Ungeformte Feuerfest-Werkstoffe I
Ungeformte Feuerfest-Werkstoffe I   **Unshaped refractories I**

Raw material concepts for SiO₂ free high strength castables in the temperature range up to 1200 °C

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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.

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]. 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 [4, 5]. With pore diameters below 1–2 µm, a penetration of liquid Aluminium also can be hampered [6, 7, 8]. So microporosi-

ty of the castables is an alternative to anti-wetting agents especially at high application temperatures.

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. [9]

Petrochemical applications with direct contact of the refractory lining to the process atmosphere are hydrogen reformers and gasifiers operating with reducing gases containing hydrogen and carbon monoxide gases. Process conditions are pressures around 25 bar and temperatures in the range of 950–1100 °C. Additionally, catalyst crackers (fluid catalytic cracking units = "cat crackers"), ethylene furnaces, pressurized fluid bed boilers, and transfer lines can be included as demanding refractory applications [10].

Important requirements of petrochemical applications are the stability of the refractory oxides against reduction, resistance against CO attack, and abrasion resistance due to the high velocities of catalyst bearing gas streams in the vessels. Oxides with lower stability like SiO_2 can be reduced by the process gases to gaseous SiO, which afterwards condenses in heat exchangers ("fouling") and reduces the efficiency of this aggregate. Due to the SiO_2 decomposition the strength of the refractory lining decreases and the porosity increases. The hydrogen attack is discussed in more detail by Tassot et al. [10]

According to the Boudouard equilibrium 2 CO = CO_2 + C, carbon monoxide can disintegrate in the temperange range around 500 °C and lead to a Carbon build up within the refractory structure, destroying it from the inside. Free iron or iron oxide impurities in the refractory material are necessary as catalysts for the reaction. This phenomena is discussed in detail by Bartha and Köhne [11] and Tassot et al. [10], including calibrations of pressures build up by the Carbon deposition and dependency of the reaction on temperature and gas atmosphere composition and pressure.

To achieve the desired hydrogen and carbon monoxide resistance, appropriate refractory materials must be selected. For example, Tabular Alumina contains only traces of SiO_2 (max. 0.09%) and iron from crushing (typically 10–50 ppm, max. 200

ppm). This results in a high resistance against CO attack [12, 13].

The abrasion resistance is part of the specifications for refractories for petrochemical applications [13], e.g. a maximum of 7 cm^3 erosion loss (ASTM C704) is specified for dense hydraulic setting castables, but the industry standard is more towards 4 cm^3.

Thermodynamic stability of refractory materials

Muan and Osborn [15] wrote: "A quantitative measure of the stability of an oxide relative to the elements is the standard free energy of formation ($\Delta G^0 = RT \ln p_{O2}$)". A graph showing this quantity (per mole of oxygen consumed) as a function of temperature for a number of oxides is shown in **Figure 1** [16]. Additionally, the reaction of 2 SiO + O_2 = 2 SiO_2 has been inserted from [17]. "The larger the negative value for G^0 is, the greater is the stability of the oxide with respect to it's elements. Hence, the farther down on the graph a curve is located, the more stable is the oxide represented by that curve. ... It is often useful, to express these stabilities also in terms of oxygen pressure p_{O2} (eq) (or as in Figure 1 also for various CO/CO$_2$ or H$_2$O/H$_2$ ratios) of the gas phase with which the metal and it's lowest oxide coexist in equilibrium. ... The intersection of such a equal p_{O2} (or CO/CO$_2$ or H$_2$O/H$_2$) curve with a ΔG_0 line (e. g. 4/3 Al + O_2 = 2/3 Al_2O_3) defines the oxygen pressure (or other resp. gas atmosphere) prevailing when metal and it's lowest oxide coexist in invariant equilibrium. If the solid line representing equilibrium coexistence of a metal-metal oxide pair is located below a chosen equal p_{O2} (or CO/CO$_2$ or H$_2$O/H$_2$) curve at any particular temperature, the oxide is the stable phase at the chosen oxygen pressure (or CO or H$_2$ resp.)".

The higher stability of Al_2O_3 vs. other refractory oxides like SiO_2, Fe_2O_3, and TiO_2 clearly can be seen from Figure 1. Therefore refractories based on high purity synthetic alumina raw materials like those presented in this paper have an advantage over natural raw materials for the demanding applications in the Aluminium and Petrochemical industries briefly described above. Although SiO_2 bonded e. g. in Mullite (3 Al_2O_3 · 2 SiO_2) has a higher stability than the pure oxide, it still can be reduced by molten Aluminium. A detailed discussion of thermodynamics and kinetics of refractories in contact with molten Aluminium is given by Siljan et al. [4].

Strength of refractory castables

The strength of refractory castables is mainly determined by the following factors (besides others):
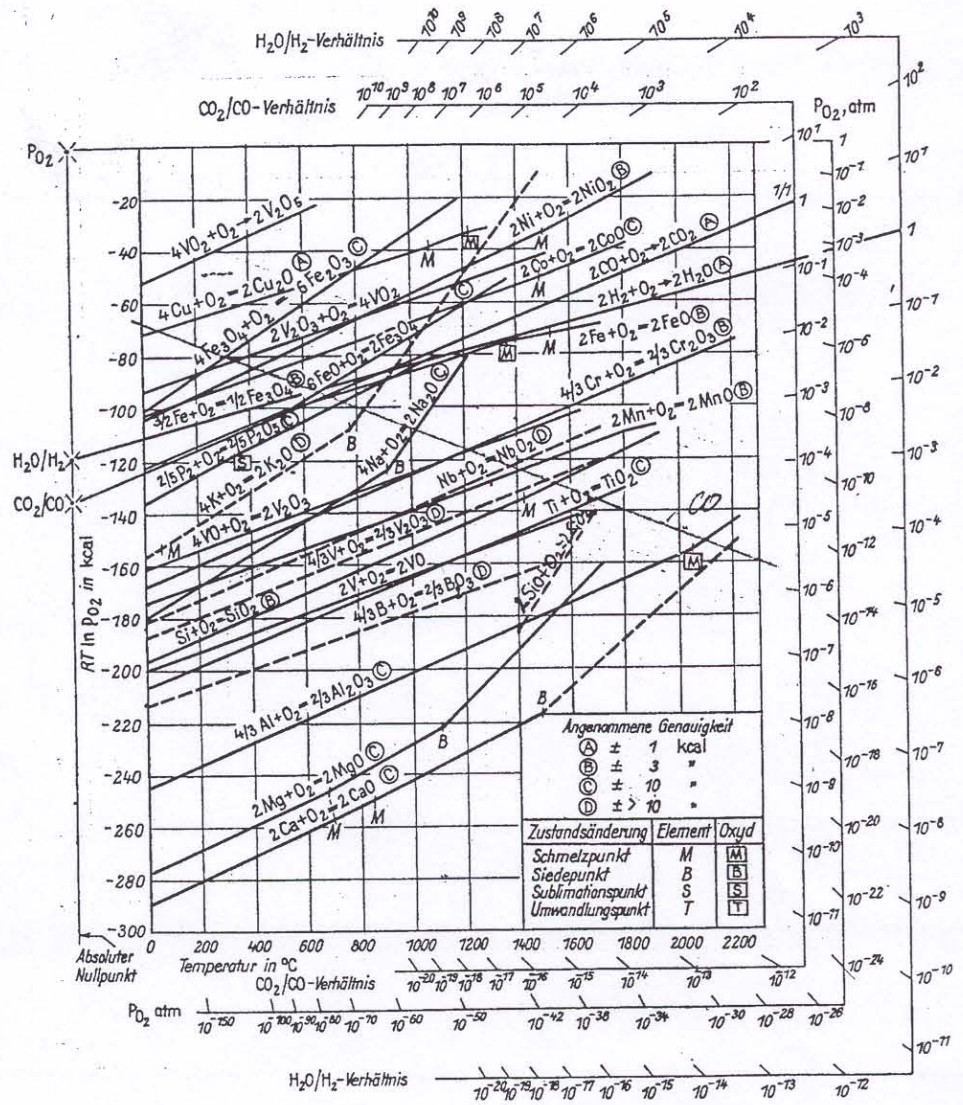– Type and content of the binder used (here high purity Calcium Aluminate cements),

Fig. 1. Stability of refractory oxides, Richardson-Ellingham diagram [15, 16]. Standard free energy of formation ΔG^0 = RT lnpO_2 (s. text)

– 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 [18]. 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 en-

Tab. 2b. Data of test castbles part 2

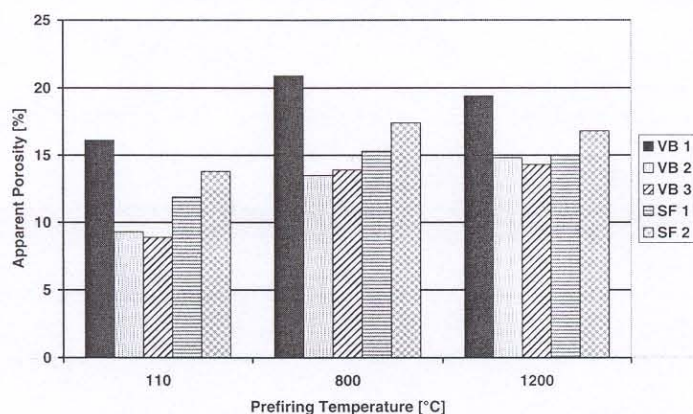|	VB1	VB2	VB3	SF1	SF2
Cold Crushing Strength (MPa)					
20 °C	31	42	33	27	27
110 °C	70	140	98	86	79
800 °C	70	208	108	76	64
1200 °C	82	300	103	134	129
Cold modulus of rapture (MPa)					
20 °C	5	8	6	5	6
110 °C	11	24	20	15	17
800 °C	11	36	13	19	9
1200 °C	12	59	20	23	24
Hot modulus of rupture (MPa)					
800 °C	5	19	12	8	7
1200 °C	7	24	10	14	9
Thermal shock resistance (cycles)					
	> 30	8	> 30	> 30	> 30
Erosion loss ASTM					
C704 [cm_]	3.7	2.5	4.0	6.0	8.6

Fig. 7. Abrasion resistance (abrasion loss acc. ASTM C704) of test castables after prefiring at 800 °C. Disadvantage of Spinel versus Tabular Alumina aggregate (s.text)

The development of the cold crushing strength (CCS) with increasing prefiring temperature is shown in **Figure 5**. 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 Microsilica 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 [e. g. 14]. All castables tested do not show a remarkable decrease in CCS below the technically required level in the temperature range around 800–1000 °C.

Figure 6 shows a comparison of Cold Modulus of Rupture (CMoR) at different prefiring temperatures and Hot Modulus of Rupture (HMoR) at 800 and 1200 °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, all test castables have a HMoR of 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 SF1 after prefiring at 540 °C.

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 sili-

ca 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.

Figure 7 shows the abrasion loss of the test castables after prefiring at 815 °C. All Tabular Alumina based castables achieved the target of max. 4 cm³ abrasion loss in the ASTM C704 test. The Spinel based castables SF1 and SF2 have a lower abrasion resistance due to the lower hardness of the Spinel compared to Tabular Alumina. Mohs hardness of Spinel ($MgAl_2O_4$) is 8 compared to 9 of the Corundum (α-Al_2O_3) in Tabular Alumina. Although Spinel additions remarkably increase the thermomechanical strength of Alumina castables especially at temperatures above 1600 °C [26, 27], Spinel aggregate should not be considered for intermediate temperature (800–1200 °C) applications, where abrasion resistance is of major importance.

Summary

With the alumina raw material concepts presented, it is possible to formulate 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. 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 Microsilica 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 Aluminium or reducing H_2/CO gas atmospheres,
– High CO resistance due to very low metallic iron contents of the synthetic aggregate raw materials Tabular Alumina T-60/T-64 (and Spinel AR 90 and AR 78) as shown from references,
– High thermal shock resistance especially compared to the Silica containing low cement castable (disadvantage of the very high sintering reactivity of the Microsilica),
– High abrasion resistance of the Tabular Alumina castables achieving the demanding industry standard of 4 cm³ in ASTM C704 testing.

Outlook

This paper discusses only dense castables. But also the insulating materials for Aluminium or Petrochemical applications have special requirements regarding stability under conditions like reducing atmospheres or low wettability by molten Aluminium. A new synthetic, microporous Calciumhexaluminate insulating raw material (SLA-92) has been developed, which has a high potential regarding application conditions mentioned before [28, 29]. Especially, as it combines chemical stability with low thermal conductivity and high thermal shock resistance [30]. It is already successfully tested in such applications and maybe focus of future reports. (F 027)
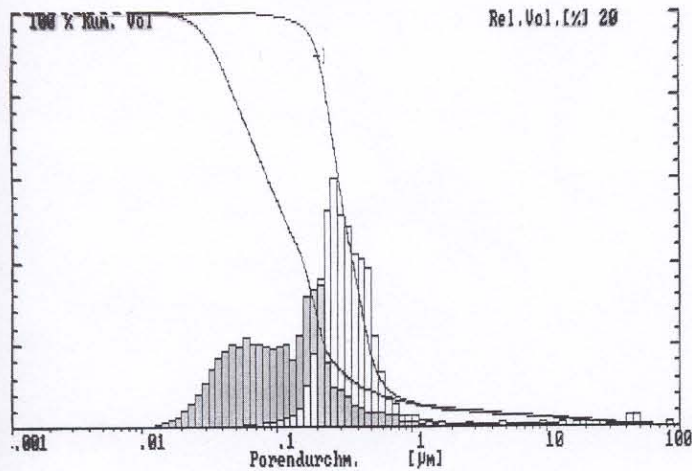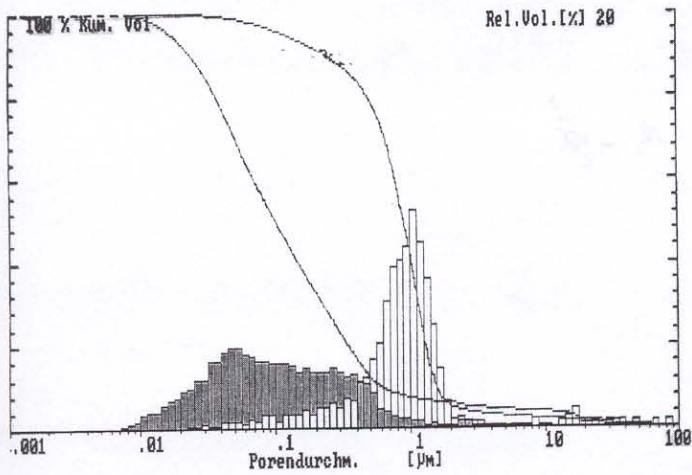
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Fig. 4. Micropore size distribution (Hg intrusion method) of test castables VB2 (up) and VB 3 (down) after prefiring at 800 °C (grey pattern) and 1200 °C. Higher increase of pore radii for the Microsilica containing VB2 at 1200 °C

Fig. 5. Cold crushing strength of test castables after prefiring at different temperatures
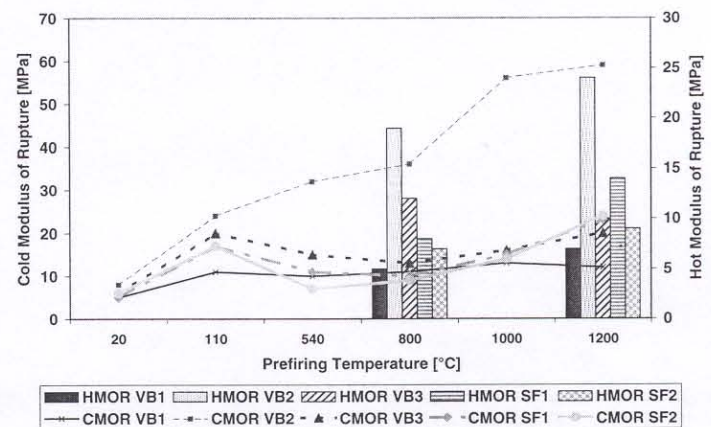
Fig. 6. Cold (lines) and hot (bars) modulus of rupture of test castables

ent porosity have been determined after curing at 20 °C for 24 hours, after drying at 110 °C for 24 hours and after prefiring at following temperatures: 540, 800, 1000, and 1200 °C for 5 hours each.

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
– Abrasion Resistance, ASTM C704 of samples prefired at 815 °C for 5 hours
– Micropore Distribution (Hg intrusion method), DIN 66 133, after prefiring at 800 and 1200 °C for 5 hours

Results and discussion

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 (s. **Figure 3**). The water demand for the Spinel selfflow castables is about 0.5 % higher than it would be for similar Tabular castables. Of
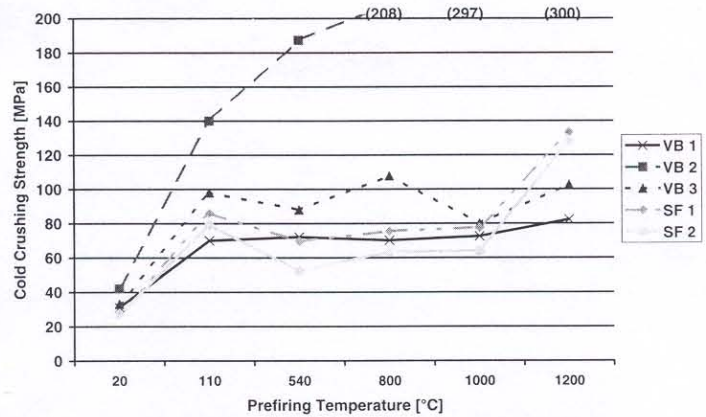
course, the higher fineness of SF2 increases the water demand and also the apparent porosity vs. the coarser type SF1. Increasing the water addition of SF1 to 5.1 % leads to a pumpable consistency of the mix without segregation of the fine fraction. But physical data for this water addition have not been measured.

The Microsilica containing castable VB2 shows a slight negative permanent linear change of 0.12% during firing at 800 resp. 1200 °C due to the very high sintering reactivity of the Microsilica even at this low temperatures. All other castables tested do not show a shrinkage during firing at 1200 °C.

As mentioned before, the microporosity of castables is important to reduce the penetration during use. After prefiring at 800 °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. Whereas the pore radii of the silica free lcc´s still are below 1 μm (median pore radii around 0.3 μm), the Microsilica containing VB2 shows an increase of median pore radius up to 0.9 μm (s. **Figure 4**). Also the cc VB1 has pore radii above 1 μm and the median pore radius increased to 0.6 μm. The 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 [8] report about castables with very narrow pores (i. e. d 50 < 0.25 μm), which behave as well as those with non-wetting agents in corrosion testing with Aluminium alloys.

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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 (Microsilica free mixes) and M-ADS 1/M-ADW 1 (with Microsilica) 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 [22]. 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;
- 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 and superground Tabular Alumina 0–0.020 mm, 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 0–0.020 mm, 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.

The superground aggregate materials Tabular Alumina 0–0.020 mm and AR 78 0–0.020 mm (95% < 20 µm, D50 of 3 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 or Spinel AR 78 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:
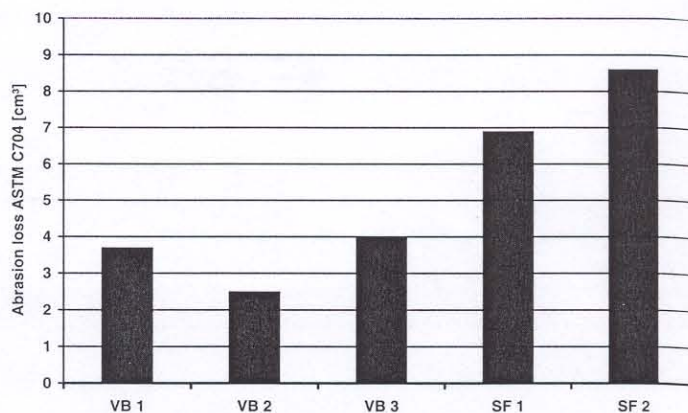

Fig. 3. Apparent porosity of test castables

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

For the low cement castables, the setting characteristics were determined by measurement of the exothermic reaction. Being hydraulic binders, calcium aluminate cements develop heat during their hydration (exothermic reaction) with the mixing water. The amount of heat generated and its time frame depend on various factors such as cement reactivity, ambient temperature, pH, and additives used to accelerate or retard setting. The heat evolution can be measured and recorded with thermocouples and a data logger and used to control the setting behaviour of castables [25]. 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 Cold Modulus or Rupture (CMoR) has been measured on $40 \times 40 \times 160$ mm bars using the three point loading device; the Cold Crushing Strength has been measured with the residual halves of the CMoR bars. Strength, bulk density, and appar-

Tab. 2a. Data of test castables part 1

	VB1	VB2	VB3	SF1	SF2
Bulk desity (g/cm³)					
110 °C	2,96	3,16	3,21	2,99	2,93
800 °C	2,87	3,13	3,21	2,99	2,89
1200 °C	2,87	3,13	3,18	2,97	2,89
Apparent porostity (%)					
110 °C	16,1	9,3	8,9	11,9	13,8
800 °C	20,9	13,5	13,9	15,3	17,4
1200 °C	19,4	14,8	14,3	15,0	16,8
Permanent linear change (%)					
110 °C	0	0	0	0	0
800 °C	−0,07	−0,12	−0,03	−0,06	−0,07
1200 °C	0,02	−0,12	0,12	0,13	0,09
Microporosity median pore radius (µm)					
800 °C	0,30	0,10	0,12	0,16	0,23
1200 °C	0,60	0,90	0,32	0,27	0,34

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tire 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 or hydrogen containing atmospheres.

Raw material concepts to enhance castable strength

In general, a castable is made from several components that include refractory aggregates, e. g., Tabular Alumina and Spinel 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 microsilica 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. **Figure 2**). The theory of optimized particle size distribution of refractory castables is discussed e. g. by Madono [20] and Myhre and Hundere [21].

Microsilica (Silica fume) 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 microsilica 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 m^2/g and soda contents often below 0.1%.
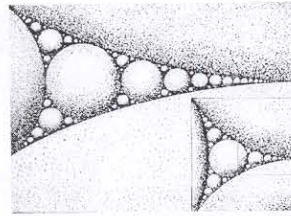
Fig. 2. Dense particle packing [18]. Voids successively filled by smaller particles to reduce water demand and enhance strength

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 it's ALCOA 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 [22–24].

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 a low cement content. In high quality cements, the total content of impurities like SiO_2 and Fe_2O_3 is below 0.5%.

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

Type	VB1 Tabular cc	VB2 Tab. lcc + Ms	VB3 TRab. lcc	SF1 Spinel lcc	SF2 Sp. lcc fine
Coarse fraction up to 6 mm (wt %)	T-60: 73	T-60: 74	T-60: 75	AR 90: 40 AR 78: 28	(up to 3 mm) AR 78: 65
Fines < 45 µm (wt %) T-60 0–0.045 mm LI	7	8			
T-60 0–0.020 mm			7		17
AR 78 0–0.020 mm				5	
CTC 20		10			13
CTC 30			13	22	
CTC 55					
Microsilica 971 U		3			
Cement (wt %)	CA-25 C: 20	CA-14 M: 5	CA-270: 5	CA.270: 5	CA-270: 5
Additive (wt %) Dispersing Aluminas		M-ADS 1: 0.6 M-ADW 1: 0.4	ADS 3: 0.4 ADW 1: 0.6	ADS 3: 0.6 ADW 1: 0.4	ADS 3: 0.6 ADW 1: 0.4
H_2O (wt %)	7,5	4,1	3,9	4,6	4,8
Flow (mm) 10 min	208	197	212	228	245
30 min	200	192	209	237	250
60 min	18,8	184	209	240	248
Chemistry (wt %) Al_2O_3	95,3	93,9	98,5	85,0	78,7
SiO		3,4			
CaO	4,0	1,5	1,5	1,5	1,5
MgO				13,4	19,5

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