Testing of small-sized samples with the Brazilian test for assessment of brittle strength of metallic materials

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Abstract. The article provides an experimental basis for application of the disk sample loaded by the Brazilian test method (disk compression in the diameter plane) for the brittle strength assessment of the metallic materials during testing of the small-sized samples. The research presents a strong correlation between strength of the cast iron, assessed by the testing of disk samples and the tensile strength. The method was used to study the mechanical properties of heavy tungsten pseudo-allows obtained by exposure to high-voltage electric pulse.

1. Introduction
Testing of modes of electropulse impact in production of advanced materials is generally carried out on small samples, often not exceeding the size of 10 mm 15 mm in diameter, with thickness than may vary from 1 to 10 mm. Standard methods of mechanical testing are not applicable for such samples. This work provides substantiation of the use of Brazilian test on small-size samples to evaluate the tensile strength of metallic materials. An experimental analysis of the test results on cast iron samples was conducted by the method of digital image correlation (DCI).

2. The results of the experimental research
An experimental research was conducted on disk samples of gray cast iron GCI 10-40 (σ_p=104, σ_s=404 MPa). The disks had three types of size D х L: 10 х 4 mm, 10 х 5 mm and 15 х 4 mm. To evaluate the mechanical properties of the material the alternative testing methods are have to be used. One of such method can be disk compression in the center plane by the Brazilian test [1, 2], which is used for the indirect determination of tensile strength of rock.

The loading of the samples was carried out on a test machine INSTRON in a special device that provides strict alignment of the planes of the punches. Simultaneously with the loading of the samples, the displacement of the surface points of each samples were registering by the DCI method [3, 4]

The distribution of the strain ε_s in surface points of cast iron sample in the initial stage of the loading and the stage preceding failure is shown on Fig. 1 a, b.
Tensile strain distribution $\varepsilon_x$ (red zones represent the maximum strain) correspond exactly to the distribution pattern of tensile stresses in the design analysis presented in [5], which indicates the identity of the results obtained by the calculation and experimental methods. The symmetrical strain distribution patterns in respect to the axes X and Y are observed at all the stages of loading the samples. In the surface points plane stress condition presents with the principal tensile stresses $\sigma_x$, stresses and compressive stresses $\sigma_y$, and consequently, significant shear stresses equal to the half the sum of the absolute values of the principal tensile and compressive stresses. The shear stresses cause the appearance of displacement cracks which combined lead to the failure of the sample in the center plane, where maximum tensile stresses apply.

The appearance of such cracks is characteristic of samples with the size of 15x4 mm and not observed for samples with the size 10x5 mm in which the failure starts in the center area of the sample. Stepped fracture in the center plane of the sample (Fig. 2) indicates that the sample failure occurs under the influence of shear stresses. There is no explosive failure typical for brittle fracture caused by normal stresses. A slow withdrawal of one half of the sample from the other is observed, which is usually inherent to plastic failure. The sample deformation diagrams are characterized by the development of plastic flow and by the transition of stress through the maximum.

**Figure 1.** Color images of strain distribution $\varepsilon_x$ over the surface points of cast iron: (a) the initial stage of the loading; (b) the stage preceding the failure

**Figure 2.** The nature of division of the cast iron sample during its destruction.
Table 1 shows the test results for 9 discs of cast iron: the maximum load corresponding to the start of the failure for all tested samples and damaging stresses calculated by the formulas (1) and (2),

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

\[
\sigma = \frac{P}{LD} \quad (2)
\]

| № sample | Sample size (mm) | P (N) | \(\sigma_t\) (MPa) | \(\sigma\) (MPa) |
|----------|-----------------|-------|---------------------|----------------|
| 1        | 10x4            | 5333  | 85,3                | 134            |
| 2        | 10x4            | 6028  | 96,2                | 151            |
| 3        | 10x4            | 6979  | 111                 | 174            |
| 4        | 10x4            | 6847  | 109                 | 171            |
| 5        | 10x4            | 7029  | 112                 | 176            |
| 6        | 10x5            | 9009  | 115                 | 180            |
| 7        | 10x5            | 8783  | 112                 | 176            |
| 8        | 15x4            | 8290  | 87,9                | 138            |
| 9        | 15x4            | 7550  | 80,2                | 126            |

The average values of pressure calculated by the formula (1) were close to the values of the tensile strength of the material. Therefore in order to calculate the failure stresses in the testing of metallic brittle disks by the Brazilian test method it is possible to use the formula (1), recommended by the ASTM D3967–95a standard.

The examined above method of testing disk samples was used to evaluate the brittle strength of the tungsten heavy alloy VNZh-90 (90W-7Ni-3Fe), obtained under various sintering conditions. Table 2 shows the test results for series of samples. Legend to the table: \(U\) – pulse voltage; \(q\) – pressure during the powder sintering; \(D\) and \(L\) – diameter and thickness of the sample; \(P_{\text{max}}\) – the maximum load at which the sample failure occurred or loading was stopped, due to a significant deformation of the sample without its failure; \(\sigma_t\) - stress calculated by the formula (1); \(\omega\) - displacement of the baseplate of the testing machine considering its ductility. It should be noted that a part of the samples wasn’t brought to failure due to the emergence of large plastic deformation or due to formation of delamination and spalling.

### Table 2. Fracture strength of cast iron, defined by the formulas (1) and (2).

| № sample | Sample size (mm) | P (N) | \(\sigma_t\) (MPa) | \(\sigma\) (MPa) |
|----------|-----------------|-------|---------------------|----------------|
| 1        | 10x4            | 5333  | 85,3                | 134            |
| 2        | 10x4            | 6028  | 96,2                | 151            |
| 3        | 10x4            | 6979  | 111                 | 174            |
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| 5        | 10x4            | 7029  | 112                 | 176            |
| 6        | 10x5            | 9009  | 115                 | 180            |
| 7        | 10x5            | 8783  | 112                 | 176            |
| 8        | 15x4            | 8290  | 87,9                | 138            |
| 9        | 15x4            | 7550  | 80,2                | 126            |

The average values 101 158,4
Table 2. The testing results for a series of disk samples of tungsten heavy alloy VNZh-90 (90W-7Ni-3Fe)

| Sample | U (kV) | q (atm) | D (mm) | L (mm) | P_{max} (N) | \sigma_t (MPa) | \omega at P_{max} (mm) | Notes |
|--------|--------|---------|--------|--------|-------------|---------------|-----------------------|-------|
| A1-1   | 5      | 2       | 10,8   | 5,2    | 17924       | 203           | 0,76222               | brittle fracture of the sample |
| A1-2   | 5,5    | 2       | 10,6   | 4,5    | 30523       | 407           | 1,16487               | plastic deformation without the failure of the sample |
| A1-3   | 5,5    | 1,5     | 10,6   | 4,5    | 50881       | 679           | 2,88742               | brittle fracture of the sample |
| A1-4   | 5,6    | 1,5     | 10,5   | 4,5    | 29863       | 402           | 1,05569               | brittle fracture of the sample |
| A1-5   |        |         |        |        |             |               |                       | Not tested |
| A1-6   | 5,5    | 1       | 10,9   | 5,5    | 34872       | 370           | 1,08068               | brittle fracture of the sample |
| A1-12  | 4,5    | 2       | 10,3   | 4,0    | 5991        | 93            | 0,58642               | brittle fracture of the sample |
| A1-13  | 5      | 2       | 10,3   | 5,8    | 24757       | 264           | 1,15809               | delamination deformation |
| A1-14  | 5,2    | 2       | 10,5   | 5,7    | 40861       | 435           | 1,55914               | delamination deformation, spalling |
| A1-15  | 5,4    | 2       | 11,0   | 5,6    | 48736       | 504           | 1,98984               | delamination deformation, spalling |
| A1-19  | 5,6    | 2       | 11,0   | 5,1    | 34788       | 395           | 1,14575               | brittle fracture of the sample |
| A1-20  | 5,7    | 2       | 10,8   | 5,7    | 40767       | 422           | 1,22948               | brittle fracture of the sample |
| A1-21  | 5,8    | 2       | 11,0   | 5,0    | 35741       | 414           | 1,24907               | brittle fracture of the sample |

Analysis of the results shown in Table 2 allows making a clear conclusion about the increasing strength of material at the increasing pulse voltage with pressure amount of 2 atmospheres, as well as about the maximum material strength at considerable plastic deformation under pressure of 1.5 atm and pulse voltage of 5.5 kV.

Figure 3 shows the deformation diagrams for the first five samples tested (see Table. 2). The diagrams also indicate the presence of the plastic flow of the sample prior to its destruction.

Another useful feature of disk samples loaded by the Brazilian test method was discovered during the testing of steel samples. It was found that symmetrical with respect to the axes X and Y strain distribution on the surface of the sample is characteristic. Violation of this symmetry signals a breach in the internal structure of the material which consequently results in premature failure of the sample in the form of spalling of its individual parts. [6]
4. Conclusion
This presents the possibility of indirect determination of the tensile strength of metallic materials based on the results of the testing of small-sizes disk samples with the Brazilian test. The test results for the disk samples of the tungsten heavy alloys show high strength and deformation properties of the material under optimal production conditions.

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