POROUS CERAMICS - EXPERIMENTAL RESEARCH AND MODELLING

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Summary The paper presents the results of experimental research and modelling of porous ceramics under uniaxial compression. Alumina specimens with the porosity up to 30% were loaded axially, then unloaded and loaded again with a certain increase of the load. The loading-unloading process was stopped at the failure of the sample. The testing allowed to estimate approximately the influence of porosity on the initial elastic constants and further on change of elastic properties of ceramic material due to damage development. A scalar damage parameter evolution was also analysed.

INTRODUCTION

Nowadays ceramic materials are commonly used in many branches of industry: as lining in furnaces for steel and cement fabrication, in spacecraft, aircraft, nuclear engineering, automobile industry and others. One of the most important group of these materials is porous ceramics. They are often considered to be polyphase materials with a gas in pores as the second phase. They are applied for filters, thermal insulation, sound absorbers and furnace lining [5].

Up to now in research conducted in the world, ceramics was treated as a linear-elastic-brittle material. This approach is too much simplified, because real materials show physical non-linearity, i.e. their mechanical characteristics evolve during deformation [3].

Ceramic materials have good mechanical and thermal strength. However, for the cause of their brittleness it seems to be justified to search the new ways of describing the evolution of ceramics' properties. One of the basic ceramic polycrystalline materials is porous alumina. It is fabricated by sintering of Al_2O_3 powders at 1400 – 1900 °C. The final product is then built-up from grains of the mean diameter 20 – 30 microns. The solid matrix (with zero porosity) has high elasticity modulus (about 400 GPa [5]). In polycrystalline materials, especially those free sintered some microcavities occur. Their mean diameter is of an order of 1 – 4 microns. The global porosity may reach 30 % and more, what yields considerable loss of mechanical strength [2].

THEORETICAL BACKGROUND

As it is known the presence of pores in ceramics comes from fabrication process (sintering) and influences the total sample response to the applied load. As an example let us consider the effect of cavities on the Young modulus. Rice [6] gives a simple relation for cylindrical pores:

$$E_{\mathrm{M}}(p) = E_{\mathrm{M0}}(1-p) \tag{1}$$

where: E_M, E_{M0} are Young moduli of the pore-weakened and fully dense ceramic matrix, respectively; p is the volumetric porosity parameter.

Similar relations are given by others, for example [2]:

$$E_{\mathrm{M}}(p) = \frac{E_{\mathrm{M0}}}{1+3p} \tag{2}$$

or [5]:

$$E_{\mathrm{M}}(p,n) = E_{\mathrm{M0}}(1-p)^{n} \tag{3}$$

where n is material parameter.

In the paper we compared these theories with experimental outcomes. In case of equation (3) we assumed that n=5 for best compatibility with the real alumina behaviour.

The next question is the influence of the internal structure degradation of ceramic materials on it's strength. We use after Lemaitre [4] the following scalar damage parameter:

$$D(E_{\mathrm{M}}, E_{\mathrm{u}}) = 1 - \frac{E_{\mathrm{u}}}{E_{\mathrm{M}}(p)} \tag{4}$$

where: E_u stands for an actual elastic modulus of damaged material corresponding to unloading path.

EXPERIMENTS

Material description

For experiments samples of porous alumina were used. They were fabricated by sintering in Institute of Electronic Materials Technology, Warsaw. Porosity of the material was up to 30 % (p=0,30), while the sintering temperature was 1400 – 1730 °C and the time 1,5 hour. The samples were of cylindrical shape, 50 mm high and 14 mm in diameter. Young modulus of fully dense material was estimated to be 410 GPa.

Testing methods and equipment

There were four strain gages ("Vishay" EA-06-240LZ-120 and EA-06-240LZ-350) sticked on each specimen for the purpose of measuring axial and circumferential strains. Each gage worked in the Wheatstone quarter-bridge. Data acquisition was conducted with the "ESAM Traveller" system consisting of 8-channel bridge coupled with the PC and supervised by the adequate software. Samples were loaded by the universal testing machine "Zwick Z100". The loading process was the following: loading to a force P_1, unloading, reloading to a force $P_2=P_1+\Delta P$, unloading, reloading to a force $P_3=P_2+\Delta P$ and so on, until final failure of the specimen. The value of the force increment ΔP depended on sample's porosity: from 2 kN for p=0,30 to 10 kN for p=0,033. Straining velocity was kept at the level of 0,5 mm/min, so that the loading –unloading process was quasi-static. The results of experiments are presented below.

RESULTS AND DISCUSSION

The results indicate substantial influence of porosity on the mechanical properties of alumina (Fig. 1). It is visible, that experimental data fit well with theoretical background. The evolution of damage state seems to be similar for samples with various initial porosity (Fig. 2).

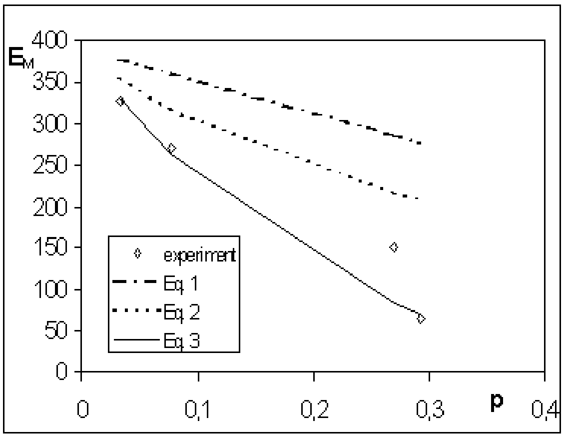

Fig. 1. Experimental values of elastic modulus vs. theory

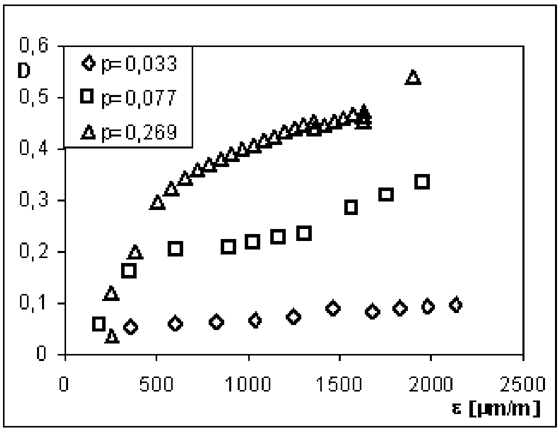

Fig. 2. Damage evolution of samples with various porosity as a function of axial strain

CONCLUSIONS

Experiments show good agreement of the ceramic material behaviour under compression with the theory. Damage evolution during loading-unloading process is connected with material structure degradation. Further research is essential. The prospective works will give detailed analysis of deformation process including material anisotropy (second order damage tensor).

References

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