Determination of tensile strength of brittle materials by bending thin discs on the annular support

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Determination of tensile strength of brittle materials by bending thin discs on the annular support

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Abstract. It is proposed to use the test of bending small thin disk specimens simply supported along the contour, to determine the resistance of material to tensile strain. The results of computer analysis of stress-strain state and test a thin disk specimens made of brittle materials are cast iron and graphite as a possible model, and directly samples made by electric pulse methods are presented. It is shown the effect of size of specimens on the resistance to their destruction and different character of deformation and destruction of cast iron and graphite samples. The possibility of application of thin disc samples for the determination the resistance to tensile strain of the composite ceramics based on SiAlON with various additives Y_2O_3, SiC, and TiN is confirmed.

1. Introduction.

Powder metallurgy plays the important role in the development of technologies of creation of materials with desired properties. Along with traditional methods of sintering, methods of electric pulse impact (EPI) are actively developing in the production of materials. The method of obtains materials with desired properties by EPI is based on researching small samples with thickness from 1 mm and a diameter from 10 to 15 mm. Standard methods for determination of materials resistance to rupture under tension to samples of such small size is not applicable. We used the method of bending a thin disk on an annular support to determine the brittle fracture of consolidated materials [1, 2].

2. Computational analysis of bending small thin discs on the ring support

The bending scheme of the thin disk on the annular support is shown in figure 1.

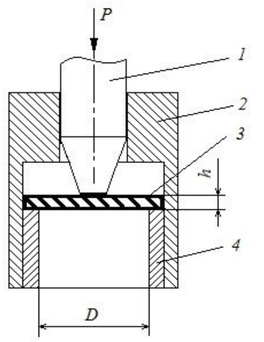

Figure 1. Diagram of bend test drive, simply supported along the contour: *1* punch, *2* holder, *3* sample, *4* foot ring.

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The calculation of the breaking stress and the resistance of the material to rupture is carried out taking into account the maximum load P_{max} withstood by the sample to failure, with a linear load diagram *P*–deflection ω according to the formula [1]:

$$\sigma_B = \frac{3P_{\max}}{8\pi h^2}\left[4-(1-\mu)\left(\frac{d}{D}\right)^2+4(1+\mu)\ln\frac{D}{d}\right] \tag{1}$$

in which *h* is the thickness of the disk; *d* and *D* are the diameters of the punch and support, respectively; μ is the Poisson's ratio.

Modeling of the process of loading a disk sample was produced in the verified computational complex ANSYS Mechanical [3]. The results of this study are presented in the paper [4]. It was shown that three-axis compression occurs in the contact zone of the indenter and the disk, while on the opposite side there is a plane stress with maximum tensile stresses, which cause brittle fracture of the sample. The origin of the destruction is possible under the action of the maximum tangential stresses in the contact zone. Figure 2 shows the stress distribution through the thickness of the sample. The beginning of the abscissa axis corresponds to the contact zone of the punch and disc.

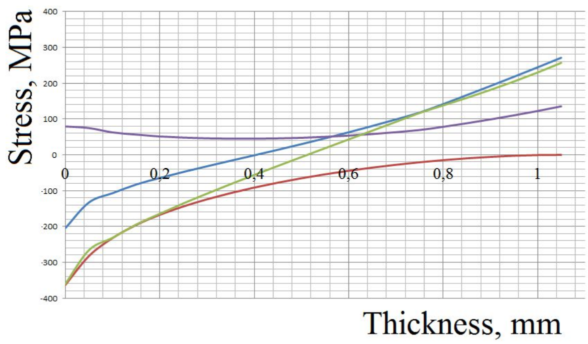

Figure 2. The stress distribution through the thickness of the sample
● – σ_1, ● – σ_2, ● – σ_3, ● – τ_{max}

In the contact area, the maximum shear stresses prevail, and on the reverse side of the disk, the main tensile stresses are maximal. The main compressive stresses on the reverse side of the disk tend to zero, which confirms the presence of a biaxial stress state.

3. Testing of model materials for circuit bending on the ring support

Cast iron SCH 10–40 and graphite MPG-6 were selected as model materials, whose physical and mechanical properties are well studied,. The mechanical properties of the tested materials are given in table 1.

Table 1. Mechanical and physical properties of tested materials

Material	σ_u^t, MPa	σ_u^c, MPa	*E*, GPa
Cast iron SCH 10-40	104	404	100
Graphite MPG-6	25	98	10

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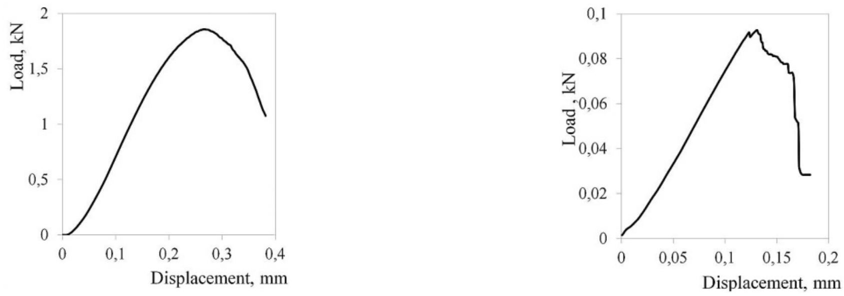
3.1. Tests of cast iron samples

In developing methods of testing, disks from cast iron had diameters of 10 and 15 mm, the thickness was changed within 1–2 mm. Comparison of numerical analysis of the stress-strain state and experimental results allows us to conclude that the cast iron in this scheme of loading is destroyed viscous under the action of tensile stresses. At first, the maximum shear stresses lead to the destruction of cut, trying to push the "plug" but when the first cracks appear they are disclosed under the action of tensile stresses. These statements were confirmed by the emergence of pushed through "crater" in the contact zone and the embossed shape of the stamp from the back side of the disc (figure 3a).

(**a**) (**b**)

Figure 3. Character of destruction of (a) cast iron and (b) graphite discs 15 mm in diameter.

The presence on the diagrams (figure 4a) of cast iron sections a gradual decrease of load after the maximum indicates the gradual divergence of the destroyed parts of the sample. Crack propagation in the radial direction suggests that they are disclosed under the action of tensile stresses. There is slow crack propagation.



(**a**) (**b**)

Figure 4. Machine deformation diagram of bending of (a) cast iron and (b) graphite disks.

The results of the test of cast iron disks with a diameter of 10–15 mm and a thickness of 1–1.5 mm showed that the level of stresses calculated by equation (1) is in good agreement with the tensile strength of cast iron [4].

3.2. Test graphite samples

Discs of graphite were two sizes Ø × *t*: 15 × 1.8 mm and 15 × 1.7 mm. Machine characteristic deformation diagram of a graphite disk is shown in figure 4b. We can see that the diagrams substantially differ from the diagrams of samples from cast iron. The destruction of the graphite disc is at maximum load. Stages in the diagram indicate stepwise crack growth. We observe the explosive nature of the destruction and the final dynamic crack propagation in the sample (figure 3b). The destructive stresses of graphite samples were 20% less than the tensile strength of the material.

4. Tests of thin disks obtained by spark-plasma sintering

he method of bending samples of small size is used in the study of the tear resistance of the materials SiAlON obtained by spark-plasma sintering.

Thin disks of SiAlON destroyed completely fragile with linear load-displacement diagram (figure 5) before break, separating into many pieces.

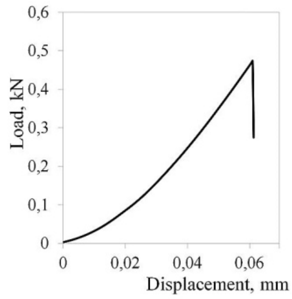


Figure 5. Engine diagram of a bending disk of SiAlON with a diameter of 15 mm.

The destruction of all samples was brittle with the separation of many small fragments. For samples with the same composition and the same sintering regime, the analysis of the dependence of the breaking stress on the thickness of the sample was carried out (figure 6).

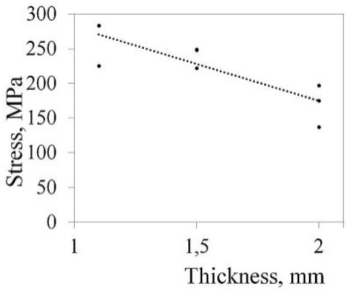


Figure 6. The dependence of the breaking stress on the thickness of the samples β-SiAlON + BN 30% +Y_2O_3 8%.

There was a slight decrease in the fracture resistance characteristics with a change in the thickness of the samples in the range of 1–2 mm.

A weak dependence of strength on the percentage of yttrium oxide Y_2O_3 in β-SiAlON in the studied range was observed (figure 7).

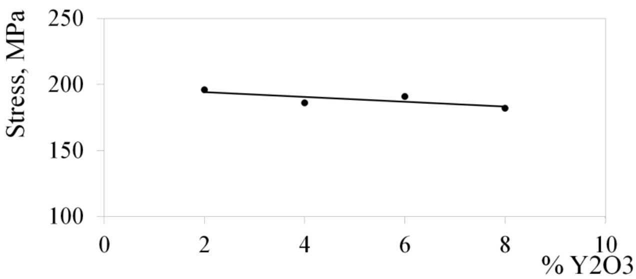
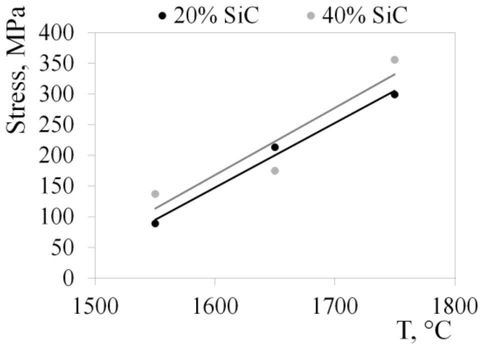
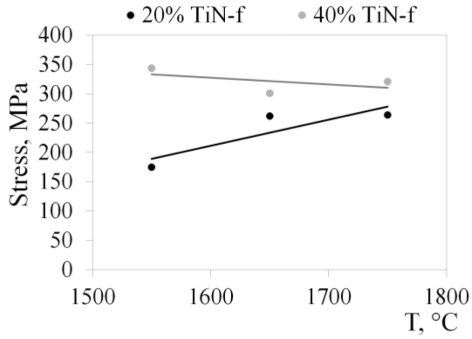


Figure 7. The dependence of the breaking stress on the percentage of yttrium oxide Y_2O_3 in β- SiAlON.

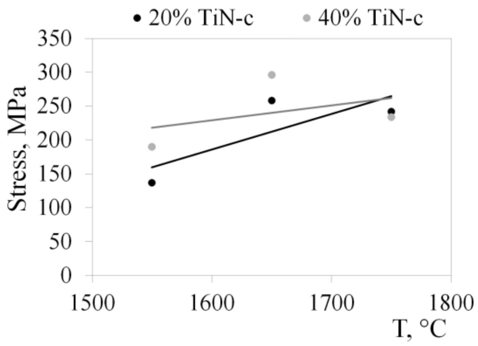
The dependence of the strength on the 2–8% of inclusions of yttrium oxide Y_2O_3 in a β-SiAlON structure was weak. It was also investigated the influence of addition of 20–40% SiC and TiN on the strength characteristics at various temperatures of sintering. The increase of sintering temperature in the investigated range for all cases gives a more solid structure (figure 8).



(a)



(b)



(c)

Figure 8. Influence of the sintering temperature of β-Sialon with different content of additives on the fracture resistance: (a) 20 and 40% silicon carbide SiC, (b) 20 and 40% fine-grained titanium nitride (TiN-f), (c) 20 and 40% coarse-grained titanium nitride (TiN-c).

5. Conclusions

The possibility of determining the brittle strength of the material of thin disks tested for bending on an annular support is demonstrated numerically and experimentally. The results of the study of a range of materials, resulting electric pulse impact method are shown.

Acknowledgments

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