A modified "Brazilian" disk test – an indirect method to determine the tensile strength of ceramics

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Introduction

During the evaluation of materials the determination of strength, in particular the determination of tensile strength, is of special importance. However the examination of the tensile strength of brittle materials in direct procedures is very complex. Today, commonly used are the methods to determine the bending strength by 3-point-testing or 4-point-testing. The disadvantage of these procedures is the comparatively small actually stressed sample volume. In addition, the results strongly depend on the surface finish and the sample dimensions.

An attractive alternative is offered by the indirect examination of the tensile strength by the "Brazilian" Disk test. It became generally accepted by the examination of concrete strength.

Advantages of this method are the unproblematic producible specimen preparation and an easy testing set-up. Because of the small sample size it's possible to prepare a larger number of samples out of the same volume. In addition samples from relatively small fragments can be prepared.

This article includes current testing of refractory ceramics, applying the brazilian disc test. Further on, the results will be compared with the results of the commonly used bending strength methods.

Calculational bases

Figure 1 shows the dimensions of an Brazilian disk test specimen. The tests have been carried out by using discs of 30 mm in diameter and 15 mm thickness. The discs are sampled from a refractory corundum-mullite-ceramic.

When a disc is exposed to a diametrical load as showed in **Figure 1**, the occurring stresses may be described by the following equations [Hertz]. The calculational derivation of the equations will not be discussed in this article.

$$\sigma_x = \frac{-2F}{\pi d}\left\{\frac{x^2\left(R-y\right)}{\beta_1^4} + \frac{x^2\left(R+y\right)}{\beta_2^4} - \frac{1}{2R}\right\} \quad (1)$$

$$\sigma_y = \frac{-2F}{\pi d}\left\{\frac{\left(R-y\right)^3}{\beta_1^4} + \frac{\left(R+y\right)^3}{\beta_2^4} - \frac{1}{2R}\right\} \quad (2)$$

$$\sigma_{xy} = \frac{-2F}{\pi d}\left\{\frac{x\left(R-y\right)^2}{\beta_1^4} + \frac{x\left(R+y\right)^2}{\beta_2^4}\right\} \quad (3)$$

Mit	σ = stress	[N/mm^2]
	F = load	[N]
	R = disc radius	[mm]
	D = disc diameter	[mm]
	d = disc thickness	[mm]

$$\beta_1^2 = (R - y)^2 + x^2$$

$$\beta_2^2 = (R + y)^2 + x^2$$

The maximum tensile stress occurs in the centre of the disc along the x-axis. When setting x = y = 0, the maximum occurring tensile stress is calculated to:

$$\sigma_{\max} = \frac{2F}{\pi\, d\, D} \qquad (4)$$

The course of crack in a cylinder after load is showed in **Figure 2.** Apart from the fact that the largest stresses occur in the disks centre, it's also advantageous that the effectively loaded sample volume is very large, going along with a small effective surface. Also the effect of the surface condition is unimportant and consequently complex methods for grinding and polishing during preparation may be reduced.

FEM-Simulation

Previously described equations can be reinforced in a simple simulation of the stress conditions by the Finite Element Methode (FEM).

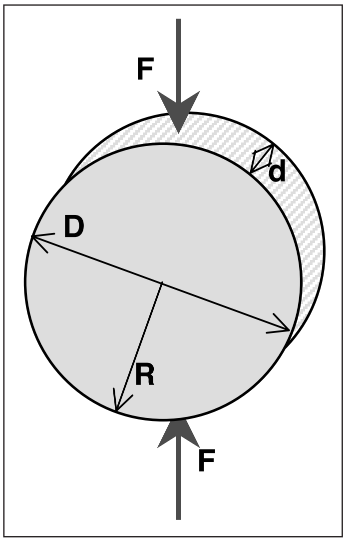

Fig. 1. Drawing of the Brazilian Disc Test Specimen

At first the specimen configuration has to be partitioned in a mesh of elements, which are connected with nodes. This simplification is called meshing or discretisation. Ideally the mesh is built up of linear plate primitives with simple geometries. The simulation needed here based on a cylindrical geometry, which can be simplified into a circle **(Figure 3)**.

For the computation, an isotropic behavior of the sample material is presupposed.

At its top side, the model is charged with a load of 90N, distributed on 3 knots. These are necessary for the computation to prevent too high calculated stresses. At the bottom, some nodes are fixed to simulate a support.

Fig. 2. Disc after Load

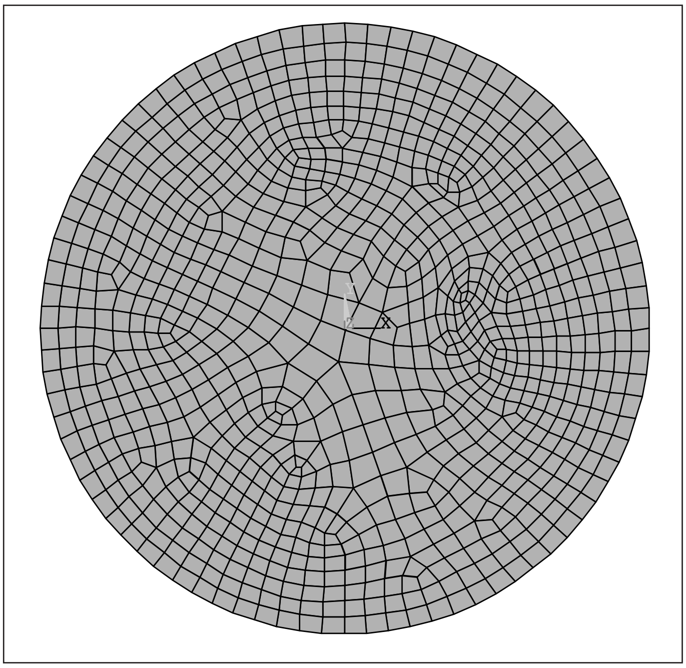

Fig. 3. Meshed into Finite Elements

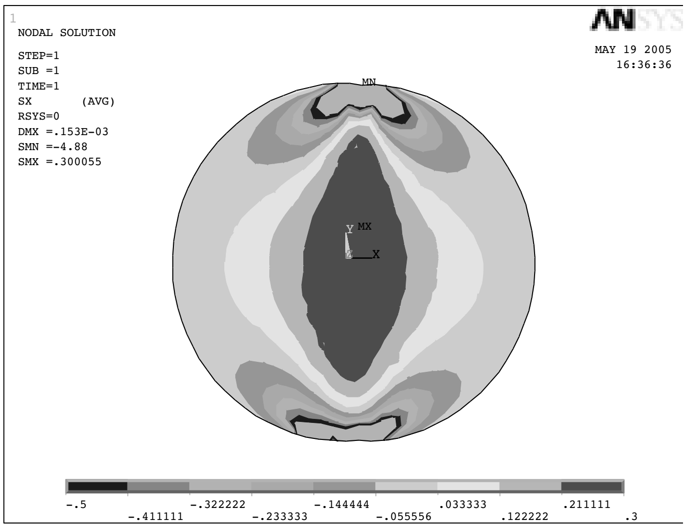

Fig. 4. Computed Stresses (x-axis)

Figure 4 shows the effecting tensile stresses in x-axis, marked in red. Stresses marked blue or green are correlating to compressive stresses. For ceramics compressive stresses are to be regarded as uncritical. The interpretation of the stresses in x-axis shows that the largest tensile stresses arise at right angle to the load transmission in the sample centre **(Figure 4)**.

Specimen Preparation

Executing the three or four point bending test at all times the crack begins at the tensile loaded angle. Consequently the measured strengths are highly depending on the surface finish requiring an accurate and extensive specimen preparation.

As mentioned before, executing the disc test results the maximum stress at the disc's centre. From there it is quite obvious that the surface finish of the sample becomes underpart. So the specimen preparation is more simplified and no polishing is necessary even when testing heavy ceramics.

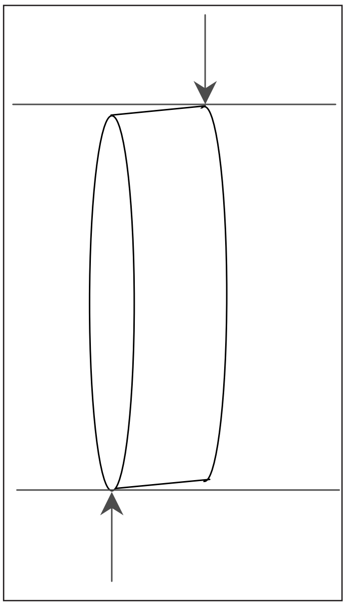

Fig. 5. Shear Stresses for non-rectangular

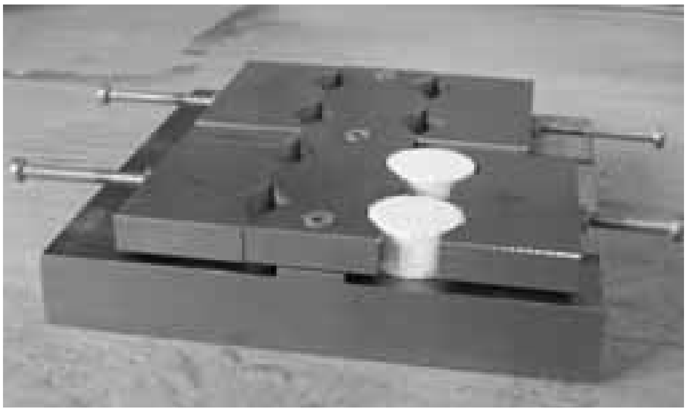

Fig. 6. Sample Preparation

It's merely to guarantee that the shells are at right angle to their frontal surfaces. Otherwise, shear stresses as shown in **Figure 5** occur and the results will be adulterated. Therefore the cylinders have to be fixed accurately during their grinding.

An example of a sample fastener is shown in **Figure 6**. The construction and utilization of hardened steel avoid the warping of the single components. The contact surfaces to the ceramic cylinders simulate a chuck and enforce a vertical orientation.

Bearing and execution of the test

Preliminary tests showed that the specimen bearing have to feature a radius in order to provide precise testing with perpendicular adjusted bearing faces. The bearing radius favorable should be dimensioned to 1,5 times magnification of the sample radius. **Figure 7** shows the bearing as applied at Werkstoffzentrum Rheinbach GmbH.

Due to the specimen geometry, five times higher loads are necessary compared to the three point bending test when analyzing refractory corundum-mullite ceramics:

- F_{max} (3 point bending test 25 × 25 mm): 800 – 1050 N
- F_{max} (modified brazilian disc test): 5000 – 5700 N

Therefore higher testing speeds are required to achieve the materials failure within 20 sec. according to the execution of the bending tests. At the same time, the necessary load drop to stop the test

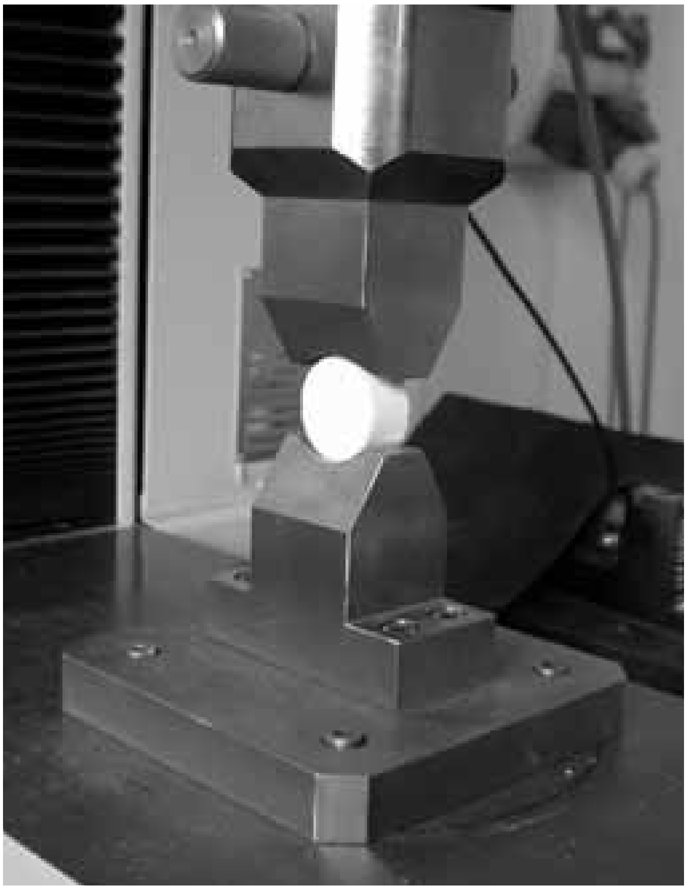

Fig. 7. Specimen Bearing for the mod. Brazilian Disc Test

has to be reduced. Otherwise the measurement continues and runs forward testing the disc fragments. In this way the results are insignificant as showed in the curve progression in **Figure 8**. The real failure is marked by the red arrow.

After optimizing load decreasing parameters the measurement was stop concurrent with the crack onset as shown in **Figure 9**.

Results of Experiments

Following test methods were compared during several test series:

- Three point bending test → quadratic sample profile 25 × 25 mm
- Four point bending test → quadratic sample profile 10 × 10 mm

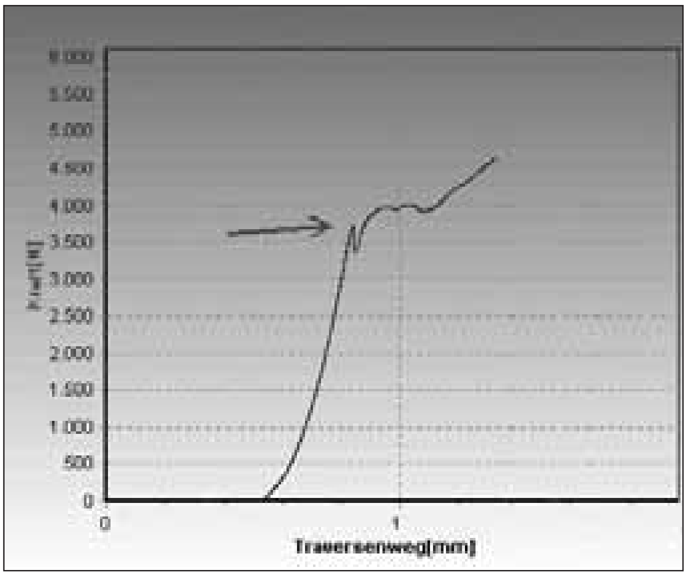

Fig. 8. Oversized Load Decreasing

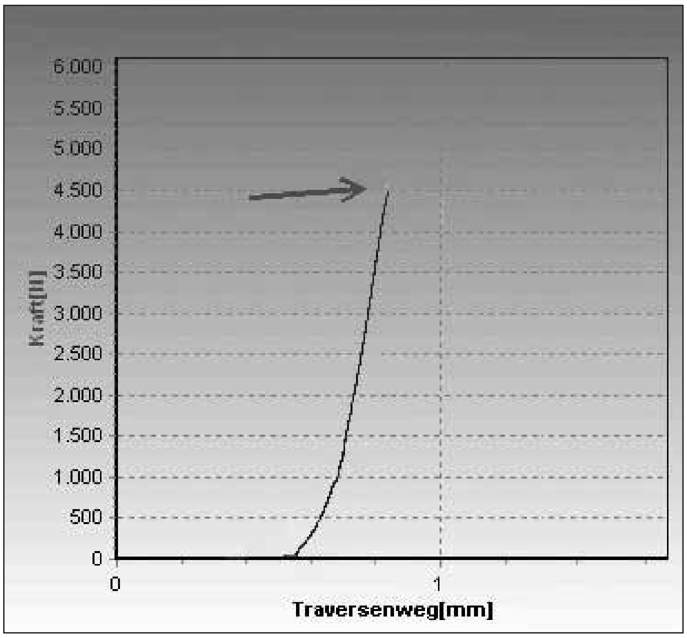

Fig. 9. Optimized Load Decreasing

- Four point bending test →quadratic sample profile 15 × 15 mm
- Brazilian Disc Test →round sample profile 30 mm

The analyzed material is a corundum – mullite refractory ceramic with a maximum grain size about 3 mm.

The results of the bending tests are comparable with the results of the Brazilian disc test as shown in **Figure 10**. Exceptionally to highlight are the excellent reproducibility and the much smaller dispersion of the single measured values using the Brazilian disc test compared to the results of three and four point bending tests.

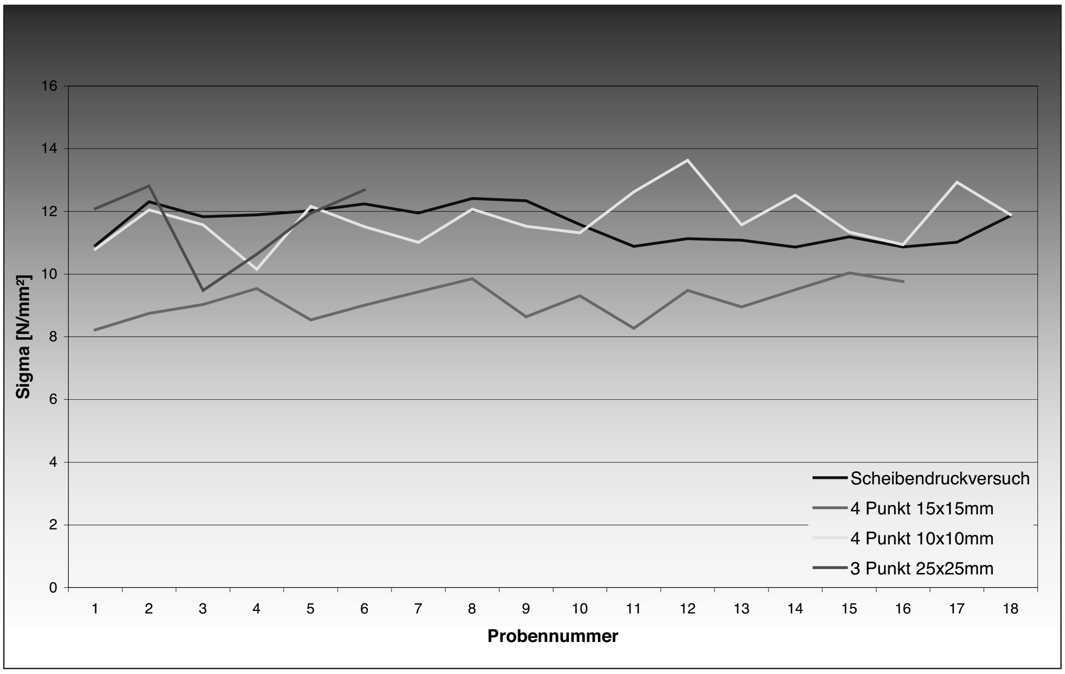

Fig. 10. Dispersion of single values

Figure 10 shows the measured strength as single values. The values of the brazilian disc test are marked dark blue. Thus it appears the minor dispersion in comparison to the other methods.

Conclusion

Advantages of the modified Brazilian disc test:

- Simple specimen geometry
  → Low operating effort, cost reduction
- Little importance of surface finish
  → Cost reduction; time reduction
- Small specimen
  → Larger number of samples from the same volume; preparing from small fragments
- Large effectively loaded specimen volume
  → Increased significance of the material grade
- small dispersion of values
  → Increased significance of single values, less number of specimens is required; better reproducibility

The results indicate a successful application and high potential for the Brazilian disc test for ceramic materials. Particularly focusing on the analysis of in use stressed materials, the disc test is an attractive method. (F 51)

References

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