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RILEM TC 127-MS: TESTS FOR MASONRY MATERIALS AND STRUCTURES

Recommendations

Foreward:
The texts presented hereunder are drafts for general consideration. Comments should be sent to the Chairlady:
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MS.A.6: Method for triaxial compression tests on mortar specimens taken from bed joints

A.6.0 CONTENTS

A.6.1 SCOPE

These recommendations describe a test method for determining the behaviour of masonry mortar under triaxial stress. The knowledge of this behaviour is necessary for various studies on the behaviour of masonry, because in masonry the individual masonry components, namely the mortar and the units, undergo a triaxial stress when masonry is exposed to various types of stress, *e.g.* centric compressive stress, or even shear stress. The reason for the triaxial stress state is the different lateral deformation behaviour of mortar and units.

A.6.2 SPECIMENS (size, shape, numbers)

A cylindrical specimen is the most convenient geometry for the tests. The height of the test specimen is determined by the thickness of the bed joints from which the specimen is taken. In Germany, for instance, the thickness of the bed joint should in general be 12 mm for masonry with standard mortar.

The diameter of the specimens should not be too small in relation to the maximum grain size of the aggregate. The practicality of handling the specimens should be considered. Moreover, specimens with a very small diameter lead to a greater scatter of the results.

The diameter of the specimens should also not be too large. Lateral (platen) restraint is largely but not completely avoided by applying the vertical stress to the specimens by means of steel brushes. Longer and laterally more flexible brushes should be used for specimens with a large diameter.

As a guide, for a specimen height of 12 mm and a maximum aggregate grain size of up to 4 mm, a specimen diameter of 30 mm is recommended. These dimensions proved to be good in references [2-8] for two regular mortar types with compressive strength, according to reference [1], of between 6 and 10 N/mm^2 and for two higher density mortar types with compressive strength, according to [1], of between 11 and 16 N/mm^2.

In general, the minimum number of replicate tests should be carried out which give a statistically acceptable result. A conceivable procedure, for instance, is to use replicates, *e.g.* two to three, to determine only the ratios sr/sl (sr = radial stress, sl = longitudinal stress) at the lower and upper limit of a range of stress ratios. The range in between can be studied by conducting one test for each stress ratio. It is, however, expedient to over-provide the number of prepared specimens such that subsequent replication is possible, if the original set of test results is obviously not reliable.

A.6.3 PRINCIPLES OF THE TEST

In the proposed method, mortar specimens are used which are obtained from bed joints. Due to the suction effect of the units, the properties of the mortar in bed joints differ substantially from specimens which are made by casting in moulds, *e.g.* according to RILEM LUM A.6. [1].

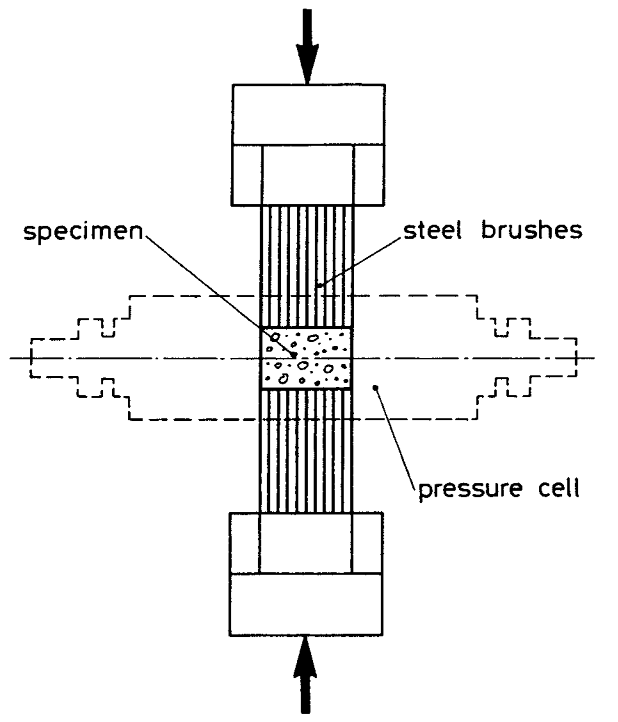


Fig. 1 – Principle of the test method.

The triaxial stress in the specimen is applied in the vertical direction by means of steel brushes. In this way, the influences of lateral restraint on the test results are almost completely avoided (Fig. 1). In the lateral direction, the pressure is applied on the cylindrical specimen via a ring-shaped membrane. Deformations are measured in both longitudinal and lateral directions.

Results of tests with uniform lateral pressure on cylindrical specimens are sufficient for the analytical study of many problems in masonry. Unequal lateral pressures in two directions can, for instance, be applied on a cube-shaped specimen. For this purpose, loading brushes are also required in the two lateral directions. It is, however, much more difficult to handle such a test set-up than the method described here.

The procedure described here is based on a research program conducted in Munich, for which the relevant literature is listed at the end of this recommendation in [2-8].

A.6.4 PREPARATION AND STORAGE OF THE SPECIMENS

Specimens are prepared in bed joints between real units. The units should be chosen as representative of the type for which the performance data are required, *e.g.* calcium silicate units, perforated clay bricks or porosified lightweight bricks. Data on the water absorption, porosity and initial rate of water absorption (suction rate) will be necessary to allow full specification of the units. Since mortar types differ considerably in water retentivity, this must also be considered in the preparation of the specimens. To take into account the different moisture contents of the units when laying the units, this parameter should also be measured and, if necessary, varied in a test program.

A detailed description of a method for preparing cylindrical specimens in bed joints and ensuring sufficient accuracy of the plane parallelism of the loaded surfaces is given in Appendix A.

A.6.5 APPARATUS

Fig. 2 shows the test equipment used in Munich and Fig. 3 the pressure cell.

The pressure cell (Fig. 4) consists of a main body with a central opening having a diameter of 30 mm. In this opening the prepared specimen is inserted, and it is loaded with a uniform lateral pressure via a ring-shaped membrane. The vertical loading brushes, detailed in Fig. 1, are only indicated in Fig. 4. Longitudinal as well as radial LVDTs allow observation of the deformations (see Figs. 2 to 5).

Further information about the construction details of the apparatus and a recommended calibration procedure are given in Appendix B.

Some aspects of the dimensioning of the loading brushes have been discussed in [7, 8, 17].

A.6.6 PROCEDURE

Before starting the tests, the specimen dimensions should be measured and recorded using a measuring device with a sensitivity of 0.001mm. The control of the plane-parallelism of the upper and lower side of the specimen is also important. Minor deviations from the desired accuracy of the order of ± 0.01 mm, correspond to strain

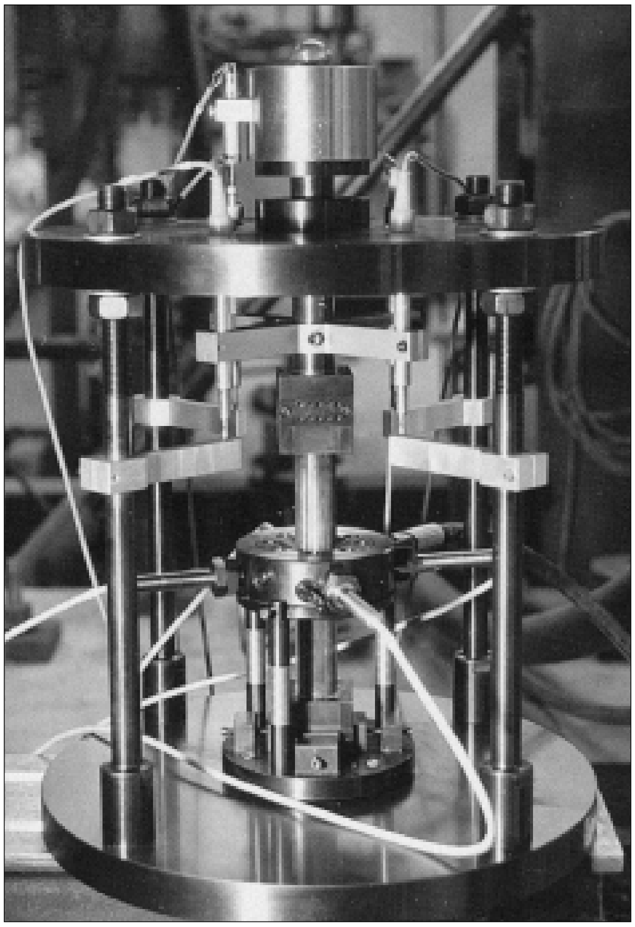


Fig. 2 – Test equipment.

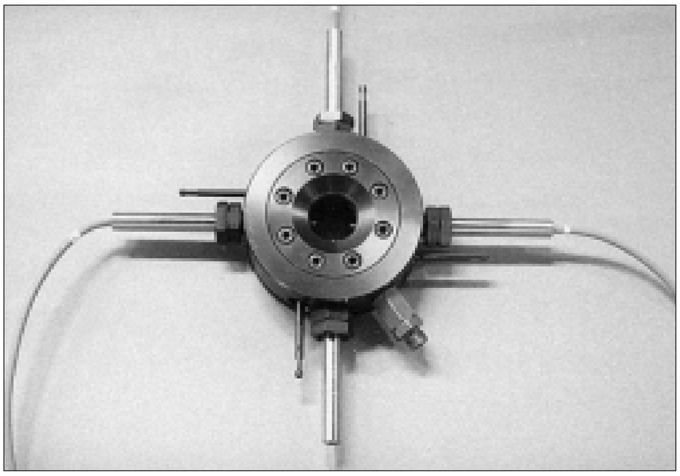


Fig. 3 – Pressure cell for application of lateral pressure.

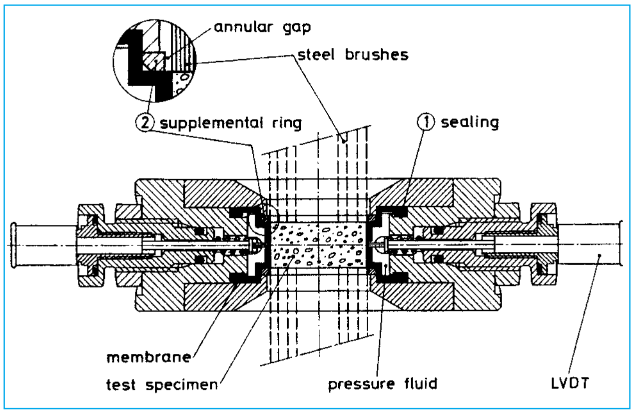


Fig. 4 – Cross-section through pressure cell.

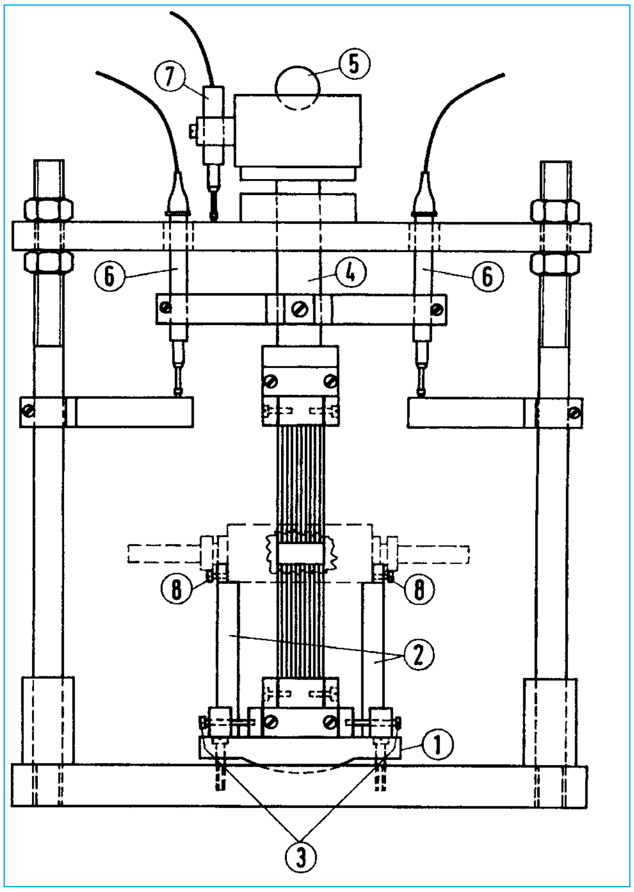


Fig. 5 – Loading frame with pressure cell. Auxiliary plate = 1; supporting bars = 2; adjusting screws for bottom brush = 3; piston = 4; centering ball = 5; LVDTs for vertical deformation measurement = 6; LVDT for deformation control = 7; adjusting screws for pressure cell = 8.

differences in the specimen of about 0.07 mm/m. In these circumstances regrinding may achieve an improvement, but if this does not succeed, or if there are major deviations, a substitute specimen must be used.

Mount the specimen in the pressure cell while it is outside the outer frame. To reduce the friction between the lateral specimen surface and the rubber membrane in the pressure cell as far as possible, wrap the lateral surface of the specimen with a thin Teflon film (approx. 0.05 mm). An identical Teflon layer is permanently bonded to the inside of the membrane. Before inserting the specimen in the pressure cell, the tracer pins of the lateral LVDT must be withdrawn from the measuring position, as they would otherwise impede the insertion of the specimen. For locking the tracer pins in the withdrawn position, a suitable aid is provided on the pressure cell. Then, the specimen can be placed into the opening of the cell by means of a slightly conical punch.

The cell is now loosely mounted in the outer frame. Its vertical position is defined by the height of the supporting bars (No. 2 in Fig. 5), so that the specimen is approximately in contact with the bottom loading brush. Before lowering the upper brush it must be ensured that the cell is precisely centered with respect to the brushes. This is important to ensure that the annular gap between the supplemental ring (No. 2 in Fig. 4) and the specimen has the same width on all sides. For centering the cell a split tube is therefore placed around the upper brush, whose outer edge precisely fits in the opening in the lid of the cell. The centered position of the test cell can then be fixed by means of the adjusting screws (No. 8 in Fig. 5). These adjusting screws remain tightened throughout the test. After the upper brush has finally been brought into contact with the specimen, the two-part tube must be removed before starting the test.

Upon loosening the locks for the horizontal LVDTs the measurement display for all transducers (horizontal and vertical transducers) is set at zero, and the load piston of the testing jack is put in very light contact with the centering ball. Vertical and axial stress is then applied as required and the deformation of the mortar is measured and recorded.

Some information about recommended test parameters is given in Appendix C.

A.6.7 TEST RESULTS

The results of the described tests provide relationships between the applied longitudinal stress and the measured longitudinal and lateral deformations for various sr/sv ratios. Figs. 6 and 7 show an example of the stress-strain relationships determined in a typical test.

In these figures, a so-called "initial run" in the deformation measurements, such as described in [9-11], and systematic influences, for instance from the displacement mentioned in Appendix B, which can occur in the screwed connections of the LVDT supports, have already been eliminated.

Differences between values of modulus of elasticity found from different types of test specimens such as cylinders from bed joints, moulded cylinders of the same dimensions or bigger prisms (*e.g.* 10 × 10 × 20 cm according to German codes) or measured by means of different measuring methods are real. Some tests on this problem are described in [12, 13].

Possible further evaluations of the measured results are described in [7, 8]. Some relevant papers are [14, 15]. An extensive list of references is to be found in [7].

A.6.8 TEST REPORT

1. A reference to this recommendation.
2. A description of the mortar and the unit used.
3. The composition and strength of the mortar used.
4. The moisture content of the units at bricklaying.
4. The method of preparing the mortar specimens.
6. Achieved accuracy for the plane parallelism of the specimen surfaces.
7. The date of the preparation of the specimens and the date of the test.
8. Ratio between vertical and radial stress.
9. Strain rate.
10. Results of calibration of lateral and vertical deformation measurement (steel specimen).
11. Curves of vertical and radial strain vs. vertical stress.
12. Principle of corrections made versus original results.
13. Short description of the crack pattern of the specimen after the test.

A.6.9. REFERENCES

[1] RILEM LUM A.6 'Determination of the compressive strength of mortar', RILEM Technical Recommendations for the Testing and Use of Construction Materials (E&F Spon, London, 1994) 490-492.

[2] Linse, D., 'Lösung versuchstechnischer Fragen bei der Ermittlung des Festigkeits- und Verformungsverhaltens von Beton unter

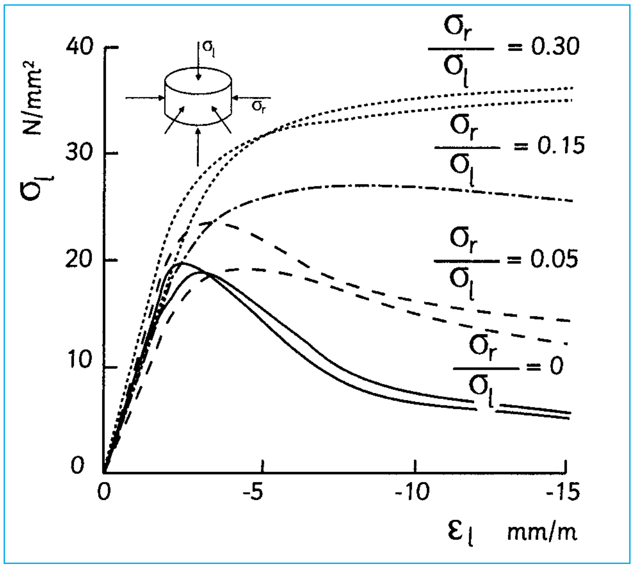


Fig. 6 – Longitudinal mortar strains el vs. longitudinal stress sl for Portland cement mortar.

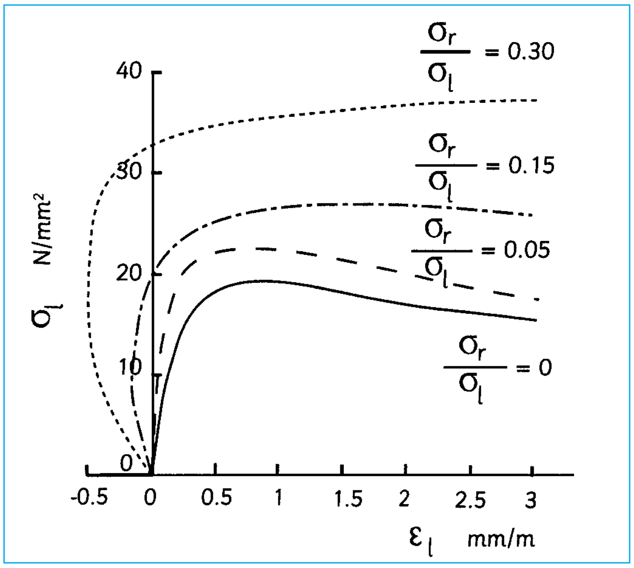


Fig. 7 – Radial mortar strains er vs. longitudinal stress sl for Portland cement mortar.

dreiachsiger Beanspruchung' (Solution of questions concerning test methods for determining the strength and deformation behaviour of concrete under triaxial loading), Heft 292 der Schriftenreihe des Deutschen Ausschusses für Stahlbeton, 1978.
[3] Bierwirth, H., Stöckl, S. and Kupfer, H., 'Entwicklung und Erprobung einer Versuchseinrichtung für Versuche an dreiachsig auf Druck beanspruchten Mörtelproben' (Developing and testing of an equipment for triaxial compression tests on mortar specimens) Lehrstuhl für Massivbau der TU München, 1990.
[4] Bierwirth, H., Dialer, C., Stöckl, S. and Kupfer, H., 'Development of a test equipment for triaxial loaded mortar specimens', Proceedings of the 9th International Brick/Block Masonry Conference, Berlin, 13-16.10.1991 (Ed.: Deutsche Gesellschaft für Mauerwerksbau e.V., 1991) 584-591.
[5] Bierwirth, H., Stöckl, S. and Kupfer, H., 'Dreiachsige Druckversuche an Mörtelproben aus Lagerfugen von Mauerwerk' (Triaxial tests on mortar specimens taken from bed joints of masonry) 28. DAfStb Forschungskolloquium, München. 5-6.10.1993, 1993, 59-69.
[6] Bierwirth, H., Stöckl, S. and Kupfer, H., 'Triaxial tests on mortar specimens taken from bed joints', Proceedings of the 6th North American Masonry Conference, Philadelphia, 6-9.6.1993 (Ed.: A. Hamid; G. Harris, 1993) 995-1007.
[7] Bierwirth, H., 'Dreiachsige Druckversuche an Mörtelproben aus Lagerfugen von Mauerwerk' (Triaxial tests on mortar specimens taken from bed joints of masonry), Dissertation (Ph.-D.-thesis), Lehrstuhl für Massivbau, TU München, 1994.
[8] Bierwirth, H., Stöckl, S.and Kupfer, H., 'Dreiachsige Druckversuche an Mörtelproben aus Lagerfugen von Mauerwerk' (Triaxial tests on mortar specimens taken from bed joints of masonry), Final Report Lehrstuhl für Massivbau, TU München, 1995.
[9] van Mier, J.G.M., 'Strain-softening of concrete under multiaxial loading conditions', Ph.-D. Thesis, TH Eindhoven, 1984.
[10] Schickert, G., 'Schwellenwerte beim Betondruckversuch', (Threshold numbers for compressive testing of concrete), Heft 312 der Schriftenreihe des Deutschen Ausschusses für Stahlbeton, 1980.
[11] Dialer, C., Lanig, N., Stöckl, S. and Zelger, C., 'Versuche zur Methode der Verformungsmessung an dreiachsig beanspruchten Betonwürfeln' (Tests on method for strain measurements on cubic specimen of concrete under triaxial loading). Lehrstuhl für Massivbau, TU München, Dezember 1988, and Heft 447 der Schriftenreihe des Deutschen Ausschusses für Stahlbeton, Beuth Verlag GmbH, Berlin-Köln, Berlin 1995.
[12] Beckhaus, K., 'Versuchstechnische Einflüsse auf die Ergebnisse von Verformungsmessungen und Festigkeitsprüfungen an einachsig belasteten Mörtelproben' (Influences of test method on the results of deformation measuring and strength testing on uniaxial loaded mortar specimens), Diplomarbeit (Diploma-thesis), Lehrstuhl für Massivbau, TU München, 1994.
[13] Stöckl, S., Beckhaus, K. and Fritsche, Th., 'Influence of test method on the results of deformation measurements of uniaxial loaded mortar specimens' to be published in *Masonry International*, 1997.
[14] Bierwirth, H., Stöckl, S. and Kupfer, H., 'Umbau und Modernisierung einer dreiachsigen Würfelprüfmaschine' (Reconstruction and modernization of a triaxial testing machine for cubical specimens), Lehrstuhl für Massivbau, TU München, 1996.
[15] Vorläufige Richtlinie zur Ergänzung der Eignungsprüfung von Mauermörtel; Druckfestigkeit in der Lagerfuge, Anforderungen, Prüfung' (Preliminary recommendation for testing of mortar, compression strength in bed joint). Version August 1992.
[16] MS.A.4 'Determination of the durability of hardened mortar', *Mater. Struct.* **31** (205) 11-15.
[17] Hilsdorf, H., 'Versuchstechnische Probleme beim studium der zweiachsigen festigkeit des betons' (Problems in the test arrangements for studying the biaxial strength of concrete) Ph.-D. Thesis, Technische Universität München, 1965.

MS.A.6: ANNEX A SUPPLEMENTARY INFORMATION ON SPECIMEN PREPARATION AND STORAGE

All units should be dried in an oven at 105°C to a constant weight. When not only dry units, but also units with a defined moisture content are to be used for the production of specimens, the dried units should be stored in an air conditioned room (95% r.h.) until a predetermined weight increase has occurred. The moistening first of all reaches mostly the outer zones of the prewetted unit. To achieve a homogeneous moisture content, the units must then be stored in a sealed condition for a further period. This can, for instance, be done in thick plastic bags for a period of two weeks.

The production of mortar should be by normal mixing methods. Only in special cases should this be done by manually mixing mortar and cement. In general, a mechanical mixer is best suited to produce a uniform mortar quality.

For obtaining specimens from the bed joint mortar, it is important that after the hardening of the mortar, the units can be separated from the mortar. This separation was facilitated in the tests described in [2-8] by inserting filter paper between the units and the bed joint mortar. The filter paper itself had little water retention capacity. In addition, it had been moistened before usage to prevent the paper from absorbing any water from the mortar. The filter paper had, in addition, a sufficient permeability, so that it impeded the water transport between mortar and unit as little as possible. Filter paper no. 0985 of the firm Schleicher & Schüll, W-3354 Kassel, Germany is suited for this purpose; alternatively, surgical textile gauze may be used, as specified in RILEM recommendation MS.A.4 [16].

Cut specimens of the desired size from the hardened bed-joint mortar. In the case of cubical specimens, for instance, this can be done by straight sawing, or in the case of cylindrical specimens by means of core drilling. In the case of low strength mortars, however, sawing and drilling results in a very uneven lateral surface, because at the saw cut the grains are torn out from the matrix. If sawing or drilling need to be avoided, the specimens can be moulded in the bed-joint. Grid-shaped or ring-shaped moulds can be used in the bed joint corresponding to the desired shape of the specimen. An inevitable disadvantage of moulding specimens in the bed joint is the fact that no horizontal water transport can take place in the mortar. This horizontal transport of moisture takes place during the hardening of the mortar, *e.g.* near the lateral surface of the masonry, or in the case of units with great perforations from the area above the holes to that above webs. The position of the moulds related to the holes of perforated bricks should be defined and it should be above the webs.

For the preparation of mortar specimens in bed joints, it is possible to prepare two-unit specimens of the desired mortar-unit combination. To this end, the lower unit is set on a flat surface and surrounded by a two-part frame (bottom frame and top frame, see Fig. A1). Subsequently, the slightly moistened filter paper is laid onto this unit.

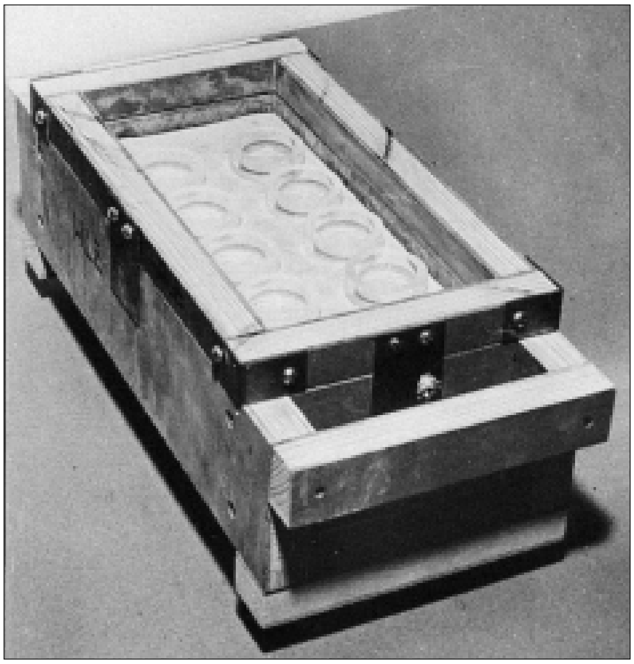


Fig. A1 – Preparation of specimens in a bed joint by means of moulds.

Then, plastic rings as moulds for the mortar specimens itself are inserted, which by means of a template are brought in a defined position in relation to any perforations and the edges of the unit. The height of the bottom frame and the plastic rings precisely corresponds to the intended thickness of the bed joint of 12 mm. Upon removal of the template, the mortar is filled in over the entire area of the form frame up to the upper edge of the top frame having a height of *e.g.* 20 mm. The top frame is then removed. The upper filter paper is placed onto the mortar surface, the upper unit is laid, and the bed joint mortar is compacted by means of a few slight hammer strokes on the upper unit. Then, the upper unit is taken away and the filter paper removed. By means of a steel ruler, the surplus mortar is then stripped off up to the upper edge of the bottom frame. Then, the upper filter paper is laid on again, the upper unit is again laid in the same position and slightly pressed once again by a few hammer strokes. Because of the inserted plastic rings for the specimens, no further compaction of the mortar is effected here. In this condition, the mortar in the two-unit specimen is cured over a period of 28 days in an air-conditioned room (65% r.h., 20°C).

It can be assumed that during the compaction of the mortar after the first laying of the upper unit, the desired joint thickness is nearly achieved. Upon removal of the top frame, only a little mortar must therefore be stripped off. In this case, unit suction has approximately already affected the upper half of the joint when first laying the upper unit, and is only interrupted by taking the unit away and laying it again. If after this interruption the upper unit is placed onto the mortar with its dry upper side, the full suction effect would occur again and therefore be overestimated.

After curing the specimens, first the upper and then the lower unit together with the filter paper are separated from the mortar joint. The specimens are pressed out from the rings. In this condition, the upper and lower side of the specimens has a usual degree of roughness mirroring the surface finish of the unit. The lateral edges of the specimen are as smooth as the plastic ring moulds, but may contain small air voids.

For the testing procedure, the upper and lower sides of the specimen must be very accurately planar and parallel. These requirements can be fulfilled, *e.g.* by capping the stripped specimen with gypsum. When low strength gypsum is used for this purpose, sufficient time (at least one day) must be available after the capping of the surfaces, so that the gypsum can harden before the test. The exacting requirements concerning the plane-parallelism of the upper and lower side of the specimens are due to the fact that for the vertical loading no hinges or universal joints can be used in the loading system (for the compensation of angle rotation) because of the loading brushes used. For producing plane-parallel surfaces of a specimen, the auxiliary device shown in Fig. A2 has proved to be useful. It consists of a two-part steel plate with a round hole having a diameter of 32 mm. The upper and lower side of this plate is ground plane-parallel. The test specimen is clamped in the opening of the plate after it has been wrapped with adhesive tape. Then, the upper side is capped with gypsum and ground, when the gypsum has hardened. The same is done for the lower side of the specimen. The auxiliary device has a height of 14 mm, which corresponds to the desired final height of the specimen. As the original height of the specimen is 12 mm it allows a capping with gypsum on both sides in a thickness of 1 mm. The described auxiliary device leads to an accuracy of the desired plane-parallelism of the upper and lower side of the specimens of about ± 0.01 mm.

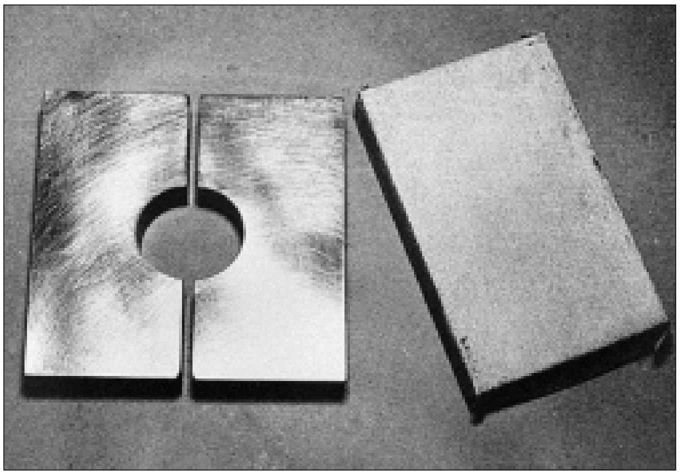


Fig. A2 – Auxiliary device for grinding of upper and lower surfaces of specimen.

The deformation properties of gypsum should be tested in separate tests, so that subsequently the deformation of the gypsum layers can be eliminated during analysis. The E-modulus of gypsum depends on the water content of fresh gypsum. For this reason the E-modulus of the thin gypsum layers on the top and bottom side of the specimens in the test arrangement presented here is influenced by the water suction of the hardened mortar. It is difficult to define the correct value of the E-modulus of the thin gypsum layers. Water suction increases the E-modulus of gypsum. A value of twice the E-modulus found on prisms produced in stiff moulds without water suction could be approximately correct. Some remarks on this problem are made in [13].

The above-mentioned air voids in the lateral surface of the specimen must be filled with gypsum to prevent the membrane, through which the lateral pressure is applied, from being pressed into these voids.

MS.A.6: ANNEX B DETAILS OF THE APPARATUS

A principal problem in the construction of the loading cell is the shape of the membrane for application of the lateral pressure (see Fig. 4). The lateral pressure should not act on the vertical loading brushes, as these then will be compressed in the lateral direction. Therefore, the membrane must end at the upper and lower edge of the test specimen. The horizontal flanges of the membrane should be narrow in the lateral direction, as otherwise they would have a remarkable stiffness to radial deformations, thus counteracting the aim of avoiding lateral restraint. Therefore, the membrane is repeatedly bent at the upper and lower side of the specimen. The actual sealing is No. 1 in Fig. 4 by means of a sealing lip.

By means of different supplemental steel rings (No. 2 in Fig. 4), the size of the annular gap between the loading brushes and the test cell can be varied. When the gap width is too small, there is the risk that the brush rods can no longer follow a larger lateral deformation of the test specimen and rest against the supplemental ring. However, the gap should also not be too large, as otherwise the membrane is pressed into this joint and will be damaged. The tests revealed that a penetration of the membrane into this gap is to be expected only in the case of high lateral pressures. With a high lateral pressure, a lateral compression of the mortar specimen occurs, so that the brush rods are deformed radially to the inside and the annular gap between brushes and supplemental ring is enlarged. Such tests must therefore be made with a supplemental ring that, at the beginning of the test, only leaves open a small annular gap.

Fig. 3 also shows that, for the observation of the lateral strain of the test specimen, four LVDTs are screwed crosswise into the test cell. The crosswise observation of the lateral strain is chosen to calculate the average between two strain directions.

The tracer pin of the LVDT must directly touch the surface of the specimen. Therefore, it must extend through the membrane. The problem of sealing the required opening in the membrane can easily be solved, as the membrane itself undergoes lateral deformation in its plane due to the oil pressure acting on it, and in this way seals the opening for the tracer pin.

Because the flanges at the upper and lower edge of the specimen should have as little stiffness as possible, and because of the desired sealing of the openings for the tracer pins of the LVDTs, the material for the membrane should not be too stiff. A rubber of NBR-quality with a Shore hardness of 40° has proved to be best suited.

The tracer pins of the lateral LVDTs are pressed against the specimen by means of springs. The spring force should not be too small. At the end of the tracer pin is a small platen in order to avoid an intrusion of the pinpoint into the specimen.

Two screwed connections (No. 3 in Fig. B1) between the pressure cell and the LVDTs include the risk of small displacements in the horizontal direction, because in the construction chosen here, the oil pressure also acts on several points of the LVDTs' support and the LVDTs themselves (No. 1 and 2 in Fig. B1). These displacements are included in the measurement results. They must therefore be measured by calibration and be deducted from the measurement results. The calibration, for instance, can be done by loading a steel dummy specimen.

The same procedure is recommended for calibrating the vertical strain measurement.

Fig. 5 shows a loading frame by means of which the test can be carried out with a normal hydraulic jack. In the middle of the figure there is shown the pressure cell, mentioned above, for applying the lateral stress with the test specimen inside. The vertical load is applied to the test specimen by the steel brushes. For the size of specimen chosen here and for a vertical stress on the specimens of up to 45 N/mm^2, brush rods with a thickness of 3 × 3 mm and a free length of 80 mm should be suitable. For higher vertical stresses, shorter brushes must be used due to the risk of buckling of the brush rods. At the same time the stiffness in the lateral direction of the brushes increases. Details of dimensioning of steel brushes can be found in [7, 8, 17]. The brush rods must be held in a brush support, for instance by clamping or by inserting the brush rods in a perforated plate. Corresponding details can be found in [14].

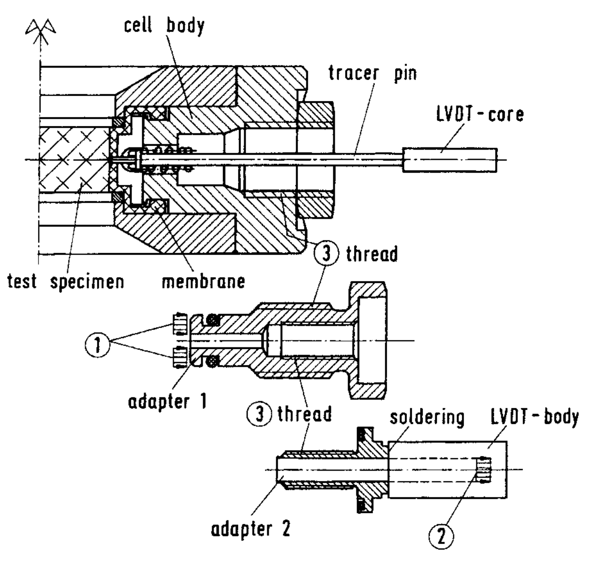


Fig. B1 – Construction detail of lateral strain measurement.

As already mentioned, the use of steel brushes does not allow the use of universal joints in the vicinity of the test specimen. Free movable spherical hinges at a greater distance from the test specimen, for instance behind the loading brushes, lead to various disadvantages and are therefore not recommended. The requirements concerning the plane-parallelism of the specimens, which result from this fact, have already been explained in Section 4.

Nevertheless, the bottom brush support is mounted on an auxiliary plate (No. 1 in Fig. 5), whose direction can be adjusted before starting a test series by means of a spherical hinge with adjusting screws, so that the end faces of the brushes are exactly parallel. Further movements of the hinge are excluded by the adjusting screws. Supporting bars (No. 2 in Fig. 5) serve to fix the position of the test cell for applying the lateral pressure. A horizontal displacement of the bottom brush support is possible by means of the adjusting screws (No. 3 in Fig. 5).

The force of an ordinary hydraulic jack acts on the upper loading brush via a piston (No. 4 in Fig. 5) and a centering ball (No. 5 in Fig. 5). The jack force is observed by a load cell at the bottom side of the hydraulic jack.

For measuring the longitudinal deformations, four LVDTs are provided in a crosswise arrangement (No. 6 in Fig. 5). The use of four LVDTs allows the calculation of average values. In this way, possible effects of angle rotation can be eliminated.

Another LVDT (No. 7 in Fig. 5) is provided for measuring the displacement of the piston (No. 4 in Fig. 5) with respect to the unloaded outer frame. It is used for the deformation controlled loading of the specimen.

MS.A.6: ANNEX C PROPOSAL FOR ADDITIONAL TEST DETAILS

The loading process can be subject to deformation control. The deformation in the longitudinal direction of the specimen is best suited as a primary control parameter. In the description of the test set-up, it has already been stated that, to this end, an additional LVDT records the displacement of the upper load piston. The strain rate should be adjusted such that the maximum load is reached after about 3 minutes. For controlling the lateral pressure, a second servo-controlled system is required. It ensures the intended ratio (*e.g.* sr/sl = 0.3) between the longitudinal and the lateral stress on the specimen.

All measured data from the test are recorded by computer controlled data aquisition system.

The deformation control allows the observation of specimen deformations also in the post-peak region. In the case of very brittle specimens (*e.g.* high-strength mortar), sudden failure can occur despite a deformation control. In the case of tests with a high lateral pressure, a descending branch of the stress-strain curve often cannot be reached. From a steeply ascending branch, the curve turns to a very small but continuous increase of the vertical stress. In this case, the maximum load is only reached at very large deformations. In general it is sufficient to continue the tests until a vertical strain of the specimen of about 25 mm/m (*i.e.* 2.5%) has been reached. It should also be noted that the loading brushes with increased vertical deformation of the specimen should penetrate only slightly in the area of the membrane, as otherwise the lateral pressure acts on the ends of the brush rods, and the membrane can be damaged by the brushes. For a specimen height of 14 mm and a vertical strain of the specimen of 25 mm/m, the displacement of the upper brush is 0.35 mm, which seems to be acceptable.

At the end of the test, the specimen is removed and the crack-patterns are qualitatively observed.

MS.B.2 Measurement of the shear strength index of bed joints

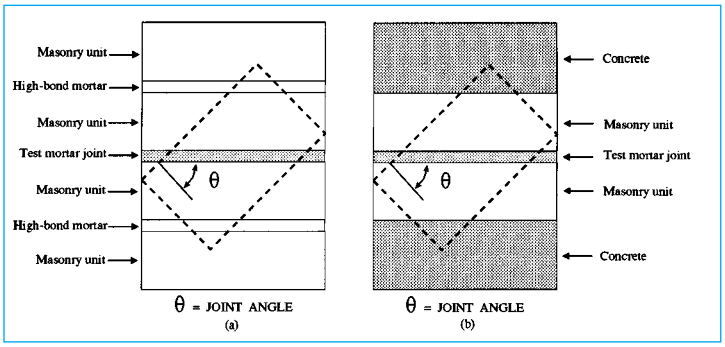
B.2.O CONTENTS

B.2.1 SCOPE

This recommendation specifies a method of measuring the relationship between shear strength and normal stress for mortar joints in typical masonry construction. Results from this test are to be used as a measure of the relative adhesion of different types of mortar to masonry units. Details regarding the principles involved, specimen preparation, the test apparatus, the method of test, the method of calculation, and the contents of the test report are provided.

B.2.2 PRINCIPLES OF THE TEST

This test utilizes a prismatic joint shear specimen which is cut, at an angle, from a stack-bonded masonry prism. The cutting angle determines the inclination of the joint being tested. The load is applied in such a manner as to produce uniform compressive and shear stresses along an inclined plane and to produce no bending stresses.



Figs. 1a and 1b – Two alternative types of shear prisms, showing outline of cut specimen.

B.2.3 SPECIMENS (size, shape, numbers)

Typical basic specimens before cutting are shown in Figs. 1a and 1b. They consist of a minimum of two masonry units separated by the test joint. Inclined joint shear specimens, as illustrated by Fig. 2, may be cut from the basic specimens along the dotted lines. The final shear test specimen has a height (h) = 190 mm (7-1/2 in.), a width (t_w) = 67 mm (2-5/8 in.), and a depth (t_d) = 90 mm (3-9/16 in.). The test joint is centred in the specimen at an angle Θ from the specimen ends.

Each specimen provides one datum. The total number of specimens shall be sufficient to provide an appropriate statistical database. For research purposes, the amount of replication necessary shall follow ISO 2859, assuming the statistical distribution of test results is unknown. To provide data for design or to justify proposed construction, a minimum of five replications shall be made at each joint angle and a minimum of four different joint angles shall be used.

B.2.4 PREPARATION AND CONDITIONING OF THE SPECIMENS

A basic shear specimen is constructed by first building a four unit high clay masonry stack bond prism as illustrated in Fig. 1. The centre joint of the prism, the test joint, is made with the specified mortar, joint thickness and tooling to be evaluated. Any additional joints, as would be required for the basic specimen in Fig. 1a, shall use a high-bond modified mortar, to reduce the possibility of failure other than at the test joint. Alternatively a concrete "cap" may be used, as shown in Fig. 1b. The bond between the concrete cap and the the masonry unit must exceed that expected for the mortar test joint.

The construction of shear prisms shall follow the general procedure outlined in RILEM LUM.B.1 and shall utilize the prism building jig. The prisms shall be constructed in stack bond with mortar joint thickness representative of the masonry being investigated. All mortar joints shall be struck flush with the surface of the units. Specimens shall remain undisturbed for 24 hours following construction, at which time they shall be removed for 7 days of moist curing in an environment with a temperature of 20 ± 2°C and a relative humidity of 100%.

Following 7 days moist cure, the joint shear prisms are prepared for cutting. The outline of the test specimen is marked on the surface of the basic stack prism, using a protractor or template to measure the desired joint angle to an accuracy of within 0.5°. The range of joint angles to be tested is based on engineering objectives; however, testing of specimens with joint angles of less than 35° often results in a failure of combined compression and shear. Joint angles, Θ, of 45° and greater are recommended to obtain a pure shear failure mode. The joint angle, Θ, should also not exceed 65°. Use a table-mounted, water-cooled masonry saw with a diamond-tipped blade to cut the specimens. Air cure the cut specimens at a temperature of 10 - 30°C and 30 - 70% relative humidity until the test date. The specimens shall be tested at an age of either 14 or 28 days.

To obtain plane and parallel loading surfaces, the bearing surfaces of the joint shear specimens are to be capped, prior to loading, using dental plaster of maximum thickness of 3 mm in accordance with RILEM LUM.A.1, Clause A.1.6.

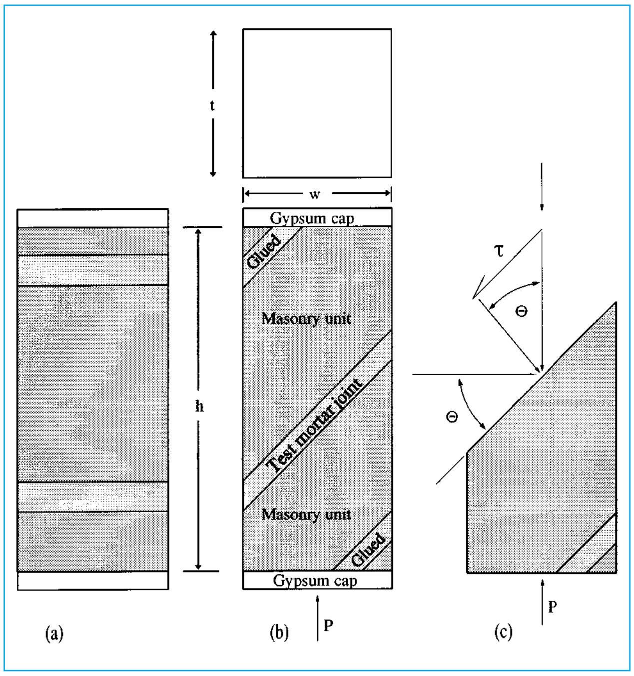


Fig. 2 – Shear specimen and forces acting upon an inclined masonry joint.

B.2.5 APPARATUS

The testing machine should be suitable for use with stiff materials and shall comply with stipulations set forth in ISO 4012. It shall be regularly calibrated to insure that it complies with the following specifications:
1. The maximum permissible error of force repeatability shall be 1.2% of the nominal force.
2. The maximum permissible mean error of forces shall be ± 2% of the nominal force.
3. The maximum permissible error of zero force shall be ± 0.2% of the maximum range force.

The testing machine shall be fitted with a spherical seat and loading beams with stiffness sufficient to ensure even displacement of the top and bottom surfaces of the specimen under load. This stiffness condition shall be considered to be fulfilled if the length of the loading beam beyond the edge of the platen does not exceed the length of the loading beam.

The testing machine shall have adequate capacity to test all specimens to failure, but the scale used shall be such that the ultimate load on the specimen exceeds one fifth of the full scale reading. The machine shall be provided with a load pacer or equivalent means to enable the load to be applied at the specified rate.

B.2.6 PROCEDURE

1. Determine the dimensions of the shear specimen to ± 0.5% by averaging the top, bottom and middle values of the dimensions t and w in Fig. 2b. Measure the angle Θ (see Fig. 2c) of the test joint to the horizontal to ±0.5° by averaging four edge measurements using a protractor.
2. Remove any foreign matter from the test machine, specimen caps, and bearing blocks. Place the specimen in the testing machine such that the centroid of the shear specimen is aligned with the centre of thrust of the spherical bearing block. Bring the loading head in contact with the specimen.
3. Apply load to the shear specimen at any convenient rate up to one-half of the expected maximum load, then readjust to a uniform loading rate such that the specimen fails in not less than one nor more than two minutes.
4. Record the maximum load resisted by the shear specimen, noting the failure mode and the location of the failure plane (*i.e.* at the unit/mortar interface, through the mortar, through the unit, or any combination of these).

B.2.7 TEST RESULTS

The stresses acting upon the inclined joint are shown in Fig. 2, and can be calculated as follows:

$\sigma_n = (P/A)\cos^2\Theta$, the average compressive stress perpendicular to the joint.

$\tau = (P/2A)\sin^2\Theta$, the average joint shear stress.

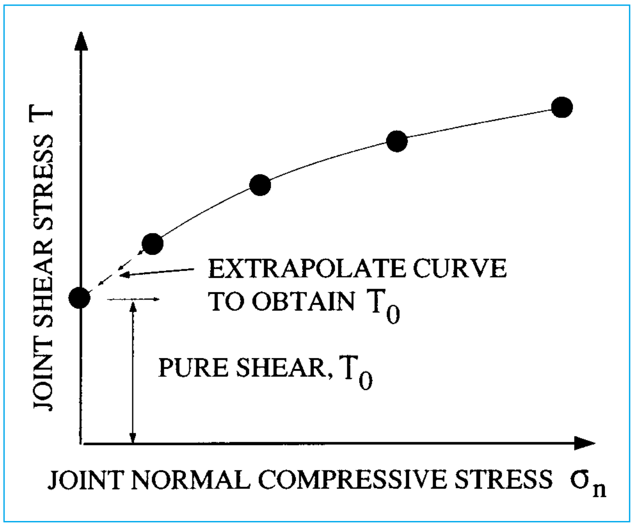


Fig. 3 – Typical plot of joint shear stress versus normal stress.

Where:

P = the maximum compressive load carried by the joint shear specimen.

A = specimen cross-sectional area measured in a plane perpendicular to the applied load P.

Θ = measured inclination of the mortar test joint from a plane perpendicular to the applied load P.

Data from tests using various joint angles may be tabulated or plotted as shown in Fig. 3 to describe joint shear strength as a function of normal stress for a given unit and mortar type. The joint shear stress index (τ_o), is defined as the magnitude of mortar-unit adhesion when the joint normal stress is zero and may be determined by extrapolating a best fit curve through the data points to the zero value of joint normal stress.

B.2.8 TEST REPORT

1) A reference to this RILEM method.

2) The type and model of the equipment used, including the date of the most recent calibration.

3) A description of the units including a sketch showing the dimensions and shape pattern and size of any holes. Include unit properties such as material type, strength and, where appropriate, water absorption, IRA, and density and give the method of sampling of the units.

4) The composition and compressive strength of the mortar used.

5) A description of the test specimens, including their overall size, shape, bonding, tooling and joint thickness.

6) The date of preparation of the specimens and the date of the test.

7) The conditions of curing.

8) The specification of the dental plaster used for capping.

9) All cross-sectional areas and values of inclined joint angles of individual specimens.

10) All individual failure loads in Newtons.

11) Failure modes including the location of the splitting plane, evidence of combined crushing/shear, etc.

12) A tabulation of inclined plane normal stress and joint shear stress for each specimen; mean, standard deviation, and coefficient of variation (%) for each series with identical joint angle; and a plot of normal stress versus shear stress for each combination of unit type and mortar type, if desired.

B.2.9 BIBLIOGRAPHY

[1] Nuss, L.K., Noland, J.L. and Chinn, J., 'Parameters influencing shear strength between clay masonry units and mortar', Paper No. 13, Proceedings of the First North American Masonry Conference, Boulder, Colorado, 1978.

[2] Nuss, L.K., 'The Parameters Influencing Shear Strength Between Clay Masonry Units and Mortar Tested Using Shear Masonry Specimens', Master of Science Thesis, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, 1978.

[3] Schuller, M. and Noland, J., 'Finite Element Analysis of Inclined Bedjoint Shear Test', Report for RILEM Committee 127 MS, Atkinson & Noland Associates, Boulder, Colorado, 1993.

MS.B.3 Bond strength of reinforcement in bed joints

B.3.0. CONTENTS

B.3.1 SCOPE

This recommendation specifies a method of measuring the bond properties between reinforcing bars and mortar in bed joints of masonry using a small scale assemblage of reinforcement, units and mortar. Guidance is given on the number of tests required, preparation of the specimens, the apparatus, the test procedure, the method of calculation, and the contents of the test report.

B.3.2 SPECIMENS (size, shape, numbers)

Fig. 1 shows the test specimen. It represents a part of a wall and consists of two stretchers and two headers with the mortar joints between them. In the bed joint the reinforcing bar of nominal diameter ds to be tested has been inserted at the intended distance from the edge. The right hand end of the bar protrudes by about 200 mm to allow it to be gripped and the left hand end by about 20 mm. At one end of the bar the tensile force is applied and at the other end of the bar the slip is measured. A joint thickness of t = $\mathbf{d_s}$ + 10 mm is recommended (where $\mathbf{d_s}$ is the diameter of round bars or the height of flattened bars). This leads to a mortar cover between reinforcing bar and unit of nominally 5 mm, and for typical bar thicknesses to a maximum bed joint thickness of around 15 mm. The clear distance from the embedded length of the bar to the edges of the specimen should be at least 30 mm. To allow for variations of the compaction of the bed joint mortar, a bond length of 10 × $\mathbf{C_s}$ / π should be used (where $\mathbf{C_s}$ is the circumference of a circular or flattened bar. The length of the bar bonded to the mortar should be approximately at the center of the specimen in order to include the vertical (head) joint as part of the sampled length. The adjoining bond-free bar lengths in the specimen are provided by screening off those sections of the reinforcement by means of tubes and a mastic seal (see Section 4).

Five specimens are recommended for each measurement.

B.3.3 PREPARATION OF SPECIMENS

A straight piece reinforcing bar of the required length is sheathed with two plastic tubes in those areas which should remain bond-free. Between these areas the intended bond length of 10 $\mathbf{d_s}$ remains unsheathed. At both ends of the bond length tubes are sealed with a plastic material, *e.g.* silicone or a mastic.

A mortar bed having a thickness of 10 mm is first applied onto a plane baseboard, and the stretchers are

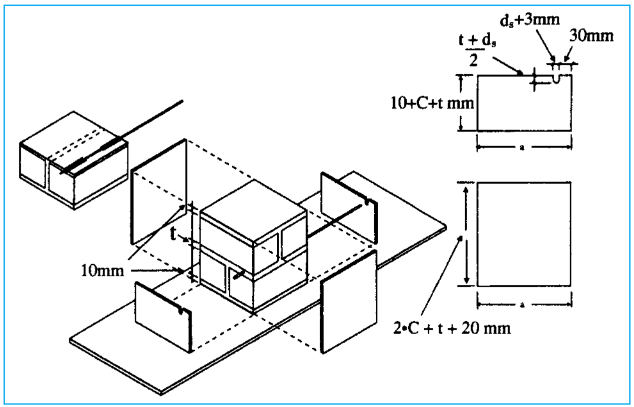


Fig. 1 – Production of the test specimen.

placed thereon (Fig. 1). The units are pre-wetted in accordance with normal practice. Then, the longitudinal joint is filled with mortar from the top. To define the test bed joint thickness and the location of the reinforcing bar, two patterns (jigs) (Fig. 1) are used, which are secured to the stretchers by means of clamps. Then, about half the bed joint mortar is introduced, the reinforcing bar is inserted and the remaining bed joint mortar is filled in. The transverse ribs (deformations) of the reinforcing bar should be located at the upper and lower sides of the bar, as this is the most unfavourable case for bond testing. The bed joint mortar is compacted by means of a trowel, and is then removed at the upper edge of the pattern. The headers are placed, the vertical joint is filled with mortar, and an upper mortar bed with a thickness of 10 mm is applied. The upper surface of this mortar bed is made parallel to the base. For this purpose, two sheets are used which are clamped to the upper units transverse to the direction of the reinforcing bar.

B.3.4 CONDITIONING OF SPECIMENS

Upon completion of the specimen the auxiliary sheets are removed and the specimen is covered with wet cloth and a plastic film. It is left in this condition for 2 days and is then stored in an air conditioned room (20°C, 65% r.h.) until it is tested at the age of 28 days.

B.3.5 APPARATUS

For generating the tensile force a hollow piston jack is used, which after a felt interlayer and a load distribution steel plate is moved over the long protruding end of the bar. It transmits its force to the bar by means of a clamping sleeve or collet as used in prestressed concrete construction. The hollow piston jack must act on the bar without constraint. For instance, a suspension system including turnbuckles and springs as shown in Fig. 2 is suited for this purpose. Between the hollow piston jack and clamping sleeve a load cell is arranged. The slip of the reinforcing bar relative to the adjacent units is measured by means of an inductive strain gage at that end of the bar which has not been pulled. This inductive strain gage is mounted on a rigid frame which is glued on the units near the upper and lower edges of the test specimen. For a simple evaluation, the registration of the force and the slip by means of an x-y- recorder is sufficient. It should be possible to register a slip of about 1 mm and the corresponding force. For a more detailed evaluation, it is necessary to register force and slip by means of an electronic data aquisition system.

B.3.6 PROCEDURE

After a first reading of the two measured values (force, slip) the clamping sleeve is pressed on and the load increase is started. Initially, the force should increase so that the bond stress τ increases by 1N/mm²/minute.

$d\tau / dt = 1\ N/mm^2.min$

This requirement results in various values dF/dt (F = force) for bars of various thicknesses. The values dF/dt must be calculated prior to the test. For the specimen dimensions in accordance with Figs. 1 and 2, a value of dF/dt = 2 kN/min is obtained, for instance, for a reinforcing bar with a diameter of 8 mm. In the case of non-linearly increasing slip values and a constant adjustment of the hydraulic valve, the rate of force increase dF/dt is decreased. This must be accepted in order to achieve comparable results. With a constant valve position the test will generally pass through a maximum force range and then through a range of decreasing force. When the force F and the slip s are registered by means of a x-y-recorder in accordance with section 6, a continuous curve is obtained. When the measurements are made using an electronic data aquisition system, the measured values can only be read in intervals. One can, for instance, proceed as follows:

Slip range		Reading interval
0	(< s < 0.02 mm)	s = 0.001 mm
0.02	(< s < 0.20 mm)	s = 0.010 mm
0.20	(< s < 2 mm)	s = 0.100 mm

B.3.7 TEST RESULTS

The basic value of the bond stress τ is obtained by dividing the load P after a slip of 0.1 mm by the surface area of the embedded length of the bar. The average bond stress is the mean of the 5 determinations.

$$\tau = \frac{P}{\pi \times \mathbf{d_s} \times 10\mathbf{d_s}} = \frac{\text{load}}{\text{circumference} \times \text{bond length}}$$

Note: A more detailed evaluation method is described by Barlet in [1].

B.3.8 TEST REPORT

1) A reference to the method used.
2) A description of the test specimens, including

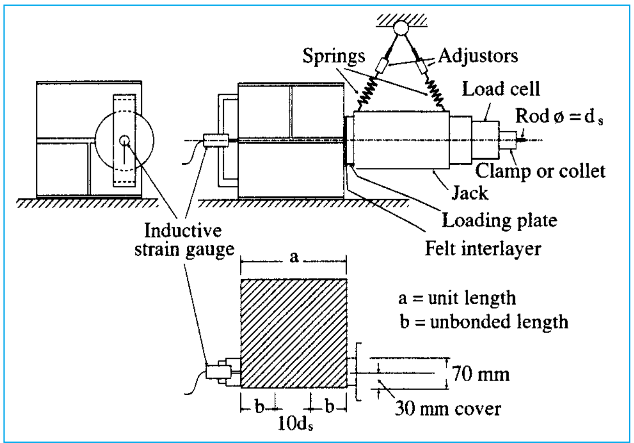


Fig. 2 – Apparatus.

their overall size, shape, bonding, tooling and joint thickness.

3) The method of sampling of the units.

4) The properties of the units including strength and, where appropriate, water absorption, IRA, and density.

5) The composition and strength of the mortar used.

6) The specification of the reinforcement including that of the base materials and any protective coatings, the yield strength, the nominal diameter, the cross sectional shape.

7) The date of preparation of the specimens and the date of the test.

8) The conditions of storage.

9) All individual failure loads in Newtons and relevant dimensions in mm.

10) The position of all the cracks in each failed specimen. It is particularly important to record whether the failure is predominantly at the upper or lower unit/mortar interface or through the mortar.

11) Individual values of bond shear strength calculated as specified.

12) Sample means, standard deviations, and coefficients of variation.

B.3.9 BIBLIOGRAPHY

[1] Barlet, U., 'Verbund zwischen Stahl und Mortel im bewehrten Mauerwerk', (Bond between steel and mortar in reinforced masonry) Ph.D.-thesis, Technical University Munich, 1989.

[2] Kelch, N.W., 'Some properties of reinforced grouted brick masonry', ASTM Bulletin (168), September 1950.

[3] Shrivastava, S.N.P. and Dayaratnam, P., 'Bond of deformed steel bars in reinforced brick masonry beams under repeated loads', *International Journal of Masonry Construction* **2** (2) (1982).

[4] prEN 846-2:1996, Methods of test for ancillary components for masonry: Determination of bond strength of prefabricated bed joint reinforcement in mortar joints.

A nearly complete list of references up to 1989 is to be found in [1].

MS.D.2: Determination of masonry rebound hardness

D.2.0 CONTENTS

D.2.1 SCOPE

This method utilizes a compact instrument known as the Schmidt Rebound Hammer to provide a measure of relative material surface hardness. Details regarding the principles involved, the preparation for the test, the apparatus, the method of test, the method of calculation, and the contents of the test report are provided. An alternative device, the pendulum hammer, may be suitable for some applications on vertical surfaces (the pendulum hammer is described in RILEM MS.D.7 [1] where it is used to assess pointing hardness).

D.2.2 SPECIMENS (size, shape, numbers)

Test locations shall be chosen to represent the range of masonry qualities which can be expected throughout the structure. Generally, a large number of replications is required, to provide an adequate statistical data base. The level of replication required depends on the variability of the test results.

D.2.3 PRINCIPLES OF THE TEST

The rebound hammer consists of a spring loaded plunger which, when released, strikes a surface and causes a mass within the hammer to rebound. The magnitude of the rebound is indicated on a scale (the rebound number), and gives an indication of surface hardness which can be correlated to the strength or condition of the material. At each test location, multiple impacts are made at each test point without removing the hammer, and the Rebound Number is taken as the mean of the upper 50% of recorded values. The upper 50% values are used because any inconsistencies in procedures generally lead to lower readings.

The rebound hardness method is suggested only for determination of the uniformity of properties over a large area of a structure. It evaluates only the local point and layer (wythe or leaf) of masonry to which it is applied, and is unreliable for detection of subsurface flaws or for investigation of inaccessible masonry wythes. It may be suitable for detecting near surface delamination due to frost or salt action of units and stonework. It may be used for prediction of masonry compressive strength only if correlated with results of controlled destructive tests conducted on masonry removed from the structure being evaluated or by *in-situ* compressive tests using flatjacks (see RILEM LUM.D.3 [2]), and then only with appropriate confidence intervals.

D.2.4 CONDITIONS OF TESTING

Tests are to be conducted under ambient conditions, however the work shall not be carried out in heavy rain or other conditions likely to cause serious fluctuations in the state of the specimens or the instrumentation.

D.2.5 APPARATUS

A Schmidt Rebound Hammer is shown in section, in Fig. 1. Such hammers are available in four basic varieties, distinguished primarily by their impact energy: Type L (impact energy = 0.075 kgm), Type N (impact energy = 0.225 kgm), Type M (impact energy = 3 kgm), and Type P (pendulum type, impact energy = 0.09 kgm). Versions are also available with recording devices. A type L hammer is recommended for use with most types of masonry, especially older or soft masonry.

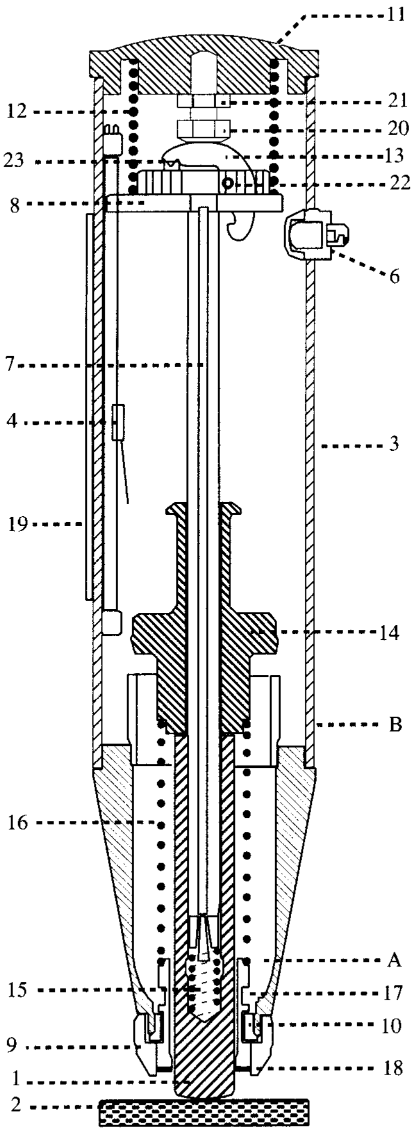
The Schmidt Hammer is calibrated against a hardened steel test anvil, supplied by the manufacturer for that purpose. Regular calibration of the device shall follow a schedule based upon the manufacturer's recommendations. When the calibration rebound value deviates from the required value, a correction formula provided by the manufacturer may be used to modify the measured values to the correct value.

D.2.6 PROCEDURE

The Schmidt Hammer test should be conducted on masonry units at three or more locations for each structural element or section of element (wall, pier, etc.) under consideration. If, within a structural element, there are obvious visual differences in the material quality, representative tests should be conducted in each such area of the element. The test unit should have no free edges, no visible cracks, and be surrounded on all sides by uncracked mortar. Where variation in boundary conditions can not be avoided, the conditions should be properly documented.

KEY (numerical)

1 .... Impact plunger
2 .... Rubber bellow
3 .... Housing
4 .... Rider with guide rod
5 .... Seeger-ring
6 ...... Push button complete
7 .... Hammer guide bar
8 .... Disc
9 .... Cap
10 .... Two-part ring
11 .... Cover
12 .... Compression spring
13 .... Pawl
14 .... Hammer mass ('L' Hammer)
15 .... Retaining spring
16 .... Impact spring
17 .... Guide sleeve
18 .... Felt washer
19 .... Window & scale
20 .... Trip screw
21 .... LockNut
22 .... Pin
23 .... Pawl spring
24 .... Screw-window
26 .... Carrying case
27 .... Calibration chart



KEY (alphabetical)

Calibration chart 27
Cap 9
Carrying case 26
Compression spring 12
Cover 11
Disc 8
Felt washer 18
Guide sleeve 17
Hammer guide bar 7
Hammer mass .... 14 ('L' Hammer)
Housing 3
Impact plunger 1
Impact spring 16
LockNut 21
Rubber bellow 2
Pawl 13
Pawl spring 23
Pin 22
Push button complete ... 6
Retaining spring 15
Rider with guide rod 4
Screw-window 24
Seeger-ring 5
Trip screw 20
Two-part ring 10
Window & scale 19

Fig. 1 – Schematic representation of the Schmidt Rebound Hammer.

The test is to be carried out with the hammer oriented normally to the masonry surface. If the hammer orientation deviates from a horizontal position, the angle of the hammer axis with respect to horizontal shall be recorded, and the results corrected to a horizontal position using correction curves supplied by the manufacturer. The point of impact shall be centred on the unit to be tested. The point of impact shall be smooth and free of dirt. Where the desired testing surface is not smooth, it may be ground smooth.

Place the tip of the plunger on the surface of the masonry unit and impact 3-4 times to seat the plunger on the masonry surface. Record the rebound number from ten successive impacts without removing the tip of the hammer from the masonry surface.

If desired, destructive or *in-situ* tests may be conducted to correlate the rebound number to compressive strength. However, it is not recommended that the Schmidt Hammer be used for direct prediction of compressive strength, but only for evaluation of material uniformity. The correlation to strength is useful primarily for determining the expected relative change in compressive strength between locations with different rebound numbers. Locations for destructive tests are chosen in areas that represent the full range of recorded rebound numbers. A minimum of four destructive tests are suggested to establish a reliable correlation.

D.2.7 TEST RESULTS

The rebound hardness for each test location shall be recorded as the mean of the five highest values from the ten successive impacts at each point. The standard deviation of the five test values shall also be reported.

The variation of test results is as important as the computed means of results, and statistical tools for analysis of variance may be useful for interpretation of data. The mean and variance of rebound hardness values for the entire structure or structural element should be computed to aid in comparisons of relative material quality.

D.2.8 TEST REPORT

1) A reference to this RILEM standard.
2) The date of the test.
3) Description of the testing conditions, *e.g.*, site, geographical location, environmental conditions, temperature, building identification, date of construction (if available), and name of the technician conducting the test. Include details of the type and quality of construction.
4) Description of equipment used, including make and model of rebound test hammer and calibration schedule.
5) Identity and description of the specific test locations in the structure, including a diagram of the structural element being tested, adjacent masonry, and all pertinent dimensions.
6) A tabulation of the mean and standard deviation of the rebound number determined for each test location. The mean and variance of rebound hardness values for the entire structure of structural element shall also be recorded. Locations showing a significant deviation from the mean value shall be noted.
7) Results from any companion destructive or *in-situ* tests which were conducted, including any correlations between compressive strength and rebound number.

D.2.9 REFERENCES

[1] Rilem Recommendation MS.D.7, 'Determination of pointing hardness by pendulum hammer', *Mater. Struct.* **30** (200) (1997) 323-324.

[2] RILEM Recommendation LUM D.3: 'In-situ strength and elasticity tests based on the flat jack'. RILEM Technical Recommendations for the Testing and Use of Construction Materials, (E&F Spon, London, 1994).