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Influence of the thermal history on the mechanical properties of two alumina based castables

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Abstract

Monolithic refractories are of importance due to their increasing applications in the metallurgical industries. In a wide range of industrial applications, refractory castables are subjected to demanding requirements, and their properties strongly depend on their thermal history.

This work is devoted to the study of the evolution of the mechanical properties of two refractory castables related to different thermal treatments corresponding to their conditions of use. The studied materials are two alumina refractory castables: an ultra low cement content bauxite based one (Bau-ULCC) and a low cement content andalusite based one (And-LCC).

Samples of both refractories have been fired at different temperatures (110, 250, 500, 700, 900 and 1100 °C) in order to simulate several conditions of use. During these firing stages, microstructural evolutions have been monitored by Young's modulus ultrasonic measurements. Then, the tensile loading behaviour of each sample has been determined both at room temperature and for a specific temperature (800 °C), chosen according to thermal history ultrasonic measurements.

Keywords: Refractories; Thermal history; Mechanical properties; Tensile behaviour

1. Introduction

The share of monolithic materials in the whole refractories market is growing worldwide. In general, wherever fired refractory bricks are used, they can be advantageously replaced by monolithics, in terms of production cost, installation efficiency, safety, material consumption, etc.[1]

Refractory castables are subjected to demanding loads, especially from a thermomechanical point of view and can be degraded by a combination of several mechanisms, mainly thermal shock, abrasion, corrosion and mechanical impact. The response of these materials is influenced by many factors such as their chemical composition, their microstructure as well as phase transformations which occur at high temperature during firing process, and/or in service.[2]

The physical properties of a refractory concrete are highly temperature dependent. This is primarily caused by the complex hydration and dehydration reactions of calcium aluminate cement.[3] The installation sequence for monolithics containing calcium aluminate cement involves several steps such as mixing, placing, drying out, curing and finally using in service. Each of these steps has influence on the hydration–dehydration processes of calcium aluminate cement (CAC).[4]

Previous studies have already been performed in the field of the high temperature behaviour of refractory castables.[2,5] This paper deals with thermal history and mechanical properties of two alumina castables and with results of an experimental approach developed to characterise the microstructural transfor-

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Table 1
Chemical analysis and characterisation data of the two refractories.

Castable type	And-LCC	Bau-ULCC
Aggregate type	Andalusite	Bauxite
Al_2O_3 (wt%)	58	85
SiO_2 (wt%)	37.5	10
CaO (wt%)	2.3	1.1
Fe_2O_3 (wt%)	0.9	1
Max. aggregate size (mm)	5	5
Water requirement (wt%)	4.5–5.5	4.2–5.2
Open porosity (vol.%)	6	10
Apparent density (kg/m^3)	2600	2970

mations and damage processes, which occur in such materials during the first heating.

2. Materials and experimental procedures

2.1. Materials and sample preparation

Two commercial castables are considered. The first one is a low cement andalusite castable (And-LCC) made of andalusite aggregates, fumed silica, alumina and of a calcium alumina cement. The second is an ultra low cement bauxite castable (Bau-ULCC) made of bauxite aggregates, fumed silica, alumina and of the same calcium–alumina cement. Both materials are characterised by the same fumed silica content (~10 wt%). In Bau-ULCC, the alumina content is two times higher than in And-LCC. Table 1 shows the chemical compositions of the castables supplied by TRB company.

The high difference between the silica contents of the two materials is mainly due to the high silica content in the andalusite aggregates compared to the bauxite ones. For both castables, the maximum aggregate size is about 5 mm. The materials were cured for 24 h at 110 °C (as-cured state). Fig. 1 shows pictures of polished sections of the as-cured materials. After machining, some samples have been fired at 250, 500, 700, 900 and 1100 °C in order to simulate a variety of thermal histories before characterisation. These temperature levels have been chosen due to the temperature range encountered by refractory castables in the considered industrial applications. Firing thermal cycles are characterised by 5 °C/min heating and cooling rates and by a 5 h isothermal dwell at the maximum firing temperature.

2.2. Ultrasonic measurements

An ultrasonic technique based on a continuous in situ measurement of the velocity of longitudinal long bar mode waves in the material has been used to monitor the evolution of the elastic modulus versus temperature on both materials.[6,7] Fig. 2 is a schematic representation of the ultrasonic device. The ultrasonic pulse is transmitted from the transducer to the sample through a wave-guide. The measurement of the time τ between two successive echoes within the sample makes it possible to calculate the wave velocity and then to obtain the value of the Young's modulus by $E_{US} = \rho(2L/\tau)^2$, where L and ρ are sample length and density, respectively.

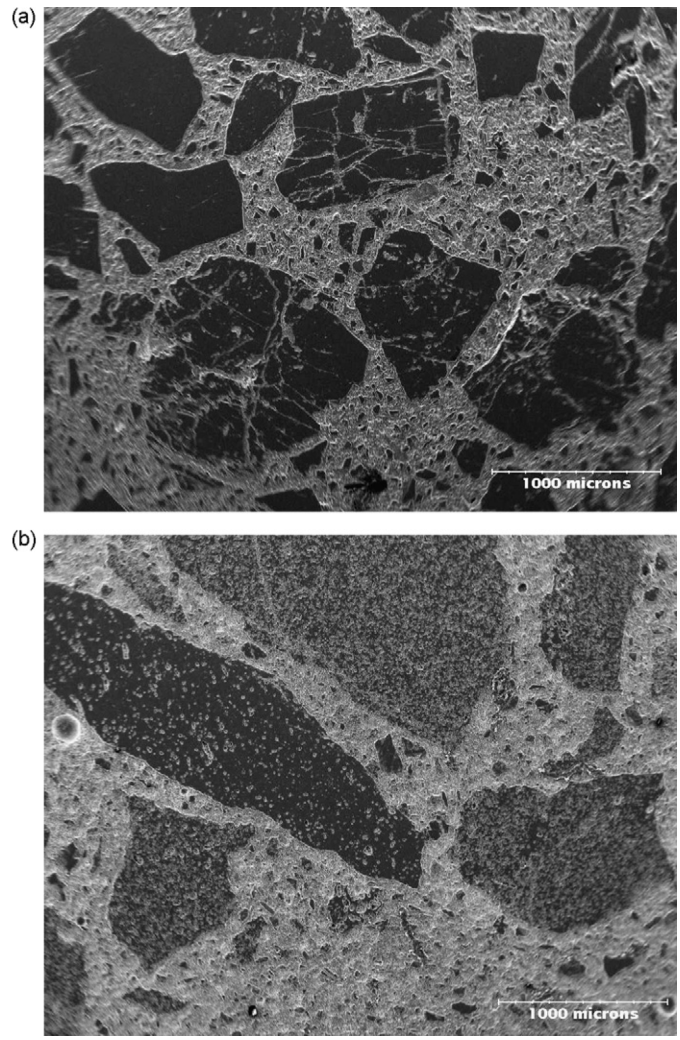

Fig. 1. Microstructure of as-cured refractories: (a) And-LCC and (b) Bau-ULCC.

2.3. Tensile test

Tensile tests have been performed with an INSTRON 8862 electro-mechanical universal testing machine at room temperature. Fig. 3 represents a schematic of the tensile test device. The variation of length is measured by two extensometers equipped

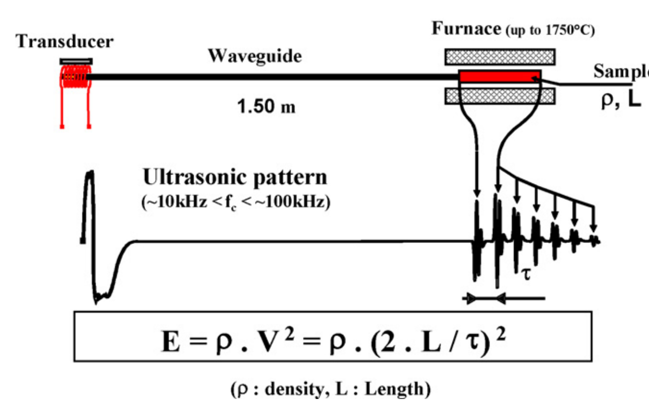

Fig. 2. Experimental setup used for Young's modulus measurement at high temperature by long bar mode ultrasonic pulse technique.