INFLUENCE OF THERMAL SHOCK ON THE SUBSTRUCTURE AND STRENGTH OF SINGLE CRYSTALLINE CUBIC BORON NITRIDE

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Control of the strength characteristics of brittle materials is possible by the action on them of sharp thermal cycling — thermal shock [1]. Depending upon the amount of the temperature differential $\Delta T = T - T_q$ ($T$ is the hardening temperature and $T_q$ is the quenching temperature) and the number of thermal cycles, thermoelastic stresses leading either to strengthening or to loss of strength in the material develop incrystalline bodies. The capacity to resist thermal action is an important service characteristic of a material which depends particularly upon its structural condition [2, 3].

This work presents the results of an investigation of the influence of thermal shock on the structure and strength characteristics of single crystalline cubic boron nitride $\text{BN}_c$.

Material and Method of the Investigation. The object of the study was type LP elbor abrasive grains with a grain size of 16 (size of the primary fraction 160-200 µm) and specially selected single crystals of $\text{BN}_c$ with a size of 300-500 µm. These relatively brittle single crystals were used to investigate the structural changes occurring in an abrasive grain under the action of sharp thermal cycles.

The thermal loading was accomplished by annealing the material for 5 min at the specified temperature and subsequent sharp cooling.

Room-temperature water was used as the quenchant. The amplitude of the thermal shock was varied within limits of $(473-1073^\circ K)$ to $293^\circ K$. The strength of the $\text{BN}_c$ grains was determined by the method of crushing a single grain on a PPEA tester built by the All-Union Scientific-Research Institute for Abrasives and Grinding. For this a sample of 100 single crystal grains close in shape and dimensions was taken. The substructure of the single crystals before and after hardening was investigated by the Laue and topography x-ray diffraction methods [4].

The results of determination of the strength of single grains of $\text{BN}_c$ were processed on the computer to calculate the average values and the dispersion and to exclude major errors such as anomalously low and high values of strength beyond the limits of the normal distribution.

Results of the Investigations and Discussion of Them. In the original condition the strength of a single crystal grain with a grain size of 16, characterized by the amount of the load for crushing, is about $3.7-4$ N. If we apply this value to the average surface area of a grain in uniaxial loading, then the failure stresses are $\sigma_{\text{fail}} = 0.2$ GPa. Values of $\sigma_{\text{fail}}$ close to this value were obtained in uniaxial directed compression (in the [111] direction) of 200-400 µm single crystals of $\text{BN}_c$. For single crystals with unfinished cutting $\sigma_{\text{fail}} = 0.2-0.3$ GPa, and for holohedral crystals with a small quantity of surface defects $\sigma_{\text{fail}} = 0.4-0.7$ GPa.

After heat treatment of an LP16 grain by thermal shock, the two-factor relationships of the strength of the grain to the parameters $T$ and $N$ were determined from the results obtained. Statistical models in the form of third- and fourth-degree polynomials were used (polynomials of a lower degree were inadequate). The factors of the models were determined with the use of factor plans close to the D-optimum. The plans were calculated on the computer, taking into consideration the form of the model, containing 16-20 points.

To calculate the coefficients of the regression polynomials an algorithm was used, taking into consideration the property of orthogonality of the projection of the vector of the

regression values of the strength at M points of the \( P_p(T, N) \) plan on the subspace A stretched by the vectors

\[
\vec{T} = (T_1, T_2, ..., T_m) \text{ etc.}
\]

(1)

to the vector of the error \( \vec{P} - \vec{P}_p \). The length of the vector of the error is a minimum, which corresponds to the minimum of the sum of the squares of the deviations [5]. The sought-for errors were established by orthogonalization of the system of vectors (1), finding of the matrix of the transition to the orthogonal base obtained, and determination of the coefficients of divergence in this base of the mentioned projection of the vector \( P_p(T, N) \) on the subspace A.

The coefficients of divergence found are the sought-for evaluation of the coefficients of the mathematical model. The described algorithm was realized on the computer. The mean-square relative deviation of the calculated values from the experimental averages was \( \delta \leq 4\% \). Checking according to the Fisher criterion showed that the approximating polynomials adequately describe the experimental data at the 5% significance level.

The models obtained were used for construction of lines of equal strength \( P_i \). The points of such curves were determined by realization on the computer of the search for the roots of the equation \( \vec{P}_p(N_k, T_1) = P_i \) with the specified \( N_k \). Figure 1 presents curves of the lines of equal strength. The isolines of Fig. 1 are curves projected on the plane of the coordinate axes T and N and obtained as the result of intersection of the surface \( P = P(T, N) \) by the parallel planes \( F = \text{const} \) equidistant from one another.

From a study of Fig. 1 it follows that the strength reaches the maximum values at the boundary of the area of the experiment in the \( T = 693-773^\circ K \) temperature range with a number of thermal shocks \( N = 1-2 \), and also with \( T = 473^\circ K \) and \( N = 35 \). With these values of the temperatures and the number of thermal shocks the strength increases by 23 and 37\%, respectively. It should be noted that with high values of \( T \) and \( N \) on the boundary of the area of the experiment, the strength drops, reaching the minimum (\( P_{\text{orig}} \)).

In a practical sense the interest is in one or a small number of thermal shocks. Therefore, with \( N = 1 \), with an increase in temperature the strength first increases and then at \( T \approx 1073^\circ K \) drops to the original value and lower (\( P_{1073^\circ K} \leq P_{\text{orig}} \)).

In accordance with the established experimental conditions of thermal shock under which the effect of strengthening and loss of strength is observed six specially selected flattened single crystals were hardened from 773 and 1073\(^\circ K\).

An x-ray investigation of the substructure of such samples was made before and after thermal shock. According to the Laue diffraction patterns, the BNc single crystals studied have in the original condition a mosaic structure with angles of disorientation of the blocks of the mosaic of about 30-40'. The dislocation density in the crystals \( \rho \approx (1-4) \cdot 10^7 \text{ cm}^{-2} \).

\*P is the load breaking the grain, N.