A NEW METHOD TO INVESTIGATE THE SURFACE TENSILE STRENGTH OF CONCRETE AND MASONRY STRUCTURES

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SUMMARY

A new method to determine the surface tensile strength of concrete and masonry structures is introduced in this study. The method consists of three parts: a tension test instrument, a surface glued steel stamp and a specifically developed bearing steel plate. The test device was experimentally verified by 32 tests at each specification. There were used lime-sand bricks and two different types of clay bricks, with one clay brick having a porous texture.
The test results were compared with a certified traditional test set-up that is documented in the national German Code (*DIN 1048 T.2*). Moreover, the results will be compared with centric tensile strength test results obtained from core drilled test specimens.

INTRODUCTION

The surface tensile strength is one of the main parameters describing the design resistance of the bond between Fibre-Reinforced-Polymers (FRP) and brittle materials. For concrete, certified devices can be used to determine the surface tensile strength. These devices use a steel stamp with a diameter of 50 mm which is glued onto the concrete member after a circular groove is cut into the surface. With this method the tension area is exactly defined. For masonry surfaces it was found that drilling of circular grooves leads to damages on the microscale causing a reduction of the surface tensile strength. To avoid inefficient testing results and to obtain values closer to reality, a new test method was developed which uses a steel plate with a circular opening (diameter 55 mm) instead of the circular groove, to define the tension area.

MATERIALS

Generally, test devices should be suitable for different structural materials. Therefore, three typical types of bricks were used: a solid lime-sand brick and two different types of clay bricks with one of them having a porous texture.
The compressive strength for each type was determined on five cylindrical cores of approximately 45 mm diameter. The cores were drilled in z-direction (Figure 1).

Table 1. Characteristics of bricks

	type		compressive strength * $f_{c,z}$ [N/mm²]	texture	density [t/m³]
KS20	solid lime-sand brick	KS20-1,8-NF	22.8	normal	1.8
Mz20	solid clay brick	Mz20-2,0-NF	35.2	normal	2.0
Mz12	solid clay brick	Mz12-1,8-NF	27.2	porous	1.8

* tests carried out on five cylindrical core drilled specimens of approx. 45 mm diameter

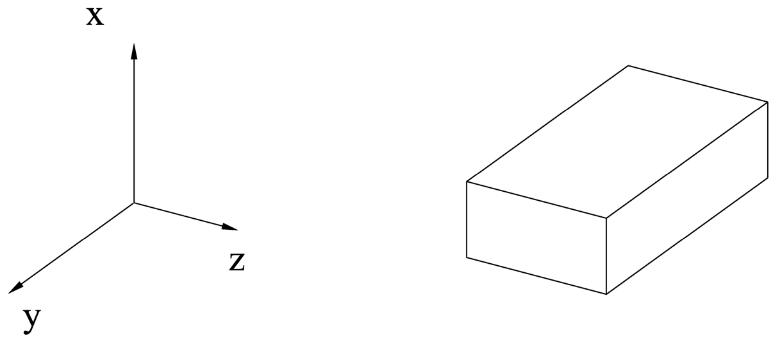


Figure 1. Coordinate system

SURFACE TENSION TEST DEVICES

Two test devices were used: a traditional certified test set-up where the preparation of a circular groove is necessary and a newly developed test device. For each brick type between 16 and 32 tests were conducted (Table 2).

Surface preparation

Both the traditional and new developed test method use a steel stamp which has to be glued to the specimens surface. To ensure a strong connection between stamp and test specimens the surfaces were cleaned with compressed air and a thin layer of adhesive was applied subsequently. In order to account for influences of adhesives, two types of adhesives with different viscosities were used, with *adhesive B* having a lower viscosity.

Test device with circular grooves

The well-known traditional test is a certified test procedure for the determination of surface tensile strength of concrete structures and is documented in the national German Code (*DIN 1048 T.2*).
Circular grooves with a diameter of 50 mm have to be cut into the specimen surface. The purpose of the circular groove is to define the tension area exactly. The depth is given in *DIN 1048 T.2* as 10 to 20 % of the diameter and was thus 5 mm to 10 mm. The groove was formed with a core drill.
Subsequently, the steel stamp has to be glued to the brick surfaces with a fast-curing two component Methyl-Methacrylat adhesive (Figure 2b).

(a) (b) (c)

Figure 2. (a) drilling machine with core drill, (b) prepared masonry unit with radial groove and adhesive, (c) glued steel stamp

The steel stamps were pulled-off with a electronic test device (F15D-Easy-M2000), which was specifically designed for surface tension tests. The test set-up ensures a perfect direct tension without any moments or shear stresses. During tests the load was increased with a rate of 0.05 N/mm² per second, leading to 100 N/s.

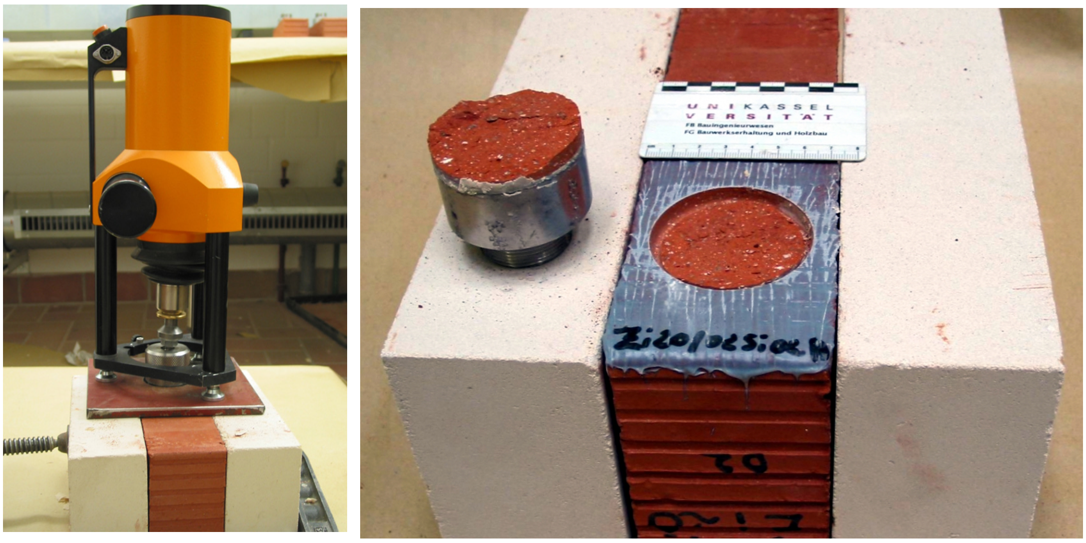
The tensile strength can be calculated using the following equations:

$$f_{t,t,z} = \frac{F_u}{A} \quad (1)$$

$$A = \frac{\pi \cdot d^2}{4} \quad (2)$$

where: F_u - ultimate tension force for pull-off
A - circular tension area (diameter 50 mm), limited by circular groove

The tension test procedure and a typical fracture surface of clay brick (Mz20) is illustrated in Figure 3.



(a) (b)

Figure 3. (a) tension test procedure with circular groove, (b) post test specimen with typical failure area

Test device without circular grooves

The new test procedure was developed to achieve results closer to reality, to decrease variation of test results and to simplify test procedure. Again, the surfaces were cleaned by compressed air and the adhesive was applied to the surface. Subsequently, a steel stamp with a diameter of 50 mm (similar to test device with circular grooves) was glued to the surfaces. The test method does not require a circular groove, because a steel plate with a circular opening defines the tension area.

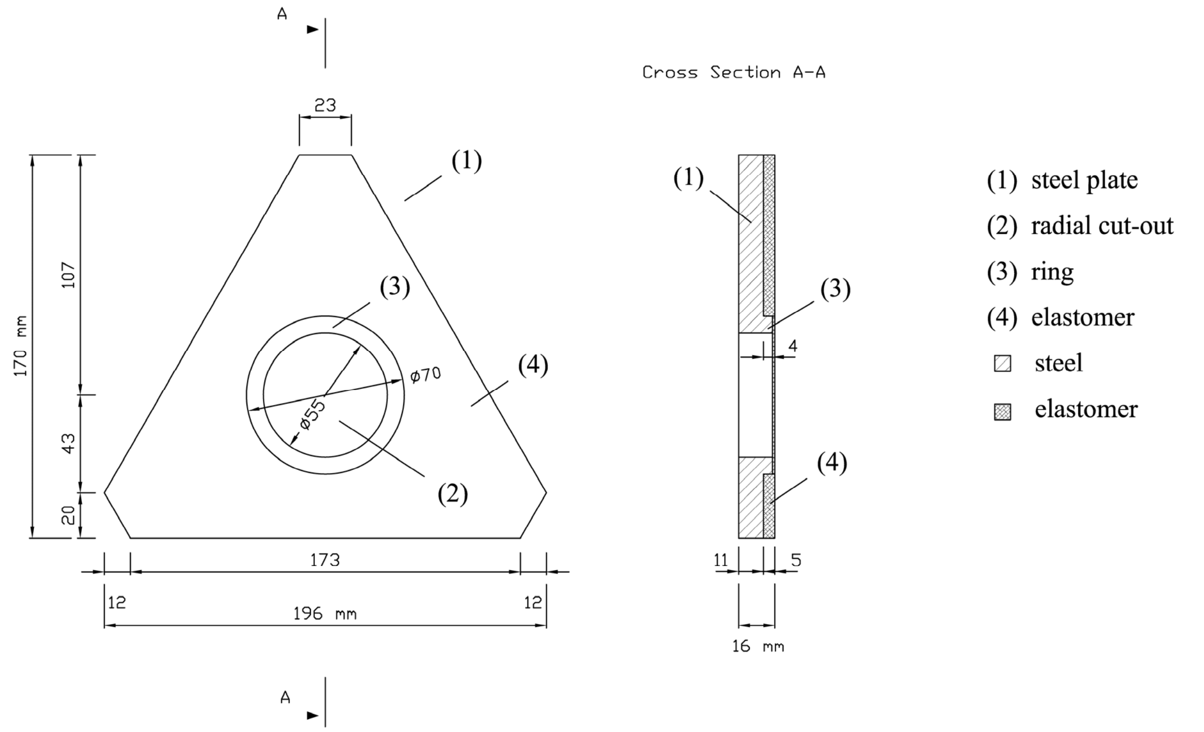
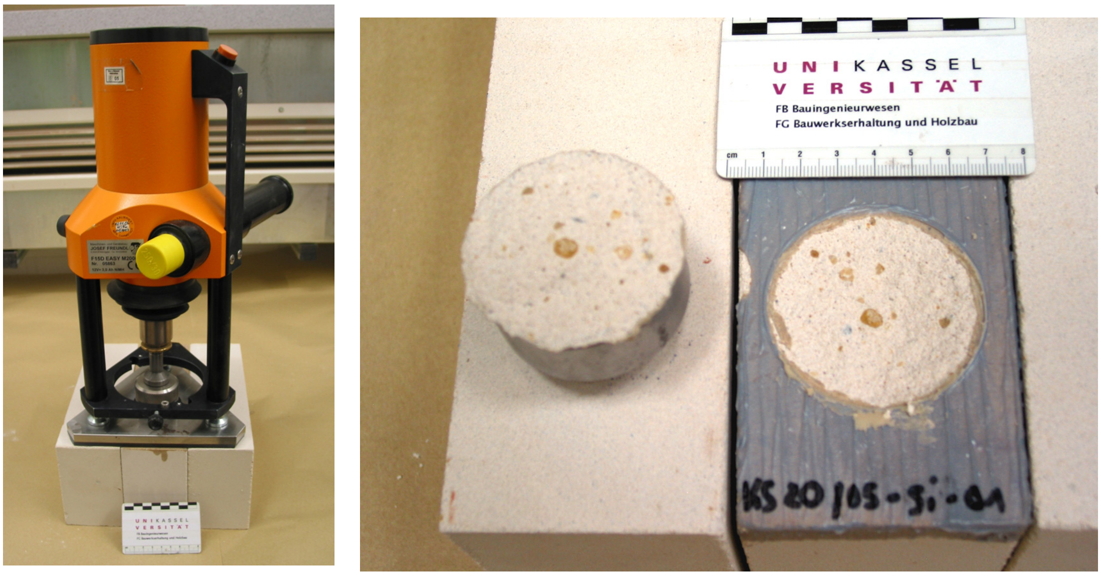


Figure 4. Illustration of steel plate

The "abutment" consists of four elements (Figure 4): (1) a steel plate with a thickness of 11 mm, (2) a circular cut-out in the centre with a diameter of 55 mm, (3) a circular enlargement which was pushed against the brick surfaces and (4) a elastomer to ensure stability in the case of uneven specimen surfaces. To allow tolerances, the opening was 5 mm wider in diameter than the steel stamp resulting in a 2.5 mm wide gap around the stamp.

The surface tensile strength $f_{t,n,z}$ was calculated using Equation 1 and 2. It should be noted that in comparison to the traditional test device where the test area was limited by the groove, the tension area is now defined by the circular opening in the steel plate (55 mm) leading to an increase of calculation considered tension area of about 20 % (1963 mm² to 2376 mm²).

Figure 5 illustrates a typical fracture surface after pull-off test. The tensile failure occurred generally in a depth of 2 mm to 3 mm into bricks.



(a) (b)

Figure 5. (a) tension test procedure, (b) typical fracture surface

Results

It was assumed that drilling of circular grooves leads to microscopically damages. This was confirmed by the scattering of the test results. The test results of the new test method showed less variation. E.g. for lime-sand brick (KS20) the standard deviation was half of the standard deviation obtained of the traditional test method. Furthermore, higher tensile stresses were obtained with the new test method (Table 2).

Table 2. Results of surface tension tests

	traditional test method (with circular groove)			new test method (without circular groove)		
	number of specimens	surface tensile strength $\bar{f}_{t,t,z}$ $[N/mm^2]$	standard deviation $[N/mm^2]$	number of specimens	surface tensile strength $\bar{f}_{t,n,z}$ $[N/mm^2]$	standard deviation $[N/mm^2]$
KS20	29	2.24	0.44	31	2.62	0.24
Mz12	32	1.70	0.27	16	2.04	0.28
Mz20	30	2.17	0.60	28	2.35	0.48

Nearly hundred surface tension tests were carried out, however, not all results were valuable. Some specimens showed adhesion failure at the interface of steel stamp and adhesive. A few clay bricks (Mz20) failed prematurely due to the existence of manufactory produced cracks within the bricks. Then results are not included in table 2 and figure 7.

For porous bricks (Mz12) the gluing of the steel stamp with *adhesive B* (lower viscosity) resulted in a adhesion failure between adhesive and brick surface for 16 test specimens. These results were disregarded.

A summary of all individual results is reported in *Hempel & Orschulok (2007)*.

TENSILE STRENGTH TESTS ON CORES

To examine tensile strength of bricks tests were carried out on cylindrical cores. The specimens were 90 mm high and approximately 45 mm in diameter (Figure 6). In order to control the fracture plane, a radial notch was cut at mid-height of the test specimens resulting in a reduction of tension area with an reduced diameter of approximately 36 mm. The centric tension stress $f_{t,c,z}$ was calculated using Equation 1 and 2. The diameter of the tension area was measured exactly for all test specimens.

To ensure a smooth planar surface, top and bottom of test specimens were ground. Subsequently steel stamps were adhered to the top and bottom of the test specimen with additional steel plates glued over the joint to avoid adhesion failure. Pin-jointed connections between test frame and specimens were used. Tests were performed load-controlled with a rate of loading of 50 N/s.

Figure 6. Test set-up and typical fracture surface, test KS20

The test specimens failed in the designated plane except for two tests (Mz20) where failure occurred outside the radial notch. These results were neglected.
The results of the centric tension tests are summarized in Table 3. The highest centric tensile strength was obtained with lime-sand bricks (KS20) and, as expected, lower strength were measured for clay brick (Mz12). Also, a low deviation of test results was achieved.

Table 3. Results of centric tension test on cores

	diameter of tension area $[mm]$	tensile strength $f_{t,c,z}$ $[N/mm^2]$	tensile strength (mean value) $\bar{f}_{t,c,z}$ $[N/mm^2]$	standard deviation $[N/mm^2]$
KS20	35.72	3.06	3.04	0.13
	35.79	3.16		
	35.80	2.90		
	35.72	3.16		
	35.75	2.92		
Mz12	35.70	2.38	2.51	0.24
	33.81	2.26		
	35.87	2.89		
	33.84	2.50		
	35.76	2.53		
Mz20	-	- *	2.63	0.66
	35.90	3.36		
	-	- *		
	35.80	2.45		
	35.88	2.07		

* failure occurred outside the radial notch

COMPARISON OF TEST RESULTS

Adopting the new method resulted in tensile stresses approximately 7 % (clay brick, Mz20) to 16 % (lime-sand brick, KS20) higher than the results of traditional test method. The results back up the hypothesis that microscopically damages from notching of test specimens lead to lower tensile strength. The lower variation of test results also supports this assumption. The standard deviation of tensile strength tests of lime-sand bricks (KS20) for the new method was about 45 % lower when compared to the traditional test results.
Figure 7 illustrates the results of surface tension and centric tension tests. As expected for the traditional test method, the surface tensile strength was lower than the centric tensile strength. For tests with the new test method, it was expected that the surface tensile strength would be close to the centric tensile strength. It might be concluded that the real tension area of the new test device - which is limited by the circular opening in the steel plate – is lower than 55 mm or that peak stresses along the stamp perimeter resulted in premature failure. However, no evidence could be found to support these hypotheses.

As expected, the highest tensile strength in the current study was achieved for lime-sand bricks (KS20). According to *Schubert (2006*) the tensile strength of bricks is approximately 8 % of the compressive strength. Similar results were obtained in this study with the centric tensile strength between 7,5 % (Mz20) and 13 % (KS20) of the compressive strength (Table 1).

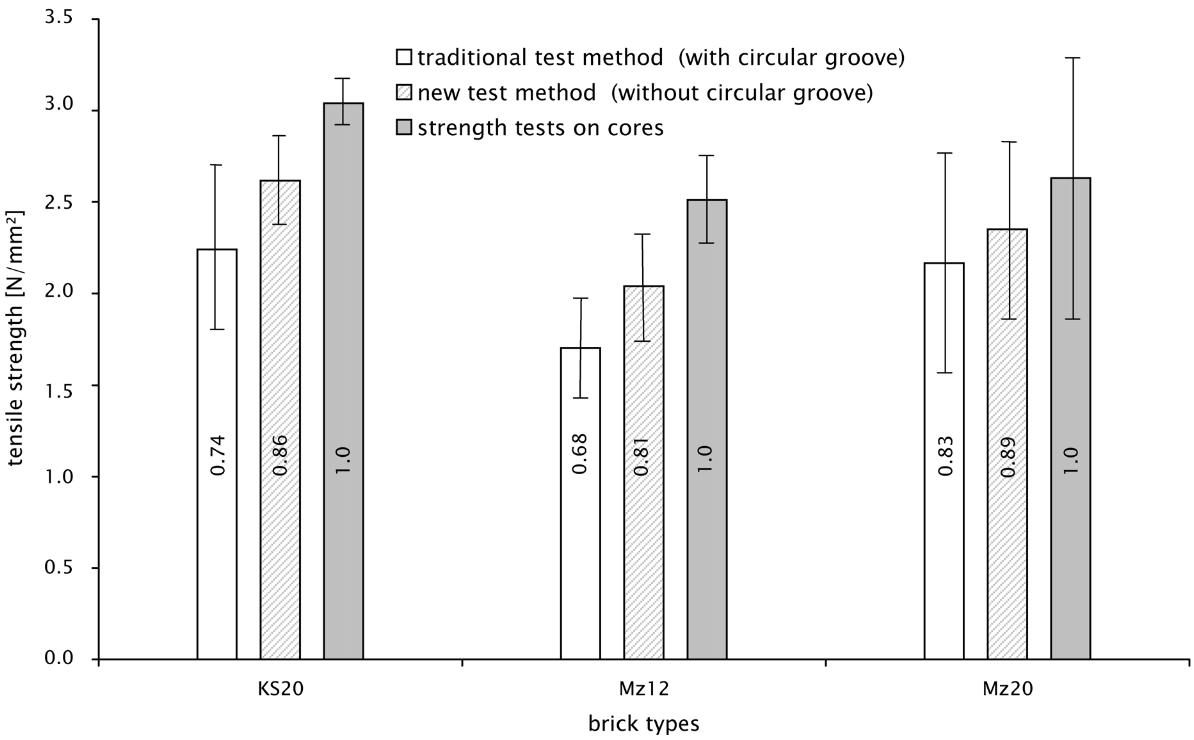


Figure 7. Comparison of tension test results: mean tensile strengths and standard deviations

CONCLUSION

A new test device for testing of surface tensile strength of brittle materials, such as masonry units and concrete, was developed. The test device consists of three elements: a tension test instrument, a steel stamp which has to be directly glued onto surfaces and a steel plate acting as “abutment”. The tension area is defined by a circular opening in the steel plate. This enables a test procedure without cutting a circular groove.
The surface tension tests were carried out on solid lime-sand bricks and two different types of clay bricks with one clay brick (Mz12) having a porous texture. The new test device was validated with 32 surface tensile strength tests and five centric tensile strength tests for each test sequence.
It was shown that test results of the proposed new test device lead to less deviation and higher strength values. The standard deviation in the tests of lime-sand bricks (KS20) with the new method was about 45 % lower than with the traditional method. Moreover, preparation work of test specimen was greatly reduced with the new test device.

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