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Influence of the mechanical behaviour specificities of damaged refractory castables on the Young's modulus determination

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Abstract

This paper deals with the problematic of the determination of the Young's modulus of refractory castables by the way of mechanical tests. Two materials are considered: a cordierite based refractory castable that is reinforced with short steel fibres and an andalusite based refractory castable. Discrepancies in Young's modulus values are noticed depending on whether they are determined on direct tensile test curves, four points bending test curves or compression test curves. Damage due to a first thermal cycle is underlined as enhancing these discrepancies. Original mechanical tests have been performed in order to understand the influence of such a damage on the four points bending and compression behaviours. Results show that depending on the method that is used to measure displacements and strains, the calculated Young's modulus values can be highly influenced by local strain effects that occur at the contact between the sample and the loading system. Related to the damage that develops in these materials during the first heat treatment, these effects are more important when samples have been previously fired.

Keywords: Elastic modulus; Mechanical properties; Refractories

1. Introduction

In a wide range of industrial applications, refractory castables are subjected to severe solicitations, especially from a thermomechanical point of view. Previous studies have already been performed in the field of the high temperature behaviour of refractory castables.[1–7] Nevertheless, they have been less studied than engineering ceramics[1] and there is still a need in obtaining high temperature mechanical behaviour curves and in developing constitutive laws for these materials. This is particularly true to develop numerical simulation approaches in order to improve the design and the service life duration of structures that are based on refractory castables. Bending tests are easy to perform at high temperature and are largely used to study refractory castables. But, it remains difficult to develop constitutive laws from their results. This is mainly due to the non-linear behaviour of these materials and to the dissymmetry that is classically observed between the tensile and compression behaviours. In order to be able to obtain behaviour curves under these two loading modes, high temperature tensile tests and compression tests are now under development.[1,8] This paper deals with the comparison of the Young's modulus values that can be obtained from the three considered test types. Large differences can be obtained, even if the Young's modulus is normally an intrinsic property of the tested materials. Such observations have already been made by several authors who have performed two types of mechanical tests at least.[5–7,9,10] In this paper, an explanation of these Young's modulus discrepancies is proposed by considering the results of classical and of complementary original mechanical tests that have been made on two refractory castables.

As for as the paper structure is concerned, the compositions and the processing routes of the two considered materials are first given, as well as a description of the experimental devices that are used. Then, results of conventional tensile tests, four points bending tests and the compression tests are briefly presented. More attention is paid to the determination

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of the Young's modulus. The discrepancy phenomenon that is observed between the Young's modulus values is particularly underlined. It is then established that this phenomenon is enhanced for the materials that have been previously fired at high temperature. The cases of four points bending tests and of compression tests are presented and discussed successively. Causes of the differences between the Young's modulus values are exposed and explained.

2. Materials and experimental methods

2.1. *Presentation of the refractory castables*

Two refractory castables are considered in the present paper. One of these materials (FRRC) is a geopolymer based refractory castable that is reinforced with 1.5 vol.% of metallic fibres. It is made of a geopolymer based matrix and of cordierite aggregates. The matrix is obtained by mixing a major alumino-silicate oxide, thermal silica fume and an aqueous solution of potassium polysilicate.[11] Concerning aggregates, a mixture of four granulometric ranges of a cordierite grog is performed with a maximum aggregate size close to 3 mm. Metallic fibres are made of an AISI 310 stainless steel and are processed by cold drawing. They are characterized by a 0.38 mm diameter and by a 12.5 mm length. The FRRC refractory castable is shaped by mixing these different components during 5 min in a planetary mixer and by casting the mix under vibrations. The vibration amplitude is controlled to remain constant and the vibration time is of 10 min. Complete polymerisation of the matrix is obtained after an isothermal heat treatment of 12 h at 80 °C. The material is then fired at high temperature in order to stabilize the microstructure for high temperature applications. Such heat treatments are known to generate damage in the FRRC microstructure, mainly because of the differential dilatometric behaviours of the matrix, of the aggregates and of the metallic fibres.[12,13] Three firing temperatures are considered for this material: 110, 500 and 900 °C. Examples of damage which is generated by first heat treatments are given in Figs. 1 and 2. Damage mechanisms deal with aggregate/matrix decohesions, fibre/matrix decohesions and with matrix microcracking too. In the considered temperature domain, the higher the firing temperature is, the higher the damage level is.

The second material (And-LCC) is a commercial grade of a low cement andalusite based castable made of andalusite aggregates, silica fume, alpha-alumina and of a calcium aluminate cement. The samples are prepared by mixing the raw materials in a planetary mixer with a 5 wt.% water addition and during 5 min. The mix is then cast in the moulds on an amplitude controlled vibration table and during 2 min. Moulds and samples are then immediately wrapped in plastic. They are cured at room temperature during 24 h and then extracted from the moulds before a 110 °C-24 h drying step. As for the FRRC castable, high temperature heat treatments are known to develop damage in this And-LCC castable. Previous works have shown that this particularly true for firing temperatures that are in the 110–900 °C temperature range.[14,15] As these results have shown that firing this material at 700 °C leads to an important damage state in the microstructure, this firing temperature level will be considered in the present paper for this And-LCC castable. Figs. 3 and 4 enable us to observe the damage mechanisms that have occurred in this material after a 700 °C heat treatment. They deal again with aggregate/matrix decohesions and with matrix microcracking. They are mainly due to the differential dilatometric behaviour between the matrix and the aggregates. The case of the 110 °C dried And-LCC castable will be considered in that paper too.

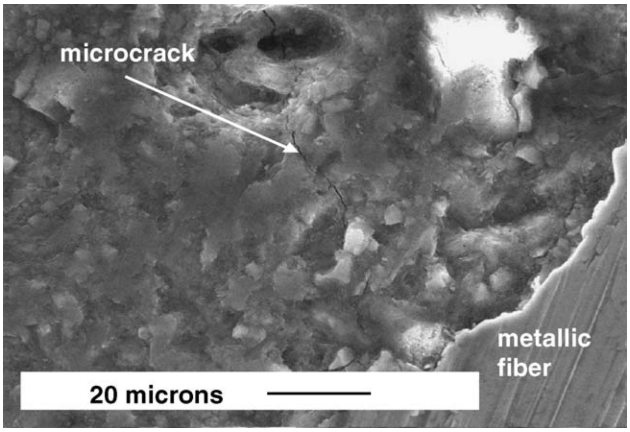

Fig. 1. Observation of damage in the FRRC castable after drying at 110 °C (scanning electron microscopy).

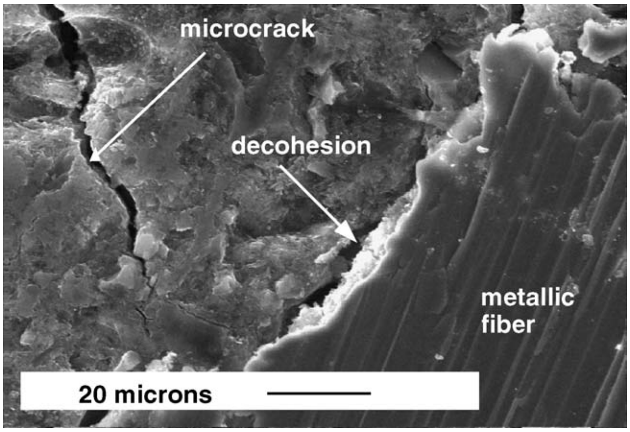

Fig. 2. Observation of damage in the FRRC castable after firing at 500 °C (scanning electron microscopy).

2.2. *Experimental methods*

2.2.1. *Uniaxial tensile test*

Uniaxial tensile tests are performed on a MTS 810 servo-hydraulic universal testing machine by the way of a non-articulated tensile system (Fig. 5). Sample extremities are glued on metallic plates that are water-cooled. At high temperature, the central part of the specimen is placed in a MTS