EFFECTS OF GRAIN SIZE DISTRIBUTION AND TEMPERATURE ON THE ABRASION RESISTANCE OF LOW CEMENT CASTABLES.

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ABSTRACT

Abrasion resistance is a key concern for castables used in various applications in cement and boilers industries, where the typical operating temperatures vary between 800-1100°C. The current study is evaluating the effect of grain size distribution of a low cement castables commonly used in such applications that fails due to lack of abrasion resistance. Experiments have been conducted both at room and high temperatures to simulate the conditions existing in reality. Studies have revealed the fact that the varying grain size distribution and test temperature has varying influence on the abrasion resistance of castables while keeping the other variables such as chemistry, cement content and casting water at the same level.

INTRODUCTION

Refractories are very often subjected to abrasion due to application conditions in blast furnace, cement preheaters and cooling zone, various parts of incinerators, boilers, rotary kilns, lime kilns, and aluminium furnaces etc. When fine dust particles hurled against the refractory in a stream of hot gases moving with a considerable velocity or the charge of material or scrap falling against the refractory and damages lining. The damage of refractories by scrap falling is due rupturing the bond between particles on the surface and is totally different from destruction caused by dust in the high velocity gas stream [1-3]. Apart from these two mechanisms, the changes in the surface nature, micro-structure of refractories and the interaction of refractories with the conditions existing in applications also strongly influences the abrasion resistance of refractories being used.

In most cases, the cold (room temperature) abrasion of sintered/fired material was considered as a guideline for understanding the abrasion of materials in real use. At present, the measurement of abrasion resistance mostly follows ASTM C704 or EN932-20, which are the procedures for room temperature testing to simulate the abrasion resistance of refractories. There are several variables influencing the cold abrasion resistance of a refractory material. The cold abrasion tests carried out by various researchers tried to correlate the abrasion resistance with cold modulus of rupture (CMOR), cold crushing strength (CCS), modulus of elasticity (MOE), and apparent porosity (AP) with acceptable correlations [4-7].

There have been various attempts in recent time to design a suitable apparatus for measuring and comparing abrasion resistance of materials both at room and high temperature. However, the understanding and the importance of abrasion testing at the high temperature has started even in 1930s, on bricks of various chemistries with significant results [1]. Since then, there has been a continuous improvement in designing abrasion testing apparatus for high temperature measurements with acceptable improvements.

The recent designs of apparatus for testing abrasion resistance of refractories consider the effects of all the variables in the design and abrasive media (SiC, Alumina type). Especially, the design of high temperature abrasion testing apparatus imposes serious concerns in design to maintain homogeneity of temperature and pressure during high temperature testing [8-11].

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.

As, it is difficult to simulate the exact conditions prevailing in applications like temperature, and atmosphere (alkali, reduction, oxidation, etc.), with a same apparatus, the measurements made in the laboratory can be considered only as a guideline for selecting refractories.

The current study attempt to explore the influence of temperature and varying grain size distribution on the abrasion resistance of a low cement castable. Though there are lots of discussions going around about the suitability and design of apparatus for high temperature abrasion tests [9, 11], this study uses a commercially available abrasion tester and focuses only on material behaviour and not about apparatus design.

EXPERIMENTAL

Sample Preparation

A 60% Al_2O_3 chamotte based low cement castable (LCC) was used in this work. The ingredients were dry mixed for 5 minutes, followed by wet mixing with required water. Samples of 115x115x65 mm^3 were cast and cured at 20°C for 24 hrs. The demoulded samples were dried at 110ºC for 24 hrs, followed by pre-firing at 815 and 1100 °C (heating rate of 5°C /min and soaking time of 5 hrs). The details of castables made are presented in Table 1. The pre-firing and testing temperatures are presented in Table 2. The bulk densities (D) of all the samples were measured as per EN 993-2.

Abrasion Resistance Testing

The details of abrasion testing machine used in this experiment can be found elsewhere [12]. This test method measures the volume of abraded material from a flat surface by blasting (pressure of 0.45MPa) 1000 grams of 36 grit SiC, at right angle to the surface. The pre-fired samples were tested both at room temperature and at high temperatures (Table .2).

For calculating abrasion of materials, the samples weights before and after testing were measured. Using these details, the abraded volume in cubic centimetre (cc) was calculated using the following equation;

$$\text{Abraded volume} = [(W1-W2)/ D], \text{cc} \quad (1)$$

Where, W1 is the weight of the samples before testing in grams, W2 is the weight of the sample after testing in grams and D is the bulk density in g/cc.

Tab.1 Details of samples.

Ingredients, %	LCC1	LCC2	LCC3
60% alumina aggregate Calcined alumina, Fume silica, Calcium aluminate cement additives	Various		
Max grain size, mm	10	5	3
Casting Water, %	5.5	5.5	5.5
Bulk Density, g/cc			
After 110°C	2,58	2,56	2,57
After 815°C	2,51	2,52	2,51
After 1100°C	2,52	2,51	2,51

Tab. 2 Details of testing of samples.

Pre-firing temperature, °C	Testing temperature, °C
815	RT
815	815
1100	RT
1100	1100

RESULTS

Sample Surfaces

The samples after abrasion testing at room temperature are presented in Fig. 1 and 2 respectively. Figures 3 and 4 are the samples tested for abrasion resistance at high temperature of 815°C and 1100°C respectively.

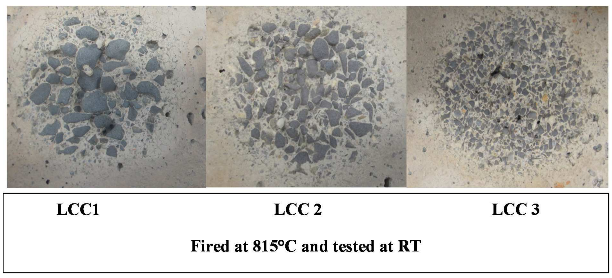

Fig.1 Samples pre-fired at 815°C and tested for abrasion at room temperature.

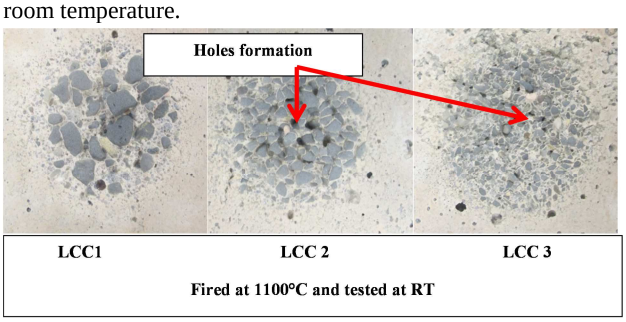

Fig.2 Samples pre-fired at 1100°C and tested for abrasion at room temperature.

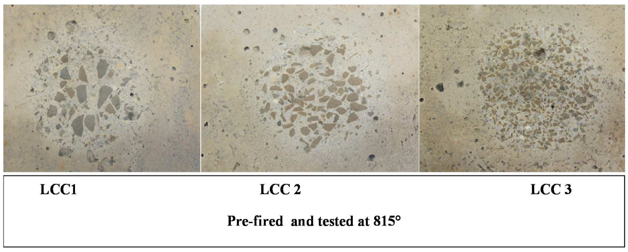

Fig.3 Samples pre-fired and tested for abrasion at 815°C .

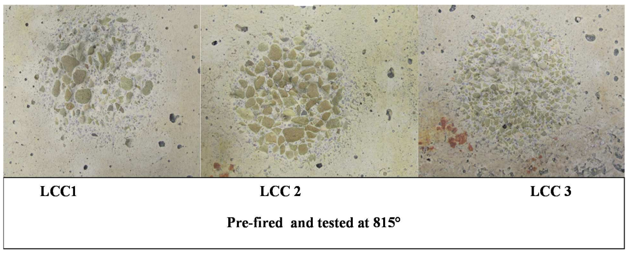

Fig.4 Samples pre-fired and tested for abrasion at 1100°C .

Abrasion Loss

The abrasion test results of samples at room and high temperatures are presented in Fig 5 and 6 respectively. The tests at RT and high temperatures compared in figures 7 and 8 respectively.

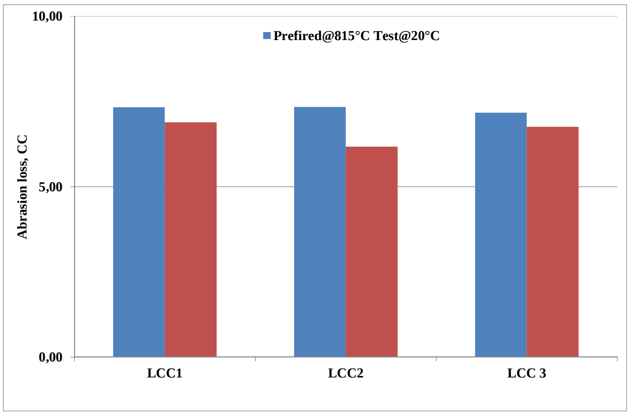

Fig.5 Samples pre-fired at high temperature, and tested at RT

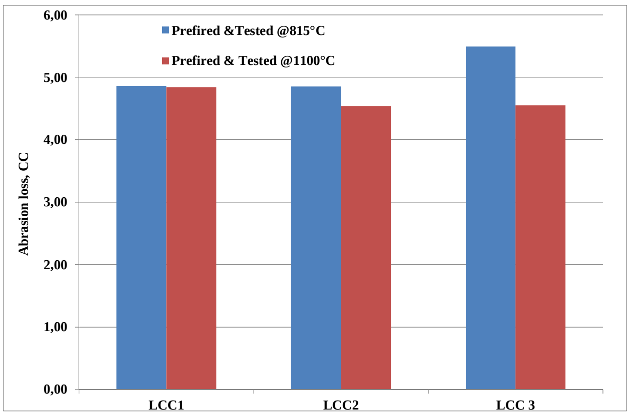

Fig.6 Samples pre-fired at high temperature, and tested at high temperatures

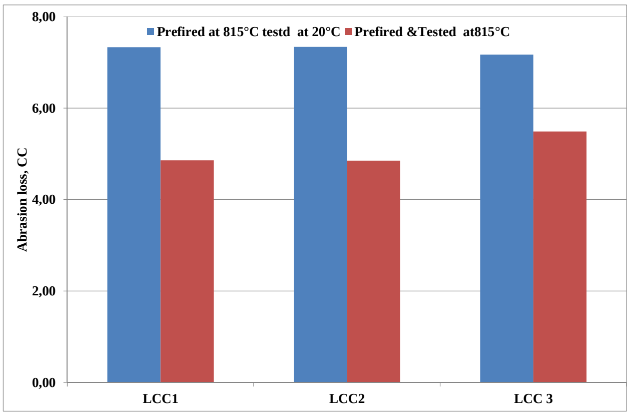

Fig.7 Comparison of low and high temperature testing of samples pre-fired at 815°C

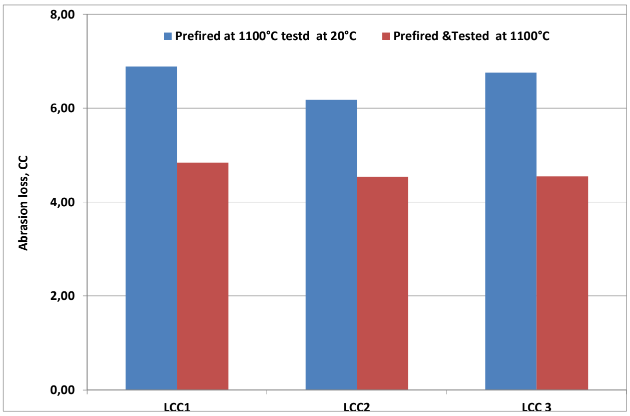

Fig.8 Comparison of low and high temperature testing of samples pre-fired at 1100°C

DISCUSSIONS

The samples tested for abrasion at room temperature (Fig.1 and 2), have shown matrix removal is the primary abrasion mode and the coarse grains are less abraded. Also, the abrasion tends to be conical pattern. This is the case in all 3 LCCs with various grain sizes distribution. The loss incurred is though removals of surrounding matrix followed by dislodging coarse grains. The samples fired at 1100°C have shown the formation of holes which is the result of grain pull out through the abrading mechanism. The reason for this trend is the weakness of matrix compared to grains at room temperature.

The samples tested at high temperatures (Fig.3 and 4), have shown less conical pattern with uniform abrasion of both fine matrix and coarse grains. This is attributed to the changes in elastic properties a as well as the thermal expansion characteristics making matrix stronger against abrasion(9).

The abrasion loss measurements of castables tested at room temperature is presented in Fig.5. The abrasion loss is at same level for all castables irrespective of changing grain size distribution. There is a minor improvement of abrasion resistance for the samples tested at 1100°C. This is the result of mild sintering happening at that temperature.

The abrasion resistance of samples tested at high temperatures (Fig.6) has resulted in 30% less loss at both testing temperatures (Fig. 7 and 8). However, there is no significance difference in abrasion loss between testing temperatures or change of granulometry. The energy imparted from abrading particle on to the surface of castables at high temperature is absorbed in the better way than dislodging particle from surface. The change in elastic properties plays a vital role in this mechanism, especially for the castables below the temperature of liquid formation (>1200°C) during sintering.

CONCLUSIONS

The abrasion test conducted on low cement castable, by changing grain size distribution, both at high and low temperature has resulted in the following conclusions;

- Change of granulometry doesn’t affect the abrasion loss significantly both at high and RT measurements.
- Increasing testing temperature has resulted in 30% reduction in abrasion loss with the current testing method for the chosen castable.
- Thermo-physical changes in castables plays a vital role in abrasion mechanism.

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