BASIC SHAPES FOR APPLICATIONS IN STEEL LADLES AND CONTINUOUS CASTING

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ABSTRACT

Recent advances have been made in the technology to produce refractory shapes from doloma and magnesia. This has led to the application of doloma and magnesia shapes in areas of the ladle and tundish that had traditionally used an alumina shape or basic brick. The application and properties of these basic shapes will be discussed in this paper.

INTRODUCTION

Refractories based on doloma and magnesia are used extensively in EAF ladles and tundishes. Combinations of resin bonded doloma, magnesia and/or fired doloma brick are used to construct the working linings of ladles while monolithics based on magnesia and doloma are used to line tundishes. Items such as the well block and porous plug block have traditionally been made from alumina-based castables. The ladle lip is one area in which pre-cast alumina shapes have been used. In many cases this area is rammed in place with alumina or doloma based plastics.

In the tundish area, numerous references [1-2] have been made regarding the benefits of using weirs and dams based on MgO and CaO. The benefit most cited relates to the reduction of inclusions. A British patent [3] describes the benefits of using lime-based nozzles for the reduction of clogging by alumina during the continuous casting of AK steel.

The application of basic refractories into the aforementioned areas, or as replacement for large sections of basic brick has been restricted due to limitations in the current technology. The primary challenge associated with making large shapes from doloma and/or magnesia is finding a suitable binder system that will not cause hydration during casting, curing and firing. Shapes based on magnesia are susceptible to hydration but water based systems can be utilized. On the other hand, formulations based on doloma require non-aqueous binder systems.

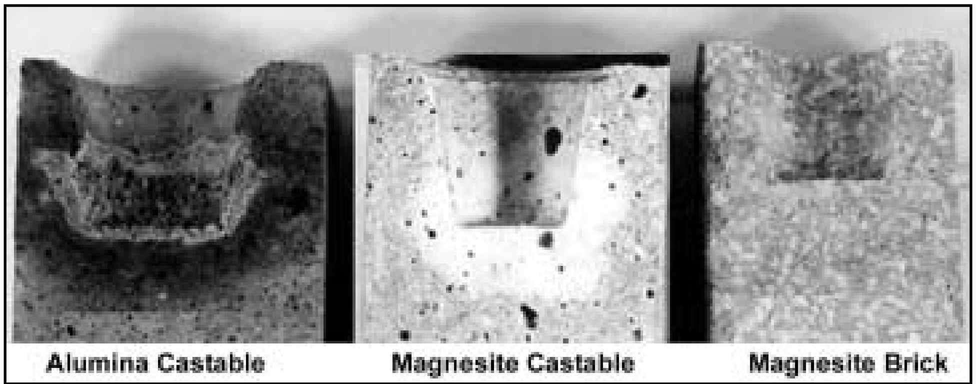

Figure 1. Cup slag Test of alumina and magnesite refractories using AK slag at 1600°C.

One problem associated with shapes based on magnesia is the potential for deep infiltration of fluid slags during service. This leads to densification and eventually failure by structural spalling of the refractory. Henry et al [4] showed that alumina additions to magnesia based castables, used for the production of large shapes, suppressed slag infiltration by forming spinel in situ. This led to improved performance of these materials. Another way to prevent slag infiltration in magnesia and doloma systems is through the addition of carbon to the formulation. The addition of carbon to castables and/or other monolithic systems typically has an adverse effect on the properties of the final shape (lower strength, higher porosity etc.).

In the past several years there have been significant research efforts to overcome

Table 1. Chemistry And Physical Properties Of A Phosphate Bonded Magnesia Castable

Chemical Analysis (%)	
MgO	88.5
CaO	3.4
Fe_2O_3	0.2
Al_2O_3	2.7
SiO_2	0.3
P_2O_5	2.8
Physical Properties	
Dried Porosity (%)	11.5
Dried Density (g/cc)	2.879
Fired Porosity (%)	17.4
Fired Density (g/cc)	2.855
Dried MOR (MPa)	10.5
HMOR(MPa) @ 816°C	11.6
HMOR (MPa) @ 1093°C	10.7
HMOR (MPa) 1371°C	15.7
HMOR (MPa) 1482°C	12.4

some of these problems so that basic shapes can be more widely applied. In this paper some of the advances with regard to basic shapes technology will be described along with some new applications of these products.

LADLE SHAPES

1. Ladle Lip Blocks

Ladle lip blocks are used to retain the sidewall refractories during service. For ease of installation, ladle lip blocks are supplied in large pre-formed shapes. Because of the large size, lip blocks are usually supplied as a pre-cast shape instead of a pressed shape. This application requires physical strength and resistance to thermal cycling during the ladle campaign. When basic slags are present during steelmaking basic lip blocks are the most compatible, withstanding the chemical corrosion during slag off better than acidic refractories. A typical reaction test to basic slags is shown in Figure 1. In this case a basic slag was tested for 8 hours at 1600° C. It shows the degradation associated with basic slag and alumina refractories. This test also shows the tendency of MgO materials to absorb slag when held for prolonged periods at temperature. In the case of ladle lip refractories, temperatures generally do not reach slag liquidous temperatures for extended times, resulting in little damage to the MgO refractory.

A magnesia based castable has been developed that is phosphate bonded to fill the needs of steel makers using basic slag practices. Phosphate bonding is used for its advantages in casting and suppression of hydration during casting and drying of ware [4]. A small addition of ultra fine alumina is added to improve rheology and form spinel in service. Shapes are supplied in pre-cast and dried form. The chemistry and physical properties of this material are given in Table 1. Stainless steel fiber reinforcement is used to improve service life, similar to other cast refractories [5]. The fibers are helpful if the blocks crack in service, preventing catastrophic failure. Since magnesia refractories are more susceptible to failure by thermal cycling than alumina materials, stainless steel fibers are considered a prerequisite in this application.

Cast magnesia lip blocks have been used successfully at several steel mills in recent years. In one case hand rammed alumina chrome was previously used with limited success, particularly in the one third of the ladle lip exposed to arc flare at the LMF. In this area the refractories were severely damaged resulting in cuts in the metal shell. The ladles were refitted with magnesia cast lip blocks, which eliminated damage to the steel shell. In more typical applications, alumina lip refractories are severely eroded by basic slags. This creates the need for patching or replacement half way through the ladle campaign. Conversion to basic lip blocks eliminates this type of maintenance.

Table 2. Chemical And Physical Properties Of Doloma Carbon, Magnesia Carbon Well Blocks

Chemical Analysis (%)	Rammed Doloma Carbon	Rammed Magnesia Carbon	Pressed Magnesia Carbon
MgO	62.9	97.0	97.0
CaO	35.1	2.2	2.2
SiO_2	0.9	0.6	0.6
Fe_2O_3	0.6	0.1	0.1
Al_2O_3	0.4	0.1	0.1
Retained Carbon	8.0	8.0	8.0
Physical Properties			
Bulk Density (g/cc)	2.70	2.75	2.80
MOR (MPa)	15.0	15.2	17.2
Coked Porosity (%)	18.0	18.0	17.0
HMOR (MPa) @ 1371°C	3.5	14.9	9.7

Table 3. Chemical Analysis Of Various Well Block Sands

Chemical Analysis (%)	Zircon Sand	Chrome Sand
MgO	0.01	7.9
CaO	0.02	0
Fe_2O_3	0.1	19.5
Al_2O_3	1.6	11.2
SiO_2	32.8	21.5
Cr_2O_3	-	39.0
ZrO_2	64.7	-

2. WELL BLOCKS AND POROUS PLUG BLOCKS

Initial experiences with using basic materials in the well blocks occurred approximately 10-12 years ago. Some steel makers who had used doloma based materials to ram between the doloma brick bottoms and alumina well blocks also used these materials to repair well blocks. This later led to ramming the top 8 – 12 inches of the block with doloma ram to form the initial well block. In some of the shops where this was tried the wear of the rammed doloma sections yielded similar or better results compared to the previously used precast alumina well blocks at a significant cost savings.

These initial experiences led to the development of a resin bonded, magnesia enriched doloma well block. The blocks produced from this material were made using a pneumatic ramming machine. The properties of this material are shown in Table 2. One problem that became apparent in using doloma to construct the entire block was the potential for hydration from water containing mortars used to set the ladle nozzles. In order to take advantage of the wear characteristics seen with the doloma materials yet avoid the potential of hydration, a composite block was designed. This design utilized a precast alumina insert around which the resin bonded doloma material was rammed (Figure 2). The alumina insert was cast from an 80 – 85 % Al_2O_3 high strength low cement castable. The alumina insert had several functions:

Figure 2. Typical Well Block Cross Section.

1. Eliminated the potential of hydration between the doloma material and the mortars used to set the nozzle.
2. Significantly reduced the potential for contact reactions between the alumina in the mortars and the CaO in the doloma.
3. The higher strength of the alumina insert gave it much better resistance to mechanical abuse during nozzle changes.

Steel fibers were later added to the precast alumina insert to further improve its mechanical resistance.

These resin bonded doloma blocks yielded good performances in numerous steel mills until there was a shift from zircon to chrome ore containing nozzle sands (chemical analyses are shown in Table 3). With the use of the chrome containing sands the doloma based blocks exhibited increased wear. The reaction between the CaO in the doloma and the chrome resulted in the formation of low melting components that led to increased erosion. In order to improve the wear of the basic section of these blocks a magnesia carbon formulation was developed. Chemical and physical properties of this material are shown in Table 2.

The shift to the magnesia carbon block significantly reduced the wear originally caused by reaction with the chrome containing nozzle sands. Additionally the blocks showed other advantages as compared to precast alumina blocks. These included the following:

1. A reduced tendency to crack during service. This is attributed to its higher thermal shock resistance.

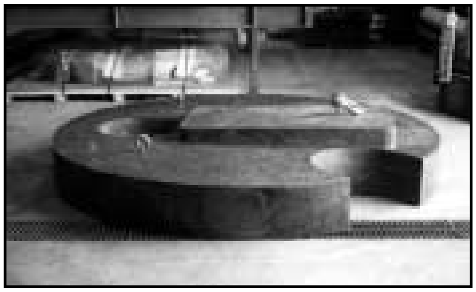

Figure 3. One Piece Resin Bonded Doloma ladle Bottom with Raised Impact Pad.

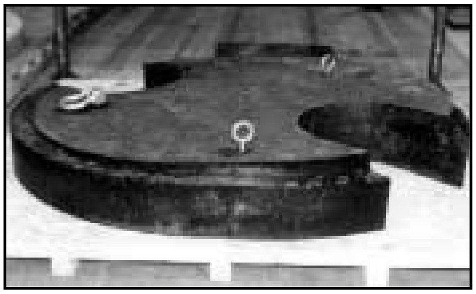

Figure 4. A Sloped One Piece Resin Bonded Doloma Ladle Bottom.

2. Resistance to basic slags. Slag can enter into the block's bore during tapping of the steel.
3. Resistance to metallic oxides created during oxygen lancing.

A further improvement was made to the block through production on a vibratory impact press. This resulted in an increase in bulk density and a reduction in coked porosity. A comparison of the properties of this block is also shown in Table 2. Currently there are over 25 plants using the magnesia carbon/alumina composite block. In addition to well blocks there has also been use of the magnesia carbon formulation to produce porous plug blocks. Similar advantages have been observed with the porous plug block as have been seen with the well block.

3. IMPACT PADS, LADLE BOTTOMS AND LARGE PRECAST SHAPES

There has been a keen interest in recent years to efficient use of ladle refractories. One possibility is large precast shapes based on doloma for basic steel making processes. A resin bonded doloma refractory composition has been developed and successfully trialed in the US. The advantage of using large precast shapes for ladle bottoms are reduced labor and installation time, while employing doloma as the refractory lining for clean steel production. The biggest challenge in producing any cast shape is optimizing physical properties, to as near as possible to a pressed brick. The base aggregate of doloma also presents a challenge due to its incompatibility with water-based systems.

Given in Table 4 are the chemical and physical properties of one resin bonded doloma composition that has been successfully used in steel mills in the US. Also shown are typical values for a pressed resin bonded doloma brick of comparable quality. This composition is cast using conventional methods. It is cured with carefully controlled schedules and shipped in hermetically sealed packaging to prevent hydration before installation at the site. It has been found that the best physical properties are obtained by widening the particle size distribution [6]. This was done by the addition of coarse aggregate run of kiln periclase, which increases overall MgO content to 57.7 percent. The addition of coarse aggregate increases density and provides better impact resistance from the steel tap stream.

The composition in Table 4 was initially field trialed in steel ladles in the bottom impact pad. After promising results in the impact area, the operation was scaled up to complete ladle bottoms. Shown in Figure 3 is a typical one-piece ladle bottom (plug bottom installation) with a raised impact pad. Figure 4 shows another one-piece ladle bottom (conventional installation) with a contoured shape. In this case the impact area is thick, tapering to a bottom well area for steel drainage. This bottom configuration has been used with favorable results in over 40 ladle installations in the past year. Typical ladle bottom life in this 90-ton ladle lined with pressed brick is 75

Table 4. Chemistry And Physical Properties Of A Resin Bonded Doloma Castable Compared To Pressed Brick

Chemical Analysis (%)	Castable	Pressed Brick
MgO	57.7	41.0
CaO	40.6	57.0
Fe_2O_3	0.6	0.8
Al_2O_3	0.4	0.4
SiO_2	0.7	0.8
Retained Carbon	3.7	3.1
Physical Properties		
Cured Density (g/cc)	2.80	2.93
Cured MOR (MPa)	15.4	21.0
Coked Density (g/cc)	2.75	2.89
Coked MOR (MPa)	3.8	3.7
Coked Porosity (%)	17.9	12.1
HMOR (psi) @ 1371°C	2.6	3.9

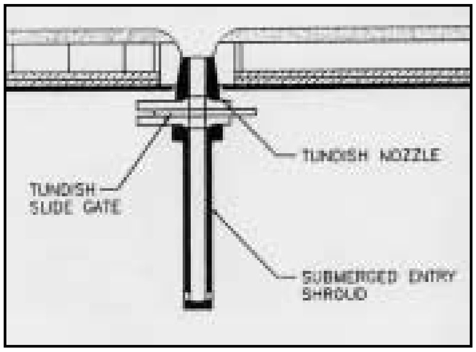

Figure 5. A Typical Tundish Nozzle Configuration.

heats. This is achieved with a well block and slag line change at 38 heats of the campaign. At 75 heats ladle brick erosion is generally 7.25 inches. With a precast bottom, the refractory consumption increased to an average of 9 inches in a 75-heat campaign. The calculated refractory consumption increased from 73 pounds per heat to 90 pounds per heat. This increase in refractory consumption is directly related to the decreased density of the product. One advantage to the shaped bottom design at this mill has been the use of a custom shaped bottom with no added labor cost. The ladle bottom is contoured so as to give maximum steel yield on each heat. This has resulted in an approximate one-ton yield increase in steel tapped per heat.

One resin bonded doloma precast ladle sidewall section has also been field trialed with good results. The precast section was approximately 5 feet wide and 2 feet tall and was installed at the bottom of the ladle. In this case the erosion rate was approximately 2.5 inches, as compared to 2 inches for brick in the same area.

TUNDISH SHAPES

1. Tundish Nozzles

Alumina or magnesia based refractories have typically been used to form the upper tundish nozzle. This is the nozzle within the tundish that mates to the top plate of the tundish slide gate/tube-changing device (Figure 5). When aluminum killed steels are cast the upper tundish nozzle is prone to clogging. Alumina inclusions in the molten steel deposit on the nozzle bore and restrict steel flow from the tundish. At this point the nozzle can be physically reamed open with a rod, but this practice produces poor quality steel, so more often the tundish is replaced by a new one.

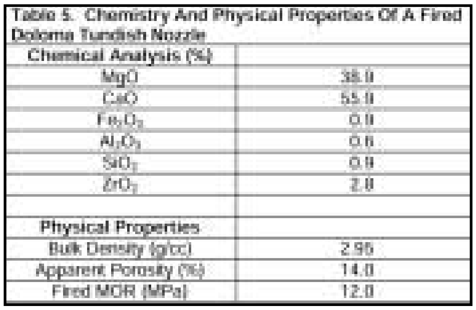

Table 5. Chemistry And Physical Properties Of A Fired Doloma Tundish Nozzle

Chemical Analysis (%)	
MgO	38.0
CaO	55.0
Fe_2O_3	0.8
Al_2O_3	0.6
SiO_2	0.8
ZrO_2	2.0
Physical Properties	
Bulk Density (g/cc)	2.95
Apparent Porosity (%)	14.0
Fired MOR (MPa)	12.0

Argon purging of the upper tundish nozzle is commonplace when aluminum killed steels are cast. This practice is effective in reducing the rate of alumina build-up on the nozzle bore, but does not prevent it. Clogging of the upper nozzle limits tundish life in some steel plants.

Doloma based upper tundish nozzles, without argon purging, have been trialed in an effort to prevent clogging due to alumina build-up. Potential benefits include increased tundish life and the absence of argon. Elimination of the argon offers cost savings and possibly improved steel quality.

The doloma nozzles are fired at high temperature to achieve direct bonding. A zirconia addition is made to enhance thermal shock resistance. This refractory technology is hardly new. Baker has used it for many years to manufacture refractory bricks for use in AOD converters, ladles, and cement rotary kilns. Typical properties of a fired doloma tundish nozzle are shown in Table 5.

Field trials have been conducted at a single strand slab caster and a three-strand billet caster. The doloma nozzles performed very well at the slab caster. At the billet caster the results were mixed. The performance of the doloma nozzles appears to be dependent on the type of steel being cast. Of particular importance is the sulfur content of the steel. Calcium sulfide (CaS) forms on the nozzle bore when the CaO in the doloma reacts with the sulfur in liquid steels with low oxygen contents. If enough CaS forms, the nozzle will become prone to clogging.

A variety of steel grades were cast during the billet caster trials. The doloma upper tundish nozzles remained non-clogging when steel sulfur levels stayed near to or below 0.015%. However, clogging occurred when aluminum killed, resulfurized steel grades were cast. Examination of the nozzles after service revealed a dense calcium sulfide layer on the hot face of the bore.

The steels cast during the slab caster trials were all low sulfur (less than 0.015%), and fully aluminum killed. During service the doloma upper tundish nozzles picked-up some sulfur on the bore, but not enough to affect performance and they remained non-clogging. Sequence lengths ranged from 16 to 19 heats, with more than 3500 tons poured through each nozzle. Bore wear was negligible.

SUMMARY

Continued progress in the technology to produce large shapes from doloma and magnesia has been made. Large shapes have been made from these materials for applications in ladles. This has allowed the steel maker to take advantage of the compatibility of these materials to their basic slag practices while reducing labor for installation of these refractories. These shapes have given similar performance to their brick counterparts. Trial of doloma shapes in the area of continuous casting refractories has shown potential for improvements in refractory performance while eliminating alumina clogging which has been a continuing problem for steel makers producing AK grades.

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