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Determination of mechanical properties and thermal treatment behavior of alumina-based refractories

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Abstract

Two different types of alumina-based refractories have been investigated. Chamotte and bauxite were the raw materials, being molded using a system of aluminate cement and water or a phenol–formaldehyde resin, as binder. Different raw material's grain size, water content, molding pressure, and firing temperature were selected for the preparation of the specimens. The mechanical strength of all specimens was determined using compressive tests, where parameters with physical meaning, such as maximum stress, maximum strain, elasticity parameter, and viscoelastic parameter were obtained after modeling the collected stress–strain data. In addition, water quenching test was performed for both samples, in order to present their thermal stability and mechanical wear after certain cycles.

Process conditions as well as the raw materials' characteristics were correlated with the compressive properties. More specifically, maximum stress seemed to increase when increasing all parameters except grain size both for bauxite and chamotte samples. The increment of bonding phase, grain size, and molding pressure caused an increment in maximum strain for both types of refractories. However, the higher the firing temperature was the higher the maximum strain of bauxite appeared, while the maximum strain of chamotte samples was decreased. Modulus of elasticity seemed to increase with bonding phase content and firing temperature and decreased with grain size for both types of refractories. For bauxite samples higher molding pressure caused a decrement in elasticity parameter while for chamotte in caused an increment. As far as the quenching tests are concerned chamotte samples seemed to be more tolerant to thermal shock. After data acquisition, the change presented in elasticity parameter (E) was also modeled with the number of cycles. Both bauxite and chamotte samples showed a decrement in maximum stress after thermal treatment, while elasticity parameter seemed to have a more severe decrement for bauxite samples.

Keywords: Bauxite; Chamotte; Compressive strength; Modeling; Quenching test

1. Introduction

Refractory materials, by definition, are resistant to heat and are exposed to different degrees of mechanical stress and strain, thermal stress etc. [1]. Refractories act as a thermal barrier between a hot medium and the wall of the containing vessel, they insure a strong physical protection, preventing the erosion of walls and they act as thermal insulation, insuring heat retention.

One of the most commonly used raw materials for refractories is bauxite since it appears high bulk density and therefore high compressive strength. Bauxite is an alumina-silica raw material and has the attributes of being relatively inexpensive-at least compared to most basic brick. In addition, they can be used in cases where modern castable refractories have disadvantages. Chamotte also denotes a mixture of calcined clay and spent ground bricks and it is also used as an inexpensive raw material [2].

One of the most well-known techniques for the production of refractories and ceramics is the mixing of several components in the form of powder, formation of the mixture to the final shape and firing to the suitable temperature, where desired properties are attained [3]. For the formation of refractories different bonding systems can be used, such as ceramic bond, hydraulic bond and organic bond. Ceramic bond is a bond which comes into play typically at high temperatures through ceramization reactions, while hydraulic bond is ensured by the hydration of an aluminous refractory cement added to the product. Finally, in the past decades for the formation of resin bonded refractories phenol–formaldehyde resins are mostly used [4], and are considered as carbonaceous organic binders. The role of the binders is essential in the production of

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refractories since they determine the moldability of the product [5] and they ease the transfer of the product from the production line to the kiln, where sintering occurs [3].

Properties such as structural, mechanical and chemical and thermal depend on the type and content of bonding phase, as well as other process conditions, such as molding pressure of the final product, grain size of the raw materials and firing temperature [6,7]. Mechanical properties in room temperature, such as compressive strength and elastic modulus, are essential when selecting refractories and designing refractory components. Therefore, many authors have already examined the mechanical properties of refractories [3,8–11].

On the other hand, thermal shock resistance shows the ability of a structure to withstand rapid changes in temperature with minimal cracking. This situation may occur under conditions when the material is heated or cooled suddenly and it characterizes its thermal profile [1]. One of the common techniques for evaluating thermal shock resistance is the thermal cycling of materials until fracture occurs [12]. Thermal shock tests have been also investigated by many authors [13–15] leading to interesting results for composite materials.

The innovative aspect of this study is the fact that mathematical models were introduced in order to define the mechanical properties in correlation with raw materials' grain size, bonding phase content (resin or water/cement), molding pressure and firing temperature. A number of mathematical models were examined in order to select the most suitable and simple, according to the experimental data [16–18]. The mathematical model for compression involves parameters with physical meaning, such as maximum stress (σ_{max}), maximum strain (ε_{max}), elasticity parameter (E), and non-linearity parameter (p). On the other hand, thermal shock resistance can be a significant issue, since it causes loss of material due to cracking or even detachment of large sections of the kiln, and is a prospect that should be eliminated. Through this study, selection of optimum conditions for material preparation would be possible in order to result in final products with high strength and toughness, and with the best possible thermal shock resistance.

2. Materials and methods

2.1. Sample preparation

Samples were prepared, using shaft kiln bauxite with particle size from less than 90–315 μm and a phenol formaldehyde resin addition with a content varying from 5 to 10%. In addition, samples using chamotte, having grain sizes varying from less than 200 to 400 μm and water–cement addition with a content varying from 5 to 20% for water and 10% aluminate cement. As grain size it is considered the sieve diameter. The mixing of the raw materials was conducted using a Heidolph RZR 2041 mixer, which ensures uniform mixing. Cylindrical specimens 13 mm in diameter and 14 mm in height where molded applying 60–400 MPa pressure, using a Specac manually operated hydraulic press (25 tn). The bauxite specimens were fired at 1100–1400 °C, while the samples produced from the chamotte raw material were fired at 1100–1200 °C. Firing at 1100 and 1200 °C was conducted in a Nüve muffle furnace (MF 120), while firing at 1300 and 1400 °C took place in a LECO furnace (model no. 542-500). Table 1 describes the producing conditions thoroughly. All combinations of those parameters were selected, in order to produce samples having different production conditions. For each sample 3 different specimens where fabricated.

Table 1
Production conditions of tested refractories.

Production conditions					
Bauxite					
Grain size (μm)	90	100	200	315	–
Resin content (%)	0	3	6	10	–
Molding pressure (MPa)	60	100	200	300	400
Firing temperature (°C)	1100	1200	1300	1400	–
Chamotte					
Grain size (μm)	200	315	400		
Resin content (%)	5	10	20		
Molding pressure (MPa)	60	100	200		
Firing temperature (°C)	1100	1150	1200		

2.2. Compression analysis

Compression tests were conducted using an Instron 4482 testing apparatus. Three different specimens for each sample were fitted to the instrument. The uniaxial compression tests were performed at room temperature (25 °C). Constant deformation rate of 0.5 mm/min was used for all examined materials and data acquisition was performed in a rate of 4 points/s. Force and deformation were recorded electronically and the resulting stress–strain compression curves were constructed. The compression test was continued until there was a break point of the specimens. Fig. 1 illustrates the specimen before and after the compression test.

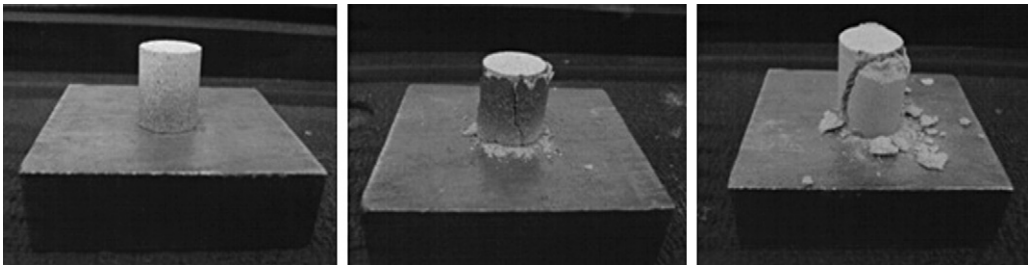

Fig. 1. Specimens before and after compression tests.