

TENSILE BEHAVIOUR OF OPEN CELL CERAMIC FOAMS

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Tensile test methodology for ceramics foam has been developed and first findings are described. The tested material was the commercially available alumina based ceramic foam. Two cell sizes were included into the study, namely 10 and 60 PPI. The test procedure critically depends on the fixation of the ceramic foam into aluminium pots by a suitable adhesive. Two specimen geometries with cross-section 10×10 and 15×15 mm were tested and results statistically analysed. Fractographic observations enabled to explain specimen behaviour during tensile loading.

INTRODUCTION

Ceramic foams with open cell porosity are of the technological interest because of their potential use in a number of industrial branches. Applications like catalytic substrates [1,2], high temperature filters for melted alloys [3,4], in tissue engineering as bone replacement material [5,6], insulation materials [7] etc. require high permeability, high surface area and good insulation characteristics but also a good response to different types of mechanical loading typical for given applications. Mechanical behaviour including the fracture response of ceramic foams thus plays an important role in their potential applications.

In order to fully understand mechanical response of ceramics foams it is necessary to cover all typical loading modes. At present, it is common to estimate the mechanical properties of ceramic foams by compressive tests only [8,9]. The most frequently used mechanical parameter is a crushing strength that is associated in some way with the compression test curve. When a compressive load is applied to the foam structure, it will initially deform elastically. At some strain, depending on the sample size, the foam structure begins to buckle and collapse continuously at a relatively constant stress. Depending upon the initial relative density of the foam, this collapse will proceed under constant load to a relatively high strain level. At a certain point, the stress - strain curve begins to rise, the compressed foam enters to the "densification" phase. The point in the stress - strain curve typical for transitions from the elastic to plastic deformation phase (if there is any) defines the crushing strength of the ceramic foam [7].

A very limited number of works has attempted to apply also a modified bending test [10-11]. The greatest complication consists in avoiding crushing between the rollers and the tested ceramic foam. A suitable thin (e.g. rubber) sheet must be applied into the interface between the roller and specimen surface. It must be rigid and tough but not too much to assure load transfer [12].

Tensile loading of ceramic specimens always brings difficulties. When highly porous material is being tested, additional obstacles usually inhibited the application of this test. It is necessary to ensure efficient load transfer and alignment of the specimen with loading axis of the system, which is not a simple task. Brittleness of this type of material brings complications in fixating of the material in some clamps. It is impossible to use any fixing methods by means of compression, friction, threaded joint and their combinations. The only possibility is to employ adhesion evoked by some kind of adhesive or resin. Another difficulty connected with the tensile testing of brittle foam-like materials is the measurement of deformations (e.g. tensile elongation). The strain value read off from the crosshead displacement transducer is not suitable for determination of the deformation characteristics. Direct placement of a contact strain gauge on the specimen is inapplicable due to risk of premature specimen surface damage.

Data of tensile tests of the ceramic foams are completely missing in the literature. For interpretation of the mechanical behaviour and modelling the ceramic foam response in the given applications some material data are needed, however. The aim of the paper is the presentation of the knowledge obtained with tensile testing of ceramic foams and in the interpretation of the resulting data.

EXPERIMENTAL

Materials

Alumina based foam (85 vol. % Al₂O₃, 14 vol. % SiO₂, 1 vol. % MgO) was used for the test methodology development. It is a commercially produced material (Vukopor[®]A, produced by Igor Láník - Techservis Boskovice, Czech Republic) typically used e.g. for molten aluminium alloy filtration.

The material was produced by a typical replication technique consisting in slurry coating of polyurethane foam. Typical for this kind of ceramic foam fabrication is a highly porous structure with open type of porosity and triangular holes within the strut.

Two types of cell sizes were applied for investigations, namely 10 and 60 pores per linear inch (PPI). It corresponds to typical cell sizes of 2.2 (±1.2) mm and 0.8 (±0.3) mm, respectively. Figure 1 shows the distribution characteristics of both foam structures including optical pictures of the foam structure. The filling was about the same, typically about 24 % for 10 PPI and about 22 % for 60 PPI.

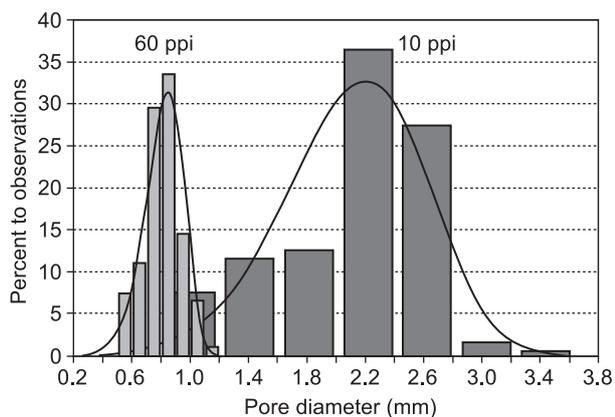
The material was provided in form of test specimens with agreed geometry having the form of rectan-

gular bars. The dimensions of specimens with both porosity types (10 and 60 PPI) were 10×10×30 mm³ and 15×15×40 mm³, respectively.

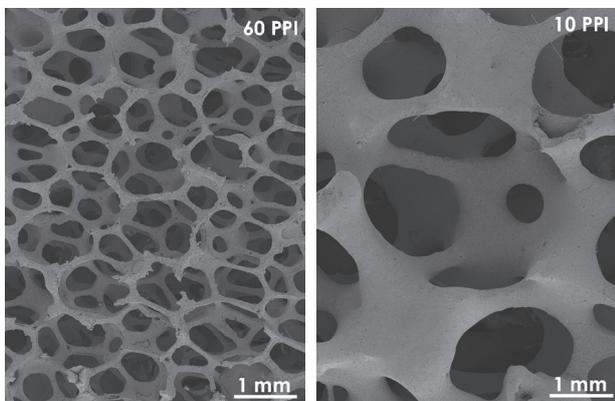
Test methodology

For mechanical loading of the aforementioned specimens a universal testing machine Instron 8862 with 1 kN loading cell was used. For transfer of the load to the ceramic foam specimen a special fixture and testing rig was developed. The sample gripping is schematically drawn in Figure 2. The ceramic specimen was embedded into two tusked aluminium pots by an adhesive which ensured homogeneous transfer of load forces from the machine fixtures to the specimen. Difficulties connected with alignment of specimen and loading axis were solved by designing of special aluminium pots holders. The upper holder was equipped with a cardan shaft and claw mounted on a pivot, and lower the claw was connected by a bulb to the shaft. A cross-head speed of 0.1 mm/min was applied throughout.

The adhesive medium used for the fixation of the specimen in the pot was Duracryl Plus (Spofa Dental, Czech Republic). This epoxy type adhesive is composed of a powder and a liquid activator. The advantage of this composition is seen in the easily controllable viscosity of the fixative liquid and the controllable infiltration of specimens with different cell size. This configuration produces quite good conditions for load transfer to the struts of the specimen. The other advantage being the fact, that the hardening time of the resin does not



a)



b)

Figure 1. Cell size distribution (a) and optical micrographs (b) of investigated ceramic foams.

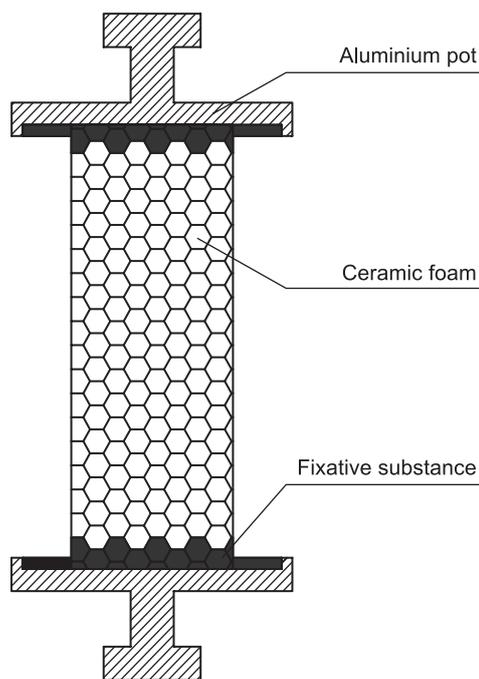


Figure 2. Schematics of the specimen gripping; using aluminium pots and adhesive.

exceed 20 minutes. The shrinkage of the adhesive during solidification and the possible formation of tensile stresses imposed on the separate struts must be also taken into account. The adhesive thus must be selected in correspondence with expected properties of the foam.

RESULTS AND DISCUSSION

Tensile strength

Characteristic tensile load curves for specimens from alumina foam are shown in Figure 3. It is possible to observe a linear increase of load up to fracture of the first strut suitably oriented to the acting load and/or crack propagation through several struts both represented by pop-in marked by black arrow. This strut fracture did not lead to overall specimen fracture, however, and further increase of the load was possible to observe. The maximum load leads to the critical damage in the cell structure usually associated with the fracture of several cells and unstable drop of the load. The white arrow shows features during the final stage of fracture. This step is caused by simultaneous fracture of many struts and obviously the whole specimen is broken at this stage.

Tensile strength values were determined as maximum force from the loading diagram related to cross-sectional area of the specimen at fracture. The cross-sectional area needed for this procedure was measured by digital picture capturing of the fracture surface of the samples by optical microscope with digital camera and by carrying out image analysis associated with dimensions measurement. The cross-sectional area contains more than 80% of air and estimation of fracture strength is

complicated. Therefore “fracture strength” is denoted as “apparent tensile strength”.

Average values of apparent strength determined for both types of tested specimens and both cell sizes of alumina based ceramic foam are shown in Table 1. Specimens of larger cross-section $15 \times 15 \text{ mm}^2$ are marked with letter B in the label.

Table 1. Mean values and standard deviation of apparent tensile strength of ceramic foam specimens.

Specimen parameters	Label	σ_{f} (MPa)	s (σ) (MPa)
10 PPI ($10 \times 10 \text{ mm}^2$)	V10	0.33	0.141
10 PPI ($15 \times 15 \text{ mm}^2$)	V10B	0.28	0.097
60 PPI ($10 \times 10 \text{ mm}^2$)	V60	0.13	0.045
60 PPI ($15 \times 15 \text{ mm}^2$)	V60B	0.12	0.038

As expected, the scatter of apparent tensile strength values is affected by specimen size. Specimens with cross section of $15 \times 15 \text{ mm}^2$ showed noticeable lower data scatter thanks to larger sampling volume averaging the structural heterogeneity. As analysed elsewhere [13] noticeable scatter of the apparent tensile strength is caused (i) by the heterogeneity in distribution characteristics of the cell sizes in the given sample and, in addition, (ii) by fatal macroscopic material defects typical for this kind of material and fabrication technology applied. The observed relations between the ceramic foam microstructure and measured apparent tensile strength however confirm very good susceptibility of the measurements to microstructural differences.

The specimen size (in the range of dimensions applied in this investigation) does not affect substantially

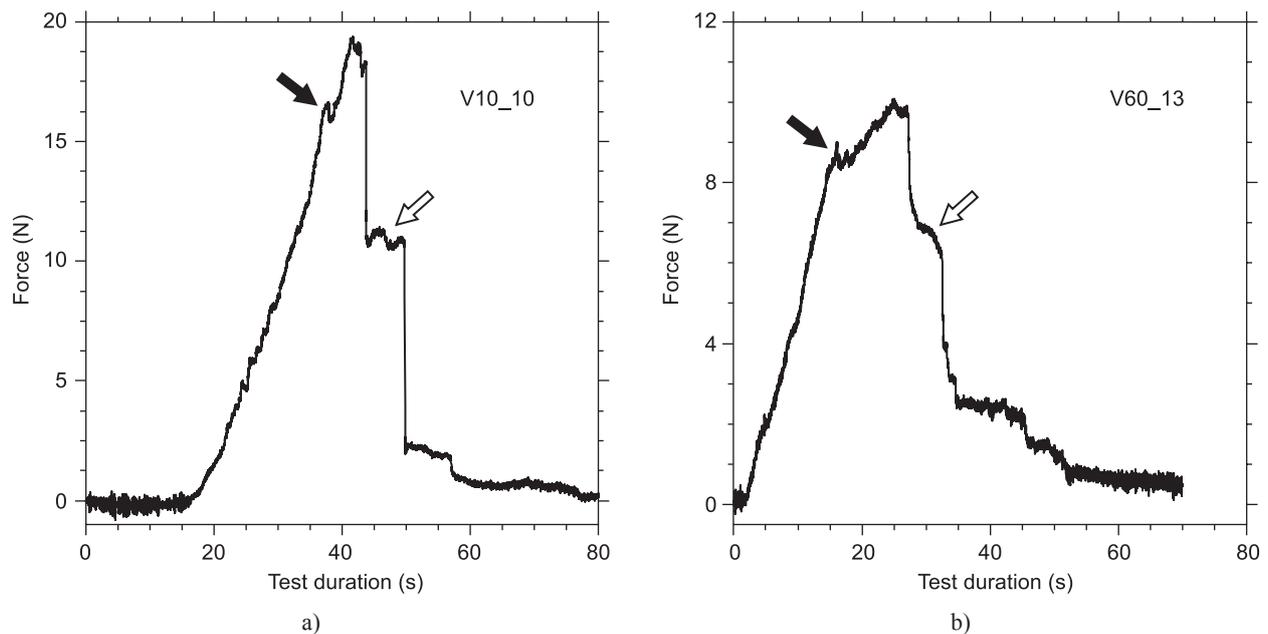


Figure 3. Tensile loading curves of specimen $10 \times 10 \times 30 \text{ mm}^3$, 10 PPI (a), and $10 \times 10 \times 30 \text{ mm}^3$ (b).

the average values of tensile strength as it is obvious from the Weibull plot in Figure 4. The data sets for both specimen sizes and for both cell sizes, having 10 and 60 PPI, respectively are plotted. It is evident, that there are no substantial differences in the quality of data obtained from smaller and larger specimens. Both specimen geometries, whether having larger or smaller cross-section exhibit the same slope in the Weibull distribution.

Some of the data are lying out of typical scatter. This is because of the above mentioned fatal defects in the microstructure. Either presence of filled cells representing more a bulk material behaviour than porous one or absence of the material having the dimensions of several cells (i.e. large voids) can lead to these differences.

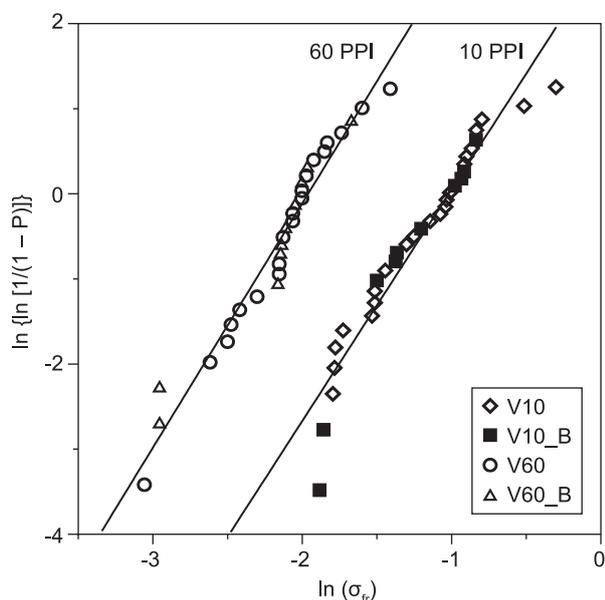


Figure 4. Weibull plot of apparent tensile strength values of specimens with 60 PPI and 10 PPI.

Specimens with higher PPI have lower apparent tensile strength compared to those with lower PPI. The larger the cell size the higher apparent tensile strength. This fact is mainly a result of the strut thickness of the cell which is significantly lower in specimens with 60 PPI compared to samples with 10 PPI.

Figure 5a shows typical gripping of the struts by the adhesive. In the optimal case the residual stresses associated with adhesive soldering and shrinkage are too low and thus no microcracks are initiated.

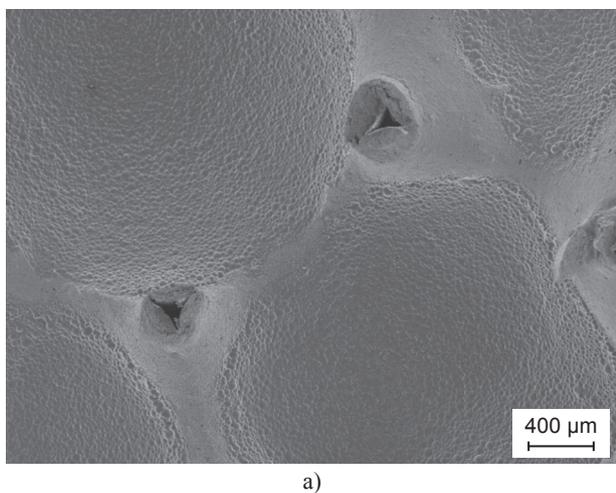
CONCLUSIONS

A methodology for tensile testing of highly porous cellular ceramics was developed. This method is based on embedding the specimen in alumina pots with a carefully chosen gripping adhesive. In this way a homogenous load transfer from the test machine fixtures to the specimen is ensured. The special design of the loading pot holders ensures loading axis alignment.

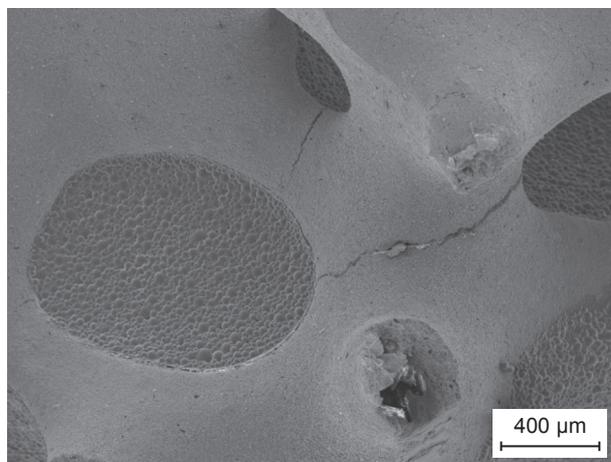
Specimens of commercially available alumina foam ceramics Vukopor®A were tested in tension. Scatter of obtained data was observed being caused by the random structure of ceramic foam and by inhomogeneities produced during manufacturing. The scatter is dependent on the specimen size and porosity type of the foam. With increasing sample size and decreasing cell diameter the scatter of measured data was found to decrease.

An influence of increasing PPI (decreasing cell size) on the apparent tensile strength of specimens was demonstrated experimentally. With increasing PPI the apparent tensile strength decreases.

The presence of macrostructural defects in the foam strongly affects the apparent tensile strength of the tested material. Specimens containing hole-like defects inside have lower apparent tensile strength in comparison with defect - free specimens.



a)



b)

Figure 5. Example of the good struts gripping of ceramics foam (a) and microcracks formed due to adhesive shrinkage (b).

A slight dependence of apparent tensile strength on sample size of the examined material was observed in the range of the specimen dimensions investigated.

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