addition of 3 wt% water and were formed by ramming (40 pokes with sand rammer). The cylindrical samples (d=50 mm x 50 mm) were stored at 30 °C. After 3, 6 and 24 hours respectively the cold crushing strength was determined.

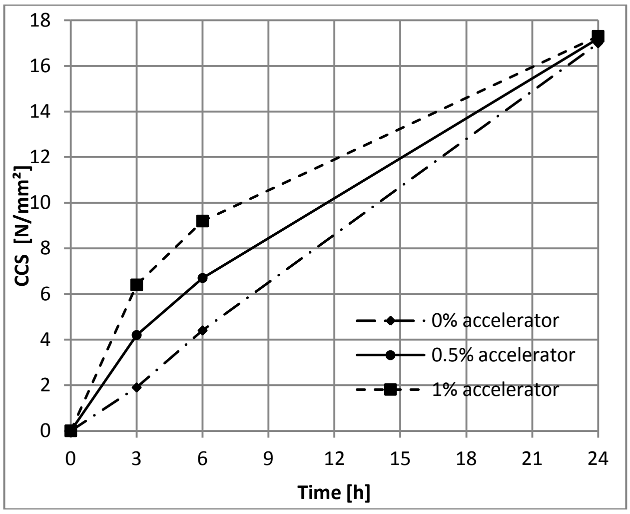

Fig. 2: Development of CCS for chemical bonded mixes using different amounts of accelerator at 30 °C.

The addition of different amounts of accelerators changes the setting time especially in the first 4 hours but the achieved end strength remains the same. In addition to the setting time, the behavior of the binding strength relative to temperature is a critical issue. Since the temperature in the permanent lining rises with proceeding age of the vessel (declining residual wear lining thickness), a reasonable strength of the mix must be ensured over a wide temperature range. Therefore the CCS at various temperatures was measured for the chemically bonded mix with 0.5% accelerator addition. As seen in Fig. 3 the chemical bonded mix provides a reasonably good strength from room temperature up to the measurement limit of 1200 °C.

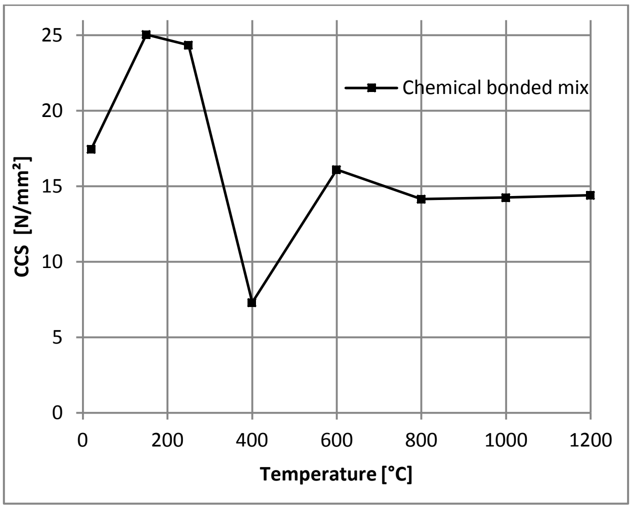

Fig. 3: CCS relative to temperature for chemical bonded mix.

To simulate the application and behavior of the chemically bonded mix during the lining process, field trials with a continuous mixer were carried out. During these trials the setting behavior in a 150 mm wide gap was studied for different compaction methods as illustrated in Fig. 4.

Fig. 4: Lining of chemically bonded mix with continuous mixer.

Layers with approximately 200 mm of height were lined and compacted individually. After each layer the machine was stopped for approximately 30 min to evaluate the setting behavior in the machine. As a result it was concluded, that the mix achieves a proper setting strength with a bulk density of 2.7 g/cm³ when using a hand rammer for compaction. Without compaction the strength of the mix was not sufficient resulting in a collapsed sidewall after template removal. Furthermore no setting in the machine and no problems during the lining were observed.

READY-FOR-USE MIX

As the use of a continuous mixer is impractical in most of the lining procedures and considering that a certain strength at room temperature must be available, ready-for-use mixes may be a solution. The mixes contain an organic liquid binder and different additives to ensure sufficient strength over a wide temperature range. The organic binder ensures a low, but in most cases sufficient, strength after lining at room temperature to stabilize the wear lining bricks and develops, in combination with the other additives, a sufficient strength at temperatures above 150 °C. The achieved bulk density of approximately 2.7 g/cm³ after proper hand ramming at lining temperature is similar to the chemical bonded mix. The achieved CCS of approximately 0.20 N/mm² is much lower but still provides enough strength to stabilize the wear lining bricks. Since the mix has only the function to stabilize the wear lining bricks during the lining process and to withstand some movement of the vessel prior to preheating, the strength development with temperature is far more important. Fig. 5 shows the development of the CCS relative to temperature for a mix containing only the organic binder and for an optimized mix using different additives.

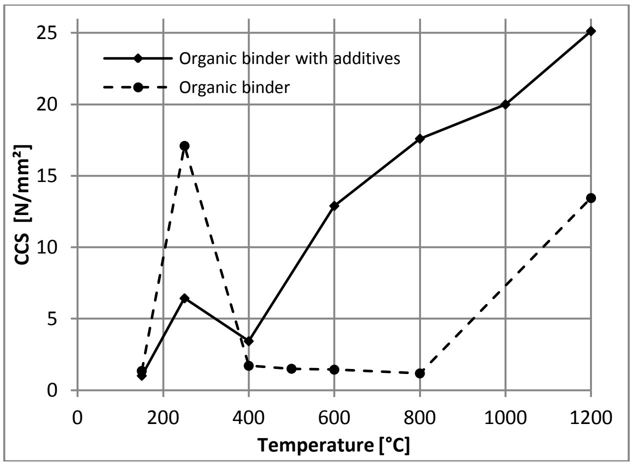

Fig. 5: CCS relative to temperature for ready-for-use mixes with and without additives.

The pure organic binder develops a fairly high strength above 150 °C but due to the organic components it will be decomposed under oxidizing conditions above 400 °C. Therefore the addition of additives is required to ensure a continuous sufficient strength over the entire temperature range. Depending on the vessel and the lifetime of the wear lining (usually MgO-C bricks) the temperature in the permanent lining can range from room temperature (after lining) up to approximately 1200 °C (during operation), this requires a continuous strength over a broad temperature range. As seen in Fig. 5 such a continuous strength over the complete temperature range could be achieved by adding different binder components. The organic binder used in the mix develops some smoke and dust release during setting and temperature treatment. Due to the availability of a sufficient exhaust system in most BOF and EAF vessels this smoke and dust formation during preheating is not problematic.

DRY SETTING MIX

Contrary to the BOF and EAF an exhaust system is not installed in most ladle preheating areas, hence the formation of smoke may be a negative issue during the preheating of the steel ladle. As the ladle is usually not tilted prior to preheating, a solution based on a dry setting mix is possible. Such solutions using a dry mix based on Al_2O_3-SiO_2 have been successfully established for some customers. This dry setting mix, similar to a standard tundish dry setting mix, has negligible strength at room temperature. The mix requires temperatures of approximately 150 °C to develop a reasonable strength and maintains that strength over a wide temperature range as illustrated in Fig. 6.

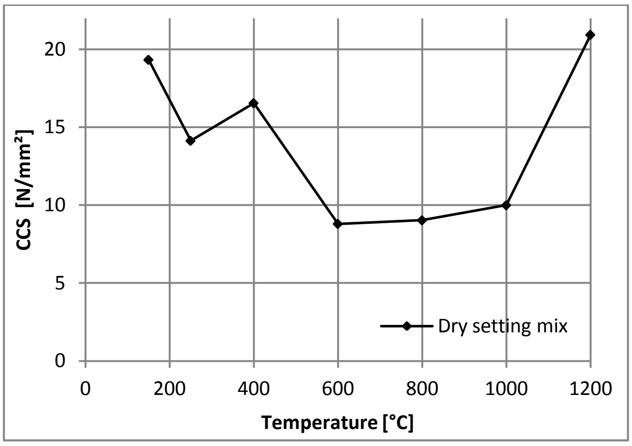

Fig. 6: CCS relative to temperature for the dry setting mix.

Using a proven binder concept, the smoke and gas release is minimized, hence the ladle can be preheated with the standard procedure.

One critical issue is the relining of the ladle, where the worn wear lining is broken out to be replaced. The permanent lining must withstand severe mechanical stresses during break out. A complete testing or simulation of such a relining process is not possible in the laboratory however in a trial a section of a permanent lining was lined and preheated to 1000 °C to verify the strength of the mix during a relining process. This temperature simulates the typical temperature of the permanent lining near the hot face before the relining process. As seen in Fig. 7 the stability of the block after firing was sufficient and it can be assumed that this mix will withstand a relining procedure.


Fig. 7: Simulated permanent lining with dry setting mix fired at 1000 °C.

INDUCTION FURNACE TEST

To determine the slag and steel resistance of the developed mixes, two tests in an induction furnace (IF) were carried out at 1650 °C using 60 kg of steel. In these trials a calcium-aluminate slag was used to determine the corrosive wear and the material loss of the refractory material. This type of slag tends to be aggressive and is representative for the steel ladle, where the first field trials were carried out. The chemical composition of the slag used is shown in Tab. 2.

Tab. 2: Chemical composition of slag for IF trial.

MgO [%]	CaO [%]	SiO_2 [%]	Fe_2O_3 [%]	Al_2O_3 [%]
1.1	47.9	7.2	4.9	36.6

The lining of the induction furnace was segmented to be able to compare different trial mixes with standard permanent lining materials. The slag was changed and refreshed each hour, 3 times in total (each hour 3 kg of fresh slag was added) leading to a total slag-refractory reaction time of 3 hours. During the last slag addition 10 wt% of fluorspar was additionally added to lower the viscosity and further increase the corrosion potential of the slag. In addition to the three types of basic mixes, two typical alumina-silica mixes and a standard fired basic permanent lining brick were used as a reference. After the IF test the different segments were cut and the chemical corrosion in the slag zone was evaluated. As an example the ready-for-use mix with additives is shown in Fig. 8 and Fig. 9 .

Fig. 8: Cut segment of ready-for-use mix with additives from IF test.

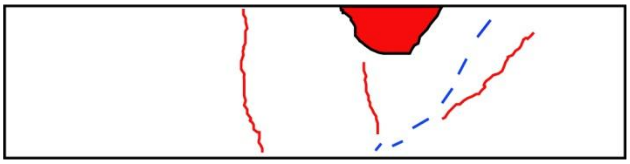

Fig. 9: Schematic of corrosion measurement for the ready-for-use mix with additives shown in Fig. 8 (red area: material loss by corrosion, red line: cracks, blue line: infiltrated area).

The total wear observed in the IF trials expressed as a corroded area with material loss is shown in Tab. 3 for all used materials.

Tab. 3: Material loss of individual samples after the IF test.

	Area of material loss [mm²]
Basic fired brick (94.5% MgO)	80
Alumina-silica dry setting mix (~78.5% Al_2O_3)	500
Alumina-Silica casting mix (~82.5% Al_2O_3)	330
Ready-for-use mixes without additives	560
Ready-for-use mixes with additives	400
Chemical bonded mix	90
Dry setting mix	< 50

For the two individual IF trials using the calcium-aluminate slag the results can be summarized:

- All mixes withstood the steel and slag contact for the desired 3 hours trial.
- Macroscopically the lowest wear among all tested samples was observed with the dry setting mix followed by the fired basic brick and the chemically bonded mix.
- Both alumina-silica mixes showed a wear similar to both types of the ready-for-use mix.

In addition to the macroscopic determination of the chemical wear, all samples were cut and the corrosion zone was mineralogically analyzed. Microscopically the dry setting mix showed a stronger structural degeneration compared to the basic fired permanent lining brick, which is due to the higher density and the lower reaction zone of the brick compared to a mix.

However all tested mixes show a reasonable wear resistance even in contact with this aggressive type of slag. In particular the dry setting mix, designed for steel ladle application showed outstanding resistance against the ladle slag used (Fig. 10).

Fig. 10: Cut segment of dry setting mix from IF test.

CONCUSION AND OUTLOOK

The development of a basic mix used as the permanent lining for different vessels such as BOF, EAF, and steel ladle was the main target of this work. Due to the different requirements of each vessel, three different types of mixes with individual binder concepts have been developed. These mix concepts include a chemically bonded mix, where the setting is achieved with minimal water addition through mixing in a continuous mixer, a ready-for-use mix based on a liquid organic binder, and a dry setting mix. All the desired mixes have been characterized by measuring the cold crushing strength relative to temperature. Typical application issues (e.g., lining with a continuous mixer) have also been tested.

Furthermore the emergency properties in case of direct slag contact were measured using an induction furnace test and the addition of an aggressive ladle slag. The results of this test, demonstrated that all sample mixes show an acceptable wear resistance. In particular the dry setting mix for ladles will withstand direct calcium-aluminate slag contact for a certain period of time.

Field trials in the different vessels will be carried out shortly to obtain a further evaluation of these developed basic mixes as an adequate alternative to the currently used fired basic bricks.

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