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Response of alumina foam to tensile mechanical loading including stress concentrator effect

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Abstract

Tensile test methodology for ceramic foams has been elaborated and test specimens of different dimensions and those containing central sharp notch (simulating a crack) were tested. Tested material was commercially available alumina based ceramic foam commonly used as filters of light metals melts. The foam cell size used within this study was 60 PPI. The main aim of the investigation has been to prove experimentally whether there is any stress concentration effect in the open cell structures. The fracture load (tensile strength) values were analysed and, in particular, the samples containing central sharp notch and comparable unbroken cross-section were compared with the unflawed samples. Specimens with central through thickness sharp notch have shown demonstrably the strength values comparably lower than the strength level of samples having the same cross-sectional area without stress concentrator. The explanation has been seen in stress concentration effect beneath the internal sharp notch root.

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1. Introduction

Ceramic foams with open cell porosity structure are of the growing technological interest because of their potential use in a number of industrial branches. There are applications already proven like high temperature filters for melted alloys, by Taslicukur et al. (2007) or Patcas et al. (2007), insulation materials, e.g. Gibbson and Ashby

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(1999), catalytic substrates by Garrido et al. (2008), Dawson et al. (2006), in tissue engineering also as bone replacement materials, Chen et al (2006), Bertolla et al. (2014a) and (2014b) etc. In almost all cases, high permeability, high surface area and good insulation characteristics but also a corresponding response to different types of mechanical loading is required for the given applications. In order to understand fully to mechanical response of ceramics foams it is necessary to cover all typical loading modes.

It is common to estimate behaviour of ceramic foams by compressive tests. A crushing strength is usually determined from the compression test curve. When a load is applied to the foam structure, it will initially deform elastically and then, depending on the sample size, the foam structure begins to buckle and collapse continuously at a relatively constant stress. Depending upon the initial foam relative density, this collapse will proceed under constant load up to a relatively high strain level. At a certain point the compressed foam enters to the “densification” phase and the stress - strain trace begins to rise. The point typical for transition from the elastic to plastic deformation phase defines the crush strength of the ceramic foam, Gibbson and Ashby (1999).

Very limited number of investigations has attempted also a bending test, e.g. Brezny and Green (1990). The most complication is associated with measures to avoid the crushing between the rollers and the examined foam. Suitable thin, usually rubber, sheet must be applied onto the interface between the roller and specimen surface. It must be rigid and tough but not too much to assure load transfer, Brezny and Green (1989).

Tensile loading always brings difficulties and data of tensile tests of the ceramic foams are completely missing in the literature. It is necessary to solve efficient load transfer from load fixture to specimen struts and ensure alignment of the specimen with loading axis of the test system. Brittleness of this type of material brings complications in fixating of the material in some claws. It is impossible to use any fixing methods exploiting compression, friction, threaded joint and their combinations. Only one possibility is to employ adhesion evoked by adhesive or resin, Rehorek et al. (2009). Another difficulty connected with the tensile testing of the brittle foam-like materials supposes measurement of deformations (tensile elongation, local displacements etc.). Direct placement of any contact strain gauge on the specimen is inapplicable due to risk of premature specimen surface damage. For interpretation of the mechanical behaviour and modelling the ceramic foam response in the given applications real material data are needed however, Marcian et al (2012). Thus noncontact methods are necessary.

The aim of the paper is seen in presentation of knowledge obtained with the tensile tests of ceramic foams carried out with different specimen size with and without internal through thickness crack. The question is whether there is any stress concentration effect at the crack tip of such artificial internal crack.

2. Experimental details

2.1. Material and specimen preparation

Alumina based foam (85 vol. % Al_2O_3, 14 vol. % SiO_2, 1 vol. % MgO) was applied for the tests. It has been a commercially produced material (Vukopor®A, produced by company Lanik, Czech Republic) typically used e.g. for melt aluminium alloys filtration. The material was produced by replication technique consisting of slurry coating of polyurethane foam. Typical for this kind of ceramic foam fabrication is highly porous structure with open type of porosity with triangular hole within the strut. Cell size used for this investigation was nominally 60 pores per linear inch (PPI), it corresponds to typical cell size of 0.8 (±0.3 mm), respectively. Fig. 1 shows distribution characteristics of the structure including SEM picture of the foam taken from the fracture surface. The distribution characteristics have been generated from quantitative analyses of computer 3D tomography pictures.

The material was provided in form of test specimens with agreed geometry having form of rectangular bars. The dimensions of specimens were 10x10x30 mm^3 (labelled as A), 15x15x40 mm^3 (B), and 30x30x90 mm^3 (C), 15x30x90 mm^3 (T). The last was also fabricated with the artificial through thickness sharp notch simulating a crack of the length 10 mm, i.e. remaining unbroken part having the area of 15x20 mm^2 (T-CR).

2.2. Test methodology

For loading of the above mentioned specimens the electromechanical machine ZWICK Z050 with 1 kN load cell controlled by TestXpert software was used. A special fixture and testing rig was developed, by Rehorek et al.