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MATHEMATICAL MODEL OF THE INFLUENCE OF ELONGATED GRAINS ROTATION ON THE HIGH-TEMPERATURE DEFORMATION PROCESS OF SILICON NITRIDE BASED CERAMICS

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Abstract. *The speed of direct high-temperature extrusion of ceramics based on silicon nitride was analyzed. The influence of rotation of elongated grains on mass transfer processes and deformation rate is established. The influence of the parameters of the high-temperature deformation process on the deformation rate is shown. An equation is proposed that describes the effect of rotation of elongated grains on the strain rate. The described equation of strain rate can be used to create technological processes of plastic deformation of ceramic materials.*

Keywords: *silicon nitride, deformation, deformation mechanism, rotation of elongated grains, model of deformation process.*

The obtained data on the deformation kinetics of samples of materials based on silicon nitride (the nature of the deformation rate curves, the range of the deformation rate) and the structure in the initial state and after deformation, as well as the analysis of literary sources devoted to this issue, allow us to draw some conclusions regarding the deformation mechanism of silicon nitride ceramics with additives of Al and Y oxides and other additives that form a liquid intergranular phase at the deformation temperature under extrusion conditions.

The ability to deform can be the result of the action of a single mechanism with a very high sensitivity to the rate of deformation, the result of the interaction of several mechanisms of deformation, or the result of the action of the main mechanism supported by secondary (compensatory, supporting) processes.

Based on the obtained experimental data, it can be stated that the irreversible deformation of silicon nitride materials according to the direct extrusion scheme at a specific pressure on the punch up to 30 MPa is caused by fine grain in the structure of the material before deformation and the presence of a stress state in the transition zone of the matrix.

During the process of high-temperature deformation according to the direct extrusion scheme, in the transition zone of the matrix, the elongated grains are in a non-uniform stress field. Under the action of the moment of forces that arises in this inhomogeneous field, elongated β-Si_3N_4 grains will occupy a position coaxial with the longitudinal axis of symmetry of the matrix.

Previously, the formula for the dependence of deformation ε on the rotation of elongated grains was proposed, based on the change in the angle of inclination of the grain axis to the direction of deformation from the initial θ_0 to the final θ [1]:

$$\varepsilon = \frac{2}{3}\ln\frac{\cot\theta}{\cot\theta_0} \tag{1}$$

However, the assumptions made in the derivation of this formula make it valid only for acicular grains without thickness. According to various data, the proportion of rotation of elongated grains, depending on the number of such grains in the structure of the material, can be from 10 to 30% of the total deformation [2-4].

Therefore, the magnitude and contribution to the overall deformation of grain rotation at the initial stage will be maximum. A gradual decrease in the amount of liquid intergranular phase will lead to a gradual deterioration of the conditions for the reorientation of elongated grains and a slowing down of their rotation speed. Upon reaching the region of stable deformation rate, the intensity of the decrease in the speed of rotation of the grains will decrease due to the facilitation of grain boundary sliding, which promotes rotation. After passing through the region of stable strain rate, the grain rotation will further slow down until it settles at a certain constant level at the stage of the final constant strain rate.

The rate of deformation due to the rotation of elongated grains and the rate of deformation when the elongated grains pass through the angle of maximum tangential stresses:

$$\dot{\varepsilon}_2 = \frac{PK_2K_3}{TUK_1t} \tag{2}$$

$$\dot{\varepsilon}_{2\max} = \frac{PK_2}{TU} \times e^{-K_2 \times (t-t_0)^2} \tag{3}$$

where P – the pressure on the punch;
K_1 – amount of intergranular phase in the process of deformation;

K_2 – the number of elongated grains in the structure of the material;
K_3 – average length of elongated grains;
T – temperature during deformation;
U – degree of compression;
t – deformation time;
t_0 is the time of the maximum passage of the elongated grains to the position of the greatest tangential stresses.

Equations (2), (3) reflect the directly proportional dependence of the rate of deformation during rotation of elongated grains on the applied pressure and the number of elongated grains in the structure, and the inversely proportional dependence of this value on temperature and the degree of crimping.

Equation (2) represents the main contribution of rotation of elongated grains to the total strain rate. The greater the length of the elongated grains (K_3 coefficient), the greater their contribution to the overall deformation. The presence of the amount of intergranular phase (coefficient K_1) in the denominator of this equation reflects a slower decrease in the velocity component due to the rotation of elongated grains with a greater amount of intergranular phase.

Equation (3) represents a normal distribution function and will contribute to the total deformation rate only around time t_0 during the passage of the grains at an angle of 45^0 to the matrix axis. The combination of the velocity components expressed by equations (2) and (3) at some point in time will lead to the appearance of a horizontal section on the strain rate curve. The duration of the manifestation of the component expressed by equation (3) is determined by the K_2 coefficient, i.e., the number of elongated grains in the structure. The more such grains, the longer they will travel through the 45^0 angle and the longer the horizontal section on the strain rate curve will be.

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МАТЕМАТИЧНА МОДЕЛЬ ВПЛИВУ ПОВОРОТУ ВИДОВЖЕНИХ ЗЕРЕН НА ПРОЦЕС ВИСОКОТЕМПЕРАТУРНОГО ДЕФОРМУВАННЯ КЕРАМІКИ НА ОСНОВІ НІТРИДУ КРЕМНІЮ

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Анотація. *Проаналізовано швидкість високотемпературного деформування кераміки на основі нітриду кремнію при схемі прямої екструзії. Встановлено вплив повороту видовжених зерен на процеси масопереносу та швидкість деформації. Показано вплив параметрів процесу високотемпературного деформування на швидкість деформування. Запропоновано рівняння, яке описує вплив повороту видовжених зерен на швидкість деформації. Описане рівняння швидкості деформації може бути використано для створення технологічних процесів пластичного деформування керамічних матеріалів.*

Ключові слова: *нітрид кремнію, деформація, механізм деформації, поворот видовжених зерен, модель процесу деформації.*