INVESTIGATION OF THE STRENGTH CHARACTERISTICS OF THE NANOCRYSTAL MATERIAL BASED ON ZIRCONIUM DIOXIDE PARTLY STABILIZED BY YTTRIUM OXIDE.

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The development of the modern and promising aerospace technique production requires applying of the high-tech materials, which exceed the existing materials by the set of their properties. Among those properties is the strength. One of such materials is the nanocrystal material of the new generation which is based on the zirconium dioxide (Zr_2O_3), partly stabilized by yttrium oxide (PSZ crystals).

Receiving PSZ crystals became possible due to the new method of directional crystallization of the melt in the cold container by using of the direct high frequency heating. This method was developed in the Institute of the General Physics RAS. Obtained by this method PZS crystals posses tetragonal structure and are stable against aggressive media and high temperatures.

In IMASH RAS the PZS crystals main mechanical characteristics were estimated. At that the influence of specimen cutting orientation towards the crystallographic axis as well as many technological parameters of crystal producing (the crystal grow rate, concentration of the stabilizing addition (Y_2O_3), the annealing regimes, the degree of alloying) were investigated.

Taking into consideration the peculiarities of the material investigated, its anisotropy, brittleness, high hardness, the limited sizes of the initial crystals, laboriousness and high cost of the specimens cutting and producing, the methods of testing by three-point bending and compression were developed. The methods for crack-resistance and fatigue strength estimation were developed as well.

The investigations of the influence of stabilizing yttrium oxide percentage content on the mechanical characteristics were carried out. It should be noted that all the specimens showed the linear dependence during testing up to breaking, which was brittle, and in compression testing the specimen breaking was of explosion character with the flame release. Fig. 1 shows the typical stress-strain diagrams (a- bending, b- compression).

Specimens made of based on $Zr_2O_3 - Y_2O_3$ crystal with stabilizing oxide content from 2,5moll% Y_2O_3 up to 35moll% Y_2O_3 with 10 mm/ hour grown rate were investigated. The results are shown in Table 1.

The results analysis shows that the practical application of the material with the concentration more than 4% is no purpose because of the not so good mechanical properties. The further study was carried out on the specimens of crystal with the stabilizing oxide concentration in the range 2,5-4 moll.%, which corresponds to maximum value of mechanical characteristics. The results are shown on Fig.2.

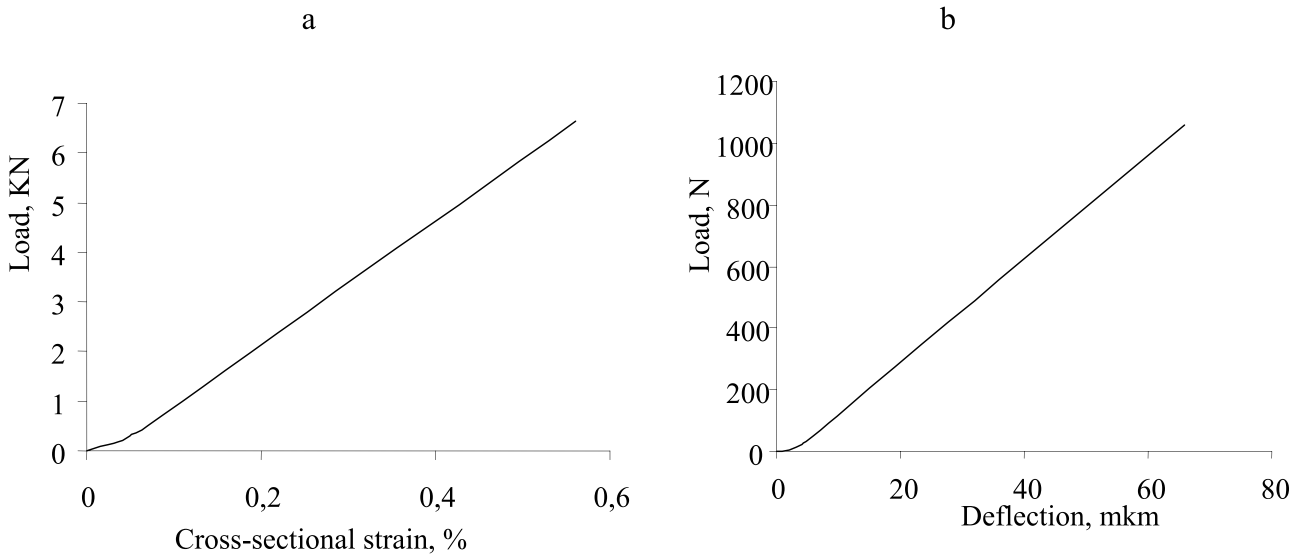

Fig.1

Table 1

Moll., % Y_2O_3	Ultimate strength, MPa	Young's modulus, GPa	Dynamic module			Poisson ratio μ
			By height, GPa	By width, GPa	By length, GPa	
2,5	2700	294	305	303	353	0,25
3,5	2330	278	269	238	307	0,28
4	1775	267	342	338	304	0,22
8	1530	254	305	288	305	0,31
15	1680	244	285	295	318	0,29
35	1115	209	245	255	258	0,27

For the crystal PSZ crack-resistance estimation the Vickers pyramid indenting method has been chosen. The new universal formula for the estimation of the critical stress intensity coefficient was introduced

$$K_{1c} = \left(H_v \sqrt{a_0} Y\right) / m^2 ,$$

where m – is the coefficient, which takes into consideration the material Young's modulus

$$m = \left\lfloor 1 + 3,427 \left(H_v / E\right)^{0,5} \right\rfloor$$

Y - is the evening function, depends on a_0 / c,

where $c = a_0 + l$, a_0 – is the half-diagonal of the stamp, l – is the crack length,

E – is the Young's modulus.

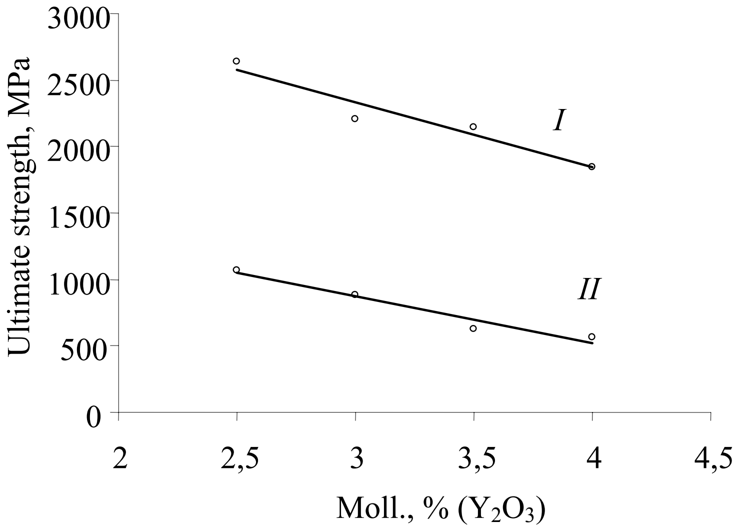

Fig. 2. Strength dependence on concentration of the stabilizing oxide: *I* - compression, *II* – bending.

$$Y = 10,469(a_0 / c)^4 - 22,5625(a_0 / c)^3 + 17,0335(a_0 / c)^2 -$$
$$- 4,8032(a_0 / c) + 0,59755.$$

$$\mathrm{H}_V = \frac{463,6\mathrm{P}}{a_0^2} GPa,$$

where P - is the load in Newton.

On Fig. 3 the typical diagram of the continuous Vickers pyramid indention into the polished specimen crystal PSZ surface is shown. On Fig.4 the dependence of the critical strength intensity coefficient on the stabilizing additional percentage content is shown.

This method allows obtaining several K_{1c} values on one specimen. From the obtained results (Fig.4) one can see, that with the stabilizing additional Y_2O_3 percentage content growth the values of K_{1c} decrease. This fact does not contradict the references for the similar materials. The results on K_{1c}, obtained by the direct notched specimens testing and by indenting, have shown the coincidence within the scattering width. This gives the reason for developed method application.

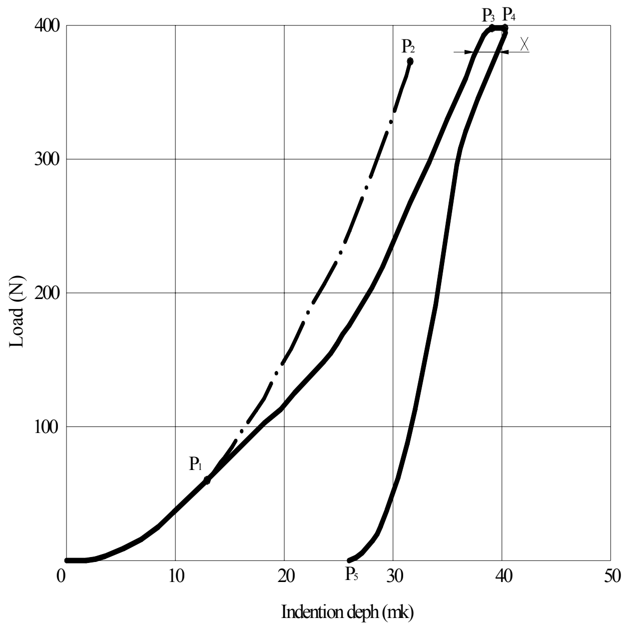

Fig. 3

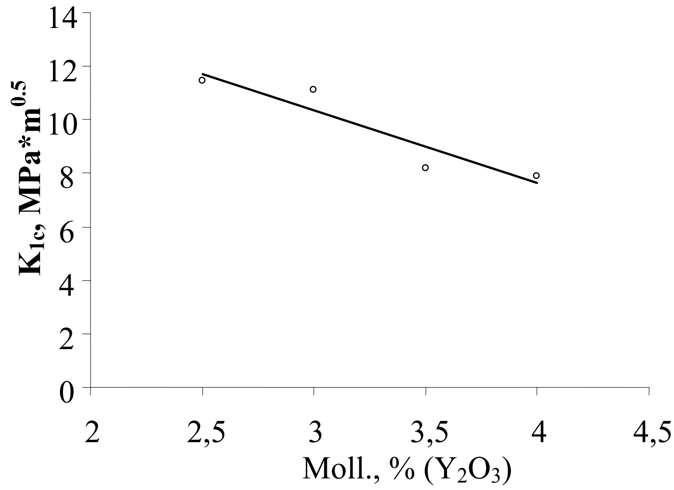

Fig. 4

The obtained results show the good mechanical properties of the material investigated. In particular, under optimal production modes the mechanical properties are: the ultimate strength under bending is up to 1600 MPa, under compression is up to 4000 MPa, crack resistance is up to 16 $MPa*m^{0,5}$, the hardness is up to 15 GPa, Young's module are up to 400-500 GPa.

Taking into consideration the good values of mechanical characteristics and at some extend lower density (comparing with high-strength steels) under the same strength allowance, one can conclude, that the developed material by the weight characteristics is considerable better than the high strength steels and high strength titan. For comparison we cite the properties of the high strength steels ЭИ643: Ultimate strength - 2000 MPa, young's modulus - 200 GPa. One can estimate the gain by the weight characteristic of the developed material under the same strength allowance by the example of the machine part compression. The part weight might be expressed as

$$F = \frac{Pl\rho}{\sigma},$$

where P- is the loading, l- is the linear dimension of the element, ρ-is the material density, σ-is stress.

Let F_1- be the PSZ material weight, and F_2-is the same for steel, when for the same P and l we get

$$\frac{F_1}{F_2} = \frac{\rho_1 \sigma_2}{\rho_2 \sigma_1} = \frac{6}{7,8} \cdot \frac{2000}{4000} = 0,385$$, that is the weigh gain is 2,6 .

The data shown allow recommend the crystal PSZ application in varied production of aerospace engineering.