SHORT REPORT

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Rationalised production of double-leaf masonry achieved by line anchorage of external shell

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1 AIM OF THE RESEARCH PROJECT

The double-leaf wall with thermal insulation as external masonry has long since been a much reliable wall construction with which all essential requirements – load bearing capacity, thermal - and sound insulation as well as weather protection can be met in an optimal way. As a rule, the connection of the external shell of the double-leaf wall with the load-bearing internal shell is made by the laminar arrangement of wire anchors. This construction method is laid down in DIN 1053-1. By means of a line-like anchorage, e. g. floor by floor technical and economic advantages can be yielded. According to DIN 1053-1, line anchorage is basically permissible, design and execution rules regarding the relevant building material properties, primarily the flexural tensile strength of the external shell of the double-leaf wall, have been missing so far. If this were the case, the building process of this well proven outer wall construction could be significantly rationalised as well as a higher safety level could be yielded in the execution on site.

Therefore, it is the aim of this research project to develop the essential basic principles for a more rationalised execution of double-leaf masonry by means of line anchorage.

2 REALISATION OF THE RESEARCH PROJECT

At first, in a literature research, basically applicable ultimate load models and calculation methods for a biaxial bending stress of the facing shells were compiled. This is followed by a comparative consideration and evaluation of the methods. The literature research was supplemented by construction and execution recommendations of line-like external shells of double-leaf walls.

The present test reports regarding masonry flexural tensile strength, the main building material characteristic of masonry under bending stress, were prepared. The test results were evaluated with respect to the examination of correlations between masonry flexural tensile strength and building material characteristics which are determinable as replacement. Characteristic values of the flexural tensile strength parallel and normal to the bed joints were specified. The bending stiffness of the walls was determined by approximation with the given load deflection curves. Furthermore, the respective literature was viewed regarding tests under a biaxial load, i. e. bending stress at simultaneous normal force load.

On the basis of the results of the literature research, a test programme was developed. Initially, extensive tests on the applied building materials were conducted. On the one hand, this was made with regard to being able to correctly describe the flexural tensile tests on masonry walls taking the essential building material properties as a basis. On the other hand, however, this was also made against the backdrop of finite element simulations possibly becoming necessary for a more accurate analysis of the load bearing behaviour of masonry walls. The conducted tests enable a determination of the complete material laws of the masonry units and of the bond under shear stress and tensile load which also describe the post-failure behaviour. These laws are of utmost importance for the use of the load bearing capacity of the system. Moreover, the verification of the respective values of the masonry flexural tensile strength is made with alternative test methods. Subsequently, flexural tensile tests parallel and normal to the bed joints (altogether 9 test series with 3 tests specimens, each) were carried out on facing masonry made of solid and vertically perforated bricks. In doing so, due to the missing findings, especially the influence of the overlap on the flexural tensile strength of the facing masonry was investigated. To determine the bending stiffness of the masonry walls and to describe the failure mechanisms in the masonry, extensive deformation measurements were conducted.

The literature research and evaluation of the different design models showed that, due to the absence of findings regarding the system load bearing behaviour of the facing shells, the determination of the load bearing capacity should be made on a horizontal continuous beam. In doing so, an increase in the load bearing capacity can be made by a plastostatic determination of the internal force variable. For this purpose, the value of the plastic bending moment due to friction must be known. To describe the bearing behaviour depending on the superimposed load upon exceeding the flexural tensile strength parallel to the bed joints, four-point bending tests under superimposed axial load normal to the bed joints as well as torsion tests under simultaneous normal force load were carried out.

3 SUMMARY OF THE RESULTS

3.1 Results of the literature research

On the basis of the literature research, at first possible calculation models for the design of biaxially stressed facing shells were compiled and assessed. On the basis of the Canadian Masonry Standard a calculation method for the application was modified. The special fixing of the veneer wall with the ties embedded in the mortar may lead to a loss of the horizontal support so that the presented calculation models can only be recommended to a limited extent. Therefore, the determination of the load bearing capacity of a horizontal continuous beam must be preferred. The deduction of a respective calculation model could not be made within the framework of this research project. First tasks concerning this subject carried out at the TU Darmstadt showed that the knowledge of the plastic material behaviour at a column-by-column anchorage after exceeding the flexural tensile strength parallel to the bed joints and pure friction behaviour at the failure of the joints is necessary to be able to use the increase in load bearing capacity due to the plastostatic determination of the internal force variable. Further literature research regarding construction and execution recommendations is limited to a few construction rules and standard solutions for a structural design, respectively, which mainly come from Switzerland.

Based on the evaluation of former flexural tensile tests parallel and perpendicular to the bed joints – Figure 1 shows the flexural tensile strength perpendicular to the bed joints depending on the flexural tensile strength parallel to the bed joints – the application of a characteristic flexural tensile strength of 0.54 N/mm² parallel to the bed joints and of 0.11 N/mm² normal to the bed joints seems justifiable.

It must however be mentioned that, following the contemporary safety philosophy, the values of the masonry flexural tensile strength determined in tests should be converted into the respective minimum values of the shear bond strength, unit tensile strength and tensile bond strength. This requires however correct calculational approaches which are presently not yet available. Here it is pointed out explicitly that the characteristic values of the flexural tensile strength were derived from tests which feature a considerably higher bond strength than the values required according to DIN V 18580 with the calcium silicate unit as reference. At the application of the a. m. characteristic values of the flexural tensile strength in the design, it must be ensured that these values are yielded at the applied combinations of masonry unit and mortar. The orthotropy factor (ratio of the flexural tensile strength perpendicular to the bed joints to the flexural tensile strength parallel to the bed joints) then amounts to $\mu = \beta_{BZ,s,k} / \beta_{BZ,p,k} = 0.2$ for the a. m. characteristic values.

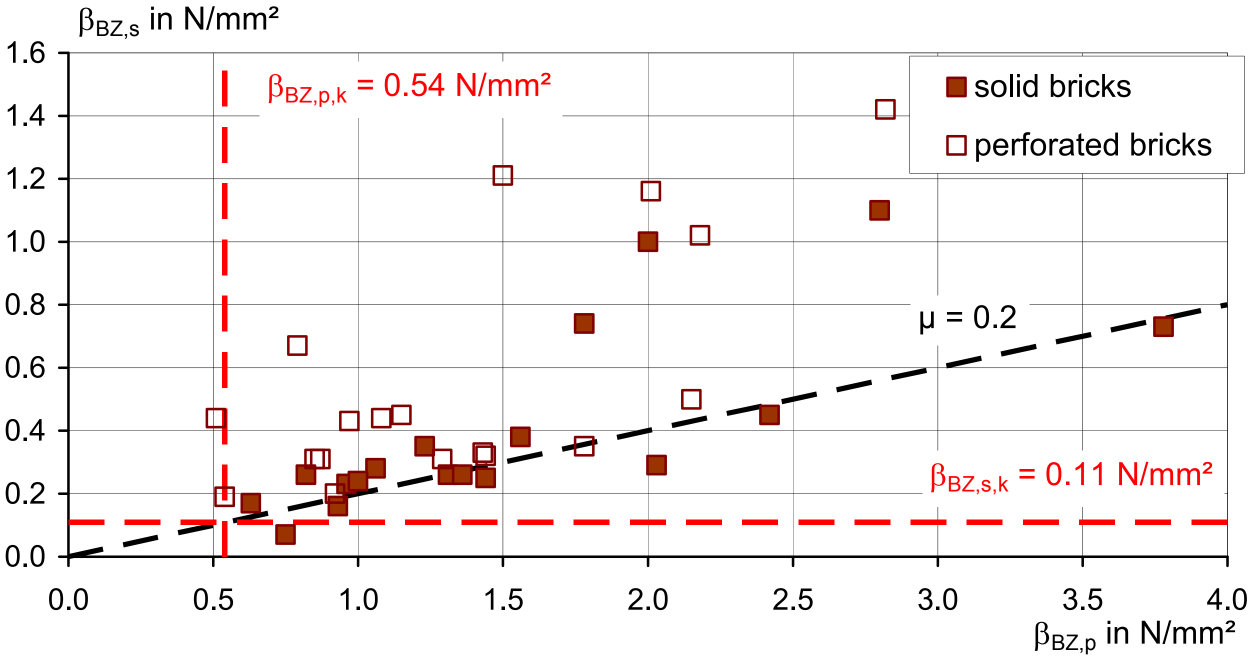

Figure 1: Flexural tensile strength perpendicular to the bed joints depending on the flexural tensile strength parallel to the bed joints

A correlation between the masonry flexural tensile strength and characteristics which are determinable as replacement could be deduced on the basis of the evaluated data base only for the masonry flexural tensile strength normal to the bed joints and the flexural tensile bond strength of masonry columns. Evaluating the load deformation curves, guide values of the bending stiffness of the facing shells at vertical and horizontal stress direction could be determined. Examinations regarding the flexural load bearing behaviour parallel to the bed joints at a simultaneous normal force load – especially to describe the friction behaviour – are available only to a very limited extent. The test programme was developed particularly against the backdrop of the significance of this material behaviour and the absence of respective findings.

3.2 Experimental test results

Flexural stress perpendicular to the bed joints

On the basis of the present test results, the determination of the flexural tensile bond strength as alternative method to determine the masonry flexural tensile strength normal to the bed joint seems to be fundamentally suited. The evaluation of the data base resulted in a ratio of masonry flexural tensile strength to column flexural tensile strength of $\beta_{BZ,mw,s} / \beta_{BHZ} = 0.76$. Tests applying the Bond-Wrench method showed a very wide scattering. This test method is therefore unsuited as alternative test method for the flexural tensile strength normal to the bed joints. The application of this test method seems however basically suited for the quality control upon determination of a material specific ratio at the verification of the reproducibility of the results as well as for a rough estimate of the flexural tensile strength.

Figure 2 exemplarily shows a comparison of the completely determined load deflection curves of columns made of perforated and solid bricks. The considerably lower load decrease at the perforated bricks is due to the indentation of the mortar pins which develop in the perforation of the units.

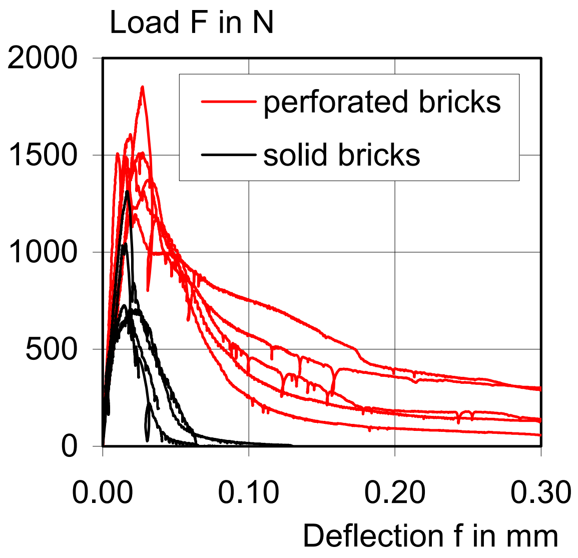

Figure 2: Flexural tensile bond test on columns; load deflection curves of vertically perforated bricks H2 and solid bricks W2 with normal mortar

Flexural stress parallel to the bed joints

Figure 3 displays the load deflection curves of masonry walls made of solid bricks and vertically perforated bricks in combination with a normal mortar, each with a half-unit overlap and the minimum permissible overlap of 45 mm according to DIN 1053-1, respectively. The decrease in the overlap to the minimum size according to DIN 1053 leads to about 25 % lower values of the flexural tensile strength (ratio about 1.3). Thus the influence of the overlap on the flexural tensile strength is considerably lower than according to the design equations in DIN 1053-1, in which the overlap is calculated linearly. Consequently, the ratio of the flexural tensile strength of a half-unit overlap to that of a minimum permissible overlap amounts to about 2.5. Independent of the execution of the head joints and the overlap, walls made of vertically perforated bricks feature a more distinct non-linear curve with larger deflections when reaching the maximum load. This is presumably due to the favourable indentation effect of the mortar pins.

The smaller bending stiffness of the walls made of vertically perforated bricks is to be ascribed to the higher modulus of elasticity of the solid bricks. The overlap exerts nearly no influence on the bending stiffness. A sudden, significant change in the stiffness (gradient) which hints at a failure of the tensile bond strength in the head joints – as mentioned in part of the respective literature – could not be observed at the investigations conducted here.

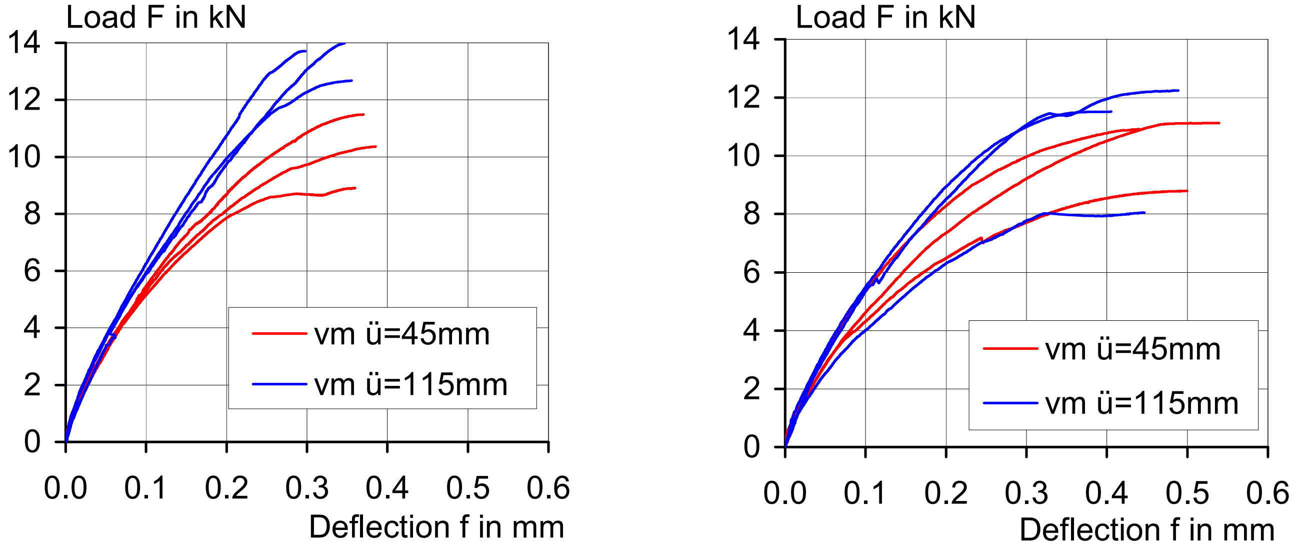

Figure 3: Load deflection curves (average centre deflection)
Solid brick W2 (left) and vertically perforated brick H2 (right) with normal mortar test of the flexural tensile strength parallel to the bed joints

It was attempted to deduce a correlation between the masonry flexural tensile strength and the shear bond strength as well as the torsional shear bond strength, respectively. The correlation detected on the basis of the tests conducted here partly showed large differences between experimentally and calculationally determined values for tests carried out in the past. Amongst others, this must be ascribed to the large scattering at the material properties especially of the bond. Basically the test method to determine the torsional shear bond strength seems however suited as alternative test method to determine the masonry flexural tensile strength parallel to the bed joints.

Influence of a load applied normal to the bed face

A normal force load vertical to the bed joint leads to an increase in the flexural tensile strength in case of a failure of the joints as well as to a plastic bending moment as a result of residual friction which characterises the post-peak behaviour. To examine the influence of the superimposed load on the load bearing behaviour, torsion tests and flexural tensile tests parallel to the bed joint at a simultaneous normal force load were carried out on solid bricks W2 and on vertically perforated bricks H2 with a normal mortar.

Figure 4 comparatively shows the results of the torsion tests on solid and vertically perforated bricks for three different superimposed load levels. The correlation between the superimposed load and the maximum torsional moment as well as between the superimposed load and the residual moment (residual friction) could be appropriately described by quadratic parabolic approaches. The determined residual friction coefficients depend on the superimposed load whereas the values of the vertically perforated bricks (value range 1.15…1.60) are higher due to the indentation effects than those of the solid bricks (value range 1.01…1.25).

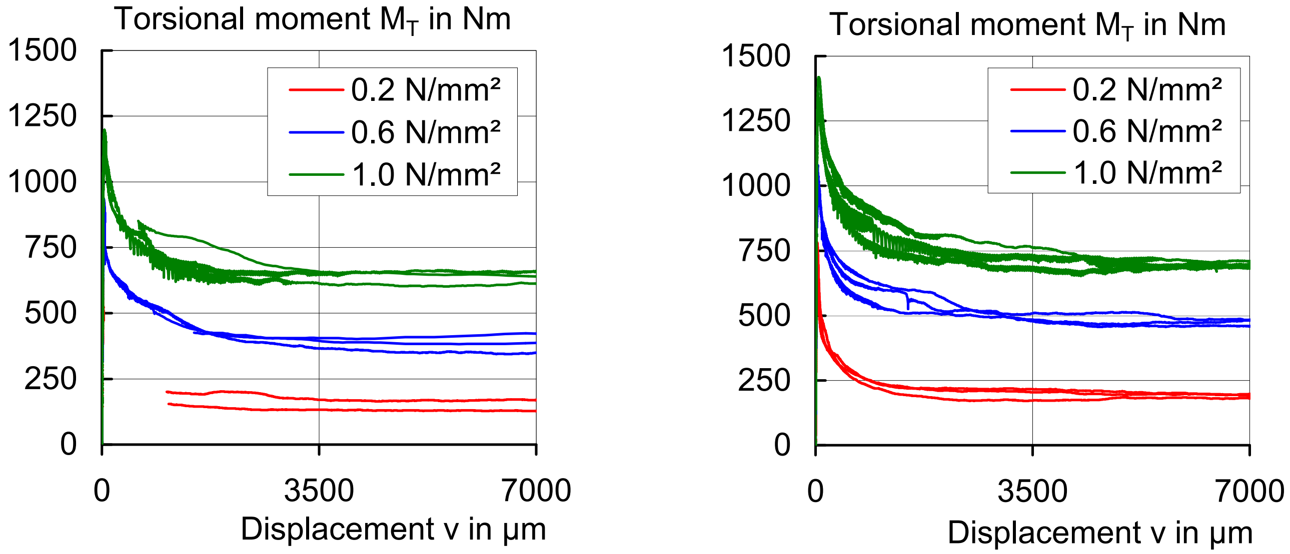

Figure 4: Torsional moment-displacement curves, solid brick W2 (left) and vertically perforated brick H2 (right) with normal mortar at different superimposed load levels

Figure 5, left, depicts the test setup to determine the flexural load bearing behaviour of masonry walls at a simultaneous normal force load. Figure 5, right, shows the load deflection curves determined on masonry made of solid bricks at different levels of superimposed load. Correlations between the torsional tests and the flexural tensile tests regarding the ultimate load and the friction behaviour could be identified for the examined masonry unit / masonry mortar combinations.

At first, the flexural tensile strength increases at increasing normal stress. At solid bricks, a noteworthy increase in strength cannot be observed at a normal stress of about σ ≥ 0.2 N/mm² and at perforated bricks of σ ≥ 0.04 N/mm², because of an increasing failure of units alone or a mixed failure, respectively.

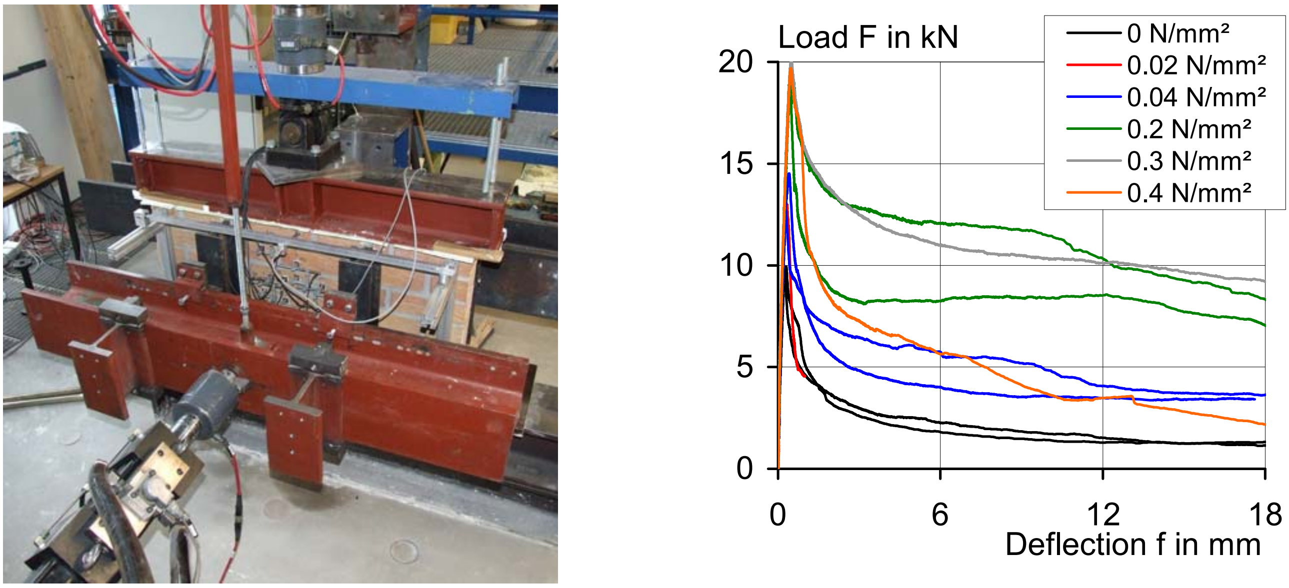

Figure 5: Test setup to determine the flexural tensile strength parallel to the bed joints under superimposed load (left) and load deflection curves (average centre deflection) of the masonry walls made of solid bricks W2 with normal mortar at different superimposed load levels

Due to the unit failure, in Figure 5, right, at a higher normal stress (here σ = 0.4 N/mm²) a steeper load drop as well as a lower residual friction compared to the walls under lower superimposed load can be discerned. Thus, a higher bond strength, also induced by the superimposed load-dependent friction rate resulting from the higher superimposed load, may however at first lead to a higher flexural tensile strength, but, because of the lower residual moment as a result of the mixed or the unit failure, it may have an unfavourable influence on the total load bearing capacity at a column-by-column anchorage.

4 CONCLUSIONS

In conclusion, the conducted tests furnish essential findings regarding the flexural load bearing behaviour of facing masonry which are necessary for the deduction of an applicable design model which uses the system load bearing capacity of masonry without overestimating it. There is further research demand for the deduction of a respective design model. First tasks concerning this subject carried at the TU Darmstadt showed that a column-by-column anchorage seems to be target-oriented. Especially, however, findings regarding the load bearing behaviour of the ties and their effects on the determination of the system load bearing capacity at uni- and biaxially load-transferring facing shells. There are further unsolved problems concerning the structural execution, e. g. in mounting the thermal insulation into the cavity. Even means to design the inner shell of the double-leaf wall with regards to the line-like load imposed by the rows of ties would be helpful in practice. Moreover, there is further research demand in the validation and deduction of correlations between flexural tensile strength and building material characteristics which are determinable as replacement.