Abrasion Resistance of Shotcreted Low Cement Castable at Elevated Temperatures

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Refractory gunning is a very common method especially in construction and hot/cold repair applications. Conventional dry gunning has high application areas because of the easy installation and low labor cost. Shotcreting (concrete gunning, spray cast) methods have high potential to overcome low erosion resistance of conventional dry gunning methods. In this work, the physical, mechanical and abrasion/erosion properties of gunning materials produced by dry and wet gunning methods were investigated. The abrasion properties were investigated at high temperatures (25 – 800 – 1200 °C). The blast abrasion properties of shotcreted material have very low wear loss compared to conventional gunning methods.

1 Introduction

Particulate abrasion is one of the most deleterious mechanisms for refractory monolithics in various applications such as calcination chambers and cyclones in cement industry, stoves in blast furnaces, gas transport chambers in EAF and chimneys in coal power plants. The particulate matters in flue gas causes abrasion erosion in the refractory materials. It is shortening the life of refractory linings.

Refractory gunning materials were commonly used in these applications because of their easy and fast installation advantage. In conventional gunning (dry gunning), materials were transport by pressurized air to the nozzle, where water is added. There are some limitations in dry gunning methods such as high cement and high water ratio and very low mixing time in the nozzle during gunning. Shotcreting (wet gunning, spray cast) methods have high potential to overcome the low erosion resistance of conventional dry gunning methods. In shotcrete gunning, low cement castables are prepared in a mixer by adding water and are then pneumatically transported to the nozzle, which sprays the slurry mix by pressurized air. The shotcreted materials are denser than the conventional ones and have low cement content, which is important in high temperature applications.

Abrasion wear of refractory materials is affected by several factors, which are classified into three groups: material properties (hardness, density, porosity), test conditions (test temperature, duration, test angle), and erodent powder properties (particle shape, size, flow, velocity, hardness) [1]. The most important parameter is material properties, which is most dominated by abrasion resistance. The blast abrasion test is used to simulate erosion wear of refractory gunning materials in abrasive conditions. In the present study, abrasion wear properties of gunned samples by conventional and shotcrete were investigated at high temperature (25 – 800 – 1200 °C). Abrasion loss and material properties were examined before and after abrasion test.

Tab. 1 Chemical properties of gunning material used in this study

Commercial Name	Application Method	Al_2O_3	SiO_2	CaO	Fe_2O_3	TiO_2	Na_2O+K_2O
GUNMOR 160	Dry gunning	70,2	20,82	6,17	1,02	1,15	0,6
GUNMOR 60 ST	Shotcrete	64,73	31,37	1,40	0,77	0,96	0,6

2 Experimental procedure

Two refractory materials were studied in the present work. They include conventional dry gunning (GUNMOR 160) and shotcreting (GUNMOR 60 ST). The main aggregates are andalusite in all samples. The chemical composition of the castables is given in Tab. 1. The conventional gunning sample has higher lime content (6,17 % CaO) than the shotcreting sample. Shotcreting samples are very similar to low cement castable compositions. In the conventional dry gunning method, the monolithic mix is transported by pressurized air to the nozzle. At the nozzle 14 mass-% water is added and the slurry mix is sprayed. In the shotcrete gunning method, the monolithic castable is prepared in a mixer by adding water (5,5 mass-%) and then pneumatically transported to the nozzle. After adding a quick setting agent at the nozzle the slurry mix is sprayed. The entire tests were conducted with a commercial gunning machine.

The samples obtained were gunned into 400 mm × 400 mm × 65 mm cubic moulds. The setting time of these casted blocks were measured by IP 8 ultrasonic tester. The

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Tab. 2 Erosion test parameters

Erodent Material	SiC Grain (Angular)
Erodent size [µm]	850–250
Erodent feed rate [g/min]	50
Impact angle [°]	90
Test temperature [°C]	25, 800, 1200
Test time [min]	20 min/cycles
Nozzle diameter [mm]	5
Stand-off distance [mm]	135
Sample size [mm]	115 × 115 × 65

Tab. 3 Physical properties of samples after pre-firing at 1200 °C for 3 h

Sample	BD [g/cm³]	AP [%]	CCS [kg/cm²]
Conventional dry gunning	1,98	39,11	173
Shotcreting	2,37	18,76	943

gunned bodies are demolded after 24 h at room temperature and then dried for 24 h at 110 °C as per the ASTM standard procedure. The dried concretes were cut into 115 mm × 115 mm × 65 mm sized blocks, which are placed in an electric furnace and then heated up to 1200 °C at a heating rate of 6 °C/min in air. After 3 h the furnace was shut off and the samples were cooled down to room temperature in the furnace at a cooling rate of 1,5 °C/min. The gunned blocks after firing were characterized by bulk density (BD), apparent porosity (AP), and cold compression strength (CCS) according to ASTM standard C 20 00.

Blast erosion tests on conventional gunned and shotcreted test samples pre-fired at 1200 °C were carried out according to ISO/TC 33 N 891 standards. The test parameters are shown in Tab. 2. The sample was first cleaned by pressurized air and then weighed using an electronic balance. The samples were then fixed to the sample holder of the erosion rig and eroded with SiC particles at a pre-determined particle feed rate, impact velocity and impact angle for a period of about 20 min at 25, 800 and 1200 °C respectively in air. Original gunning surfaces were used as abrasive surface to eliminate cutting defects. Two samples were used simultaneously.

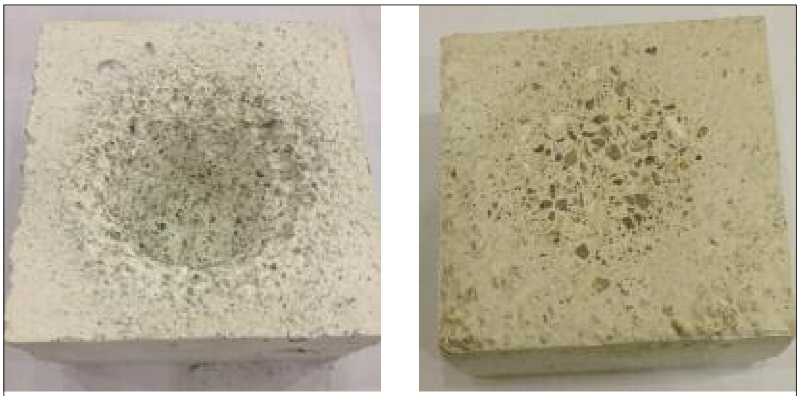
3 Results and discussion

The physical properties results obtained for the materials are presented in Tab. 3. CCS and apparent porosity of the samples prepared by conventional gunning is 173 kg/cm² and 39,11 % respectively. These samples have low CCS and very high apparent porosity values. This is due to formation of pores, which are caused by the high water additions and air entrapment during dry gunning. The porosity of the samples is found to increase with increase of water addition. The dry gunning method needs a high water content because of the limited mixing time of refractory mass with water in the gunning nozzle. For this reason, dry gunned samples need high cement addition (>15 %) because of the low mixing time and high water addition during gunning. Shotcreting samples show higher bulk density, CCS and lower porosity values. The properties of shotcreting samples are very similar to low cement vibrating castables. This is related to the low water demand in shotcreting samples. They have about 5 times higher cold crushing strength. The bulk density of a conventional gunning sample is about 1,93 g/cm³ where as density of shotcreting sample is about 2,37 g/cm³.

From data in Tab. 3, it can be concluded that the CCS of the dry gunned sample after firing at 1200 °C is lower than of the shotcreted material and the apparent porosity (AP) is higher compared to shotcreted material.

Fig. 1 shows a sample surface view after an abrasion test at 25 °C. The visual inspection of each sample noted that there are big surface differences between them. At 25 °C test, the conventional gunning samples showed a very big crater in the eroded region. The abrasion loss is about 64,5 cm³. This might be related to lower CCS and higher apparent porosity of material. There is a correlation between cold crushing strength and porosity [2, 3]. The lower CCS of a material shows a lower abrasion resistance, because of the weak bond between the particles and the matrix. The erodent material will be easily penetrated and small particles are easily knocked out from it due to the porous structure of the gunned surface. The low CCS and high porosity of dry gunning samples are responsible for promoting the formation of high abrasion rates on conventional gunning samples.

The shotcreting samples show very high abrasion resistance. A thin layer was flaked off on the eroded sample surface. The abrasion loss at 25 °C is about 6 cm³, which is very low compared to the conventional gunning method. Low water addition in shot-



(a) (b)

Fig. 1a–b The surface view of samples prepared by conventional gunning (a) and shotcreting (b) after the blast abrasion test at 25 °C after pre-firing at 1200 °C

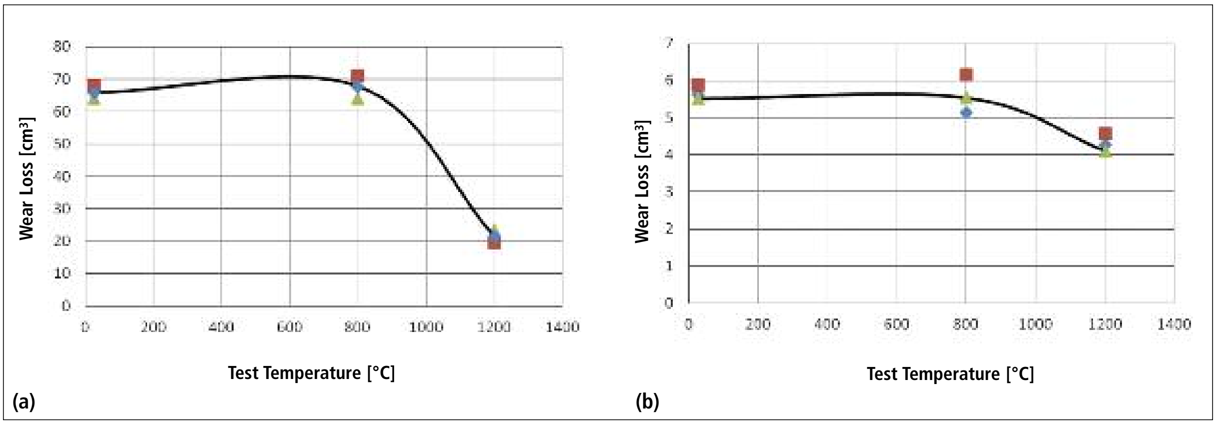


Fig. 2a–b **Abrasion loss of samples by conventional gunning (a) and shotcreting (b) after hot abrasion test at elevated temperatures**

crete samples produce a denser surface resulting in a superior abrasion resistance. There is a correlation between mechanical properties and abrasion wear [4–6]. The physical attrition of concrete starts at the surface. This behavior is related to obtaining a more compact and stronger surface. High density and strength of a material is associated with less material loss. The abrasion loss is increased when apparent porosity increases. Pores in the matrix behave as defects points and increase the abrasion.

Fig. 2 shows hot abrasion test results of samples prepared by conventional gunning and shotcreting. The volume erosion loss of samples by conventional gunning (Fig. 2a) showed 65,9, 67,5 and 21,4 cm^3 abrasion loss respectively at 25, 800 and 1200 °C respectively.

Abrasion resistance of a sample treated at 800 °C is very similar to one kept at room temperature. When the abrasion test temperature was increased from 800 °C to 1200 °C, a sharp decrease was observed in the abrasion loss. The hot abrasion test results of samples prepared by shotcreting showed 5,67, 5,61 and 4,31 cm^3 abrasion losses respectively at 25, 800 and 1200 °C respectively. There is almost no change in abrasion loss up to 800 °C, but it begins to decrease after 800 °C.

The samples prepared by conventional gunning and shotcreting shows a similar abrasion loss behavior. The slope of the lines looks almost linear for all gunned samples up to 800 °C. It implies that, abrasion behavior looks like an elastic deformation behavior. After 800 °C, there is a decrease in the slope of the line. One of the possible reasons for this is the formation of liquid phase at 1200 °C [5, 7, 8]. The liquid phase may behave like a shock absorber at elevated temperatures.

Alumina silicate materials have different thermal linear change behavior during heating up. They show thermal expansion behavior up to 1200 °C and start then shrinkage at elevated temperatures [9]. The shrinkage of alumina silicate materials at higher temperatures may decrease porosity. This might be another reason for concretes to exhibit lower abrasion resistance at elevated temperatures. According to particles size distribution, coarse particles exhibit higher abrasion resistance than fine particles [3, 5]. In the conventional gunning method, the particle size range is typically 0–4 mm while in shotcreting 0–8 mm is typical. This also has positive effects on the erosion resistance of shotcrete samples.

The abrasion coefficient is an index for abrasion resistance of concretes. The abrasion coefficients of gunned samples are shown in Fig. 3. The abrasion coefficient of conventional gunning sample is about 2–2,5 cm^3/cm^2 where as the abrasion coefficient of shotcreted sample is about 0,3–0,4 cm^3/cm^2 up to 800 °C. The slope of the line shows almost linear change for shotcreted samples, however, there is a sharp decrease in slope of the line for conventional gunned samples after 800 °C. Shotcreted samples have uniform erosion resistance up to 1200 °C.

4 Conclusion

The influence of the gunning method and material properties on the abrasion resistance of concretes has been investigated. The present work revealed that cold crushing strength is one of the most effective factors in predicting the erosion behavior of a gunning material. There is a linear relationship with CCS and abrasion resistance.

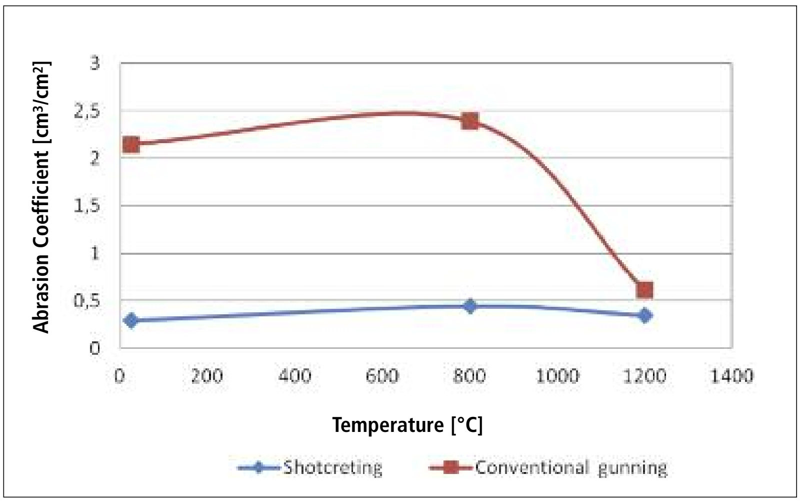


Fig. 3 Abrasion coefficient change of gunned samples at elevated temperatures

The porosity influences the erosion rate by lower plastic deformation strength due to void lacks in mechanical support. These results show that there must be a strong microstructural bonding for high abrasion resistant features. After 800 °C, there is a decrease in abrasion resistance because of the liquid phase formation in the matrix. According to their abrasion coefficient, shotcreted samples have uniform erosion resistance up to 1200 °C. It is found that shotcreted material showed the best performance when compared to conventional gunning concrete.

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References

[1] Adamiak, M.: Abrasion resistance of materials. Published by InTech, Croatia, 2012

[2] Grdic, Z.J.; et al.: Abrasion resistance of concrete micro-reinforced with polypropylene fibers. Construction and Building Materials 27 (2012) [1] 305–312

[3] Liu, Y.W.; Yen, T., Hsu, T.H.: Abrasion erosion of concrete by water-borne sand. Cement and Concrete Research 36 (2006) [10] 1814–1820

[4] Denisov, D.E.; et al.: Refractories in heat units. Abrasion resistance of refractory concretes and linings. Refractories and Industrial Ceramics 48 (2007) [1] 4–8

[5] Simmat, R.; et al.: High temperature abrasion resistance of refractory products. 10th Biennial Worldwide Conf. on Unified Int. Technical Conf. Refractories (UNITECR), Dresden/DE, 2007, 514–517

[6] Ntakaburimvo, N.; Allaire, C.: Abrasion wear of alumina silicate refractories. Advances in Refractories for the Metallurgical Industries IV, CIM Proc., ed. by M. Rigaud and C. Allaire, August 2004, 373–388

[7] Denisov, D.E.; et al.: Refractories in heat units. Abrasion resistance of refractory concretes and linings. Refractories and Industrial Ceramics 48 (2007) [1] 4–8

[8] Peng, X.; et al.: Research on abrasive resistance of several kinds of refractory products et elevated temperature. 11th Biennial Worldwide Conf. on Unified Int. Technical Conf. Refractories (UNITECR), Salvador/BR, 2009, Vol. 1 of 2, 34

[9] Peng, H.; Myhre, B.: High temperature properties of bauxite based castables with microsilica. 51th Int. Coll. on Refractories, Aachen/DE, 2006