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IMPROVED MONOLITHIC MATERIALS FOR LINING ALUMINUM HOLDING & MELTING FURNACES

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Abstract

To remain competitive, aluminum producers continue to increase productivity through their Melt-Hold furnaces. Increasing heat input to the furnace using more powerful burners is common practice. But faster melting leads to increased metal losses from surface oxidation and to segregation from large heat gradients. These effects are countered by increased use of fluxes and increased stirring. Given the increasingly challenging environment within which the refractory lining has to work, traditional lining solutions can no longer be relied upon to provide the service lives that were previously achieved. Therefore, a new generation of furnace lining materials is required to cope with today's aluminum furnace. This work reports on a new monolithic material with improved performance, compared to existing materials, designed for use in the ramp/hearth area of aluminum furnaces. Improved behavior against the critical performance criteria in this furnace region are demonstrated in the laboratory using industry standard test methods.

Introduction

The refractory lining of a typical furnace used for holding and melting aluminum has to withstand a wide variety of physical and chemical environments. The different areas within the furnace are shown in Figure 1. Each of these areas presents a different set of operating conditions, in terms of peak temperature, temperature fluctuation, metal contact, salt contact, impact from ingot loading, etc. Therefore, in order for a monolithic material to successfully perform in a particular area of the furnace, it needs to be able to cope with the specific environmental conditions in that region of the furnace. This is why furnace linings are complex arrangements, with different materials installed in different locations [1].

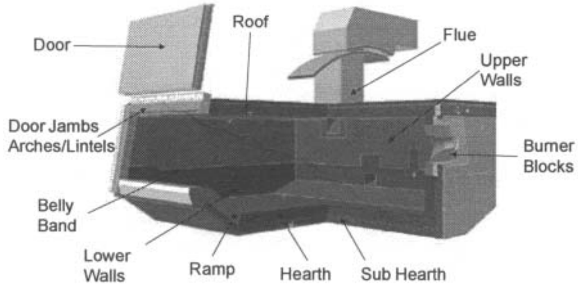

Figure 1. Furnace lining zones in a typical Aluminum Melt-Hold furnace.

Background

Over the last 30 years, a group of Monolithic technologies has emerged which have been designed specifically to perform within the unique environment of Al melt-hold furnaces. These Al-resistant grades often contain 'non-wetting' additives, particularly in the metal contact areas, to minimize interaction between the refractory and the melt to suppress damage to the lining from 'corundum growth' [2].

As aluminum producers strive to increase productivity, the environment within the Melt-Hold furnace is becoming more arduous. Chamber temperatures are increasing and more aggressive fluxes are being used, necessitating more frequent and severe cleaning operations of the refractory wall. A key requirement for maintaining high levels of productivity is the need to minimize the frequency and duration of furnace downtime. The more aggressive conditions within which the refractory lining has to work today means that the Al-resistant lining materials developed in the past to cope with these applications are now being used beyond their original intended design boundaries and their service performance is under threat, leading to more frequent lining repairs. In order to minimize the frequency of furnace downtime a new breed of Al-resistant products are needed by Al producers, specifically designed to perform within today's more aggressive operating environment. This paper describes the development and behavior of once such newly developed material.

Approach

An Al producer will make the decision to take a furnace off-line for repair once a critical lining area has degraded to the point of affecting the efficiency &/or safety of the operation. At this stage, not all the lining will have degraded to the point that it is in need of replacement or repair. Therefore, the frequency of furnace lining repairs and furnace downtime is determined by the area of the furnace that is most quickly and frequently degraded during operation. Therefore, in order to increase campaign times and decrease frequency of repair stoppages, we need to improve the service life of this weak link in the lining arrangement. To identify the region most frequently & quickly degraded, we worked with a number of Al producers. Their feedback suggested that the most common area that was the cause of repair downtime was the ramp/hearth area.

The failure mechanisms within the furnace environment, that limit refractory service life, are of two main types, chemical attack (corundum growth, corrosion from flux addition) and mechanical damage (e.g. ingot loading, cleaning practices, thermal shock) [1]. Since our target is to improve refractory performance in the ramp/hearth region, we need to understand which of these failure modes are most critical to lining performance in this region.

Performance Targets

A study of working practices and furnace operating conditions at a number of Al producers revealed that the ramp/hearth region of an Al melt-hold furnace is subjected to severe mechanical and thermal stress during the loading of large ingot down the ramp. Frequent loading of heavy ingot to feed the furnace, often by fork lift truck, subjects the ramp to severe abrasive forces. As the ingot is usually at room temperature, there is also considerable thermal shock on the ramp/hearth refractory, which is at furnace operating temperature. As the bottom of the ramp and the complete hearth are in contact with molten metal, the refractory is also subject to chemical attack from the alloy, alloying elements and flux additions. A study of ramp/hearth degradation of Al-resistant materials containing 'non-wetting' additives suggested that damage leading to furnace downtime is mostly due to the mechanical action of the erosion and thermal shock from ingot loading. We therefore focused our work on developing a new Al-resistant material with improved abrasion & thermal shock resistance. To achieve significant improvements in performance we set out to increase abrasion and thermal shock resistance by 20% compared to existing materials. As metal and alkali resistance are secondary performance parameters in this furnace region, we also had to ensure that any changes we made to the materials did not degrade chemical resistance.

Experimental

Two existing, industry leading Al resistant monolithic materials used by many Al producers in the ramp/hearth area of melt-hold furnaces were selected as baseline materials for the study. The in service performance of both these materials is well known and so serve as useful benchmarks against which to compare new developments. A detailed analytical investigation of the baseline materials was undertaken in order to identify those aspects of the materials technology that were considered to be constraining performance in terms of abrasion and thermal shock behavior and thus leading to premature mechanical failure. The bond chemistry and aggregate granulometry were then re-engineered through several iterations to find the optimum balance of material types and grain size, shape and distribution that produced the maximum improvement in abrasion and thermal shock performance without negatively affecting other important properties. This paper presents the results of performance and property measurements of the final, optimized development composition compared to the baseline standards. All materials in the study were tested against the four key performance parameters using industry standard test methods;

Primary Performance Parameters

1. Abrasion Resistance Test (ASTM C704); Pre-fired samples are blasted with a stream of SiC grit of specified grain size for a set time. Samples are cross-sectioned and the amount of material abraded across the section is measured and reported in cm^3.
2. Thermal Shock Resistance Test (ASTM C1100 – Ribbon Test); Pre-fired samples are subjected to alternating heating and cooling cycles on one face using a ribbon burner. The Modulus of Elasticity (E-modulus) of samples is measured non-destructively by ultrasonics before and after testing. The percentage of retained E-modulus is used as a measure of retained strength.

Secondary Performance Parameters

1. Aluminum Resistance 'Cup' Test; 'Cup' samples are prepared (Figure 2) and filled with 7075 alloy. Samples are ramped up to 1000°C and held for 100 hours. After cooling, the samples are sectioned vertically and visually assessed for the degree of metal penetration and corundum growth. The alloy is then analyzed for any pick up of critical elements from the refractory during the test. Maximum allowable is 0.5% Si and 0.1% Fe. The test method is described in more detail in the literature [3].
2. Alkali Resistance 'Cup' Test; Sample preparation is the same as for the Al resistance cup test. Instead of Al, the samples are filled with mixtures of K_2CO_3 and Na_2CO_3 and fired to either 900°C, 1000°C or 1100°C for 5 hours. After sectioning, samples are analyzed by visual inspection for cracks, bulges, depth of penetration and color change.

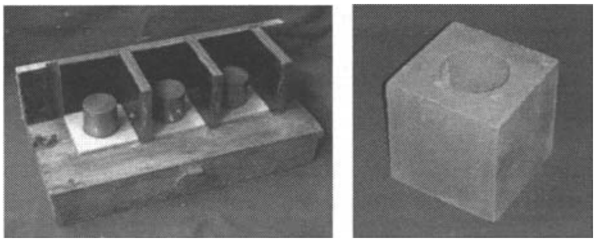

Figure 2. Mold & test sample for Al Contact & Alkali Tests.

Results & Discussion

The physical characteristics and chemical composition of the optimized new material compared to the two standard baseline materials are displayed in Tables 1 & 2.

Table 1. Physical Properties of Materials Studied.

		Standard 1	Standard 2	New Material
Water (%)		5.5-6.5	5.7	5.3
Bulk Density (kg/m^3)	110°C	2840	2630	2640
	815°C	2800	2590	
	1000°C	2790		2580
	1300°C		2570	**2510**
PLC (%)	815°C	-0.29	-0.43	
	1000°C	-0.32		-0.26
	1300°C	-0.35	0.38	0.95
CCS (MPa)	110°C	128	122	**147**
	815°C	163	99	
	1000°C	129		95
	1300°C	138	119	144

Table 2. Chemical Analysis of Materials Studied.

	Standard 1	Standard 2	New Material
% Al_2O_3	80.6	65.8	66.6
% SiO_2	11.2	26.7	25.6
% CaO	1.8	3.6	3.2
% TiO_2	2.0	2.1	2.2
% Fe_2O_3	1.2	1.0	1.0
% MgO	0.2	0.1	0.2
% Alkalis	0.2	0.2	0.2

In order to be of practical use to the Al producer, it is important that any new material developed not only meets the performance targets, but also can be installed easily. Both baseline materials are low cement, vibrocast grades. The optimized new material in Table 1 could be cast at 5.3% water, lower than the baseline grades, and gave free flow of 125 mm and tapped flow of 160 mm.

Primary Performance Parameters

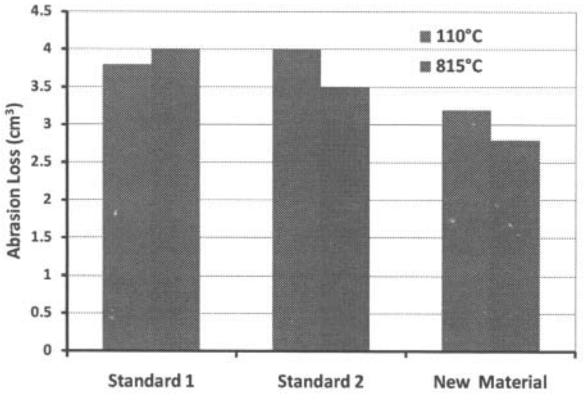

Figure 3. Abrasion Loss Resistance of Test Materials.

Abrasion resistance test results of the materials, one of the primary performance parameters in the ramp/hearth region, are presented in Figure 3. As dried, the new optimized material was observed to deliver 16% better resistance to abrasion compared to Standard 1 and 20% better resistance compared to Standard 2. When pre-fired to operating temperatures, the new material delivered a 30% improvement on abrasion resistance compared to Standard 1 and 20% compared to Standard 2.

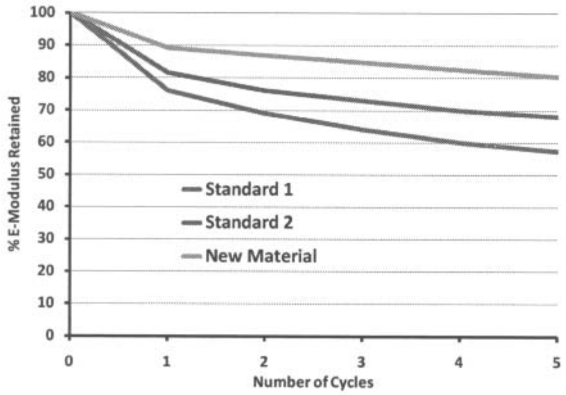

Figure 4. Thermal Shock Resistance of Test Materials.

Thermal shock resistance test results of the materials, the other primary performance parameter in the ramp/hearth region, are presented in Figure 4. After 5 test cycles, Standard 1 lost 42% of its E-modulus and Standard 2 lost 32%, compared to only 20% loss for the new optimized material. These results suggest that the new material is capable of delivering 52% improvement on thermal shock resistance compared to Standard 1 and 38% compared to Standard 2.

Secondary Performance Parameters

As the baseline materials 1 & 2 are commonly used in service around the world, we fully expected them to pass the Aluminum resistance 'cup' testing. Both these materials, and all of our new development formulations, contain well proven 'non-wetting' additives. Our final, optimized new composition passed all Al contact testing and performed identically to Standards 1 & 2 in the visual assessment of Al 'cup' test samples after testing, both dried at 110°C (e.g. Figure 5) and pre-fired to 1200°C (e.g. Figure 6).

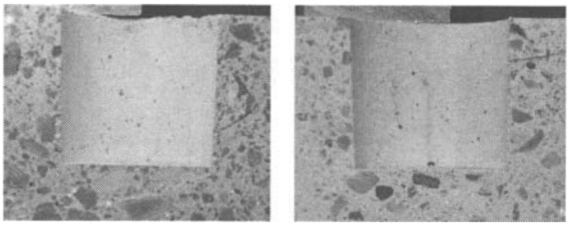

Figure 5. Al 'Cup' testing – Standard 2 (left) & New Material (right) – dried samples.

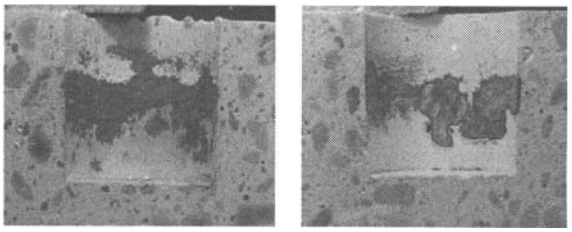

Figure 6. Al 'Cup' testing – Standard 2 (left) & New Material (right) – pre-fired samples.

However, subsequent analysis of the alloy after testing in the pre-fired state revealed subtle differences in interaction between the alloy and refractory. Table 3 reveals that although all materials pass the test (target pick up <0.5% Si, <0.1% Fe), Si pick up is much reduced in the new material compared to the two standards. Since 'Cup' test failures are normally accompanied by increased concentrations of Si & Fe in the alloy after testing, this result may be an indication of a much reduced interaction between the new material and the test alloy compared to the standards and thus may indicate superior 'non-wetting' behavior. Similar behavior has been noted in the literature [3].

Table 3. Alloy analysis after Al 'Cup' Testing.

	Standard 1	Standard 2	New Material
% Si pick up	0.314	0.093	0.011
% Fe pick up	0.052	0.04	0.04

As with the Al contact testing, for the alkali resistance testing, we expected Standards 1 & 2 to possess good resistance to alkalis as they are used commonly in service and so should have already passed Al producers' approval testing. Our final, optimized new composition passed all Alkali contact testing with K_2CO_3 and Na_2CO_3 and performed identically to Standards 1 & 2 in the visual assessment of Alkali 'cup' test samples after testing, at all test temperatures (e.g. Figures 7-12; samples tested at 900°C (left), 1000°C (middle) & 1100°C (right)).

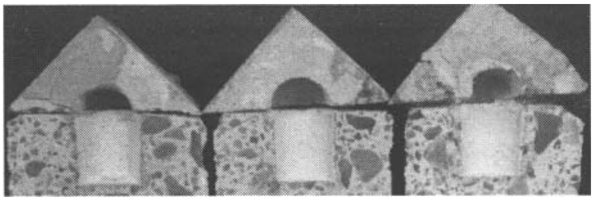

Figure 7. Standard 2 after alkali testing with K_2CO_3

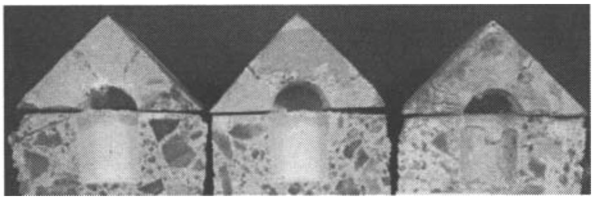

Figure 8. Standard 2 after alkali testing with Na_2CO_3.

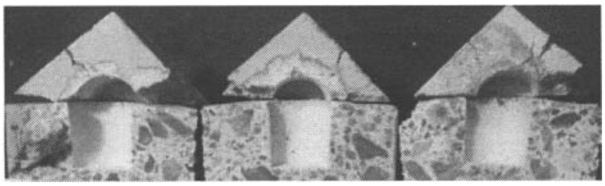

Figure 9. Standard 2 after alkali testing with K_2CO_3/Na_2CO_3.

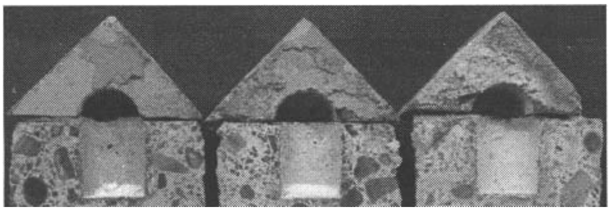

Figure 10. New Material after alkali testing with K_2CO_3.

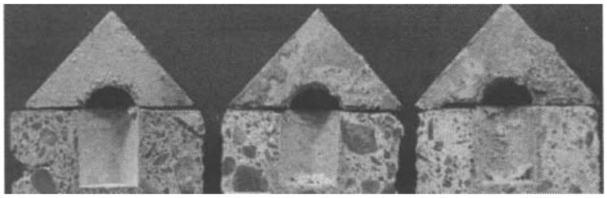

Figure 11. New Material after alkali testing with Na_2CO_3.

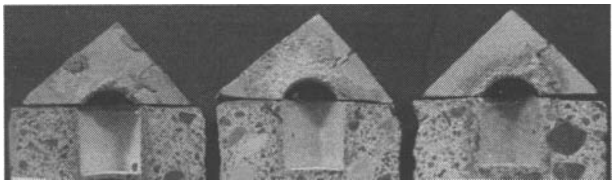

Figure 12. New Material after alkali testing with K_2CO_3/Na_2CO_3.

Conclusions

1. By working closely with Aluminum producers, the most frequent cause of melt-hold furnace downtime has been identified as mechanical damage in the ramp/hearth region of the refractory lining.
2. The main factors leading to mechanical damage in this region have been identified as severe abrasion and thermal shock from the frequent loading of heavy, cold ingot.
3. Through re-engineering of the bond chemistry and aggregate granulometry of a series of Monolithic formulations, significant improvements have been achieved in abrasion and thermal shock resistance for material in the ramp/hearth region of Al melt-hold furnaces.
4. An optimized formulation has been developed which has been shown to deliver 20-30% improvement in abrasion resistance and 40-50% improvement in thermal shock resistance compared to existing materials.
5. The new material has been shown to pass industry standard Aluminum contact and alkali resistance tests. More detailed investigation has indicated that the new material interacts less with the industry standard test alloy and therefore may possess superior 'non-wetting' characteristics compared to existing materials in the ramp/hearth area.
6. The results of our development program and subsequent laboratory analysis work suggest that the new material should be capable of surviving the unique set of service conditions in the ramp/hearth region of aluminum melt-hold furnaces, better than the existing materials used in the industry and thus deliver longer service life.
7. Extended service life in the ramp/hearth area is expected to reduce the frequency of furnace downtime and thus allow Al producers to run longer production campaigns, increasing productivity and minimizing the need for expensive repairs.
8. The new Monolithic material has been designed as a vibrocast grade, with a degree of free flow, for improved ease of installation at low water content.
9. This new material is now on trial in the ramp/hearth area of melt-hold furnaces at several Aluminum producers around the world.

References

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