[5] Hundere, A. M.; Myhre, B.: Substitution of Reactive Akumina with Microsilica in Low Cement and Ultra Low Cement Castables, Part II.: The Effect of Temperature on Hot Properties, UNITECR'97, 1997, 91–100.
[6] Roy J. M.; Tingley L. R.: High-Performance Aluminas for Refractories, Interceram, Vol. 43, No. 4, 1994, 236–239.
[7] Kriechbaum, G. W.; Gnauck, V.; Laurich, J. O.; Stinnessen, I., Routschka, G., van der Heiden, J.: The matrix advantage system, New raw materials for low moisture, Self-leveling and Vibration Placed Alumina and Magnesium Aluminate Spinel Castables, Proceedings of UNITECR'97, New Orleans, 1997, 645–655.
[8] Bier T. A.; Parr C.; Revais C.; Namba A.: The roles of fine silika and reactive alumina and their interactions with calcium alumintes in refractory castables, TARJ, Tokyo, Japan, 1998.

E-SY Pump – The new solution for pumpability of silica free high performance tabular alumina and spinel castables

Dr. rer. nat. Gunter Büchel, Manager R&D Refractories Ceramics, Polishing and Market Development Europe;
Dr. rer. nat. Andreas Buhr, Technical Director Refractories, Ceramics, Polishing; Rainer Kockegey-Lorenz, Application and Market Development Manager Refractories, Ceramics, Polishing; Dr. rer. nat. José M. Aroni, Application & Market Development Engineer – all Almatis GmbH, Frankfurt/Ludwigshafen
Robert W. McConnell, Application and Market Development Manager – Almatis Inc., Bauxite, USA

Abstract

Good pumpability of low water demand castables is a key technical challenge for high performance, high purity castables based on tabular alumina and spinel. Additions of silica fume to achieve the desired rheology for pumping at reasonable pressures is not an option for synthetic alumina based castables, since it would reduce the thermo-mechanical strength at high temperatures and reduce the corrosion resistance.

The challenge is to develop alumina matrix concepts, which give castables a low dilatancy even under extreme shear conditions which in double piston pumps for pumpcasting and shotcreting. The new products E-SY Pump 1000 and 2000 are solutions to this challenge. Field trials have proven that tabular alumina castables using E-SY Pump 1000 and 2000 as matrix aluminas fulfil the rheological requirements of these pumps and that these castables can even be pumped with small mortar pumps.

The difference between E-SY Pump 1000 and 2000 is their mineralogical composition. E-SY Pump 1000 contains only alumina components whereas E-SY Pump 2000 contains alumina and alumina-rich spinel. The addition of fine alumina-rich AR 78 spinel to castables significantly increases both slag resistance and hot strength. E-SY Pump 2000 combines superior pumpability with the advantages of alumina-rich spinel and is of high interest, for example, in steel ladle applications.

The paper discusses the properties and application results of the new aluminas based on laboratory tests and field trials.

Introduction

Synthetic Alumina based raw materials are increasingly being used in a wide range of industries such as refractories, ceramics, and polishing. There is a trend in refractory industries towards monolithic linings to replace bricks. Common technologies for pumping refractory castables during installation are different in Europe and North America. In Europe, mixer-pumps are used, which pump castables after batch mixing by pressurized air through a hose. This technology is not very demanding regarding the castable rheology and either vibration or self-flowing castables can be used. In North America castables are also batch mixed. However, pumping is often done with double piston pumps, which create high shear rates within the castable. Due to the high shear rates, castables with very low dilatancy are required which demands special attention to the castable composition and rheology. Pumpability of castables is a must for shotcreting installation, but lower dilatancy is generally an advantage for easier installation. The pumpability over long distances, even with small low-power mortar pumps, is of interest e.g. for low volume repairs. Besides pumping, low dilatant castables have advantages also in many other applications, such as self-flowing installation.

The castable rheology is mainly defined by the matrix composition below 100 µm, and particularly below 45 µm, e.g. self-flowing castables require a higher amount of fines than vibration castables [1, 2]. It is difficult to achieve pumpability of high purity Tabular and Spinel castables since very low dilatancy is required. Initial formulations used silica fume as superfine matrix components but refractoriness and thermomechanical stability decrease and therefore this limits the use in high performance applications [3].

What makes a pumpable mix?

A high quality castable formulation is principally set up by a coarse and fine fraction [1]. The coarse fraction, which contains aggregates such as tabular alumina or magnesia alumina spinel is typically defined as the part of the formulation above 45 µm up to 6–10 mm comprising about 65–75 wt.-% of the total formulation. Since aggregates are rigid components, the flow behaviour of a castable is mainly influenced by viscous deformation during the flow process. The quantity of matrix fines, defined as the fraction below 45 µm, must be high enough to prevent collision of coarse aggregates during flow. They have an important influence on the rheology, workability and strength development of the final product. Lab results show that vibration castables require approx. 25% matrix fines compared to more than 30% for self-flow castables.

Tab. 1. Typical data of E-SY PUMP 1000 and E-SY PUMP 2000

Chemical Analyses		E-SY PUMP 1000	E-SY PUMP 2000
Na_2O	%	0.3	0.1
MgO	%		12.0
SiO_2	%	0.10	0.10
Fe_2O_3	%	0.04	0.04
Physical Properties			
BET	m^2/g	3.3	3.5
Cilas D50	µm	1.9	1.9
Cilas D90	µm	16	16
Grain size distribution		Bimodal	Bimodal

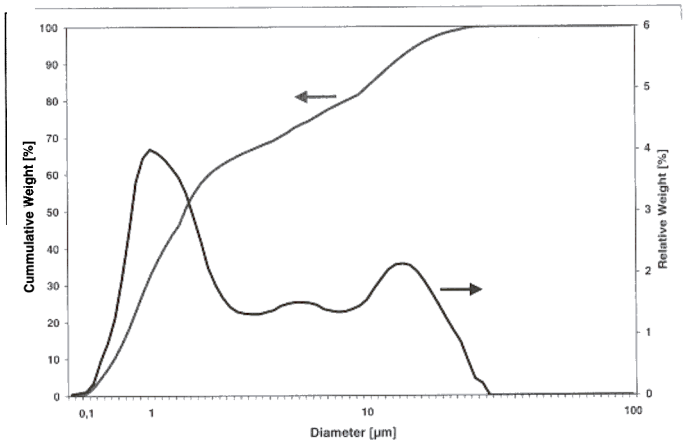

Fig. 1. Typical particle size distribution of E-SY Pump 2000, measured with laser granulometer (Cilas 1064)

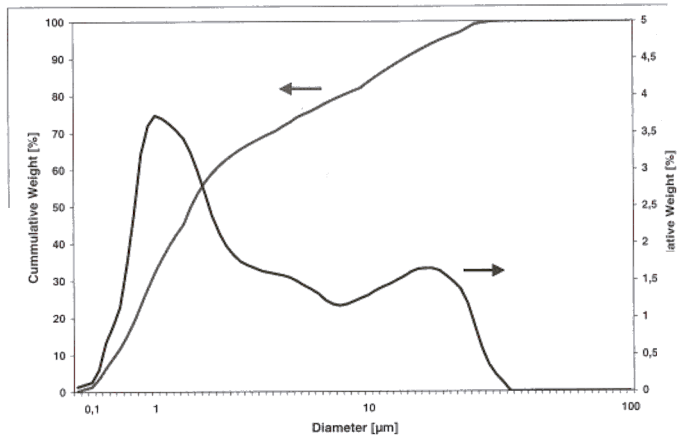

Fig. 2. Typical particle size distribution of E-SY Pump 1000, measured with laser granulometer (Cilas 1064)

As a first approach, self-flow castables were used for pumping trials. However, the experience was that their rheology was too dilatant and that they could not be pumped at all. Detailed lab investigations showed that neither vibration nor self-flow castables had a rheology to achieve steadily also pumpable properties. The dilatancy of a castable has to be low enough to achieve pumpability, however, there is no direct link between flow behaviour and dilatancy.

This observation is also confirmed in the literature [4, 5]. The theory that low mixing energy is required for pumping was tested with a special rheometer [6]. Pumping conditions were simulated by a special lid in the rheometer, which leads to volume restriction similar to pumping. Pileggi showed that self flow is no criteria to judge the pumpability of a castable. In contrary to the expectation, castables mentioned as "easy mixing castables" showed self-flow or vibration rheology. Low mixing energy and torque values at high shear rates under volume restriction have to be achieved to ensure pumpability of a castable composition.

Based on the experience gathered by extended lab trials, E-SY Pump series has been developed as a solution to provide low dilatancy for high purity (silica free) Tabular and Spinel mixes. It is composed in such a way that addition of 20–30% of E-SY Pump to the formulation leads to pumping rheology of a castable.

As a qualitative evaluation of the pumpability of a mix, the so called ball drop test has been developed. In the drop test, a steel ball (110 g, 30 mm diameter) falls from one meter above the mix surface into the mix and the time required from surface contact to complete submersion of the ball is measured. The measurement has to be conducted in a vessel with a depth not less than three times greater than the steel sphere diameter. The result is given as time in seconds for complete submersion of the ball. By experience, a castable with a ball drop time of less than 3 seconds is considered to be suitable for pumping.

Characteristics of E-SY Pump

Two different E-SY Pump products are available, which differ in their mineralogical composition. E-SY Pump 1000 is pure alumina based, whereas E-SY Pump 2000 contains alumina and alumina rich spinel. Both products are bimodal reactive aluminas, with typical d50 and BET of 1.9 µm and 3.3 m^2/g (E-SY Pump 1000) and 1.9 µm and 3.5 m^2/g (E-SY Pump 2000). Chemical and physical properties are summarized in **Table 1,** a typical Particle Size Distribution (PSD) of E-SY Pump 2000 is shown in **Figure 1** and of E-SY Pump 1000 in **Figure 2.**

E-SY Pump is, like other multimodal reactive aluminas, produced by co-grinding which gives higher homogeneity and improved rheological behaviour compared to single component formulations. The advantage of co-grinding can also be seen in the results of the ball drop test, where E-SY Pump gives an immersion time of 1 second but blended single reactive aluminas of similar composition only 3 seconds.

Castable properties with E-SY Pump

Based on E-SY Pump 2000 four different low cement castables were developed for pumping trials in a *low power mortar pump* or a *double piston pump*. The low cement castables contain a range of coarse aggregate sizes (T-60/T-64), and up to 27% E-SY Pump 2000 and dispersing additives (ADS 3, ADW 1) (see **Table 2**). Depending on the castable composition, low dilatancy could be achieved with 5.6–7.0 % water, which is reflected in a ball drop of 1–2 seconds. From all castables flow properties were determined with a cone test (lower Ø 100 mm, upper Ø 70 mm, height 80 mm). The castable setting time has been measured by the EXO method, recording the temperature development during setting. Test pieces have been prepared and tested according to the European standard ENV 1402 "Unshaped refractory products", Part 5 and Part 6. Hot properties (HMOR), density water absorption and open porosity were measured by DIFK, Bonn, Germany. Further details on sample preparation are described in a previous paper [1]. Physical properties of the castables are compiled in **Table 3.**

For trials in a ***low power mortar pump***, castables Top 2 LPP and Top 1 LPP were used. Top 2 LPP contains coarse aggregates up to 2 mm and has a low dilatancy with 20% E-SY Pump 2000 and 6.6% water. The rheology of the castable with a top cut of 1 mm is similar when 25% E-SY Pump 2000 and 7% water are used (TOP 1 LPP). Both castables have a flow at 30 minutes

Tab. 2. Composition and properties of pumpable castables with different top-cuts

Components \ Castable			Top 2 LPP	Top 1 LPP	Top 6 DPP	Top 2 DPP
			Low power pump		Double piston pump	
Coarse Fraction (0.5–6mm)	T-60/T-64	%	45	40	38	45
Fine fraction (0–0.5 mm)	T-60/T-64	%	30	30	30	25
Reactive Alumina	E-SY PUMP 2000	%	20	25	27	25
Cement	CA-270	%	5	5	5	5
Dispersing Aluminas	ADS 3 ADW 1	% %	0.7 0.5	0.7 0.5	0.7 0.5	0.7 0.5
Organic fibres	17 DTEC	%	0.1	0.1	0.1	0.1
Water		%	6.6	7.0	5.6	5.8
Ball drop		s	1	2	2	1
Pressure max.	Low power pump Double pistol pump	bar bar	2 –	2 –	– 170	– 170

Tab. 3. Characterisation of pumpable castables with different top-cuts

	Castable	Top 2 LPM	Top 1 LPM	Top 6 DPP	Top 2 DPP
	Pretreatment	Low power pump		Double piston pump	
Flow [mm]	10 min 30 min 60 min	281 279 258	307 308 299	247 249 247	239 232 235
EXO	Start 1 / min Start 2 / h Exo Max / h	578 13.3 16.9	281 7.2 9.9	254 7.3 9.5	413 10.6 13.0
CMOR [MPa]	20 °C / 24 h 110 °C / 24 h 400 °C / 5 h 1000 °C / 5 h 1500 °C / 5 h	3 12 8 12 48	2 10 8 9 56	3 13 12 12 59	3 14 12 14 25
CCS [MPa]	20 °C / 24 h 110 °C / 24 h 400 °C / 5 h 1000 °C / 5 h 1500 °C / 5 h	10 54 44 39 168	11 47 37 29 165	13 59 63 52 309	14 55 67 51 238
Permanent Linear Change [%]	110 °C / 24 h 400 °C / 5 h 1000 °C / 5 h 1500 °C / 5 h	±0 -0.08 -0.03 -0.03	±0 -0-09 -0.06 -0.33	±0 -0.06 -0.03 -0.32	±0 -0.06 -0.04 -0.37
HMOR [N/mm²]	1500 °C / 5 h	16	12	22	22
Bulk Density [g/cm³]	110 °C / 24 h 1000 °C / 5 h 1500 °C / 5 h	3.06 3.00 3.01	3.00 2.88 2.98	3.01 3.04 3.02	3.02 3.03 3.04
Apparent Porosity vol.-%	110 °C / 24 h 1000 °C / 5 h 1500 °C / 5 h	16.1 19.0 19.5	17.7 22.9 20.6	13.7 18.1 18.9	15.3 18.3 18.5
Water absorption [wt-%]	110 °C / 24 h 1000 °C / 5 h 1500 °C / 5 h	5.3 6.3 6.5	5.9 7.9 6.9	4.4 5.9 6.2	5.1 6.1 6.1

(F30) of >280 mm and a ball drop time of 1–2 seconds. The EXO start was adjusted to 4 hours to avoid setting and clogging in the hose during the trials. However, the setting time can be adjusted by changing the ADS 3/ADW 1 ratio. Despite the relatively high water content of the castables, test pieces show technically sufficient strength in all temperature ranges, e.g. CCS >30 MPa (1000 °C) and >165 MPa (1500 °C) and HMOR at 1500 °C between 12 and 16 MPa. The bulk density is around 3 g/cm³ and there is only little shrinkage at 1500 °C (permanent linear change: max –0.33%).

Pumping trials with the mortar pump

Based on the lab results, both castables were tested with a simple low power mortar pump (5 EVTM Pump, Putzmeister Mörtelmaschinen GmbH). Pump trials have been performed with 70 kg castable mix (coarse and fine Tabular sizes, Reactive Aluminas, Calcium Aluminate Cement, fibres, and Dispersing Aluminas). A mix of E-SY Pump 2000 and dispersing aluminas was filled into the mixer and homogenized with the whole calculated quantity of water for three minutes. Afterwards the Tabular sizes and the Cement where added, and mixing was continued for another six minutes. This procedure was required since the engine power of the mixer was initially not sufficient to homogenize the castable component in one step. Once the castables were homogenized, they could both be easily pumped through a hose with 50 mm diameter over a height of three meters. During pumping, the pressure never exceeded 2 bar. Due to the limited distance between the screw and the casing of mortar pump a maximum top cut of 2 mm was chosen to avoid clogging by coarser grains.

Pumping trials with the double piston pump

For the pump trials with a **d**ouble **p**iston **p**ump, castable Top 6 DPP with a maximum grain size of 6 mm was set-up. With 27% E-SY Pump 2000 and only 5.6% water pumpable consistency could be achieved. In addition, the Top 2 LPP was slightly adjusted to achieve low dilatancy with only 5.8% water and 25% E-SY Pump (Top 2 DPP). Both castables have a F30 of >240 mm and a ball drop time of 1–2 seconds. The pump trials were conducted in a double piston pump MBS 70/80 (Montanbuero GmbH). All components of the castable were dry-mixed before the pump trial. Castable batches of 500 kg were mixed with water, transferred to the pump vessel and a further 250–500 kg were mixed to complete the required quantity. Despite the high shear rates in the double piston pump, both castables could be easily pumped over a distance of 50 m through several rubber hoses and steel pipes with 50 mm and 38 mm diameter. The pumping pressure never exceeded 170 bar during the whole pump trial. The dilatancy of both castables is considered to be low enough for pumping even over longer distances, which is considered to be a normal range by the experienced operators.

Due to the better mixing equipment attached to the double piston pump, castables used for the trial required less water than

using the low power mortar pump and easy pumpability was achieved with only 5.6% water. The lower water content results in higher strength of the castable samples compared to samples from the mortar pump trial. E.g. the CCS at 1500 °C raises from 165 MPa (Top 1 LPP) to more than 300 MPa (Top 6 DPP) and the HMOR rises to 22 MPa.

All castables and pump trials have been performed with the Spinel containing E-SY Pump 2000. However, they could also have been done with the high alumina based E-SY Pump 1000.

Conclusions and Outlook

The trend towards monolithic lining requires state of the art equipment and appropriate castables formulations. The dilatancy of high purity vibration and self-flowing castables hampers the pumping application, especially when double piston pumps are used. Initial formulations used silica fume in superfine matrix but with a negative impact on refractoriness and thermomechanical strength. With the E-SY Pump 1000 (pure alumina) and 2000 (Spinel containing) two types of high purity Reactive Aluminas are available which allow the composition of low dilatancy castable formulations. Several castables compositions based on E-SY Pump 2000 gave a reduced dilatancy compared to self-flowing castables. Field trials showed that E-SY Pump castables are pumpable both with simple low power mortar pumps and double piston pumps, which are very demanding with respect to the castable rheology. Castables could be easily pumped over a distance of 50 m though several hoses with diameter of 50 mm and 38 mm.

Besides pumping, dilatant castables are difficult to install in many applications. Initial lab trials show that the general rheology of vibration and self-flow castables can be improved by E-SY Pump by exchanging some reactive aluminas for E-SY Pump products. Further studies are ongoing including also non cement castables, based on the calcia free binder Alphabond 500. (F 14)

References

[1] Kriechbaum, G. W.; Gnauck V.; Laurich, J. O.; Stinnessen, I.; Routschka, G.; van der Heijden, J.: The Matrix Advantage System, a new approach to low moisture LC selfleveling and alumina rich spinel castables, Proc. 39. International Colloquium on Refractories, Aachen, Germany, 1996, 211–218.

[2] Laurich, J. O.; Buhr, A.: Synthetic Alumina Raw Materials – Key Elements for Refractory Innovations, Unitecr '99, Berlin, Germany, 348–355.

[3] Kriechbaum, G. W.; Gnauck, V.; Routschka, G.: The influence of SiO_2 and on the Hot properties of High Alumina Low Cement, Proc. 37. International Colloquium on Refractories, Aachen, Germany, 1994, 150–159.

[4] Peleggi, R. G.; Marques, Y. A.; Vasques Filho, D.; Pandofelli, V. C.: Shotcrete Performance of Refractory Castables, Refractories Applications and News Vol. 8, 2003, No. 3, 15–20.

[5] Pileggi, R. G.; Pandofelli, V. C.: Rheology and Particle Size Distribution of Pumpable Refractory Castables, Am. Ceram. Soc. Bull. Vol. 80, 2001, No. 10, 52.

[6] Pileggi, R. G.; Paiva, A. E.; Gallo, J.; Pandofelli, V. C.: Novel Rheometer for Refractory Castables, Am. Ceram. Soc. Bull, Vol. 79, 2000, No. 1, 54–58.