ON THE ROLE OF INTER-GRANULAR LAYERS IN POLYCRYSTALLINE CERAMICS

T.Sadowski*, Stephen Hardy**, E. Postek**,

Lublin University of Technology , Department of Solid Mechanics, PL 20-618 Lublin, Poland

**School of Engineering, University of Wales Swansea Singleton Park, Swansea, SA8P, Wales, United Kingdom*

Summary Ceramic polycrystalline materials show a non-linear and complex response to applied loads due to their internal structure. The inter-granular layers significantly change the macro-response of the material.. The aim of the paper is to present a new constitutive model for the case of uniaxial tension of the polycrystalline materials, including the inter-granular metallic layers that create its internal structure. The quasi-static deformation process of this material include description of: elastic deformation of brittle grains, elasto-plastic deformation of inter-granular layers and deformation due to micro-porosity development in layers.

INTRODUCTION

Ceramic polycrystalline materials show a non-linear and complex response to applied loads due to their internal structure, [1], [2]. Experimental observations show that the important element of the internal structure is the thin layer between grains. The size of these layers is relatively small in comparison to the grain diameter. The inter-granular layers significantly change the macro-response of the material. This is particularly evident when the two phases are made of different materials. For example, the grains may be brittle but the thin layers exhibit properties of a metallic material, so the softening effect due to porosity development should be taken into account.

The aim of the paper is to present a new constitutive model for the case of uniaxial tension of the polycrystalline materials, including the inter-granular metallic layers that create its internal structure. The quasi-static deformation process of this material include description of: elastic deformation of brittle grains, elasto-plastic deformation of inter-granular layers and deformation due to micro-porosity development in layers.

The effective continuum model has been applied to obtain constitutive relations. A Representative Volume Element (RVE) was analysed taking into consideration an initial internal structure of the material obtained from SME photographs. Owing to the high complexity of the internal structure of the composite material, the FEM technique was used to obtain macroscopic stress-strain correlations. They include gradual changes of the internal structure of the material due to defects development under quasi-static tension.

THEORETICAL BACKGROUND

According to [3] and [4] the total strain rate can be split into elastic strain rate and viscoplastic strain rate

$$\dot{\boldsymbol{e}} = \dot{\boldsymbol{e}}^{e} + \dot{\boldsymbol{e}}^{vp}$$

The onset of viscoplastic behaviour of the material is governed by a scalar yield condition

$$F(\boldsymbol{s}, \boldsymbol{e}^{vp}) = F_0$$

where F_0 corresponds to uniaxial yield stress. Then the viscoplastic flow rule can be expressed as follows

$$\dot{\boldsymbol{e}}^{vp} = g \left\langle \exp[M\,(F - F_0)/F_0] - 1 \right\rangle \frac{\partial F}{\partial \boldsymbol{s}}$$

where g is viscosity parameter.

The total visco-plastic strain increment (applying implicit time stepping scheme) for the time while $t^{(n)}$ is equal to

$$\Delta \boldsymbol{e}^{vp(n)} = \dot{\boldsymbol{e}}^{vp(n)} \Delta t^{(n)}$$

whereas the stress increment $\Delta \boldsymbol{s}$ and displacement increment $\Delta \boldsymbol{d}$ are equal to

$$\Delta \boldsymbol{s}^{(n)} = \boldsymbol{D} : \Delta \boldsymbol{e}_e^{(n)} = \boldsymbol{D} : (\Delta \boldsymbol{e}^{(n)} - \Delta \boldsymbol{e}^{vp(n)})$$

$$\Delta \boldsymbol{d}^{(n)} = [\boldsymbol{K}_T^{(n)}]^{-1} : \Delta \boldsymbol{V}^{(n)}$$

where $\Delta t^{(n)}$ is the time increment, $\boldsymbol{D}$ is the elasticity matrix, $\boldsymbol{K}_T^{(n)}$ is the tangential stiffness matrix, $\Delta \boldsymbol{V}^{(n)}$ is the incremental pseudo-load.

Having calculated stress increment and displacement increment it is easy to estimate current values of stress, strain and displacements.

NUMERICAL EXAMPLE

The FEM mesh of the representative element is shown in Fig. 1, whereas loading and supporting conditions are presented in Fig. 2. AL_2O_3 grains of the polycrystal have Young modulus equal to 4,1 $(10)^{11}$ MPa and Poisson coefficient equal to 0,25. Interfaces are viscoplastic with Young modulus equal to 2,1 $(10)^{11}$ MPa and Poisson coefficient equal to 0,235.

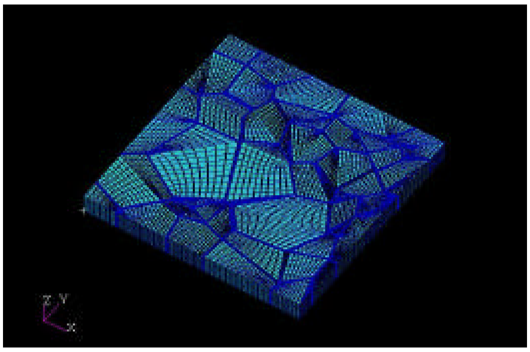

Fig. 1. FEM mesh

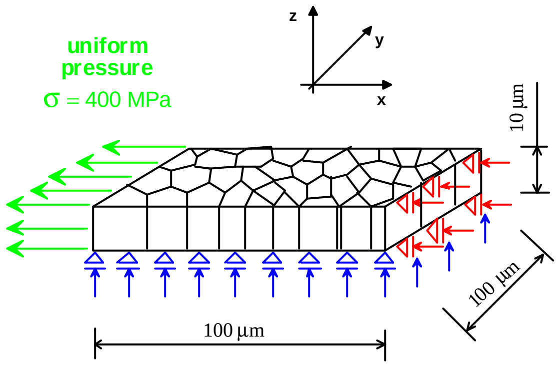

Fig. 2. Loading and supporting conditions

RESULTS AND DISCUSSION

Fig. 3 presents the distribution of equivalent viscoplastic strains in representative element. The influence of the viscosity parameter on the maximum value of equivalent viscoplastic strains is shown in Fig.4.

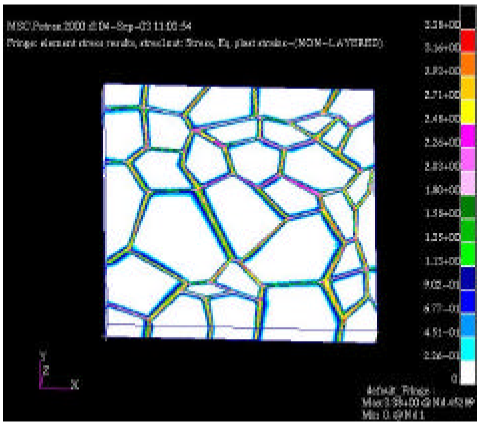

Fig. 3. Equivalent visco-plastic strains

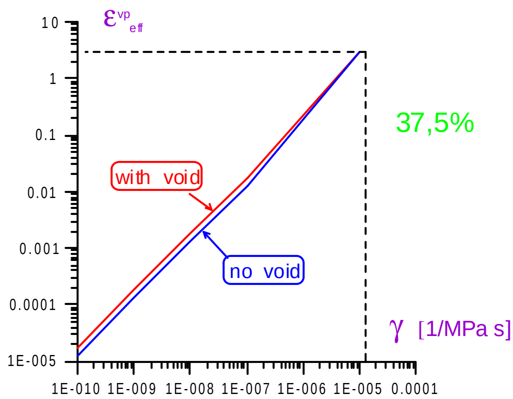

Fig. 4. Maximum visco-plastic strains vs viscosity parameter

CONCLUSIONS

- Introduction of interfaces made of different material (viscoplastic) radically changes the internal stress distribution inside the polycrystalline structure.
- Microvoid placed inside the viscoplastic interface leads to stress concentration equal to 1,58.
- Equivalent plastic strain at the void boundary is higher 37% in comparison to the interface without void.

References

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