Failure analysis of porous segmented alumina by digital image correlation method

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Abstract The behavior of porous, segmented, 50% porosity alumina under uniaxial compression loading has been studied by DIC method. The main stages of fracture were highlighted as well as qualitative and quantitative characteristics given. In the process of compressing the sample, a series of images of the material surface was obtained. The use of the DIC technique made it possible to obtain a series of fields of displacement vectors, and the corresponding spatial distributions of deformation were transformed into pseudo-images. The use of the DIC algorithm made it possible to obtain the fields of deformation vectors on their basis.

1. Introduction

When developing new structural materials, it is necessary to study in detail their physical and mechanical properties. Digital image correlation method (DIC) is widely used for this purpose that provides high measurement accuracy, good spatial resolution and relatively simple data processing algorithms.

Porous ceramics are widely used in various applications where high mechanical properties are required. Each pore can be a stress concentrator suitable for the crack initiation, and therefore the level of porosity is a factor that determines the behavior of the ceramic under load. It is well known that segmented ceramic materials can be more tolerant to defects and inhomogeneities that appear arising under loading as compared to monolithic materials. The aim of this work was to identify the main features of the structural evolution and deformation of porous segmented alumina during compression using the DIC.

2. Materials and Methods

Sintered porous alumina structurally consisted of polycrystalline alumina grains with internal 4 µm pores, a network of inhomogeneities that subdivided the sample into 210 µm in size segments. To carry out the DIC studies, a cylindrical surface was ground flat and polished to obtain a rectangular 7.45 mm × 7.40 mm plane field of interest (Fig. 1). This sample was loaded according to the uniaxial compression scheme, where the speed of motion of the movable grip was 2×10^{-4} s $^{-1}$. On one side of the sample, the surface images were captured using a Nikon D90 camera (Nikon Corp., Japan) every three seconds and recorded on a computer hard disk as separate files.

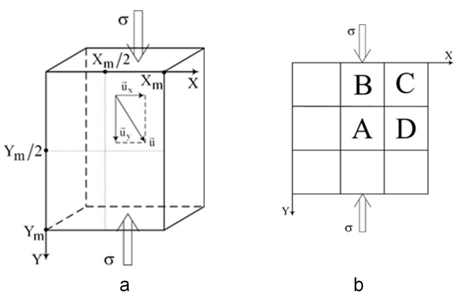

Fig. 1. Loading conditions, coordinate system (a) and areas of interest (b)

3. Evolution of displacement vector fields and deformation

From the very beginning of loading, a crack is formed in the central part of the specimen (Fig. 2, a, b, d, e). It grows rapidly according to mode I (normal separation) and covers the sample almost to its entire length, and its sides open up. However, this crack is not a main one and has a near-surface character. The unique property of this ceramics lies in the high level of pseudo-plasticity, where cracks and pores of the micro-scale are its carriers. Therefore, the crack is gradually healed, and the flow takes the form of deformation bands (Fig. 2, c). The deformation structure proves that deformation has a complex localized flow (Fig. 2, f).

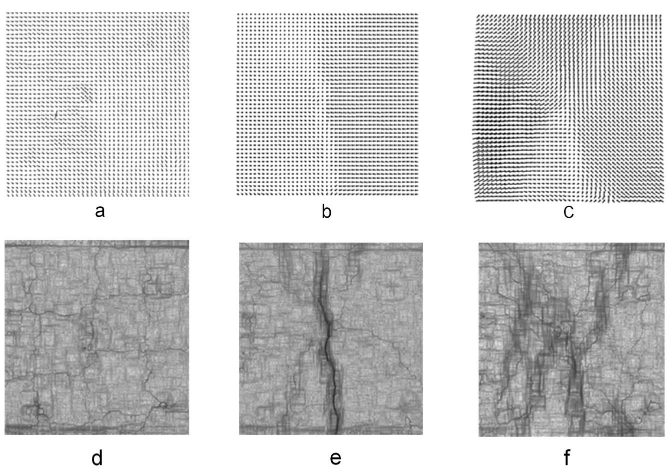

Fig. 2. Formation of a crack (a), its development (b, c). Pseudo-images of the deformation structure, reflecting the crackevolution (d), (e) and necking (f)

Calculation of displacement fields with a minimum spatial period (T = 1) allows reconstructing a spatial distribution of deformation with high resolution, which can be turned then into pseudo-images. Let us consider such pseudo-images as deformation structures, which clearly show the processes of localization of deformation and fracture in the materials studied (Fig. 2).

However, this crack is not the main crack, but occupies only a limited near-surface volume of the material. Due to the system of pores and cracks of low scale levels, pre-designed and formed in ceramics, there is a gradual arresting of the crack (Fig. 2, e) until the complete disappearance of this localization. In this case blurred lines of local displacement are recorded, caused by the action of the maximum shear stresses associated with the geometry of the sample (Fig.2, f).

4. Average deformation and its development

Based on Fig. 2 and taking into account the above data, it is possible to identify roughly the boundaries of the fracture stages. At the first stage, the flow significantly differs from the average one, since here the decisive role is played by a crack, the edges of which are opened according to the normal fracture mode (Fig. 2, b). The second stage is associated with the stable nature of the deformation of the ceramics, and the third with the unstable nature of fracture.

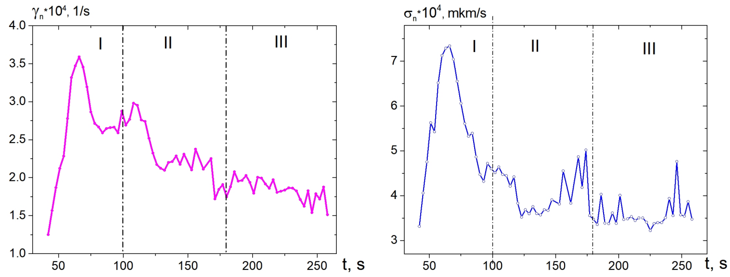

Fig. 3. Dependences of the average specific deformation and variance averaged over the areas on time.

The data shown in Fig. 3,4 were obtained by averaging over the entire observed area of the sample. Let's divide the observation area into nine areas of approximately the same size. Let us look at the most representative of them: A, B, C, D (Fig.1, b). Region A refers to the central part of the sample, where the compressive stresses are greatest. Region C is associated with the highest shear stresses, and the average strain here should probably be less than in region A. In the peripheral region D, the strain should be the smallest. Measurements confirm this behavior.

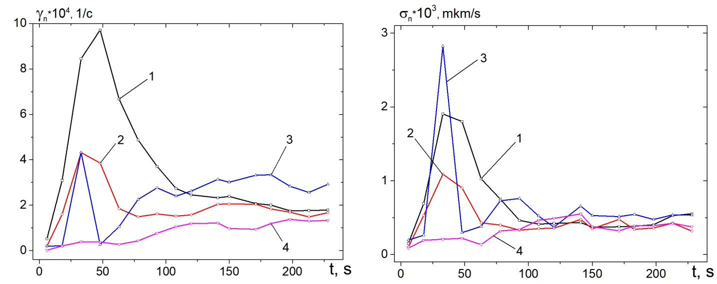

Fig. 4. Evolution of the average specific deformation and variance, averaged over the areas. 1 - A area A, 2 - B area, 3 - C area, 4 - D area.

5. Deformation vector fields (DVF)

As a result of additional calculations, a set of pseudo images of deformation structures was obtained from the very beginning of loading and up to fracture. It was found that each fracture stage corresponds to its own typical DVF. Thus, when the formation of a macrocrack occurs at the first stage, the displacement fields have the form of a localized deformation bands. In this case, DVFs have a complex, close to chaotic character, where separate regions with local vortices or / and deformation domains are formed (Fig. 5, a). At the stage of macro crack opening, the displacement fields and DVF are similar (Fig. 5, b). At the stage of unstable flow, the DVF reflects a complex system of meso-vortices resembling a “checkerboard” structure (Fig. 5, c).

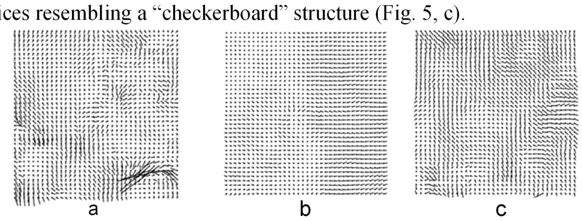

Fig. 5. Evolution of deformation vector fields at stages I (a), II (b), and III (c)

6. Conclusion

The process of deformation and fracture of porous segmented ceramics can be divided into three stages: (1) the formation of the first crack, (2) the appearance of numerous macro-bands, (3) a gradual decrease in the level of localization of deformation occurs due to the formation of compaction bands throughout the volume of the material.

The evolution of the variance of the displacements of the deformation vectors indicates that at certain points in time the deformation significantly differs from the average and has an unstable character. In this case, the average amplitudes of the displacements of the deformation vectors are approximately an order of magnitude less than the displacements of the vectors.

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