

Testing of small-sized disk samples obtained by spark-plasma sintering and electric pulse exposure

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Abstract. The article presents results of design analysis of stress and strain in the disk sample loaded by the Brazilian test (disk compression in the center plane). The research established correlations of the diameter and thickness of the sample acceptable to obtain reliable values of material strength in response to stress. Presented a strong relation of average tensile stresses in the central area of the disc to the stress parameter used to determine the strength of brittle rock materials

1. Introduction

Technology adjustments for production of advanced materials, sintering and welding sintering conditions [1, 2] are usually carried out on the small samples, which diameter size often doesn't exceed 10 mm to 15 mm, and thickness may vary from 1 mm to 10 mm. Standard mechanical test methods are often not applicable for such samples. To evaluate the mechanical properties of the material it becomes necessary to resort to alternative test methods. Examples of such methods are bending of thin discs on a ring bearing [3] and the disk compression in the center plane by the Brazilian test scheme [4, 5]. It should be noted that these methods are used for testing of brittle materials. In particular, the Brazilian test is used to determine the tensile strength of rock. The aim of this study is to investigate the possibility of applying the Brazilian test of small-size samples for evaluating the tensile strength of metal materials with low ductility.

According to ASTM D3967-95a, the tensile strength of the brittle rock materials can be established during center plane compression test on the disk sample with a diameter no less than 50 mm and thickness to diameter ratio in the range of 0.75 to 0.2.

In order to investigate the possibility of using this test method for determining the tensile strength of metal materials with low ductility a numerical modeling of disk compression process was conducted using finite element method (FEM).

2. Parameters of the design model

The simulation of the disk sample loading process was carried out in a verified [6, 7] simulation software complex ANSYS Mechanical 16.2. The design model is a basic symmetry element of compressed disk – a 1/8 part (Figure 1). The thickness of the disc was ranged from 1 mm to 10 mm at the same diameter of 10 mm. The design model contains approximately 332 thousand nodes in the 80 thousand hexahedral elements of the second order (with quadratic shape functions) for a 10x5 mm disc. Material of the model is assumed to be perfectly elastic. The elastic modulus of the material is assumed to be 100 GPa.



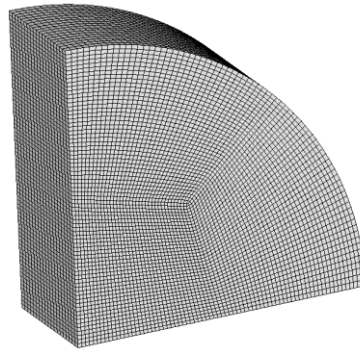


Figure 1. The finite elements grid of the computational domain.

In the model there are boundary conditions imposed of the symmetry on the clipping planes of the computational domain out of the full model. Loading of the model was made by compression of an absolutely rigid plane in the diametrical direction. The elements of the contact interaction were generated for the loading on the cylindrical surface of the disk and on the load plane. Hexahedral elements of second order SOLID186 were used in the formation of the model, as well as elements of the contact interface and TARGET170 CONTACT174 (terminology of [6]). The augmented Lagrange multiplier method was used as the contact algorithm.

The loading was conducted by assigning equal prescribed surface displacements to the surface nodes of the rigid punch. Taking into account the symmetry, total displacement corresponds to two times current displacement and effort corresponds to four times total force of the punch removed from the nodes. The final displacement of the punch amounted to 50 mm, which corresponds to the 0.1 convergence of punches.

In a nonlinear setting, the decision was made for a series of steps - increasing values of prescribed displacements with searching for the equilibrium state at each step by the Newton-Raphson algorithm and handling rigidity matrix by the preconditioned conjugated gradients method.

3. Results the analysis of the FEM modeling

Figure 2 shows the distribution pattern of the first and the third principal stresses and maximum shear stresses corresponding to the maximum model introduction of the punch - 50 microns (0.1 mm closer). The stress values are presented only for the purpose of illustrating their distribution.

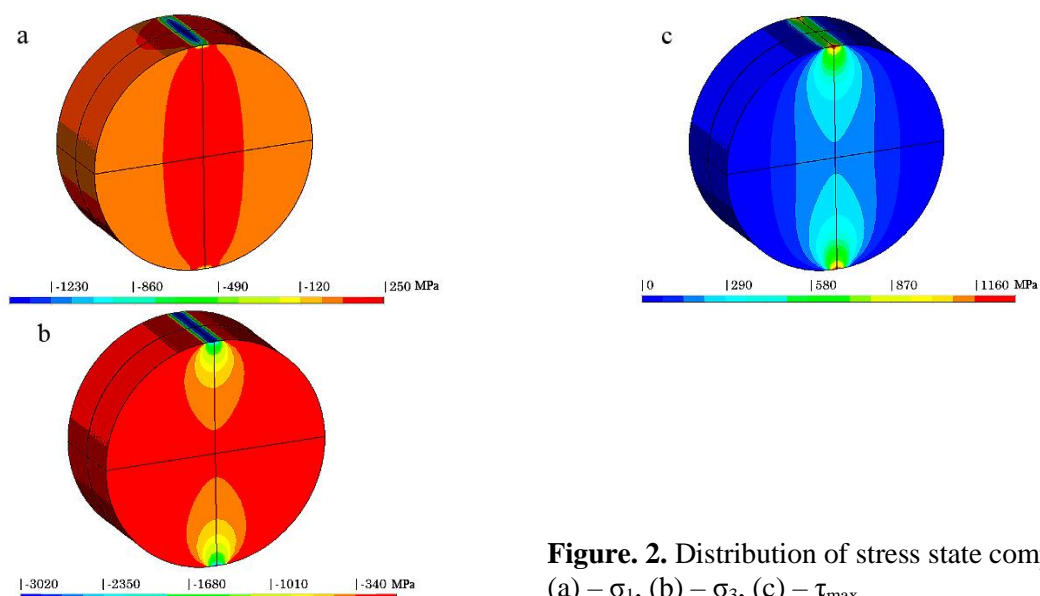


Figure 2. Distribution of stress state component:
(a) – σ_1 , (b) – σ_3 , (c) – τ_{\max}

Presented distributions are characteristic for the solution of described problem almost in the entire range of loading, with the exception of the small area of the initial load. Mostly compressive stresses are active on the main areas of the whole volume of the sample. The exception is the ZY plane of symmetry. On this and nearby parallel planes first principal stresses are positive and has the same direction X ($\sigma_1 \approx \sigma_x$) or close to it. It should be noted that maximum compressive stresses are about 1.5 times greater in absolute value than maximum tensile stresses in the plane of symmetry on the disc the surface, and maximum shear stresses at the same points exceed maximum normal stresses. Phenomenologically, when disk samples are tested on center plane compression, fracture occurs along the diameter coinciding with the direction of compression. A comparison of stress distribution pattern with an actual picture of failure leads to the expected conclusion that failure takes place under the action of maximum tensile stresses, although emergence of failure is possible under the influence of maximum shear stresses.

The maximum tensile stresses are localized near the outer surface of the disc and oriented perpendicular to the direction of compression. At the same time location of the maximum point is not constant during the loading process and shifts in the symmetry plane ZY from the initial position, in the vicinity of the contact zone towards the center of the disc. Localization of maximum tensile stress near the free surface appears to be related to the edge effect. The maximum point doesn't have constant location. The border layer of the disk works in the conditions of flat tension caused by the edge conditions. Accordingly, the stress distribution pattern may depend on the diameter to thickness ratio of the disk during tests. At the same time the ASTM D'3967-95a standard prescribes defining failure stresses by the formula:

$$\sigma_t = \frac{2P}{\pi LD} \quad (1)$$

where P – loading that caused failure, L – sample thickness, D – sample diameter. The stress parameter introduced by the standard should be compared with first principal stresses acting in the whole volume of the sample, in the geometric center of the sample volume and in the geometric center of the circular surface of the sample. Figure 3 shows graphs of correlation between these stresses and the stress parameter σ_t . For clarity of the figure the results are provided for only 4 samples of different sizes, the characteristics of elasticity of the material are assumed to be the same. The horizontal axis represents the stress parameter σ_t , calculated using the formula (1) on the basis of force acting upon the sample, and the vertical axis represents the estimated value of first principal stresses.

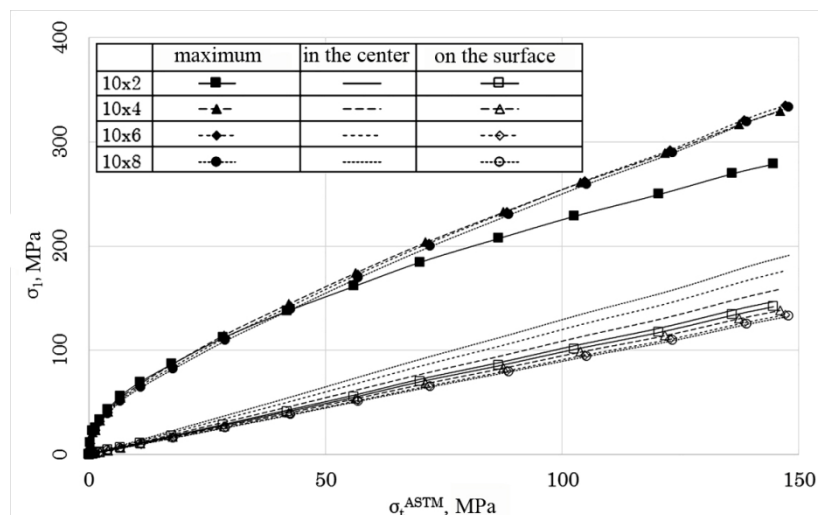


Figure 3. Correlation between the stress parameter σ_1 in the different points and σ_t with varying the thickness of the disk.

These results suggest the following conclusions: σ_{lmax} has nonlinear dependence on σ_t , it is nearly a parabolic branch relative to the σ_t axis and it depends on the disk sizes ratio – disks size of 10x1 mm, of 10x2 mm and 10x3 mm (the figure shows the curve for the 10x2 disk) have distribution different from all other sizes: dependences of σ_l on σ_t in the center of the volume and in the center of the surface of the sample are close to the linear and in strong relation with the σ_t parameter over the entire range.

Consequently, if the failure of the material occurs when maximum tensile stresses reach a certain limit, then the amount of the stress limit does not match the value of the parameter σ_t assessed by the ASTM D3967-95a method. If the failure occurs on reaching average stresses in a section of limit value, which is characteristic of heterogeneous materials such as concrete or rocks then the σ_t parameter is a good estimate of the first principal stress, averaged along the X axis of the disk.

The results of computational analysis were compared with the results of the test of gray cast iron disks. [8] A strong correlation was discovered between the pressure in the center of the sample and tensile strength of the material.

4. Conclusions

Using the FEM a design analysis was conducted on the stress distribution and deformation in small-sized metal disk samples loaded by the Brazilian test method. Strong correlation was presented between the normal stress acting in the center of the disc and the design parameter recommended by ASTM standards for determining the tensile strength of brittle materials.

5. References.

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