Phosphate Bonded Monolithic Refractory Materials with Improved Hot Strengths as a Potential Replacement for Phosphate Bonded Bricks

Jens Decker
Stellar Materials Incorporated
7777 Glades Blvd, Suite 200, Boca Raton, FL, 33434, USA
jens.decker@thermbond.com

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Abstract

The phosphate bond generally provides a lower modulus of elasticity compared to more brittle conventional cement and ceramic bonded materials. The flexible bonding mechanism results in higher impact resistance. Moreover, phosphate bonded materials show excellent resistance to aluminium metal penetration and corundum growth. In addition, phosphate bonded bricks with low alkali content possess high hot strengths at elevated temperatures which can significantly increase their performance against mechanical abuse.

Based on this information a project was started to develop phosphate bonded monolithic materials with similar or better physical and chemical properties than phosphate bonded bricks but with the advantage of installation characteristics of conventional cement bonded materials. Additional goals were to use a water based system and minimize restrictions on installations techniques. Flow and working time should be similar to conventional monolithic materials, making this material as versatile as possible.

In order to achieve these goals extensive tests were carried out in collaboration with independent research laboratories and as a secondary step, some of the new formulations were installed in severe environment applications with high mechanical abuse and chemical attack.

The development process and the physical and chemical properties of a new phosphate bonded monolithic material will be shown in context with available literature and in comparison with test data of phosphate bonded bricks and conventional cement bonded materials. The results of field tests and potential new applications will also be presented.

1. Introduction

Over the last 30 years, monolithic materials have replaced brick linings in numerous applications in the aluminium industry. Due to the ease of installation, reduction of downtime compared to brick installations, and the related reduction in labor costs, monolithic materials are often today’s industry standard. They are applied using various installation techniques.

However, in certain severe applications such as impact zones of floors, ramps, and lower side walls, phosphate bonded bricks are still a preferred solution. Due to the high performance of these bricks, the higher installation costs can be justified.

In this report the different properties of currently available phosphate bonded bricks and monolithic materials will be explained, and a potential for an improved phosphate bonded monolithic product that possesses performance properties similar to phosphate bonded bricks will be discussed.

2. Phosphate Bonded Refractories in the Aluminum Industry

Phosphate bonded materials show excellent resistance to aluminium metal penetration and corundum growth. This is one of the main reasons why phosphate bonded bricks still find wide acceptance in applications such as floor installations of round top melting furnaces where vertical impact of scrap during charging can lead to premature wear. In addition, phosphate bonded bricks possess high hot strengths at elevated temperatures. Combined with chemical resistance against alkali attack, performance is increased in areas with mechanical and chemical impact. These performance characteristics are important in hot wall applications of side well charging furnaces where archways and belly band areas are exposed to mechanical wear in combination with chemical attack.

3. Brick versus Monolithic Linings

Phosphate bonded bricks used in aluminum furnace linings are either fired above 1000°C or heat treated between 150°C and 800°C. Lower firing temperatures result in smaller pore sizes and improved non- wetting properties, leading to higher penetration resistance against alkali slags. Lower firing temperatures also allow the addition of non-wetting additives which are otherwise susceptible to decomposition at firing temperatures above 1000°C. In addition typically the modulus of elasticity is relatively lower at lower firing temperatures below 600°C due to the still incomplete conversion of phosphate phases.

One advantage of bricks over monolithic materials is that the structural properties are defined during the production process. However, tests and calculations carried out by Schacht indicate that the modulus of elasticity in the mortar joints is significantly softer than the brick modulus of elasticity, which implies the stress relaxation effect of mortar joints. It also shows that from a thermo-mechanical perspective, the mortar joint has a profound influence on the total structural behavior of the lining system, and that the brick properties themselves cannot be used to define the lining behavior. [1]

Conventional monolithic linings in contrast do not receive a uniform thermal treatment throughout the lining thickness. One of the most distinguishing differences from fired bricks is shrinkage of monolithic linings during furnace operation. In some cases shrinkage can offset the thermal expansion resulting in a significantly different thermo-mechanical behavior compared to brick linings. Thus, in larger monolithic applications, some crack initiation and development is expected due to the stresses along the thermal gradient in the lining from irreversible shrinkage or expansion, phase transformations and dehydration reactions.

Both mechanical and chemical properties of a refractory lining need to be considered, and in many cases the chemical resistance of the joints of a brick lining is the weakest link in the lifetime of an aluminium furnace. Metal infiltration, mineral transformations and corundum growth in the joints are frequent problems leading to uncontrolled expansions and bursting of bricks.

It can be concluded that the advantage of monolithic materials is the lack of larger joints in the structure which makes the lining - if designed properly - less susceptible to metal penetration. However, monolithic materials are not in equilibrium at operating temperature with regard to sinter reactions, phase transformations and volume stability. Therefore monolithic materials are more vulnerable to chemical attack if the composition is not adjusted to the typical environment of aluminum furnaces. Certain material ingredients necessary for placement and mechanical strengths are thermodynamically instable in contact with molten aluminum. Alloying elements and salt components make it necessary to reduce those ingredients as much as possible or to use so called non-wetting additives to alter the reaction kinetics.

4. Properties of Phosphate Bonded Monolithic Materials

Phosphate bonded monolithic refractories have been known and used in the aluminum industry for several decades. These monolithic refractories are based on liquid phosphate bonded two component binders, dry phosphate salt based systems mixed with water, or plastic refractories containing a mono-aluminium phosphate binder. The weakness of all these materials is their relatively lower hot strengths and lower high temperature wear resistance compared to phosphate bonded bricks.

One of the biggest problems that lead to lower hot properties of acidic monolithic phosphate bonded materials is the relatively high liquid content necessary for sufficient placement. Unlike conventional cement bonded materials that develop bonding strengths in a pH basic range, phosphate binder systems are acidic and therefore dispersants. Other water reducing placement additives used for cement bonded materials are not available or are less effective. Therefore, the water content of phosphate bonded materials cannot be reduced to very low quantities without sacrificing placement characteristics. As a result, such linings demonstrate relatively higher porosity compared to some low cement castable materials and phosphate bonded bricks that possess porosity as low as 13%. Since porosity is a determining factor for the resulting chemical and mechanical resistance of a material in contact with molten metals, it is evident that the improvement of high temperature properties requires the reduction of the porosity in the material.

5. Demand for Improved Refractory Materials in the Aluminum Industry

Higher melt rates are often achieved by increasing furnace temperature. Therefore in order to reduce investment costs, existing melting furnaces often operate at much higher temperatures and capacity than originally designed with the consequence of higher chemical and mechanical wear. Temperatures > 1100°C on upper furnace walls are not uncommon, and as a result the belly band area is overheated with deep salt and metal infiltration. Many monolithic refractories and also bricks are not stable in such an environment because the reactive components necessary to obtain non wetting and placement characteristics often show high reactivity towards flux salts and molten metal components. Particularly, non wetting additives containing fluorides tend to degrade in the presence of magnesium according to the following reaction:

$$\mathbf{CaF_2+Mg = Ca+MgF_2.} \qquad (1)$$

[2]

Considering the aforementioned, it can be concluded that there is a demand for a phosphate bonded monolithic material that possesses properties better than those currently available and similar to those in phosphate bonded bricks.

With these goals in mind, a research project was initiated to develop phosphate bonded monolithic materials with improved thermo-mechanical properties above 800°C, non wetting properties over a large temperature range and resistance against chemical attack, but with installation characteristics similar to any other high performance monolithic material. Another goal was that such a material should possess advantages over conventional monolithic materials with regard to long term stability against molten aluminum, its alloys and alkalis present in the metallurgical process.

In order to meet these goals the requirements for an ideal improved binder system can be summarized as:

- Water based in order to ease placement and handling, compared to two component binder.
- Basic to pH-neutral binder system to allow utilization of high performance additives in order to reduce the water content and porosity.
- High flowabilty to employ a variety of installation methods such as pumping, self-leveling etc.
- Phosphate binder to obtain non wetting properties and high hot strengths and impact resistance.
- No additional non wetting additives often used in conventional monolithic materials in order to guarantee long term temperature stability in contact with fluoride salts at temperatures above 1000°C.

6. Feasibility Studies

As a first step, feasibility studies were carried out to evaluate different phosphate compounds for suitability in neutral to basic monolithic formulations and in conjunction with different dispersants, setting retarders and accelerators. A test formulation was developed using the following components:

- Chinese bauxite as aggregate component
- Calcined and reactive aluminas as a filler
- Different dry phosphate compounds as reactive binder
- Dispersants (STPP, carboxylate ether, sodium acrylates, etc.)
- Setting retarders (sodium citrate, citric acid)

Based on these components, no-cement and ultra-low cement castable versions were developed. The mixing water content for formulations with self-flow properties was 4.5% resulting in 240mm flow in the standard flow cone tests for both formulations.

Chemical Analysis %		
	7004 Castable	Phosphate Bonded Brick
Al2O3	82.6	79 - 85
SiO2	7.2	8 - 11
TiO2	2.5	1.7 - 3.1
Fe2O3	1.1	1.0 - 1.5
CaO	0.6	0.1 - 0.3

MgO	0.2	0.2 - 0.3
MnO	0.0	N.A
P_2O_5	3.8	1.5 - 4.9
Alkalis	<0.3	0.2 - 0.4

Table 1. Chemical Analysis

Table 1 show the chemical analysis of the developed phosphate bonded monolithic material with the project name “7004” in direct comparison with the typical analysis of phosphate bonded bricks used in aluminum applications. Based on chemical analysis, both material types are almost identical. The phosphate content represents the binder system and leads to the non-wetting properties of the refractory. Alumina, calcium oxide and magnesium oxide are stable in contact with aluminium whereas all other elements shown in the table can be reduced by molten aluminium. Particularly, silica is of interest because it is a main component of most alumina containing refractory raw materials. The silica content and mineralogy determines to a great part the chemical stability of refractory products because liquid aluminium reduces silica according following reaction:

$$\mathbf{3SiO_2 + 4Al = 2Al_2O_3 + 3Si.} \qquad (2)$$

[3]

This reaction can cause a decrease in mechanical properties, an increase in corundum growth in the refractory lining, and changes in thermal conductivity that often result in even deeper aluminium penetration.

7. Test Procedures

With the developed test formulations following tests were carried out in collaboration with independent research and test laboratories;

- Aluminium penetration tests according to Alcoa and Aleris procedures
- Porosity and pore size distribution
- Hot and cold modulus of rupture combined with stress strain data
- Fracture toughness
- Cryolite penetration tests
- Fast firing performance tests

8. Results and Discussion

8.1 Aluminium Penetration Tests. The most important aspect of any material used in aluminum applications is the resistance to molten aluminum and its alloying elements such as magnesium, silicon, zinc etc. Results of cup tests in general are debatable because the test is static and oxidation of aluminum on the interface of molten aluminium and refractory material changes the viscosity of the metal and as a result the reactivity towards the refractory cup material. However, this test is widely accepted and used as a reference for the suitability of refractory products.

Fig. 1 shows a cup made out of 7004 after 120 hours at 900°C. The metal used for this test was a 7075 alloy enriched to 5.5% magnesium. Fig. 2 shows the same 7004 refractory material after 72 hours at 815°C tested according the Alcoa cup test procedures.

Fig. 1: Aleris /TATA cup test at 900°C

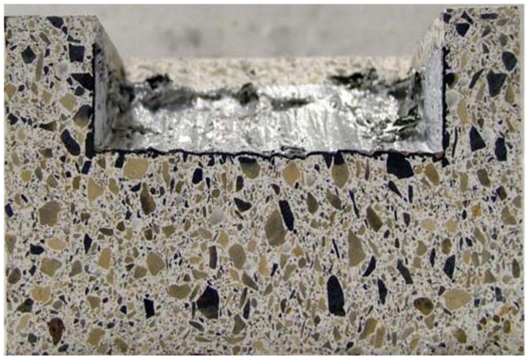

Fig. 2. Alcoa cup tests at 815°C

Most refractory materials perform relatively well at 815°C in a cup tests which represent mild furnace conditions. Because of the often higher operating temperatures of actual furnaces, it is recommended to increase the test temperature to at least 900°C and increase the test duration to reflect the harsher conditions like the Aleris/ TATA test shows. It can be seen from both tests that the 7004 materials performed very well in these tests. The refractory material was not penetrated and the metal was easy to remove after the test periods.

8.2 Pore Size Distribution. An important criterion for low aluminum penetration behavior is porosity and pore size distribution. O.J. Siljan and C. Schoening examined the influence of pore size on aluminium penetration in refractories in detail [4]. Their tests showed that the resistance of refractory material against metal penetration increases with reduced pore size below 1-2 microns. In general pore size increases with the firing temperature. When sintering effects lead to grain growth, the average grain size is a function of firing temperature. The non-wetting properties of the 7004 test material shown in the cup test can be explained by the low porosity and low average pore size diameter at given test temperatures. The overall porosity after 850°C firing was 14.8%. Fig.3 shows the pore size distribution where 93% of all pores had a diameter of less than 0.6 micron.

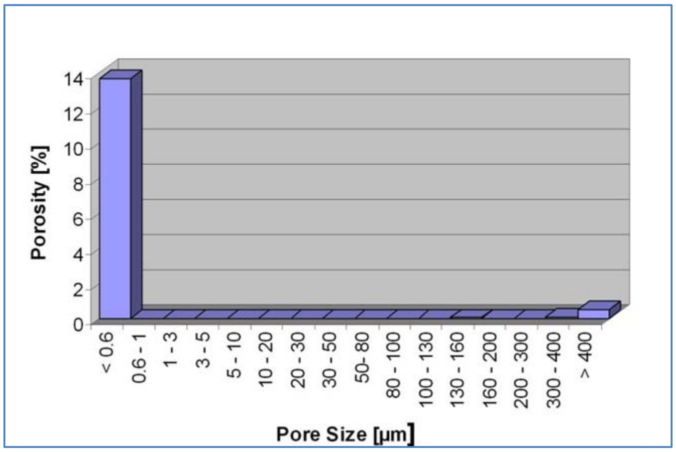

Fig.3. Pore size distribution of 7004 material

8.3 Hot Modulus of Rupture, Fracture toughness and Work of Fracture. Fracture and spalling are the primary failure mechanism of refractories in aluminum applications either induced by mechanical stresses or chemical attack.

Different types of mechanical fracture parameters determine the resistance of refractories. These parameters are tensile strengths, crack resistance and energy required for cracking. In order to get a better understanding of how the developed phosphate bonded material can resist fracture and how it can be compared with other refractory products, different strength tests were conducted in this study.

Modulus of rupture tests were performed at different temperatures. The modulus of rupture test determines the transverse bending strength of a material, and quantifies the strength to resist initial fracture. Since the refractory matrix undergoes changes during heat increase from a green to a sintered state, modulus of rupture was tested from a green state at room temperature to up to 1100°C which is a typical exposure temperature for refractories in aluminum applications. Fig.4 shows the hot modulus of rupture results. It confirms that improved strengths at elevated temperature were achieved. The results are similar or better than high performance cement bonded refractories. There was no comparison data available for phosphate bonded bricks at elevated temperatures. Manufacturers publish only cold modulus of rupture data for bricks but it can be deduced (see Table 2) that those published numbers would not lead to higher hot strengths than shown in Fig.4.

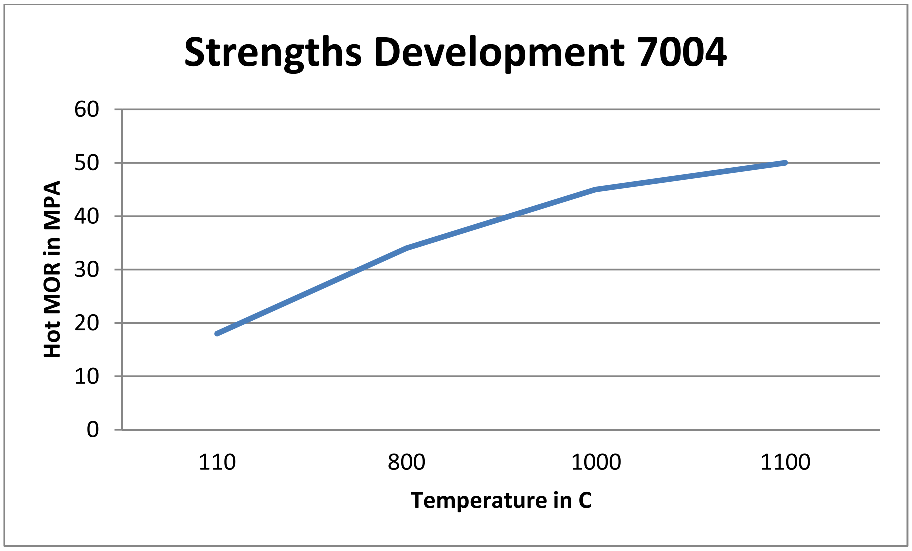

Fig.4. Hot Modulus of Rupture up 1100°C.

The relatively low initial green strengths of the 7004 material may be perceived as a disadvantage, however, it is typical for no-cement or ultra-low cement castables that the green strengths are relatively low. Experience from field testing concludes that the green strength of the 7004 material is sufficient to handle larger precast shapes of 300kg and more without any problems.

In addition, fracture toughness testing was carried out at an independent laboratory. Fracture toughness (K_{IC}) measures the resistance of a material to brittle fracture if a crack is already present. It determines the energy for crack initiation (e.g. the energy to start a crack moving). This is a relevant parameter because monolithic materials are often installed in large sections exposed to a temperature gradient and external loads. The resulting compressive stresses and thermal strain in the material often lead to cracking. However, with higher fracture toughness, such cracks will not grow unless the strain energy exceeds a critical value.

In order to simulate stress intensity in a crack, the test specimen used to determine fracture toughness K_{IC} are notched, either with a chevron or straight notch, and strained very slowly to produce a stress / strain curve. As explained K_{IC} quantifies crack growths when fracture occurs whereas “work of fracture” (WOF) measures the material’s strength in resisting the tensile stress. Work of fracture can help to quantify thermal shock properties. In contrast to fracture toughness which is the crack initiation energy, WOF is the energy that keeps the crack propagating after initiation. It relates to fracture toughness:

$$\mathbf{WOF = K_{IC}^2 / E.} \qquad (3)$$
[5]

…where K is fracture toughness in Pa√m, IC indicates mode I cracking and E is the Young’s modulus of the material.

Table 2 below represents data from various publications and compares different materials based on fracture toughness, work of fracture and modulus of rupture. All data shown was evaluated at ambient temperature. It needs to be noted that for cement bonded monolithic refractories, the hot work of fracture can significantly increase with temperature. For this study, it was not possible to conduct additional hot work of fracture tests due to time constraints and test equipment availability.

	Fireclay Brick	**Superduty Brick**	**70% Alumina Brick**	**High Alumina Castable**	**7004**	**Low cement castables**	**Dense Sintered Silicon Carbide**	**60% Alumina Brick**
MOR (MPA)	6	32	10	10	34	< 35		17.8
E (GPA)	18.6	69.8	10.5	50.1	79.5	--------		29
WOF (J/m2)	60	15	75	53	130	< 100		
K_{IC}					2.82	0.5 - 2	2.8-3.5	1.4
Reference	[6]	[6]	[6]	[6]		[7]	[8]	[9]

Table 2. Comparison of Fracture Data of Different Refractory Products

It can be seen from Table 2 that the 7004 material shows relatively better resistance against crack growths (K_{IC}) than other refractory products, and is similar to lower grade dense sintered silicon carbide. The work of fracture or crack propagation resistance values shows a similar trend. As already pointed out an increased work of fracture can have a positive impact on thermal shock properties, but it needs to be evaluated in conjunction with Young’s modulus. This can be expressed by calculating the thermal shock resistance parameters. One of these parameters is R’’’:

$$\mathbf{R'''' = E\ \lambda_{WOF} / \sigma 2\ (1- v)} \qquad (4)$$

…where λ is work of fracture, σ is the strength (MOR), v is the Poisson’s ratio and E is the Young’s modulus. From Table 2 it is also evident that the modulus of elasticity E correlates to a high degree with modulus of rupture σ which means when σ increases the modulus of elasticity E will also increase. However, there is no direct correlation between modulus of elasticity and work of fracture. In designing refractory materials it is known that decreasing the modulus of elasticity leads to improved thermal shock resistance [10]**.** Based on this, it can be concluded that with high work of fracture and with also a high modulus of elasticity the 7004 test material possesses favorable properties to prevent crack growths but is probably very resistant against transient and cyclic thermal strains that occur during thermal shock.

It can be further concluded that liquid phosphate bonded monolithic products with lower strengths are favorable for cyclic thermal strains from thermal shock applications, and fired phosphate bonded bricks and the 7004 material are more favorable for stress controlled loads like mechanical impact.

8.4 Firing Tests. The results of the porosity tests indicate very low porosity and relatively small pore size diameters that normally have a detrimental effect on heat-up and fast firing properties.

Also, WOF and K_{IC} values show a positive trend for crack resistance but a relatively high modulus of elasticity with the theoretical consequence of low thermal shock resistance.

In order to simulate thermal shock resistance, fast firing tests were carried out on 10kg specimen with a diameter of roughly 30cm and a height of 9cm. The goal was to carry out testing under more realistic conditions than traditional ISO or ASTM thermal shock tests on small test specimens.

To ease steam release, the 7004 material was cast with 0.07% polyethylene fiber additions. After casting and a 12hour setting/curing time, the test specimen was placed in a fast firing furnace (Fig. 5) and fired to totally heat soak at 1000°C in approximately 25 minutes. In this test the specimen was exposed to flame impingement at the bottom (Fig. 6). The soak-temperature was measured at the center of the specimen on the top.

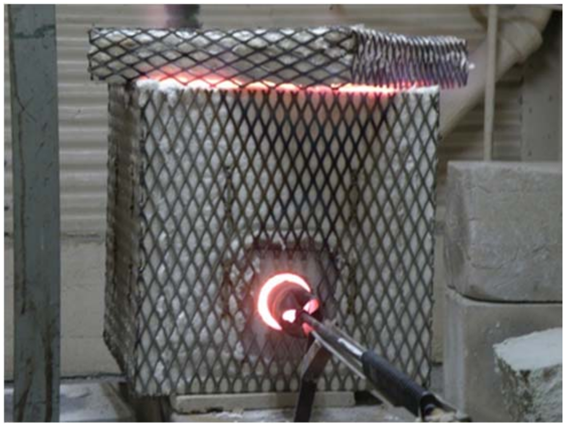
Fig. 5. Fast Firing Furnace


Fig. 6. Test Set-Up

During this sharp heat increase the test specimen did not spall. To verify the result the test was repeated 3 times with 3 specimens starting in the green state with the same mixing, setting and curing conditions. After all test cycles small hairline cracks were observed on the surface at the bottom of the specimen but none of the cracking was destructive nor did any cracking propagate from the bottom to the top of the specimen.

In order to increase surface stresses, an additional flame impingement test was carried out with two gas burners directed towards the center surfaces of a 100kg block made out of the 7004 material (Fig. 7). After 30 minutes test duration, an 850°C hot spot measured with an infrared test probe was created on each side of the block. Again, the material did not spall and showed only minor hairline cracks in the center of the spot.

It is not very clear why these tests showed very good thermal shock properties when the calculated properties were not favorable. The actual good thermal shock behavior can partially be explained by the relatively low strengths of the 7004 material during start-up in the green state. At this point the modulus of elasticity can be expected to be low, and then increase significantly at higher temperatures. The calculations in contrast were based on tests with specimens that were fired at 800°C.

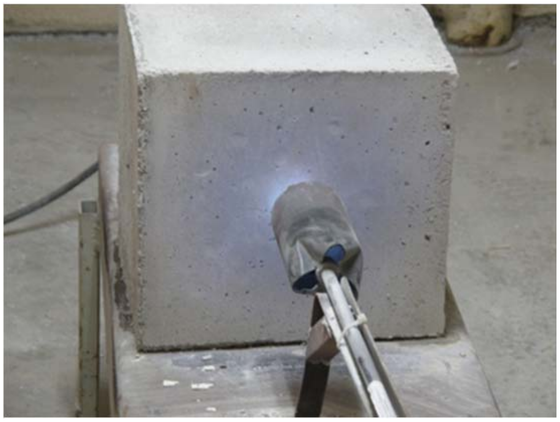

Fig. 7. Flame Impingement Test

8.5 Moisture Loss. The high water or moisture content in monolithic linings can require longer dry-out and heat up procedures compared to brick linings. This can add several days of additional furnace downtime which reduces or even eliminates the advantage of the faster installation time of monolithic materials over brick linings.

The requirement for better material performance has led to the development of monolithic materials with higher strength, density and lower porosity. The downside of this performance increase is the higher vulnerability for steam explosions during start-up because of lesser pathways for steam to escape from the material in a steep temperature gradient. Therefore it is of great importance that the heat-up process is manageable without compromising final material performance or heightening the risk for steam explosions.

Again the question was why the fast firing test of the 7004 material did not result in destructive spalling although the material is very dense with low porosity and average pore diameter. The addition of polyethylene fiber definitely contributed to steam release but conventional water based refractory materials normally show spalling in this test even with such fiber additions.

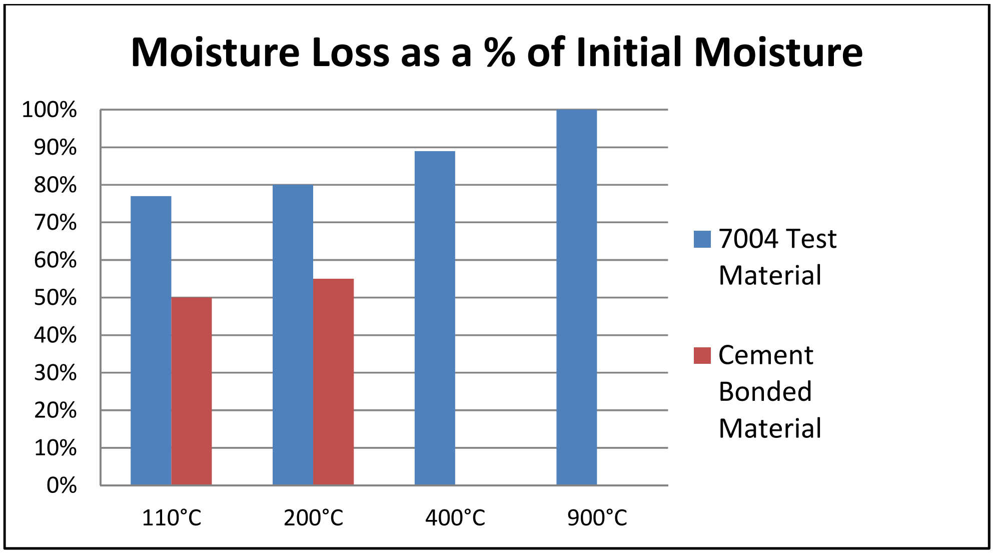

Fig.8. Moisture Loss

Another answer to this question can be found in the ability for moisture release of the developed material. Fig.8 shows the moisture loss as % of initial moisture of the 7004 test material (blue) in comparison to regular cement bonded material (red). The brick shaped specimen for the test had an initial weight of 5kg. The holding time at individual test temperatures was 5 hours.

Almost 80% of the initial moisture of the 7004 material evaporated after drying at 110°C. At 900°C all moisture evaporated. In contrast, the red column shows the average moisture loss of typical regular cement bonded castables. Depending on the type and quantity of cement the percent of moisture loss can vary slightly. In general, the moisture release of cement bonded systems is lower at lower temperatures compared to the 7004 material. One reason is that the hydration pattern of cements in conjunction with fine particles like fume silica and alumina can have a significant impact on moisture release [11]. However, a higher moisture release at low temperatures has the advantage of a lower overall steam pressure in the capillary system and opens more pathways for steam release at an early stage of the heat-up process. The 7004 material contains either very small or no cement depending on the formulation chosen and it is believed that the phosphate content has an influence on the hydration pattern of the cement and aluminates. This hypothesis needs to be evaluated in further studies.

8.6 Chemical Resistance. The most critical area in secondary aluminium furnaces with regard to chemical attack is the belly band. It is known that in such an environment, alkali chlorides are relatively stable compared to fluorides which can heavily attack alumina silica [12].

Fig. 9. Cryolite Cup Test

In this project it was not the primary goal to develop a material with the highest chemical resistance but it is understood that any refractory material installed below the metal line and belly band is to some degree exposed to chemical attack. Fig. 9 shows a test cup cast out of 7004 material that was filled with pure cryolite, Na_3AlF_6, and fired to 1100°C with a holding time of 10 hours.

It is evident and not unexpected that the cryolite attacks the high alumina refractory material in this overheated state. However, the attack mainly happened in contact with the atmosphere whereas in all other areas the material contained the cryolite very well with only slight infiltrations.

9. Summary of Physical Properties

Table 3 shows a summary of 7004 physical properties in comparison with properties of a range of phosphate bonded bricks with similar alumina content. Also from this comparison there is no indication that the 7004 material has any obvious disadvantages over phosphate bonded bricks based on physical properties.

Physical Properties Comparison		
	7004	**Phosphate Bonded Bricks**
Density	3075 kg/m3	2700 – 2850 kg/m3
Cold Crushing strengths	170 MPA (800°C)	90 – 100 MPA
Modulus of Rupture	30 MPA (800°C)	15 – 18 MPA
Hot Modulus of Rupture	34 MPA (800°C)	----------------
Porosity	< 15%	13.5% - 15%
Permanent linear Change	-0.2% (1600°C)	+0.5% - +1% (1600°C)
Abrasion Resistance	< 3cc (ASTM C-704)	5cc (ASTM C-704)

Table 3. Summary of physical properties

Based on the results of the test program it was evident that the implementation of the 7004 material did not show a high risk for failure. In 2010, field tests were started to implement the 7004 material together with a 70% alumina version and a silicon carbide based version.

10. Case Studies - Products and First Field Testing

In this section, different applications will be presented to demonstrate where this new phosphate bonded material shows advantages over existing products. These are:

- High wear applications in side well charge furnaces
- Anchoring systems for monolithic refractory linings
- Transfer launder systems

10.1 Archway installation in an aluminium side well furnace. Thermbond 7004 was installed for the first time in two archways of a divider wall of a side well furnace, Fig. 10 and Fig. 11. This furnace melts aluminum can stock. Production rates and operating parameters are shown in Table 4. The 7004 material was chosen by the equipment owner because the divider wall is traditionally installed with phosphate bonded brick. The installation of the archway with bricks is very time consuming and potential premature wear of joints in the arch bears the risk that the whole archway structure could collapse. Both material types Thermbond 7004 and brick were bauxite based with similar alumina content. The resulting similar thermal expansion allowed a uniform compressive stress in the lining. The challenge in this application is the high aluminium flow through the archways, the abrasive solid content of unmelted scrap, and the high flux salt content. The salt is charged in the side well along with scrap and passes the archway. In addition it can be assumed that there is a slight temperature gradient in the archways from the fired hearth side to the unfired side well side.

The two archways were installed in November 2010. In March 2011 the equipment owner decided to install another two archways in a similar smelter at the same facility.

Furnace Capacity	90 t
Production Rate	180 t / day
Fluxing Salt per day	14.5 t
Circulation through Archways	13.6 t/min.
Cold Cleaning Cycles	6 months

Table 4. Furnace operation data

Fig. 10. No.1 Archway Installation

Fig. 11. No. 2 Archway Installation

10.2 Anchoring systems for monolithic refractory linings. Conventional refractory anchoring systems are usually made out of pressed bricks. Because of the required high tensile strengths, the preferred material for such anchors is a phosphate bonded 80% alumina refractory, with approximately15 MPA modulus of rupture and 70 MPA cold crushing strengths. Several problems are associated with the design of conventional brick anchors.

- Anchors are square because of the manufacturing process – uniaxial pressing. Plastic refractory rammed around those square anchors tend to crack starting from the edges and corners of the anchors due to occurring stresses.

- Anchors are susceptible to spalling if applied with dense castables in flat roof applications. Often roofs are cast in large panels in order to control installation costs. The thermo-mechanical behaviors of large flat roofs depend on the panel size, the pressure loads due to the weight of the roof and the thermal loading. Thermal expansion on the hot face results in compressive stresses and tensile stresses on the cold side. In addition, the weight of the roof itself leads to a distinct lining displacement. Under these occurring loads anchors are not only exposed to a tensile stress but also to torsion from the horizontal thermal expansion of the castable. The anchor is totally restrained and stresses can lead to anchor spalling on the interface of the anchor and the cold face of the castable.

With a phosphate bonded castable version, the design of the anchor is not dictated by the manufacturing method (e.g. the square shape can be replaced by a round anchor shown in Fig. 13). This design is better suited for monolithic installations because it avoids stress build-up at the corners of the anchor. The problem of torsion stresses combined with tensile load that can lead to anchor spalling can be avoided by breaking larger panel sizes into small individual sections with an anchor design as shown in Fig. 12. In this case there is stress relief at the joints of every individual tile. The thickness of the tile can vary depending on the required furnace design. It can also be filled with a light weight back-up material. In addition such tiles can be easily replaced in case they are mechanically damaged around the door area or they can be made out of a more thermal shock resistant material.

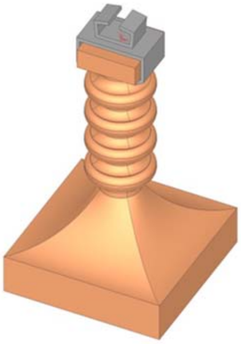

Fig. 12. Tile anchor for furnace roofs

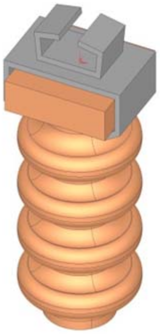

Fig. 13. Regular round-anchor

10.3 Transfer Launder. Transfer launders between melting and holding furnaces are exposed to severe thermal shock and mechanical wear from molten metal hitting the launder surface during tapping. In some cases additional alloying is carried out in the launder which requires more mechanical cleaning and as a consequence even higher wear. Once impact areas start wearing out, more turbulent metal flow occurs, which in turn leads to deeper wash outs. Such launder systems require labor intensive maintenance like patching and surface coatings to prevent metal from penetrating and wearing the launder.

In addition to the 7004 bauxite based material, materials containing 70% alumina and also 70% silicon-carbide were developed. Fig. 14 shows a silicon-carbide transfer launder section after pre-firing to 600°C. The silicon-carbide material used for this launder exhibits very similar physical properties to the bauxite based 7004 material, with hot strengths exceeding 45 MPA at 1100°C.

Fig. 14. Launder shape 3003 SiC material

Summary and Discussion

The goal of this study was to develop a binder system with better strengths and placement characteristics than currently used phosphate bonded refractory materials, including phosphate bonded bricks and currently available phosphate bonded monolithic materials. Because of Stellar Materials' company history in the aluminium industry and high level of experience with phosphate binder systems, plus their access to customers willing to field trial these materials, it was a natural course of action to focus on phosphates as a versatile binder component for the development process.

The results of this study demonstrate that it is possible to use the advantages of the low cement / no cement technology and combine it with a phosphate binder system to create a material with improved and unique characteristics that can very likely compete with currently used phosphate bonded bricks and high performance cement bonded materials in high impact areas of aluminium furnaces.

Although the 7004 material showed excellent heat-up and dry out behavior in the tests it is also clear from this study that this material, like phosphate bonded bricks, is favorable in high stress controlled load applications whereas liquid phosphate bonded materials with lower modulus of elasticity are preferred for transient and thermal shock application.

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