RAW MATERIAL CONCEPTS FOR SiO_2 FREE HIGH STRENGTH AND LOW WETTABILITY ALUMINIUM CASTABLES

Andreas Buhr, Dagmar Gierisch, Almatis GmbH,
Almatis GmbH, Ludwigshafen, Germany;
Robert W. McConnell, Almatis Inc.

ABSTRACT

Refractory castables in the aluminium industry, chemical, and petrochemical industries typically see much lower temperatures than in the steel industry. The maximum temperature is very often in the range of 800 – 1200 °C. Nevertheless these applications can also be very demanding regarding mechanical strength, abrasion resistance, and chemical stability. Mechanical strength of refractory linings is of particular interest at the intermediate temperatures, which do not provide sufficient energy for strong sintering reactions. This paper discusses raw material concepts for high purity silica free castables for demanding aluminium or petrochemical applications. Bonite, a new dense calcium hexaluminate (CA6) refractory aggregate is introduced for low wettability, high temperature stability of aluminium refractories.

INTRODUCTION

Classical castables used in the aluminium industry are high alumina low cement castables based on Alumino-Silicate or Bauxite refractory aggregates. Often, anti-wetting additives like $BaSO_4$ or CaF_2 are added to reduce the penetration by molten metal or slags. Several trends in the aluminium industry require improvements of the refractory linings [1, 2, 3, 4]. Increasing demands on the purity, e.g. for thin foils, and many different alloys containing magnesium, require refractories with a high stability against molten aluminium or Al-alloy contact. Impurities in the refractory linings like SiO_2, Fe_2O_3, and TiO_2 can be reduced by the aluminium or alloy components to their metallic state. The alloy can be contaminated and layers of corundum (Al_2O_3) are build up on the refractory lining which is a major problem of aluminium refractories.

Recycling of aluminium scraps containing impurities like salts and oil increase the chemical attack on the refractory lining. Higher production rates lead to more intense conditions and higher charging weights and temperatures in melting furnaces. Although the temperature of the liquid aluminium is below 900 °C, the roof temperature may be as high as 1200 °C with hot spots even above. Anti-wetting additives like $BaSO_4$ or CaF_2 seem to loose their effect at temperatures above 900 – 1100 °C due to decomposition or reactions with the refractory oxides [5, 6]. With pore diameters below 1-2 µm, a penetration of liquid aluminium also can be hampered [7, 8, 9]. So microporosity of the castables is an alternative to anti-wetting agents especially at high application temperatures.

Recently, a synthetically dense sintered calcium hexaluminate named Bonite has been introduced [10]. This new commercially available refractory aggregate material shows a low wettability by molten metals and slag, and provides a new alternative for demanding aluminium applications.

A trend towards dense, low porosity, low or ultra low cement castables and anti-wetting castables to replace brick linings especially in melting and holding furnaces started in North America and has become global [2]. A demand for shorter maintenance periods supports the trends towards monolithics. Monolithic linings of furnaces in the aluminium industry are discussed by Strasser et al. [11] and Tassot & Flessner [4].

STRENGTH OF REFRACTORY CASTABLES

The strength of refractory castables is mainly determined by the following factors (besides others):

- Type and content of the binder used (here high purity Calcium Aluminate cements),
- particle size distribution (PSD) especially of the fines fraction below 45 µm,
- prefiring temperature.

Conventional castables have a cement content of 15 % to 30 %, which provides sufficient strength but they also have a water demand exceeding 7 or even 10 %. The physical properties, including the strength, are critically affected by the amount of water needed for the mixing and placement of a castable. Increasing the water addition by 1 % results in an increase of about 3 % in the open porosity in dried and fired castable installations and significantly reduces their resistance against penetration of molten metal, slag or gases. Low cement and ultra low cement castables have drastically reduced cement contents (e.g. 5 resp. 2 %) and contain special fine components to improve the PSD and reduce the water demand of the castable.

Hydraulic binders like calcium aluminate cements show a decrease of bond strength around 800 - 1000 °C, a temperature where the hydrated phases have decomposed and solid state sintering is just starting [12]. Prefiring of the linings at higher temperatures is a disadvantage not only because of economics but also because it negatively affects the microporosity of low cement castables, which is a key property for their success.

A significant challenge for the intermediate application temperatures up to 1200 °C is to get sufficient strength over the entire temperature range with low cement content and mixing water demand, using refractory raw materials which are stable even under strongly reducing conditions as in contact with molten aluminium.

RAW MATERIAL CONCEPTS TO ENHANCE CASTABLE STRENGTH

In general, a castable is made from several components that include refractory aggregates, e.g., Tabular Alumina, Spinel, and Bonite (CA_6) of different grain size fractions up to 10 mm, a binder like calcium aluminate cement, and those fine-grained materials like calcined aluminas, reactive aluminas, or fumed silica which are essential for the formulation of low and ultra-low cement castables. The fine-grained fraction including the binder is called the matrix. Defined as the fraction below 45 µm, the matrix accounts for approximately 25 % of the total weight in the case of vibration castables and 35 % in self-flowing castables.

The key for minimizing the amount of water necessary for mixing a refractory castable and obtaining desired rheological behaviour is to optimize particle packing especially in the matrix down to the submicron range. Successive particle sizes must be put together in such a way as to minimize the void, which is filled with water (s. **Fig 1**). The theory of optimized particle size distribution of refractory castables is discussed e.g. by Madono [14] and Myhre and Hundere [15].

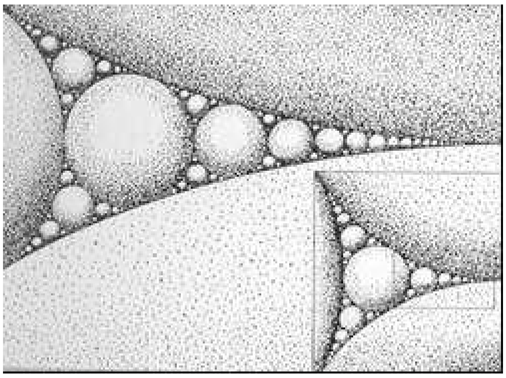

Fig. 1: Dense particle packing [13]. Voids successively filled by smaller particles to reduce water demand and enhance strength.

Silica fume (microsilica) has particle sizes ranging down to below 1 µm and has been a key component in the development of low and ultra-low cement castables with low water demand. However, the low stability of SiO_2 under reducing conditions requires alternative fines for aluminium and petrochemical applications. The development of superfine ground aluminas allowed the replacement of silica fume in the finest part of the particle size distribution. Those aluminas were used first in ceramic applications and are called “reactive aluminas” because of their high sintering reactivity resulting from their high specific surface area and small primary crystal size. Reactive aluminas are a subgroup of calcined aluminas, their BET surface areas being at or above 1.5 m²/g and soda contents often below 0.1 %.

Innovation in reactive aluminas has led to the development of aluminas with a multimodal particle size distribution, e.g. CTC 30 or CTC 55 used for the test castables mentioned below. Aluminas whose particle size distribution exhibits only one peak are monomodal (e.g. CTC 20 or its Almatis North American equivalent A 20 SG) with a majority of particles within a tight particle size range. Aluminas with two or more peaks are called multimodal. In a castable formulation, monomodal alumina covers a small portion of the particle size range of the matrix, and has to be surrounded by complimentary particle size products for the desired rheological properties to be achieved. Multimodal aluminas cover a broad range of the particle size, which helps improve the rheological behaviour of castables even with a reduced amount of water. A variety of such products are available to meet individual requirements in respect of sintering reactivity and volume stability as well as different placement technologies for vibration, self-flow, and gunning castables [16,17,18].

For low cement castables (LCC, total CaO 1 – 2.5 %) and ultra-low cement castables (ULCC, total CaO < 1%), 70 % Calcium Aluminate Cement (CAC) is preferred. The innovative 70 % Al_2O_3 cement CA-270 is optimized specifically for low water demand; compared to conventional 70 % CAC´s, CA-270 is made from much denser clinker and exhibits a bimodal particle size distribution, which contributes to dense particle packing of castable matrix. The hydraulic bonding properties of cements depend primarily on their mineralogical phase compositions, not on chemical compositions. The mineralogy of CA-270 is optimized so that castables can achieve high strength even at low cement content. In high quality cements, the total content of impurities like SiO_2 and Fe_2O_3 is below 0.5 %.

To take full advantage of the castable matrix whose particle size distribution has been optimized for the lowest water demand and desired rheological behaviour, it is essential that all the matrix components are homogeneously distributed during mixing with water. Dispersing agents are commonly used to de-agglomerate fine particles. Also used are additives that influence the hydraulic reaction of the cement and steer the setting time of castables. The Dispersing Aluminas ADS 3/ADW 1 (fumed silica free mixes) and M-ADS 1/M-ADW 1 (with fumed silica) used for the test castables of this investigation combine both functions. Their advantage is, that by varying the ratio of S : W type the setting time easily can be changed without negative impact on the dispersion effectiveness or the castables physical properties [16]. The superior dispersion behaviour of the Dispersing Aluminas contributes to the reduction of the water demand which is typically about 1 % lower compared to conventional dispersing systems for the same castable mix composition.

SET UP OF TEST CASTABLES

The purpose of this investigation is to demonstrate the potential of modern alumina raw materials to enhance the castable strength without high cement contents or silica fume (Microsilica). The following test castables have been utilized for comparison (s. **Table 1**):

- VB1 as example for a conventional castable: Tabular Alumina vibration castable with high cement content (80 % Al_2O_3 cement CA-25 C), no reactive aluminas;

Table 1: Vibration (VB) and Selfflow (SF) test castables

	VB1	**VB2**	**VB3**	**SF1**	**SF2**	**BON 1 (VB)**
Type	Tabular cc	Tab. lcc + MS	Tab. lcc	Spinel lcc	Sp. lcc fine	Bonite lcc
Coarse fraction	T60/T64: **73**	T60/T64: **74**	T60/T64: **75**	AR 90: **40**	(up to 3 mm)	Bonite: **70**
up to 6 mm [wt%]				AR 78: **28**	AR 78: **65**	
Fines < 45 µm [wt%]						
T60/T64 -45 MY	**7**	**8**				
T60/T64 -20 MY			**7**			
AR 78 -20 MY				**5**	**17**	
Bonite -45 MY						**5**
Bonite -20 MY						**7**
CTC 20		**10**				
CTC 30			**13**		**13**	**13**
CTC 55				**22**		
Microsilica 971 U		**3**				
Cement [wt%]	CA-25 C: **20**	CA-14 M: **5**	CA-270: **5**	CA-270: **5**	CA-270: **5**	CA-270: **5**
Additive [wt%]		M-ADS 1: **0.6**	ADS 3: **0.4**	ADS 3: **0.6**	ADS 3: **0.6**	ADS 3: **0.5**
Dispersing Aluminas		M-ADW 1: **0.4**	ADW 1: **0.6**	ADW 1: **0.4**	ADW 1: **0.4**	ADW 1: **0.5**
H_2O [wt%]	7.5	4.1	3.9	4.6	4.8	6.5
Flow [mm] 10 min	208	197	212	228	245	207
30 min	200	192	209	237	250	202
60 min	18.8	184	209	240	248	196
Chemistry [wt%]						
Al_2O_3	95.3	93.9	98.5	85.0	78.7	89.9
SiO_2		3.4				0.9
CaO	4.0	1.5	1.5	1.5	1.5	8.7
MgO				13.4	19.5	

- VB2 (with silica fume): Tabular Alumina low cement vibration castable with Microsilica (Elkem 971 U) and monomodal Reactive Alumina CTC 20 (North American equivalent: A 20 SG) and 70 % Al_2O_3 cement CA-14 M;
- VB3 (Silica free): Tabular Alumina low cement vibration castable with multimodal Reactive Alumina CTC 30, superground Tabular -20 MY, and bimodal 70 % Al_2O_3 cement CA-270;
- SF1 (Spinel, Silica free): AR 90 and AR 78 Spinel low cement selfflow castable with multimodal Reactive Alumina CTC 55 (contains Spinel), and CA-270;
- SF2 (Spinel, fine): AR 78 Spinel low cement selfflow castable with CTC 30 and superground AR 78 -20 MY, and CA-270. This castable has a grain size of maximum 3 mm and is shown as an example e.g. for repairing materials to fill small voids;
- BON 1 (VB, Bonite): Bonite low cement vibration castable with multimodal Reactive Alumina CTC 30 and superground Bonite -20 MY, and bimodal 70 % Al_2O_3 cement CA-270.

The superground aggregate materials Tabular Alumina -20 MY and AR 78 -20 MY and Bonite -20 MY (95 % < 20 µm, D50 of 2.5 µm) take advantage of a broad particle size distribution. This increases the amount of matrix fines without having too many particles in a narrow size range. Additionally, by using high fired Tabular Alumina, Spinel AR 78, or Bonite as matrix fines, excessive shrinkage during firing can be avoided. The overall effect is to improve flow properties, especially for selfflow castables, and high volume stability during firing.

TESTING METHODS

The test castables have been mixed dry for 1 minute before water addition, followed by 4 minutes wet mixing in a 5 kg Hobart laboratory mixer A 200. The water demand of the castable has been adjusted to achieve the desired rheological (flow) behaviour, either for vibration (VB, minimum 80 % flow at 30 minutes) or self flow (SF, minimum 100 % flow at 30 minutes). Flow has been tested 10, 30, and 60 minutes after start of mixing. Flow cone dimensions are as follows:

	Upper diameter	Lower diameter	Height	Vibration
Type	[mm]	[mm]	[mm]	30
VB	70	100	50	50 Hz, 0.5 mm amplitude
SF	70	100	80	none

The pot life has been measured by the exothermal reaction. EXO start (corresponding to end of flowability) has been adjusted by the ratio of Dispersing Aluminas to between 90 and 150 minutes. EXO max (corresponding to adequate cured strength for form removal) is between 3.5 and 7 hours.

The following tests have been made at Deutsches Institut für Feuerfest und Keramik, Bonn according to the norms mentioned:

- Bulk Density, DIN EN 993-1
- Apparent Porosity (and Water Absorption) , DIN EN 993-1
- Hot Modulus or Rupture (HMoR), DIN EN 993-7
- Thermal Shock Resistance (air quenching from 950 °C), ENV 993-11 of samples prefired at 1000 °C for 5 hours
- Micropore Distribution (Hg intrusion method), DIN 66 133, after prefiring at 800 and 1200 °C for 5 hours
- Thermal conductivity, hot wire method DIN EN 993-15

The aluminium resistance has been tested by the Corus Research Center, IJmuiden, the Netherlands. Details are given in [19,20].

WATER DEMAND AND APPARENT POROSITY

The flow data of the test castables are given in **Table 1**. All test castables achieved the desired flow target and smooth rheological behaviour. The water demand of the conventional castable VB1 of 7.5 % is much higher than for all low cement castables tested (3.9 – 4.8 %). Therefore the apparent porosity of VB1 is remarkably higher compared to the others, except for the Bonite castable (s. **Fig. 2**). Due to the higher porosity of the aggregate, the Bonite castable has a water demand of 6.5 %. The water demand for the Spinel selfflow castables is about 0.5 % higher than it would be for similar Tabular castables. Of course, the higher fineness of SF2 increases the water demand and also the apparent porosity vs. the coarser type SF1. Increasing the water addition of SF1 to 5.1 % leads to a pumpable consistency of the mix without segregation of the fine fraction. But physical data for this water addition have not been measured.

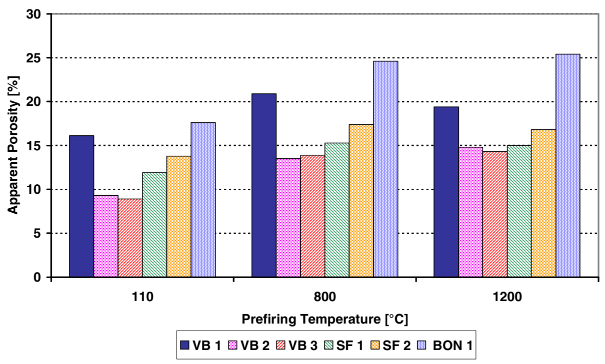

Fig. 2: Apparent porosity of test castables

MICROPORE SIZE DISTRIBUTION

As mentioned before, the microporosity of castables is important to reduce the penetration during use [7, 8, 9]. With pore diameters below 1-2 µm, the penetration of liquid aluminium can be hampered. So microporosity of the castables is, in combination with the anti-wetting behaviour of Bonite, a better alternative to Bauxite based castables with anti-wetting agents especially at high application temperatures. This has been tested by measuring the pore size distribution after prefiring at 800 °C and 1200 °C (BON 1: prefired at 900 °C and 1400 °C). The pore size distribution of all low cement castables (lcc´s) tested is similar (median pore radii 0.1 – 0.2 µm, compare data in **Table 2a**). Only the conventional castable (cc) VB1 has higher pore radii exceeding 1 µm, which is reflected in the higher median pore radius (0.3 µm). Clear differences occur after prefiring at 1200 °C.

Also the cc VB1 has pore radii above 1 µm and the median pore radius increased to 0.6 µm. Although measured at higher temperature of 1400 °C, the pore radii of BON 1 are still clearly below 1 µm.

Table 2a: Data of test castables part 1

	VB1	VB2	VB3	SF1	SF2	BON 1
Bulk density [g/cm³]						
110 °C	2.96	3.16	3.21	2.99	2.93	2.85
800 °C	2.87	3.13	3.21	2.99	2.89	2.80
1200 °C	2.87	3.13	3.18	2.97	2.89	2.78
Apparent porosity [%]						
110 °C	16.1	9.3	8.9	11.9	13.8	17.6
800 °C	20.9	13.5	13.9	15.3	17.4	23.5
1200 °C	19.4	14.8	14.3	15.0	16.8	25.4
Permanent linear change [%]						
110 °C	0	0	0	0	0	0
800 °C	-0.07	-0.12	-0.03	-0.06	-0.07	-0.04
1200 °C	0.02	-0.12	0.12	0.13	0.09	-0.08
Microporosity median pore radius [µm]						
800 °C	0.30	0.10	0.12	0.16	0.23	0.30*
1200 °C	0.60	0.90	0.32	0.27	0.34	0.54**

* at 900 °C

** at 1400 °C

For comparison the micropore size distribution has been determined also for two conventional castables based on bauxite (BX 1: bauxite - fumed silica - BaSO4 castable, and BX 2: bauxite - $BaSO_4$ - reactive alumina castable). The bauxite based castables with anti-wetting agent show, after firing at 1400 °C a remarkable increase of average pore size diameter towards 4.4 µm (BX1) resp. 16.0 µm (BX2), whereas the Bonite based castable is still below 1 µm (**s. Fig. 3**). This demonstrates the stable micropore diameter of the high purity Bonite castable even at temperatures up to 1400 °C, which provides a wide safety buffer even for demanding applications. The increase of pore size diameter for the bauxite castables is caused by two factors: the decomposition of the $BaSO_4$ and sintering reactions including a liquid phase, which applies especially for the bauxite castable BX1, containing silica fume in the fines. BX2 with reactive aluminas instead of silica fume in the fines provides a higher refractoriness of the castable matrix, and therefore less liquid phase is formed during pre-firing at 1400 °C, and pore size growth is hampered.

These results show a clear advantage of the silica free low cement systems in respect of stability of the microporosity during firing at elevated temperatures. Gabis and Exner [9] report about castables with very narrow pores (i.e. d50 < 0.25 µm), which behave as well as those with non-wetting agents in corrosion testing with aluminium alloys.

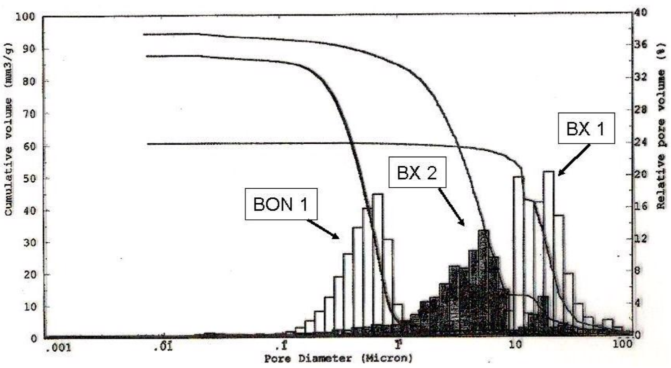

Fig. 3: Micropore size distribution (Hg intrusion method) of Bonite castable BON 1, bauxite/silica fume castable with $BaSO_4$ (BX 1) and bauxite/alumina castable with $BaSO_4$ (BX 2), all pre-fired for 5h at 1400 °C

MECHANICAL STRENGTH

The development of the cold crushing strength (CCS) with increasing prefiring temperature is shown in **Fig. 4**. The CCS of VB2 is exceeding 200 MPa when prefired at temperatures above 800 °C. This is due to the high sintering reactivity of the silica fume in VB2. However, most applications do not require such high values and a minimum CCS of 60 MPa over the entire temperature range often is considered as sufficient. All castables tested do not show a remarkable decrease in CCS below the technically required level in the temperature range around 800 – 1000 °C.

Fig. 5 shows a comparison of Cold Modulus of Rupture (CMoR) at different prefiring temperatures and Hot Modulus of Rupture (HMoR) at 800 and1200 °C (s. also **Table 2b**).

The HMoR values are about half of the corresponding CMoR values at 800 resp. 1200 °C. Except the cc VB1 and Bonite BON 1, all test castables have a HMoR of around 10 MPa at 1200 °C or higher.

The target for CMoR was a minimum of 10 MPa over the entire temperature range, which is achieved except by the fine Spinel castable SF2 after prefiring at 800 °C.

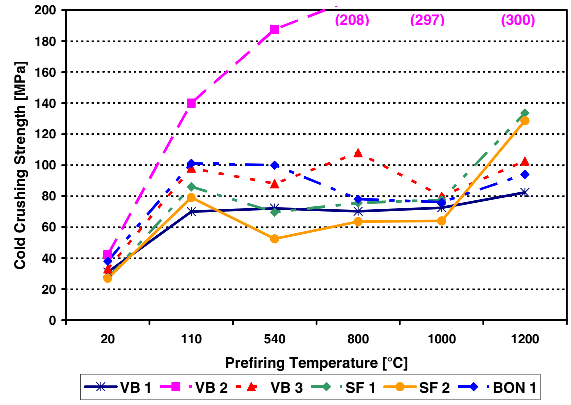

Fig. 4: Cold crushing strength of test castables after prefiring at different temperatures

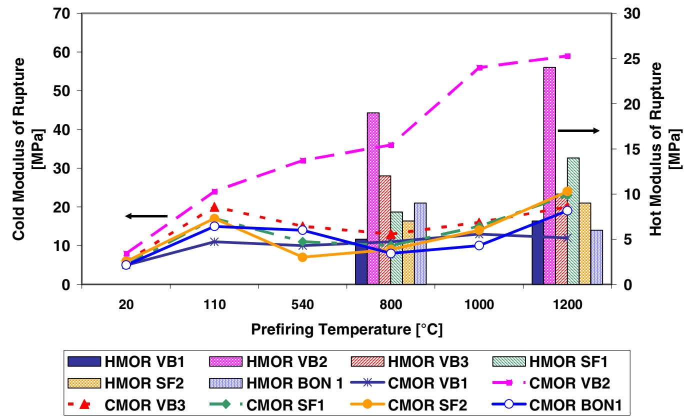

Fig. 5: Cold (lines) and hot (bars) modulus of rupture of test castables

Table 2b: Data of test castables part 2

	VB1	VB2	VB3	SF1	SF2	BON 1
Cold Crushing Strength [MPa]						
20 °C	31	42	33	27	27	38
110 °C	70	140	98	86	79	101
540 °C	72	208	108	76	64	100
800 °C	70	208	108	76	64	78
1200 °C	82	300	103	134	129	94
Cold modulus of rupture [MPa]						
20 °C	5	8	6	5	6	5
110 °C	11	24	20	15	17	15
540 °C	10	24	20	15	7	14
800 °C	11	36	13	19	9	10
1200 °C	12	59	20	23	24	19
Hot modulus of rupture [MPa]						
800 °C	5	19	12	8	7	9
1200 °C	7	24	10	14	9	6
Thermal shock resistance [cycles]						
	> 30	8	> 30	> 30	> 30	>30

All silica free castables have a high thermal shock resistance exceeding 30 cycles 950 °C – air quenching (s. **Table 2b**). Some slight cracks are formed after the first cycle but those are not increasing afterwards, which could destroy the specimen. The silica containing VB2 achieved only 8 cycles.

Here, the disadvantage of the very high strength of this castable becomes obvious, as it remarkably reduces the thermal shock resistance.

ALUMINIUM RESISTANCE

The low wettability of Bonite by molten aluminium even at temperatures clearly above 1200 °C has been tested by an enhanced aluminium resistance test at the Corus Research Center in IJmuiden, The Netherlands. In this test refractories are subjected to an aluminium alloy 7075 enriched to 5.5 % Mg. Samples were dried at 100 °C and prefired at 800 °C and afterwards submersed in aluminium alloy at 900 °C for 120 hours. These conditions are more severe than in an ordinary cup test [19,20]. Details can be reviewed in [10].

The Bonite based castables BON 1 has been compared to two conventional castables, which are commonly used as refractories in aluminium furnaces. The conventional castables are composed of bauxite, silica fume and $BaSO_4$ (BX 1) or bauxite, high purity reactive alumina and $BaSO_4$ (BX 2). **Figure 7 a-d** shows the samples before (left sample) and after (right sample) the aluminium resistance test. A pure Bonite based castable pre-fired at 800 °C shows no discoloration (BON 1); the test piece is almost as white as it was before the test (**Figure 7 a**). In contrary, the bauxite/silica fume castable pre-treated under the same conditions shows even with $BaSO_4$ as anti-wetting a discoloration (BX 1). Two infiltration zones can be observed: a thin black outer ring and a thoroughly grey discoloration to the centre of the test piece (**Figure 7 b**).

The pure Bonite sample (BON 1) and the bauxite/silica fume sample with $BaSO_4$ (BX 1) have been pre-fired at 1400 °C before subjecting to the aluminium resistance test to simulate intense temperature conditions in aluminium melting furnaces. The Bonite castable shows even after 1400 °C pre-firing only slight discoloration (**Figure 7 c**), whereas the bauxite sample shows dark discoloration (**Figure 7 d**). A yellow discoloration and the odour of sulphide have been observed which indicate the pyrolysis of the anti-wetting agent.

An explanation for the enhanced aluminium resistance of Bonite versus bauxite/silica fume/BaSO4 under extreme conditions can be explained with the corresponding pore size distribution of the castable. Besides the low wettability of Bonite, the microporosity of the Bonite castable contributes to the high aluminium resistance.

Fig. 7a: Test pieces of pure Bonite castables (BON 1) before (left) and after (right) aluminium restistance test. Test piece fired at 900 °C before test

Fig. 7b: Test pieces of conventional bauxite castable (BX 1) before (left) and after (right) aluminium resistance test. Test piece fired at 900°C

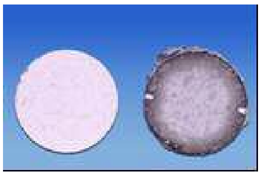

Fig. 7c: Test pieces of pure Bonite castable (BON 1) before (left) and after (right) aluminium resistance test. Test piece fired at 1400 °C before test.

Fig. 7d: Test pieces of commercially available bauxite castable (BX 1) before (left) and after (right) aluminium resistance test. Test piece fired at 1400 °C before test.

OTHER BONITE REFRACTORY PROPERTIES

The thermal conductivity of BON 1 is between 1.7 and 2 W/mK in the temperature range 300 – 1250 °C, which is remarkable low for a material with a bulk density of 2.8 g/cm³. It is much lower compared to corundum castables with 3.0 g/cm³ (3.4 – 5 W/mK), and even lower as for aluminosilicate castables with 2.5 g/cm³ (2.1 - 2.5 W/mK) [10]. This low thermal conductivity makes Bonite an interesting material for combinations of wear and insulating linings as it could make special insulating layers redundant.

SUMMARY

The new dense calcium aluminate refractory aggregate Bonite offers interesting properties especially for aluminium applications, like low wettability even at high temperatures up to 1400 °C, high alkaline resistance and low thermal conductivity. First successful applications in the aluminium industry are already ongoing. The alumina raw material concepts presented, enable the formulation of low cement castables with a high strength also in the temperature range from 800 – 1200 °C, which do not provide sufficient energy for strong sintering reactions. Bonite, Tabular Alumina, and Spinel based vibration and selfflow low cement castables containing high performance alumina raw materials for castable matrix formulation have shown the following advantages:

- Lower water demand and apparent porosity vs. conventional castable (high cement content),

- Stable microporosity with pore radii clearly below 1 µm even after firing at 1200 °C compared to the conventional and the silica fume containing low cement castable,
- Sufficient crushing strength and modulus of rupture according to industry requirements over the entire temperature range,
- Absence of oxide components susceptible for reduction by molten,
- High thermal shock resistance especially compared to the Silica containing low cement castable (disadvantage of the very high sintering reactivity of the silica fume),

OUTLOOK

This paper discusses only dense castables. But also the insulating materials for aluminium applications have special requirements regarding stability under conditions like reducing atmospheres or low wettability by molten aluminium. The synthetic, microporous calcium hexaluminate insulating raw material SLA-92 [21,22] provides a high potential for applications in the aluminium industry, because it combines chemical stability with low thermal conductivity and high thermal shock resistance [23,24]. I can also be combined with Bonite to achieve intermediate density materials, all based on calcium hexaluminate aggregates. Industrial application experiences with SLA-92 based refractory materials are reported by Kockegey et al. [25].

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