The Modified Tension Test (MTT) – Evaluation and Testing Experiences with a New and Simple Direct Tension Test

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ABSTRACT: The "Modified Tension Test" (Blümel, 2000) represents a new and innovative approach to the laboratory research of the uniaxial tensile strength. The test features a cylindrical specimen of special geometry so a unidirectional tensile stress field is created in the sample. The test may easily be carried out in any standard testing machine to test the Unconfined Compressive Strength (UCS). The presented results evaluate the MTT as an easy-to-carry-out laboratory testing method that provides a realistic value for the direct tensile strength of a rock or concrete sample.

1 INTRODUCING THE MODIFIED TENSION TEST

In addition to the unconfined compressive strength and deformability, the tensile strength is one of the most important parameters for the mechanical description of a rock or building material. Unfortunately testing of tensile strength includes a lot of technical problems, so that such tests are used rather infrequently in the field of rock mechanics and geotechnical engineering.

In contrast to this, indirect testing procedures, such as the Brazilian, point load or bending tests are widespread. A number of standards such as the DIN 1048 German standard and testing recommendations such as DGEG (1982, 1985) and ISRM (1978, 1985) deal with these tests and provide a good background for comparable test results. Nevertheless, comparisons between direct and indirect tension tests are difficult and empirical equations have to be used for such purposes.

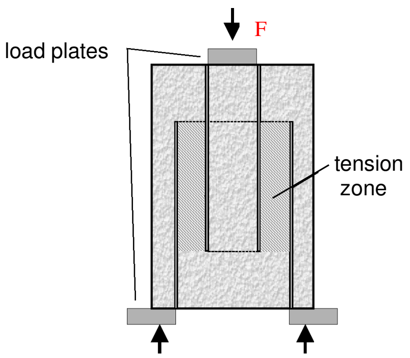


Figure 1: General testing layout and sample geometry for the Modified Tension Test.

$$\sigma_{MTT} = \frac{F_{\max}}{A_{TZ}} = \frac{F_{\max}}{r_1^2 \cdot \pi - r_2^2 \cdot \pi} \qquad (1)$$

with:

σ_{MTT}	MTT tension strength	[MPa]
F_{max}	failure load	[N]
r_1	radius of the larger core hole	[mm]
r_2	radius of the smaller core hole	[mm]

The “Modified Tension Test” (MTT) dealt with in this paper was developed at the institute for rock mechanics and tunneling at the TU Graz, Austria. Basics of the testing principle were presented at the EUROCK 2000 symposium by Blümel (2000). The test uses a simple, cylindrical specimen that is over cored from the top and bottom by two axial core drill holes with different diameters (Figure 1). After placing a load plate (top) and load ring (bottom), the sample is then loaded in a standard testing device for compressive testing. Failure occurs by tension in the area in between the both overlapping core drill holes (“tension zone”). The MTT tensile strength σ_{MTT} is calculated from the maximum compressive load F_{max} and the area of the tension zone A_{TZ} which depends on the radius r_1 and r_2 of the core holes (Equation 1).

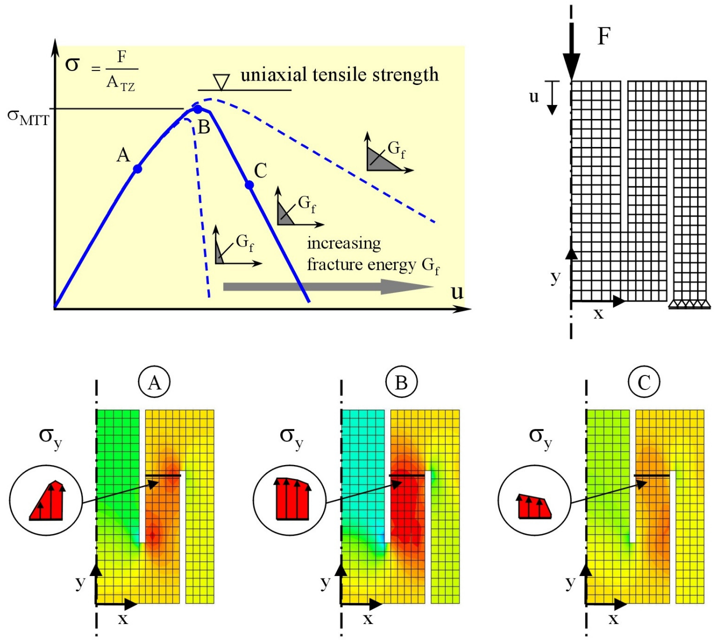
2 COMPARING TENSILE STRENGTH VALUES FROM DIFFERENT TESTS

As an example for the wide range of values that can be obtained from different testing procedures, the results from a series of tests on a homogenous and isotropic rhyolithe from the Rennsteig tunnel project at Oberhof in Thuringia, Germany are presented below (Wolski, 2002). In comparison with the MTT, other test results are up to about 90 % (Brazilian test), 110 % (point load test) or even about 260 % (bending test) higher.

Testing procedure	**Mean value**	
Modified Tension Test	3.8 ± 0.97	MPa
Brazilian Test *(acc. to DGEG 1985, ISRM 1978)*	7.2 ± 1.6	MPa
Point-Load-Test *(acc. to DGEG 1982, ISRM 1985)*	8.0 ± 1.0	MPa
Bending Test *(acc. to DIN 1048)*	13.5 ± 1.5	MPa
Unconfined Compressive Strength	102.3 ± 9.1	MPa

3 RESULTS FROM THE FINITE ELEMENT STUDIES

In order to further investigate stress distribution and stress development during testing, the MTT was modeled using four-node axisymmetric 2d elements (Figure 2, upper right). The material model is based upon the incremental flow theory within the framework of the theory of plasticity and was originally developed for the calculation of concrete and steel fiber reinforced concrete structures. Results from the FE analysis are comprehensively shown in Figure 2.



The diagram in the upper left part of the figure shows the correlation between the mean tensional stress σ_m and the axial deformation u.

In the lower part of the figure the distribution of stresses in y-direction is illustrated in cross sections through one half of the sample for 3 different stages of the test: (A) shows the stress distribution in the pre-failure area, (B) is at maximum load (failure point) and (C) shows the post-failure situation. The calculations give rise to the supposition, that the variable stress field in the pre-failure area (A) becomes more or less equally distributed when the failure point is reached (B). This effect shows to be largely influenced by the ductility of the material.

Figure 2: Models for and results from the finite element analysis.

The maximum mean tensile strength σ_{MTT} calculated from the finite element model is only a little lower than the implemented material tensile strength. The difference correlates to the ductility of the material which is described by the tensional fracture energy. With increasing ductility of the material, the calculated maximum mean tensile strength σ_{MTT} comes closer to the implemented material tensile strength due to a more equal stress distribution.

As a result of the calculations, the authors state that the tensile strength obtained in the MTT is rather equal to the theoretical uniaxial tensile strength of a material with respect to the normal variation of testing results.

4 EXPERIENCES AND SUGGESTIONS FOR MTT TESTING

From the testing programme some general experiences and suggestions may be drawn:

- *Requirements for the testing material:* Sample preparation includes at least two different coring processes which in most cases is done using water-cooled boring machines. Consequently, jointed, weak or non-durable material may not be suited for formatting.
- *Sample size:* Suggestions made by Blümel (2000) feature a sample diameter of > 100 mm, a length-diameter ratio of about 1.5:1 and special formatting of the sample faces according to UCS testing standards. The authors suggest the use of larger diameters over 200 mm for coarse grained rock samples or concrete samples. Depending on the maximum grain size of the material, such diameters are importat for a representative size of the tension zone.
- *Alignment of drill holes:* At the beginning of preparation works, it turned out to be a problem to assure both core drillings being centered and vertical. This problem could be solved by using a special guiding construction for drilling.
- *Modification of sample geometry:* Especially for investigations on steel fiber reinforced concrete, constant stress distribution in the tension zone had to be assured for the whole pre and post-failure phase of the test. This was achieved using two additional core drill holes to weaken the central area of the tension zone and to force the initial crack to propagate there (Figure 3). In combination with deformation-controlled testing and monitoring of the whole stress-strain path, this testing setup allowed realistic investigation of post-failure behavior, which for this concrete is defined by distinctive post-failure strength due to steel fibers being pulled out of the concrete matrix after failure (Figure 3).

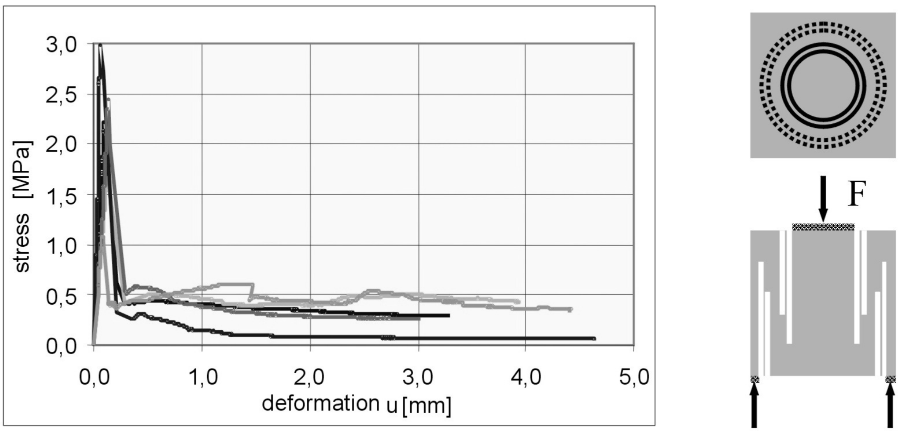


Figure 3: MTT testing results for deformation-controlled tests on steel fiber reinforced concrete samples with modified geometry.

- *Testing setup and control:* For MTT testing the ISRM suggestions for uniaxial compressive strength tests (ISRM, 1978b) should be applied as far as possible. Depending on testing material and investigation aims, the tests should either be stress-controlled to the failure point with a constant loading rate of about 0.05 MPa/s or deformation-controlled, which may include plotting of the whole stress-strain path.

- *Force application:* In the research program, forces were applied using 5 mm V2A steel plates and -rings in the exact size of the tested diameters. It appeared useful to conduct the tests without or with a deactivated ball joint at the loading plates. If an initial crack formes in one side of the tension zone, a testing frame with ball joint will further propagate only this crack, which may lead to asymmetric stress distribution and inclination of the inner core.
- *Testing results:* Total axial deformation and applied load should be plotted in a force-deformation diagram similar to that of a UCS test. The MTT tensile strength is calculated for the failure point using Equation 1. Calculation of deformation modules (e.g. a kind of Young´s module) from this plot does not appear useful since complicated load transfers take place in the sample during testing and thus a calculated deformation modulus would not be very significant for describing any compression or tension behavior of the material. For significant ductile behavior calculation of a post-failure tensile strength is recommended.

5 CONCLUSIONS

The presented research program (see also Plinninger, Wolski, Spaun, Thomée & Schikora, 2003) evaluates the Modified Tension Tests as an innovative and easy-to-carry out testing procedure for determining the direct uniaxial tensile strength of hardrock and building materials. In detail, the MTT is characterized by the following positive features:

- The tensile strength determined with the MTT comes very near to the real tensile strength of a tested material or rather equals the tensile strength with respect to the normal variation of testing results due to material differences.
- The MTT provides good possibilities for monitoring material behavior in the post-failure area of ductile materials, as for example steel fibre reinforced concrete.
- In comparison with standard UCS tests, the MTT needs no or only little extra expenses with regard to time, costs and required equipment.
- The MTT is very well suited for materials with high strength (especially hardrock), where the use of adhesives is no longer possible.

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