# ABOUT THE INFLUENCE OF THE TYPE AND SHAPE OF BRICKS AS WELL AS THE JOINT UPON THE CRACKING STRENGTH OF BRICKWORK

# ZUM EINFLUß DER MAUERSTEINART, DES FORMATS UND DER FUGENAUSBILDUNG AUF DEN RIßWIDERSTAND VON MAUERWERK

# SUR L'INFLUENCE DU TYPE ET DE LA FORME DE BRIQUES AINSI QUE DES JOINTS SUR LA RESISTANCE A LA FISSURATION DE LA MACONNERIE

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## SUMMARY

The crack resistance of masonry against drying has been determined by tests upon 3 m long and 2 m high completely fixed wall specimens. The investigated masonry was differently composed in view of brick type and shape as well as mortar and bricking. The moisture content of the investigated bricks had been adjusted by preliminary storage so that shrinkage by drying caused, according to the type of masonry, continuous cleavage cracks and, in some cases cracks appearing only in the surface area. The formation of cracks (number of cracks, crack pattern and crack width) depended upon the type of masonry. While for small sized masonry with thin mortar joints numerous cracks appeared around the bricks, large sized masonry with thin mortar joints showed a few cracks splitting the bricks. The renderings inverstigated at the same time allow the conclusion that such crack formations in the masonry may be covered completely by appropriate rendering systems.

## ZUSAMMENFASSUNG

In Versuchen wurde der Rißwiderstand von Mauerwerk gegenüber Austrocknen an rd. 3 m langen und 2 m hohen, umseitig eingespannten Wandprüfkörpern ermittelt. Das untersuchte Mauerwerk war hinsichtlich Steinart und -format sowie Art des Mauermörtels und des Vermauerns unterschiedlich zusammengesetzt. Der Feuchtigkeitsgehalt der untersuchten Steine war durch Vorlagern so eingestellt, daß das Schwinden infolge einer Austrocknung je nach Art des Mauerwerks zu durchgehenden Spaltrissen und ggf. zu auf die oberflächennahe Zone beschränkten Schalenrissen führte. Die Rißbildung (Anzahl der Risse, Rißverlauf und Rißweite) war von der Art des Mauerwerks deutlich abhängig. Während bei kleinformatigem, normalfugig gemauerten Mauerwerk die Tendenz zu mehreren, die Mauersteine umlaufende Rissen sichtbar wurde, zeigte sich bei großformatigem, dünnfugig gemauerten Mauerwerk die Tendenz zu wenigen, die Mauersteine durchtrennende Rissen. Die gleichzeitig untersuchten Putze lassen den Schluß zu, daß geeignete Putzsysteme solche Rißbildungen im Mauerwerk weitgehend mängelfrei abdecken können.

RÉSUMÉ

La résistance à la fissuration contre le séchage a été déterminée dans des essais réalisés sur des éprouvettes de mur longues de 3 m et hautes de 2 m fixées complètement. Le mur investigé avait une composition différente du point de vue du type et de la forme de brique, du mortier et du maçonnage. La teneur en humidité des briques investigées a été ajustée par un stockage préliminaire de manière à ce que le retrait dû au séchage causait, selon le type de maçonnerie, des fissures par clivage continues et, le cas échéant, des fissures seulement dans le domaine de surface. La formation de fissures (nombre de fissures, configuration de fissure et largeur de fissure) dépend du type de maçonnerie. Tandis qu'on ne constatait sur les murs petits maçonnés avec des joints normaux que des fissures autour des briques les maçonneries de grande taille unies avec des joints minces montraient la tendance à développer très peu de fissures qui pourtant éclataient les briques. Les enduits examinés permettent de tirer la conclusion que de telles formations de fissures dans la maçonnerie peuvent être recouvertes complètement par des systèmes d'enduits appropriés.

## 1. INTRODUCTION

In the last years damages upon masonry and rendering were stated which besides of transformations of shape due to temperature and creep as well as movements of the building were especially due to shrinkage phenomena in the masonry. Only a few years after manufacturing the masonry horizontal and vertical cracks became visible which in most cases appear within the vertical joints and bed joints and, at this place, separate the masonry and the rendering. Thus, the bearing capacity of the masonry and especially the function of the rendering as a protection of masonry against moisture may be essentially reduced.

These defects mainly appear while using big-size wall units with a higher extensibility under moisture conditions, which are delivered to the construction site with a too high moisture content and were walled up and/or exposed unprotected on the site or in the masonry for a longer time to the influences of weather.

While carrying through a research project in the Otto-Graf-Institute in Stuttgart investigations have been performed in view of the deformation behaviour of bricks within the border or center area under different moisture and drying conditions upon porous blocks with different binders, upon lightweight concrete blocks with different lightweight aggregates, upon lime sandstone and bricks with high thermal conductivity. Based upon the results bricks with a higher extensibility under moisture conditions were chosen for the wall tests. With these bricks wall slabs fixed at all ends were manufactured and rendered. Submitted to high drying conditions the formation of cracks was observed and the drying and deformation behaviour measured.

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## 2. TESTS

The influence of type and shape of brick as well as the type of mortar and the shape of joints upon the cracking restistance of rendered brickwork was investigated upon fixed walls. In detail the following influences were investigated, see also table 1:

- moisture condition of bricks before walling up (test series I)
- composition of binders for porous concrete (test series II)
- realization of the mortar bed for thin layer mortar (test series III)
- type of wall mortar (test series IV)
- shape of wall bricks (test series V)
- type of wall bricks (test series VI)
- different mortaring of vertical joints (test series VII)

In order to limit the test volume, such bricks were chosen by preliminary tests which have a big deformation behaviour under the influence of moisture changes, which may be manufactured in a big and small shape and walled up with normal mortar, with and without vertical joints or bonded with thin layer mortar for manufacturing masonry. These conditions were fulfilled by porous concrete blocks G 2 with a higher portion of cement and lime as binder (G 2 - Z, G 2 - K) and solid bricks Vbl 4 manufactured of lightweight concrete out of natural pumice (Vbl 4 - NB).

The masonry was put as a 3 m long and 2 m high wall panel into a stiff frame. This frame ought to force upon the testing walls the behaviour of a wall enclosed between a floor slab and a ceiling slab as well as between side walls.

3 days after the fabrication of wall specimens one wall surface was covered with a lime-cement-rendering - P II b according to DIN 18 550 part 2 - /2/, the other wall with a lightweight rendering with organic aggregates with porous structure - LP II according to DIN 18 550 part 4 - /2/; immediately afterwards these rendered wall specimens were exposed to a relatively dry climate of 30 °C and 40 % relative humidity. These testing walls were observed in view of the formation of cracks until the wall bricks have reached a moisture equilibrium. In addition the deformation of wall bricks and rendering as well as the moisture content of wall bricks in variable depth were measured.

## 3. DEFORMATION BEHAVIOUR OF BRICKS UNDER VARIABLE MOISTURE CONDITIONS

The moisture content of the bricks for the wall tests of bricks at the moment of delivery to the institute was differently high according to the brick type, their fabrication and storing and was for

porous concrete stones (G 2 - Z, G 2 - K) about 40 weight-%
lightweight concrete stones (Vbl 4 - NB) about 50 weight-%

For this reason the shrinkage due to the drying of the bricks after delivery at 23 °C and 50 % relative humidity was different, that is to say for

porous concrete stones from 0,40 mm/m to 0,48 mm/m
lightweight concrete stones from 0,63 mm/m to 0,85 mm/m

An influence upon shrinkage of the type of binder used during the fabrication of porous concrete bricks or by the type of lightweight aggregates for full blocks out of lightweight concrete could not be stated according to the results of the preliminary tests.

In order to show the influence of a humid storage of wall bricks, for instance on the site, upon the modification of shape, bricks were stored after drying ab 60 °C until constant weight in a climate at 20 °C and 95 % relative humidity. The swelling of the bricks increased extremely in the first 30 to 60 days and reached after a 6 months storage in humid environment at the exterior and bearing surfaces for

| | |
|---|---|
| porous concrete blocks | from 0,40 mm/m to 0,48 mm/m |
| lightweight concrete blocks | from 0,47 mm/m to 0,50 mm/m |

The deformation difference between the interior and exterior area of the bricks due to unilateral moistening, for instance by rain, of the unrendered masonry, was also investigated upon dried bricks one exterior face of which has been stored up to 24 hours about 1 cm deep under water.

After a 24 hours storage in water an extension was measured upon the exterior faces for

| | |
|---|---|
| porous concrete blocks | from 0,24 mm/m to 0,32 mm/m |
| lightweight concrete blocks | from 0,28 mm/m to 0,37 mm/m |

The maximum difference between the extension of the bricks at the exterior face and the extension of the bricks in the interior areas was for

porous concrete blocks from 0,17 mm/m to 0,20 mm/m
lightweight concrete blocks from 0,24 mm/m to 0,35 mm/m

## 4. BEHAVIOUR OF THE WALL SPECIMENS

### 4.1 MOISTURE CONTENT OF THE WALL SPECIMENS

After the first test (wall W 0) has shown that for usual moisture contents and the chosen testing conditions no cracks appeared, the wall bricks used for further tests (wall W 1 to W 7) were set to a high moisture content.

By a preliminary storage of the bricks in a humid room the porous concrete blocks used for manufacturing the wall specimens W 1 to W 7 had a moisture content of in the average 50 to 54 weight-%, the full blocks composed of lightweight concrete a moisture content of 56 to 58 weight-%, see table 1.

This moisture content was essentially above the mean moisture content which has been determined at the delivery of the bricks, but for the porous concrete blocks single values up to 50 weight-% and for the lightweight concrete blocks up to 60 weight-% were measured which shows that sometimes even in practice wall bricks with such a high moisture content were delivered to the building site and may be mounted /1/.

| Versuchsserie, Versuchs-einfluß | Wandprüf-körper | Mauerstein-art | Format | Mörtelart und Ausführung | Feuchtezustand der Mauersteine im Mittel | Riß-bildung | max. Verkürzung am Mauerstein beim 1. Riß | nach 180 Tagen |
|---|---|---|---|---|---|---|---|---|
| I | W 0 | G 2 - Z | 20 DF | Dünnbettmörtel vollflächig | 42 | nein | - | 0,26 |
| Feuchtezustand | W 1 | G 2 - Z | 20 DF | Dünnbettmörtel vollflächig | 51 | ja | 0,29 | 0,40 |
| II | W 1 | G 2 - Z | 20 DF | Dünnbettmörtel vollflächig | 51 | ja | 0,29 | 0,40 |
| Bindemittel | W 2 | G 2 - K | 20 DF | Dünnbettmörtel vollflächig | 50 | ja | 0,27 | 0,42 |
| III | W 2 | G 2 - K | 20 DF | Dünnbettmörtel vollflächig | 50 | ja | 0,27 | 0,42 |
| Ausführung | W 3 | G 2 - K | 20 DF | Dünnbettmörtel nicht vollflächig | 52 | ja | 0,22 | 0,40 |
| IV | W 2 | G 2 - K | 20 DF | Dünnbettmörtel vollflächig | 50 | ja | 0,27 | 0,42 |
| Mörtelart | W 4 | G 2 - K | 20 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 53 | ja | 0,28 | 0,52 |
| V | W 4 | G 2 - K | 20 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 53 | ja | 0,28 | 0,52 |
| Mauerstein-format | W 5 | G 2 - K | 5 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 54 | ja | 0,30 | 0,42 |
| VI | W 4 | G 2 - K | 20 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 53 | ja | 0,28 | 0,52 |
| Mauerstein-art | W 6 | Vbl 4 - NB | 20 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 58 | ja | 0,21 | 0,38 |
| VII | W 6 | Vbl 4 - NB | 20 DF | Leichtmörtel mit Stoßfugenver-mörtelung | 58 | ja | 0,21 | 0,38 |
| Stoßfugenver-mörtelung | W 7 | Vbl 4 - NB | 20 DF | Leichtmörtel ohne Stoßfugenver-mörtelung | 56 | ja | 0,22 | 0,42 |

## 4.2 DRYING OF WALL SPECIMENS

Notwithstanding the type of the about 15 mm renderings P II b and LP II applied to the wall specimens, the bricks at both wall sides dried with the same velocity, whereas the drying velocity of the porous concrete blocks and of lightweight concrete blocks in the exterior area was equally big, see fig. 1 and 2.

In the contrary the wall specimens manufactured of lightweight concrete blocks dried essentially slower in the interior than those manufactured of porous concrete blocks. This slow drying of lightweight concrete blocks is primarily due to the transversal web surfaces which are important for the transport of humidity in comparison to the exterior webs of the full blocks.

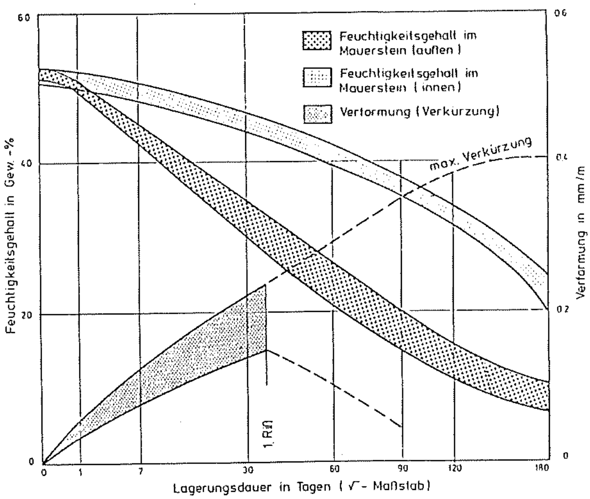


Fig 1: Moisture content and deformation of the wall specimen W 1 composed of porous concrete blocks and thin layer mortar while stored in a climate 30 °C - 40 % rel. humidity

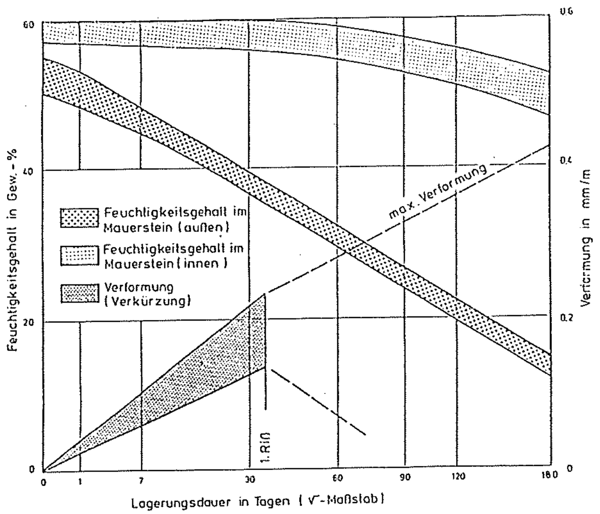


Fig. 2: Moisture content and deformation of the wall specimens W 6 and W 7 made of lightweight concrete blocks and lightweight mortar with and without butt jointing during storage in a climate 30 °C - 40 % rel. humidity

## 4.3 ABOUT THE FORMATION OF CRACKS IN WALL SPECIMENS

For all the investigated wall specimens, except the wall specimen W 0, which has been manufactured without preliminary humid storage of the used porous concrete blocks G 2 - Z, a vertical crack appeared which splitted the 3 m long testing specimens nearly in the midth, in most cases from the top to the bottom. These cracks which are separating a wall as well as the cracks described hereafter appeared upon every wall specimen at the side covered with the rendering P II b, but not at the side covered with lightweight rendering.

Upon the wall specimens W 1 and W 2 out of porous concrete blocks G 2 - Z and G 2 - K a further horizontal crack appeared in the area of a bed joint in the bricks separating them until a depth of 10 cm.

Only for wall specimens W 3 and W 4 made of porous concrete blocks G 2 - K with not fully bonded vertical and bed joint or walled up with lightweight mortar LM 21 in addition several cracks appeared in the area of vertical joints and bed joints. These cracks which only appear on the wall side covered with the rendering P II b had a width of 0,2 to 0,3 mm and run only until a depth of 10 cm.

The shrinkages measured upon the brick produced with the low adherence of the mortar or glue at the vertical joints and bed joints a widening of the wall joint as some measuring sections set upon vertical or bed joints have shown, see also fig. 1 and 2.

For the wall specimen W 5 manufactured of small-size porous concrete blocks G 2 - K joined with lightweight mortar LM 21 in comparison to the wall specimen out of big-size porous concrete blocks in total less cracks were stated running in most cases across the vertical and bed joints.

For the two wall specimens W 6 and W 7 manufactured with lightweight blocks Vbl 4 - NB and lightweight mortar LM 21 with and without vertical joints, besides the crack separating the 3 m long wall specimen in the midth, numerous cracks appeared in the rendering P II b running across the vertical joints and the bed joints. The number of cracks in the vertical joint area was, for the wall specimen W 7 with an unmortared bed joint slightly bigger than for the wall specimen W 6 with mortared vertical joints.

The first cracks appeared 30 to 70 days after the fabrication of the wall specimens when in the measuring area shrinkage of more than 0,20 mm/m was measured, see table 1.

## 5. EVALUATION OF THE TEST RESULTS

Upon the basis of the test results the following conclusions may be drawn:

Masonry normally has a high resistance against the formation of shrinkage cracks if it has been fabricated correctly and the bricks have, before walling up, a usual moisture content and/or were exposed in the masonry to usual moistening. According to the type of manufacturing and especially at an unfavorable storing until walling up, bricks may have a very high moisture content which may cause shrinkage cracks in the masonry.

If wall specimens manufactured of porous concrete blocks or lightweight concrete blocks with a high moisture content were built and if the deformation of these wall specimens is obstructed cracks <u>separating the wall</u> - the so-called crevice cracks - may appear. Besides of that further cracks may appear which only separate the exterior area of a wall and were called shell cracks.

Whereas crevice cracks mostly run vertically over the total height of the wall and separate it in the area of vertical joints and bricks, the shell cracks run irregularly. If the bond strength between the bricks and the mortar is bigger than the tensile strength of the bricks, these cracks run through the stones and joints. If the bond strength within the area of joints is smaller than the tensile strength of the bricks or the vertical joints are not mortared, cracks mostly appear within the area of vertical and bed joints.

The crevice cracks separating the wall appear if the deformation or stress causing cracks have extended over the whole wall section. The formation of shell cracks may be favoured by high deformation and stress differences due to a different velocity of drying in the exterior and interior area of a wall.

As it is known the formation of crevice cracks and their distance in the wall depend upon the degree of fixing, upon the size of the deformation and the tensile strength of the wall. The danger of a formation of shell cracks increases according to the test results determined

- with the increasing deformation difference between the exterior and interior area of a wall during drying,
- with a decreasing bond strength between the mortar and the brick, especially for an unmortared vertical joint
- with an increasing size of bricks

Upon the investigated porous concrete and lightweight concrete blocks of the strength class 2 and 4 the first cracks became visible when shrinkages from 0,5 mm/m to 0,2 mm/m appeared.

According to that the cracking danger of the bricks could be essentially reduced if they are only walled up until the deformation due to drying of the brick will no longer exceed 0,2 mm/m.

This could be reached for the bricks investigated if these are walled up at a maximum moisture content during which, while drying continues, only a residual shrinkage $< 0,2$ mm/m appears. The danger of a formation of cracks may nevertheless exist in practice even after preserving this residual shrinkage, if in addition to this residual shrinkage due to deformations by temperature and construction appear.

The danger of a formation of cracks by deformation $> 0,2$ mm/m exists, according to the measuring results, even for porous concrete bricks and lightweight concrete bricks if an unrendered wall out of normal humid bricks is wetted from outside by, for instance, heavy rainfalls.

In order to reduce the danger of a formation of cracks due to deformations by wetting and drying out, for instance by sprinkling, all bricks should be protected either by rendering, for instance by applying a projected rendering or by covering the brickwork with foils or the brickwork must be sufficiently dry before applying a rendering.

According to the results of the wall tests and the investigations upon bricks the crack resistance of the masonry has not essentially been influenced by the porous concrete blocks and by the type of porous aggregates for lightweight concrete blocks.

For wall specimens out of small-size as well as specimens out of big-size bricks the danger of a formation of cracks exists equally. However upon wall specimens built with big-size bricks with an adhesion tensile strength between the brick and the mortar smaller than the tensile strength of the bricks, cracks with a smaller crack width appear at several vertical and bed joint surfaces.

Above these cracks the danger of a formation of cracks in a rendering is less important than for cracks in a masonry made of big-size bricks.

The danger of transmitting the cracks into the rendering may be reduced by using an appropriate rendering in accordance with the base. The tests carried through show that today renderings are available, as for instance lightweight renderings or thermal insulating renderings /2/ which have a crack-bridging function and, thus, keep their capability to protect the masonry against wetting.

## REFERENCES


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