PUMPING AND SHOTCRETING MATERIALS FOR ALKALI AND ABRASION RESISTANCE APPLICATIONS

Minghua Zhang, Dr.Sankar Kannabiran
Refractory Research Centre, Höganäs Bjuf AB, Bjuv, Sweden

Abstract
Self-flowing, pumpable and shot-creting materials have found widespread applications in many industries such as boilers, incinerators, cement, steel etc. Alkali and abrasion resistance are two key performance deciding factors in most of these applications. Some applications demand combination of both. Many literatures focus on shot-creting installation method itself and its placing properties. This paper presents the physical, mechanical and hot abrasion properties of an alkali resistance 50 % Al_2O_3 low cement and another alkali and abrasion resistance 75 % Al_2O_3 low cement castables which are installed through self-flowing, pumping and shot-creting.

1. Introduction

The refractory materials research have focused upon the development of monolithic castables which offer a comparable level of performance to bricks but with more installation flexibilities. Self-flowing and pumpable refractories has evolved from low cement castables (LCC*)*. The ability of the self-flowing castables to move behind forms and around anchors in difficult to reach areas is a great advantage in installation. Typically, internal or external vibration is necessary for the placement of the low cement type castables to fill behind forms. Additionally, these self-flowing or pumpable castables may be transported to high elevations. With such high self-flowing characteristics, it might be anticipated that these products would have higher shrinkage after curing, drying, and firing than the regular low cement castables. However, maintaining a low water content with proper mix design avoids these problems. In fact, similar procedures may be used for curing, drying, and firing as for low cement castables. Sections through properly prepared self-flowing LCC reveal the high density and uniform texture of the grain structure. While these self-flowing castables utilize sizing and cement content similar to low cement and ultra-low cement castables, many separate features have been optimized to generate the self-flowing property.

Self-flowing castables are now being used, often times replacing brick, plastics, and conventional castables, in ladles, aluminum furnaces in the upper sidewalls and roofs, ceramic kiln car decks and in the steel industry in ladle covers, tundish covers, tundish safety linings, and precast shapes. Also used in rotary kilns nose rings, lifters, firing hoods, coolers, preheater maintenance, and in incinerators in charging zones and burners. Other special mixes are used in the aluminum industry at or near metal contact in the lower sidewalls, hearths, ramps, and door skills/jambs.

Pumpable installation is an affordable alternative to gunning or casting and provide easy access to difficult to reach areas. “Shotcrete” is a wet-method for the application of special monolithic refractory materials. Premixed, pumpable refractory castables are conveyed to the place of application with special high pressure pumps (approx. 250 bar) over distances of 80 m and more. The castables are “sprayed” with compressed air through a special nozzle. Simultaneously an accelerator is added and mixed in the nozzle, which guarantees the bond and stability of the applicated castables at their installation places. “Shotcrete” method achieves nearly the same physical values (density, strength) as a regular LCC. No complex formwork is necessary for the application which saves precious time and costs. Wet shotcrete has evolved as a result of the advances in pumpable castable, rheometric analyses, equipment and additives [1-15]. These developments have led to the introduction of wet shotcrete into refractory industry.

This study presents the physical and thermo-mechanical properties of castables which are installed through self-flowing, pumping and shot-creting. Alumino-silicate castables of two different Al_2O_3 content have been investigated.

2. Experimental details

2.1 Base materials

General descriptions of the low cement castables used in testing are presented in Table.1

Table 1. Details of castables used.

Materials General Description	Höganäs Pump LC50	Höganäs Pump LC75
	Good abrasion and excellent alkali resistance	Excellent abrasion and alkali resistance
Aggregate	Chamotte	Bauxite and Mullite
Al_2O_3 %	50	75
Sev.Temp.(°C)	1550	1700

2.2 Samples Preparation

Three types of samples were prepared for each material. For self-flowing consistency, castables samples were made in laboratory. Samples of pumpable and shot-creting materials were prepared from field installations. For shot-creting, two different accelerators (hydrated lime (SH-CaO) and/or sodium silicate (SH-WG)) were used. Cold crushing strength (CCS), apparent porosity (AP) and bulk densities (B.D) were measured as per EN ISO 1927 standards. For abrasion testing, samples of 100mm x 100mmx 65mm samples were prepared, dried at 110°C and pre-fired at 815°C. Cold abrasion loss measures were performed according to ASTM C 704. The details of hot abrasion testing can be found elsewhere [16-17]. For alkali resistance tests, samples 100mm x 100 mm cylindrical samples with a central hole of 50 mm in diameter and 50 mm deep were cast. After drying of samples at 110°C for 24 hours the hole was filled with 50 g of potassium carbonate powder (K_2CO_3). Samples were placed in 1100°C oven for 5 hours and at the end of the period were left to cool to room temperature. The samples at room temperature were mid-cut and examined for the influence of alkaline.

2.3 Pumping and Shotcrete Technology

Thanks to Putzmeister Shotcrete Technolgy provides us the samples of pumpable and shotcrete castables.

3 Results and Discussions

3.1 LC50 castables

The BD, AP and CCS after drying and firing at different temperatures are presented in figures in Table 2. The BD is at similar level for all materials except SH-CaO. Similar effect is noted in AP

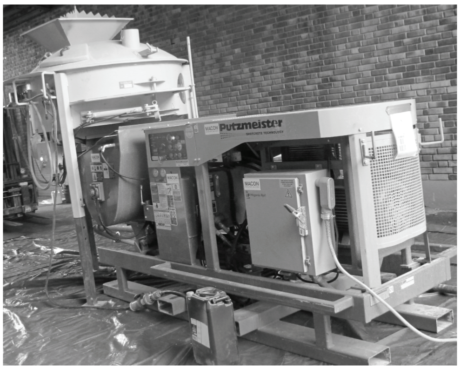

Fig.1 Equipment for pumping and/or shotcreting

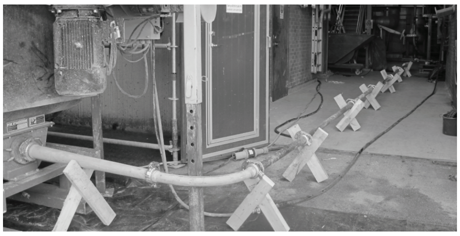

Fig.2 Setup of pumping and/or shot-creting

Fig.3 Pumping of Höganäs Pump LC50

Fig. 4 Shot-creting of Höganäs Pump LC50

and CCS also. The shotcrete accelerator type plays a major role in physical properties of installed material. The interaction of accelerator with the castables and the compaction nature during placement of castable while shot-creting varies extensively from hydrated lime slurry to sodium silicate type accelerator. The potential reason for degradation of shotcreted material has been noted due to the very high level of consumption of accelerator slurry (means high level of water) during installation (calculated from consumption in field).

3.2 LC75 castables

LC75 castables' data is shown in Table 3. Those results indicated that pumpable castable has the highest CCS. Regarding shotcrete castables, the addition of hydrated lime and/or sodium silicate accelerated the coagulating action. Compared with hydrated lime, the addition of sodium silicate make castables better strength, higher density and lower apparent porosity at various temperature treatment periods.

Table 2 Physical properties of LC50 castables

Drying / Firing temperature, °C	Self-flow	Pump	SH-CaO	SH-WG
BD, g/cc				
110	2,34	2,24	2,08	2,34
1000	2,31	2,23	1,95	2,32
1550	2,26	2,29	2,02	2,23
AP, %				
110	14,5	13,9	20,5	13,1
1000	17	17,6	27,8	16
1550	11,8	13,9	23,3	14,3
CCS, MPa				
110	54,67	80,35	25,43	61,65
1000	89,37	114,6	14,01	100,6
1550	106,9	83,4	10,38	49,34
Water %	7	6	-	

3.3 Abrasion resistance

The abrasion resistance of castables tested at various temperatures is presented in figure 5. Abrasion resistance is a key concern for castables used in various applications such as cement and CFD boilers industries, where the typical operating temperatures vary between 800-1100°C.

High temperature abrasion of refractories is influenced by combination of various factors of thermo-mechanical and thermo-chemical origin, such as thermal expansion, elastic modulus, hot strength and the reaction between the fine aggregates forming liquid phase and the viscosity of liquid. In addition, the alkali attack, oxidation of ingredients (C, SiC), the change of micro-structure, influence of corrosion and infiltration etc. can also simultaneously influence the abrasion of refractory surfaces [16-18, 21].

Simulation of hot abrasion resistance is a key evaluation process and the results of LC 75 AR (Fig.5) show hot abrasion resistance is increasing with temperature due to change in the thermo-mechanical properties with temperature such as modulus of elasticity, thermal expansion coefficient etc.

Table 3 Physical properties of LC75 castables

Drying / Firing temperature,°C	Self-flow	Pump	SH-CaO	SH-WG
BD, g/cc				
110	2,69	2,6	2,49	2,77
1000	2,7	2,61	2,45	2,74
1600	2,68	2,58	2,51	2,67
CCS, MPa				
110	48,76	96,76	40,23	88,92
1000	125,8	138,9	41,33	116,7
1600	132,9	151,6	42,33	73,19
AP, %				
110	13,4	13,6	19,3	13,5
1000	17,2	18	22,8	16,1
1600	15,3	18,5	22	14,8
Water %	6	5,6	-	

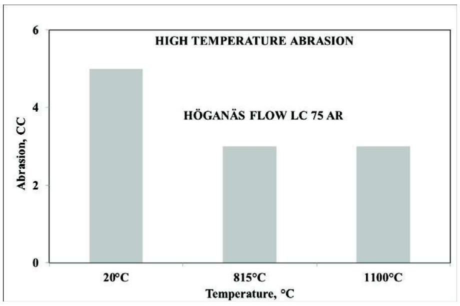

Fig.5 Abrasion resistance of LC 75 AR

7

3.5 Alkali resistance

Alkalis attack refractories severely. The alkalis generated from various sources degrade the refractories through various mechanisms; the alkalis (K_2O and Na_2O as salt of chloride or sulphate) react with refractory matrix and form various new phases which are several times volumetric and hence generate pressure within the structure. The types and nature of the new alkali-alumino-silicate phases formation is a function of chemistry of refractories; especially the matrix (i.e, alumina, silica and the other elements content in the matrix) part[19-21].Samples of LC 50 AR and LC 75 AR after alkali resistance tests are presented in figures 6 and 7 respectively, showing superiority of the materials for alkali attack.

4. Applications

Applications involving both alkali and abrasion resistance are key concern in many industries as increasing alumina content to increase abrasion resistance drastically decreases the alkali resistance.

Abrasion resistance is a property which allows a material to resist wear. Abrasion resistance is of major concern regarding the main areas found in the thermal industry.

Pump LC50 and Pump LC75 are the products developed for CFD boiler application where both alkali and abrasion resistance are prevalent in certain areas.

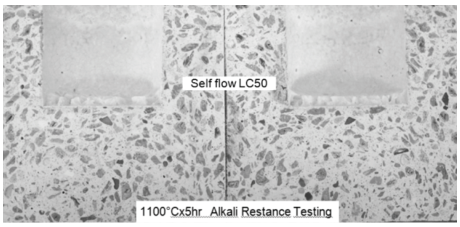

Fig.6 Alkali resistance testing of self-flow LC50

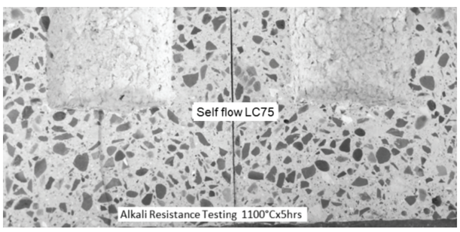

Fig.7 Alkali resistance testing of self-flow LC75 AR

5. Conclusions

- Advanced alumina-silicate castables with two different Al_2O_3 contest have been developed and used in various industries which require abrasion and alkali resistance.
- Pump LC50 for applications involving alkali attack and Pump LC75 for the application where both alkali and abrasion resistance are prevalent in certain areas, have been developed.
- Accelerator impacts physical and mechanical properties of shot-creting castables.
- Compared to pumping castables, the shotcrete castables with sodium silicate accelerator achieves nearly the same physical values (density, strength and porosity).
- However, accelerator hydrated lime makes shotcrete castable worse physical properties.

6. References

1. M.Koga, I.Takita, M.Kataoka and K.Kawasaki, New wet spray method for castables, Taikabutsu Overseas (1999), 19(3), page 14-20.
2. A.C.E.Peres, C.P.Neto, and V.C.Pandolfelli, A rheological approach on selection of additives for wet gunning castables, Canadian Metallurgical Quarterly, (2003), 42(3), page 327-332.
3. R.G.Pileggi, Y.A.Marques, D.Vasques Filho and V.C.Pandolfelli: Shotcrete performance of refractory castables, Refractories applications and news, (2003), 8(3), pages 15-20.
4. N.Cassens, Jr.,, R.A.Steinke and R.B.Videtto: Shotcreting self-flow refractory castables, Proceedings of UNITECR'97 (1997), New Orleans, USA, Vol.2, page 531-544.
5. J. E. Funk and D. R. Dinger:Predictive Process Control of Crowded Particulate Suspensions,Applied to Ceramic Manufacturing: Kluwer Academic Publishers, 1994, 327-371.
6. K. Watanabe, M. Ishikawa and M. Wakamatsu ;Rheology of Castable Refractories, Taikabutsu Overseas, (1989) **9** [1] , page 41-53
7. R.W. McConnell, G. Büchel, A. Buhr, R. Kockegey-Lorenz, and D. Gierisch: E-SY aluminas – the new solution for pumpability of silica free high performance tabular alumina and spinel castables, **www.almatis.com.**
8. S.Kannabiran, Luc Tremblay and Michel Rigaud: Role of fine aluminas on rheological behaviour of brown fused alumina based self-flow castables, 39th Annual Symposium on Refractories (2003), St. Louis section, University of Missouri-Rolla, April 9-10.
9. X.Zhou, S.Kannabiran, M. Rigaud, Design of bauxite based low-cement pumpable castables:a rheological approach, Ceramics International (2004) 30 (1), page 47-55
10. X.Zhou, S.Kannabiran, M.Rigaud, N.Zhou, S.Zhang, Influence of Calcium Aluminate Cement on Rheological Behaviour of Bauxite-Based Low-Cement Pumpable Castable, Refractories Application and News,(2004), 9(1),page 18-24
11. X.Zhou, S.Kannabiran, M.Rigaud, N.Zhou, S.Zhang, Effect of Microsilica on Rheological Behaviour of Bauxite-Based Low-Cement Pumpable Castable, INTERCERAM, (2004), 53 (3), page 166-173
12. X.Zhou, S.Kannabiran, M.Rigaud, N.Zhou, S.Zhang,Influence of Fine Fillers on Rheological Behaviour of Bauxite-Based Low-Cement Pumpable Castable, Canadian Metallurgical Quarterly,(2005), 44(1), page 23-32.
13. X.Zhou, S.Kannabiran, M.Rigaud, N.Zhou, *Influence of Aging Time on the Rheological Behaviour of Bauxite-Based Low-Cement Pumpable Castable,* Refractory applications-Transactions, (2006), 2(1), page 2-8.
14. X.Zhou, K.Sankaranarayanane, M.Rigaud, N.Zhou, S.Zhang, Effects of Dispersants on Rheological Behavior of Bauxite-Based Castable, COM'04 – *Proceedings of 4th International Symposium on Advances in Refractories for the Metallurgical Industries*, (2004), Hamilton, Canada, page 811-826.
15. Xianxin Zhou, Rheology of Bauxite-based Low-cement Shotcreting Castables, Ph.D thesis, (2004), CIREP, Ecole Polytechnique, Montreal, Canada.
16. Kannabiran,S; Alibasic,E; Yiakoumi,A; Influence of an antioxidant on hot abrasion resistance of SiC containing castables, UNITECR 2015, September 15-18, Austria.

17. Kannabiran,S; Zhang, M; Effects of grain size distribution and temperature the abrasion resistance of low cement castables, communicated to UNITECR 2017, to be presented.
18. Simmat,R;Dannert,C;Krause,O; Uirmbach , P; Implementation of a standard test method for abrasion resistance of refractory materials for testing at elevated temperatures, UNITECR 2013, 121-126.
19. Kannabiran,S; Evaluation of Al_2O_3 – SiC Materials for Alkali Resistance applications, Eighteenth Arab-International Cement Conference and Exhibition 2013, 11-13 November, King Hussein Bin Talal Convention Centre, Dead Sea, Jordan.
20. Kannabiran,S; Alibasic,E; Yiakoumi,A; Design of castables and their relevance to alkali resistance applications Aachen Refractories colloquium, 2014, p
21. S. Kannabiran: Growing with challenges, opportunities and innovations, refractories WORLDFORUM, 9(2017) [3].