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VERSATILITY OF GEL-BOND CASTABLE/PUMPABLE REFRACTORIES

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1. INTRODUCTION

Application of sol-gel ("GEL-BOND") technology as a refractory bonding system had been developed about twelve years ago. Although the initial application was to eliminate an environmental problem, it was soon realized that the new bonding system had huge potential for application in monolithic refractories. The products that were subsequently developed, were non-toxic ramming mixes, and to install easy and better performing gunning mixes and castables. Initially, the castables were installed by vibra-casting similar to low-cement castables. But soon it was observed that the castables flow by gravity and did not need any vibration. This gave birth to the application of refractory castables by pumping. The new method of refractory castable application with its convenience of time and labor savings along with its ease of placement, promoted the cement-based castable technology to redirect their attention of converting the vibra-casting technology to pumpable refractory. During the early nineties, significant work had been done to readjust the grain sizing, particularly, following the principles of Andreassen to introduce self-flow characteristics in the low-cement castable compositions, which became quite prevalent during the mid-nineties.

The most recent outcome of the low-cement technology, from its pumping capability, the process of "SHOTCRETE" became quite prevalent. The "SHOTCRETE" process found its multifarious ways of applications. Almost all the torpedo ladles in the US steel plants are repaired by the "SHOTCRETE" process. Recently, the "GEL-BOND" castables were made capable of application by the "SHOTCRETE" process.

This paper will provide a comprehensive documentation of the castable/pumpable refractories that were developed based on the "GEL-BOND" process. The chemical, physical, thermal as well as their corrosion/erosion characteristics will be described. The multifarious application of this technology with specific performance characteristics will be presented.

2. PROPERTIES OF "GEL-BOND" REFRACTORIES

As mentioned earlier, the "GEL-BOND" bonding system is extremely versatile in all varieties of refractory compositions. These are applied in ramming mixes, gunning mixes, castable/pumpable systems in a wide range of chemical compositions [1] such as, silica, alumina-silicates to all alumina, alumina-silicon carbide, alumina-silicon carbide-carbon, all silicon carbide, silicon carbide-carbon, zirconia and zircon based materials. In this paper, the properties of the "GEL-BOND" castable/pumpable refractories will be described according to their application characteristics.

2.1. Castable/Pumpable Compositions

The impact of "GEL-BOND" castable/pumpable compositions in monolithic refractories has been quite significant during the past 12 years. The versatility of "GEL-BOND" castable/pumpable compositions led the refractories industry to a new path where monolithic refractories are increasing the share of applicability in ferrous and non-ferrous metals, glass and other industrial applications. The unique properties of the "GEL-BOND" castable/pumpable compositions will be provided, followed by the applications in various industries with their important contributions.

2.1.1. Silica-based "GEL-BOND" Castable/Pumpable Composition

Silica based gel-bond compositions are unique in nature, since there is no other major ingredient present in the refractory, and the properties will be totally governed by the properties of silica. The form of silica used in the compositions will dictate the properties of the final product. The use of fused silica is the best choice since, the effect of phase transformations of silica is minimal in the fused state. The following properties are based on fused silica compositions (Table 1).

From the above properties, it is obvious that the silica castable/pumpable "GEL-BOND" composition is superior to both the silica bricks. The physical properties are better and thermal expansion characteristics (Figure 1) are superior to the bricks.

Table 1. Comparison of silica-based gel-bond composition with silica brick

Properties	GEL-BOND	Silica brick #1	Silica brick #2
Bulk Density , Kg/m^3			
After firing to		1700	1790
315°C	1820 - 1850	(as received)	(as received)
1178°C	1850- 1900		
Porosity, %			
After firing to		23.7	22.0
315°C	15.5 - 16.0	(as received)	(as received)
1178°C	16.4 - 16.8		
Cold Crushing Strength, MPa			
After firing to		17.9	22.7
315°C	26 - 27	(as received)	(as received)
1178°C	31 - 32		
Abrasion Loss, cc			
ASTM C-704		47	31
@ 1178°C	22-23	(as received)	(as received)

Table 2. Chemical compositions of alumina and alumina-silicate compositions

Composition (%A1umina)	95	90	85	70	60	50
$A1_2 0_3$	94.5	87.8	86.5	67.8	58.5	51.0
$Si0_2$	4.5	12.4	9.5	30.5	39.7	46.5
$Ti0_2$	-	-	2.8	1.1	1.0	1.0
$Fe_2 0_3$	-	-	0.7	1.1	1.8	1.5

Table 3. Chemical compositions of alumina and alumina-silicate compositions

Physical properties	% Alumina					
	95	90	85	70	60	50
Bulk density , Kg/m^3, After heating to						
110°C	3107	2810	2925	2610	2480	2310
815°C	3110	2985	2925	2610	2450	2310
1400°C	3115	3000	2925	2620	2430	2320
Porosity, %, After heating to						
110°C	13.0	13.5	16.5	14.5	15.6 .	17.5
815°C	13.3	11.5	17.5	14.5	16.3	17.5
1400°C	13.2	12.5	16.5	14.5	16.4	16.5
Cold Crushing Strength, MPa						
After heating to						
110°C	85	74	34	38	33	23
815°C	105	85	49	43	44	42
1400°C	110	98	59	76	65	56
Cold Modulus of Rupture, MPa						
After heating to						
11 0°C	13	10	5.5	5.5	4.4	5.5
815°C	15	12	9.5	9.5	6.6	7.5
1400°C	21	18	13.5	17.5	12.8	12.8
HMOR, MPa, @						
1400°C	22.5	15	12.5	13.5	12.8	11.5

2.1.2. Alumina and Alumina-silicate Compositions

The high alumina and alumina-silicate compositions are perfectly compatible with the "GEL-BOND" system. Due to the absence of any RO group (such as CaO, FeO and MgO), the ceramic bonds are of superior quality. At high temperature, the main ceramic bond formed is mullite. The mullite not only provides a high temperature ceramic bond but also imparts better thermal shock resistance to the refractory due to its differential thermal expansion from alumina. Tables 2 and 3 show the chemical and physical properties of the "GEL-BOND" based on high alumina and alumina-silicate compositions.

It is apparent from the properties that the "GEL-BOND" refractory bodies are stable throughout the temperature range. These compositions do not contain any chemically combined water Unlike CA cement bonded compositions which have to release the chemically combined water at elevated temperatures, these compositions are unaffected by rapid increase in temperature.

2.1.3. Alumina-Silicon Carbide-Graphite Compositions

Traditionally, blast furnace cast house refractories contain alumina as the main constituent with SiC and C to provide slag/metal corrosion/erosion resistance. Since C is susceptible to oxidation at higher temperatures in the aerial atmosphere, some form of metals such as Si, Al or a combination of metallics are added to reduce the oxidation.

It has been shown by corrosion/erosion studies of both ULCC based castable and "GEL-BOND" based pumpable that there are some differences in the wear pattern of these refractories, primarily because of their bonding systems (Tables 4 and 5). From the corrosion/erosion studies in

Table 4. Chemical compositions of ULCC and “GEL-BOND” castables for blast furnace trough

Composition	ULCC	"GEL-BOND"
Al_2O_3	68-70	72 -73
SiO_2	8-9	7.4-7.8
TiO_2	1.5 - 2.0	1.4-1.6
Fe_2O_3	0.4-0.6.	1.0-1.2
SiC	19 - 21	17.0-18.0
CaO	0.4-0.5	-

Table 5. Physical properties of blast furnace trough castable/pumpable mixes

Properties	ULCC	"GEL-BOND"
Bulk density, Kg/m^3, Porosity, %		
After heating to		
110°C	2805/15.6	2915/14.3
815°C	2740/19.7	2835/17.2
1400°C	2740/18.5	2805/18.4
Cold Crushing Strength, MPa		
After heating to		
110°C	8.9	21.8
815°C	11.7	53.1
1400°C	48.2	43.3
Cold Modulus of Rupture, MPa		
After heating to		
110°C	2.1	4.0
815°C	2.4	8.3
1400°C	11.7	9.6
HMOR, MPa, @ 1400°C (In N_2 Atm.)	2.2	3.8

induction furnaces [2], with rotating bars in a molten pool of iron and slag, it has been shown that the penetration of the corroding oxides such as CaO and MgO is much less in the "GEL-BOND" based pumpable. This enhances the resistance to wear in the blast furnace trough applications.

3.4. Shotcrete compositions

As mentioned earlier, the development of "GEL-BOND" as a pumpable castable led to the self-flow or pumpable low- and ultralow-cement castables. Based on the ability of low cement castables of pumping, the "Shotcrete" technology [3] came on the market during the early nineties. The "Shotcrete" technology provided superior properties of the low cement technology as well as ease of spray gunning. Although the properties of the "Shotcrete" refractory are not as good as the castable ones, it still is far superior to gunning with better control in application, liquid content and almost complete elimination of rebound loss.

Furthermore, "GEL-BOND" compositions can also be applied as "Shotcrete" which increase the versatility of this new technology and provides significant improvements in application where other refractories failed to perform. Table 6 shows some of the physical characteristics of the LCC and "GEL-BOND" "Shotcrete" compositions.

4.DISCUSSION

"GEL-BOND" refractory compositions have some unique characteristics which are quite different from other conventional refractory bonding systems. With clay, the strength comes from hydration (chemically bonded water) at lower temperatures and ceramic bonding at elevated temperatures. With phosphate bonding, the strength comes from the formation of phosphates accompanied by some form of hydrates With CA cements, the strength comes from the hydration of cement. All these bonding systems contain chemically bonded water for the initial refractory bonding. Before raising temperatures, the chemically bonded water needs to be slowly removed without interrupting the refractory body, whereas, "GEL-BOND" refractory compositions develop their initial strength from sol-gel formation, which contains loosely bonded water molecules in the gelling network. Because of the absence of chemically bonded water, the drying process is easy, quick and devoid of any disruption of the refractory body. In addition, the permeability of "GEL-BOND" refractory compositions at low temperatures is higher than other conventional refractory bonding systems because of the viscous nature of the colloid. This facilitates drying of moisture and provides superior thermal shock resistance.

4.1. Some Characteristic Properties

"GEL-BOND" silica pumpable is much more stable than silica brick through the temperature range as is shown in Figure 1. Figure 2 shows that the "GEL-BOND" pumpable for blast furnace trough application is more stable than the ULCC based castable.

Thermal shock resistance of "GEL-BOND" refractory compositions is far superior to CA cement bonded castables (both LCC and ULCC). The retained strength (CMOR) after ASTM C-1171 thermal shock test is four to five times better as is shown in Figure 3 below.

In addition to thermal shock resistance, these refractories have better resistance to the reaction and penetration of mill scales experienced in reheat furnace uses. The lack of reaction and hence ease of removal of mill scales combined with the thermal shock resistance, allows them to last for longer periods of time.

5. APPLICATIONS

Applications of "GEL-BOND" refractories have been increasing progressively as newer needs appear. The uses are seemingly becoming more versatile with time. The following specific uses are mentioned due to their proven records and other applications are in progress, which will be recorded later.

5.1. Coke ovens and glass tank furnace

As discussed earlier, the thermal stability of silica based "GEL-BOND" castables allows them to be used in the coke ovens as repair materials for the roof, sidewalls and floor. Also, coke oven door plugs perform and last much longer because of their thermal shock resistance and resistance to coke penetration. The silica-based "GEL-BOND" castables proved to be effective repair material for the glass tank furnace roof and doghouse because of their superior thermal stability.

5.2.Blast furnace

Application of monolithic refractories inside the furnace has been prohibited excepting for repairs. Concerns about the stability and integrity of the steel shell along with the cooling characteristics kept users away from utilizing monolithic refractories. The first application of monolithic refractory castables/pumpables inside the blast furnace along the lower and upper stack was done in Germany about a year ago. Initial concerns about the steel shell stability have already been ruled out. Since the application, the furnace has been running smoothly without any problems. Future reports will indicate its overall performance in time.

5.2.1. Blast furnace cast house

One of the major and initial applications of "GEL-BOND" castables/pumpables was in the blast furnace cast-house trough, iron and slag runners. At one time the majority of the blast furnace troughs in the US had been lined with and maintained by "GEL-BOND" pumpables. A significant number of troughs are still lined with "GEL-BOND" pumpables throughout the world. The ease of application, quicker dry-out and heating along with their superior, thermal shock resistance, oxidation resistance and adhesion characteristics allow the prolonged use of these refractories with accompanying reduction in cost [4]. Recent developments in "Shotcreting" of "GEL-BOND" pumpables made the total application complete in the blast furnace cast-house trough, iron and slag runners. "Shotcreting" allows the repair and maintenance of the runners to prolong their life and reduce cost.

5.3. Foundry applications

Until recently, foundry applications have been dominated by conventional monolithic refractories like ramming and gunning mixes and vibratables. In recent years, the application of "GEL-BOND" pumpables in the cupola well, iron well and slag runners showed remarkable improvements in the lives of the refractories. Even application of 50% alumina "GEL-BOND" castables in the stirrer beams and 60% alumina in the ladles showed remarkable improvement in their life, reducing cost and down time In the melt-zone area in the cupola; the steel shells are left uncovered and water-cooled. They used to crack and warp and often needed repairs in less than a year. Here no refractory proved to be effective before. The "Shotcreting" of high SiC containing "GEL-BOND" pumpables are showing significant successes in several cupolas in the US. The refractory lining not only protects the shell, it also reduces coke consumption by 10- 15%.

5.4. Reheat furnace

Pusher type, walking beam and rotary hearth furnace hearths used to be lined with high alumina plastics. Traditionally, the sub-hearth and roofs were lined with brick. Installation and preparation for heating of phos-bonded plastics in the hearths used to take significant amount of down time. The application of "GEL-BOND" pumpables not only reduced the down time for installation, it also improved the life of the hearth by more than three times. The "GEL-BOND" pumpables have also been applied in the sub-hearth and roof of these furnaces with significant improvement in lives. Also, the heated steel slabs, bars and billets come out less defective due to gauging since the reaction of the mill scales with the refractory is minimal.

5.5. Pre-cast shapes

Pre-cast shapes from "GEL-BOND" castables, although not easy to make, are highly effective where intricate shapes are made and are subjected to severe thermal shock. These shapes are used for tundish flow control devices such as turbo-stops, baffles, dams and weirs, electric furnace deltas, steel ladle covers, and blast furnace trough skimmers.

5.6. High temperature rotary and shaft kilns

High alumina (90%) "GEL-BOND" pumpables have been used for lining high temperature shaft kilns, such as making tabular alumina (where the temperature may reach as high as 1900°C) with success. In high temperature (about 1750°C) rotary kilns, 70% alumina-based "GEL-BOND" pumpable has

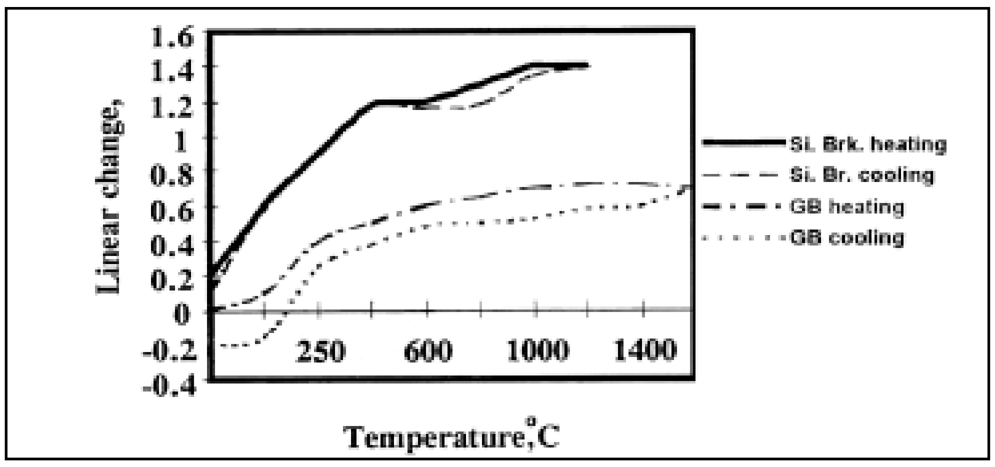

Figure 1. Thermal expansion characteristics of "GEL-BOND" silica compositions and silica brick.

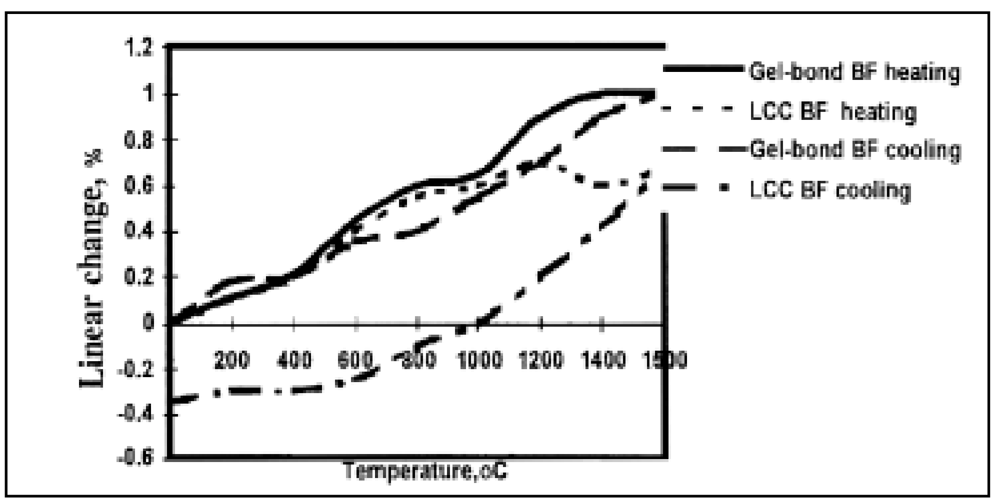

Figure 2. Thermal expansion characteristics of ULCC and "GEL-BOND trough castables/pumpable

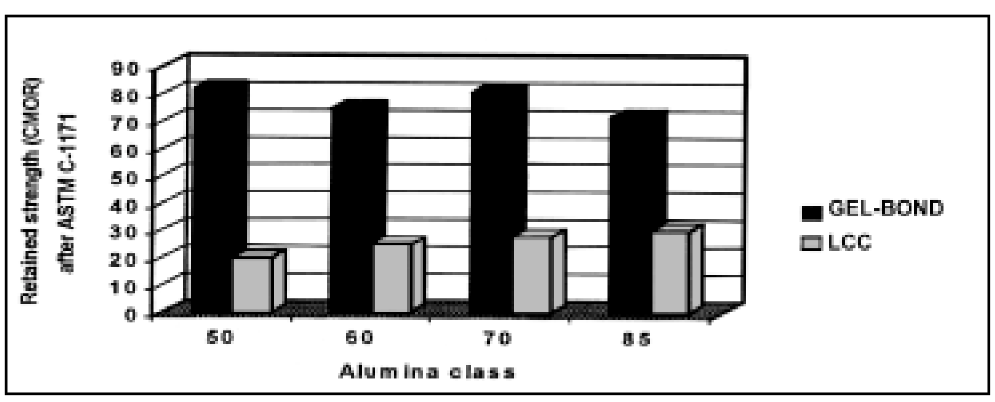

Figure 3. Retained strength of refractory compositions after ASTM C-1171 Thermal Shock Test.

Table 6. Physical properties of "shortcrete" compositions for blast furnace trough

Properties	LCC	"GEL-BOND"
Bulk density, K/m^3,/ Porosity, %, After heating to (reducing atm.)		
110°C	2810/18.5	2850/18.5
815°C (reducing atm.)	2815/19.0	2860/19.0
1400°C (reducing atm.)	2830/19.5	2890/18.5
CCS, MPa, After heating to		
110°C	28	24
815°C (reducing atm.)	22	37
1400°C (reducing atm.)	18	40
CMOR, MPa, After heating to		
110°C	6.5	5.5
815°C (reducing atm.)	4.2	6.9
1400°C (reducing atm.)	3.5	8.5
HMOR, MPa, (Under N_2 atmos.),		
@ 1090°C	2.2	3.5
@ 1400°C	1.5	2.5

been found to be the best refractory used to date in the application.

5.7. Aluminum furnaces

"GEL-BOND" pumpables of various compositions have been used for lining metal contact areas, belly-band and upper sidewalls for aluminum melting, holding and casting furnaces with good success. Of course, the metal contact areas are doped with non- wetting agents to prevent aluminum metal penetration.

6. CONCLUSION

During the last decade, significant improvements took place in monolithic refractories - in terms of bonding systems as well as in refractory grains and additives. These developments helped in replacing classical monolithic refractories by the advanced ones and increased their share from brick. The progressive improvements from castable to vibra-castable to pumpable and then followed by "shotcreting" brought the use of monolithic refractories to new domains of applications where the applications were not even conceived of. The future looks quite hopeful when use of initial refractories lining will be few and far between. The processes will run against heir own chemistry such as slag splashing in BOP.

7. REFERENCES

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