# MECHANICAL PROPERTIES AND APPLICATION FEATURES OF CASIELS

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## SUMMARY

CASIELs are 100 to 300 mm thick building elements of 600 x 900 $mm^2$ which became popular since the mid 1980s due to their suitability for application in medium rise buildings (Berkers, 1995). A complete building system developed by the calcium silicate industry is available. Results of experimental studies into the mechanical properties of CASIELs loaded in axial compression, bending and shear are presented. Compressive strength of CASIELs ranges from 16 to 36 $N/mm^2$. Variation in properties is relatively small compared to other materials used for masonry.

## INTRODUCTION

This paper first presents the production of calcium silicate (CaSi) units, its dimensions and how walls, using CaSi-elements (CASIELs) are built. Then the basic characteristics of CaSi and mortars, like compressive, shear and tensile strength are discussed. This paper is a review of some previous work, highlighting the main results and it gives more detailed information of recent research into the kicker joint thickness effects on compressive wall strength and into the tensile capacity of CaSi.

Compressive strength is one of the main properties used in the design of load bearing masonry. As the tensile strength of masonry is relatively small and unreliable (C.o.V. 25% - 40%) most building codes, such as NEN 6790, specify that no tension capacity is available. This is motivated by the fact that at wall-floor connections, bonding does not exist because either floors are put directly onto the wall or Neoprene layers are used. However, for numerical simulation of fracture, tensile capacity and shear properties are important parameters which have to be established with dedicated tests.

## CASIEL FEATURES

When a mixture of approximately 92% sand, 8% lime and some water is compressed in a mould and then cured in an autoclave, the sand and lime will react. An artificial sand-limestone, called calcium silicate (CaSi) is formed. The properties of the material depend on the chemical reaction of the sand-lime mixture and on the pressure during moulding, the (chemical) composition and mixing ratios of the constituents and the hardening time.

Autoclaving is done under a pressure of 1.6 MPa and a temperature of 202 °C for approximately 8 hours. This process is different from the hardening of sand-lime mixtures in natural conditions, where only the lime reacts with $CO_2$ from the atmosphere. Short term shrinkage effects become minimal by storing the CASIELS for a few weeks before shipping and using them. Long term effects (cracks) can be prevented by using vertical movement joints at distances of 6 m maximum.

Three unit sizes are produced by the CaSi industry, i.e. brick, block and element. Bricks can be picked up with one hand, blocks must be lifted with two hands and elements with a small crane. CASIELs measure 900 to 1000 mm in length, 600 to 650 mm in height and 100 to 300 mm in thickness. With a specific mass of approximately 1800 kg/m$^3$, the weight varies from 1 to 4 kN. The moulding and hardening process results in units with smooth and level surfaces and relatively small dimensional tolerances allowing for the use of thin joints (thickness 2 to 3 mm). With these thin joints, together with the tongue and groove in the elements, smooth wall surfaces can be made, ready for finish, for instance, with wallpaper or paint. Consequently, finishing costs are significantly reduced. Calcium silicate elements include excellent structural performance, environmental friendliness and better quality products, (Berkers 1995).

Figure 1. Building with calcium silicate elements.

Units, cut to size are delivered at the right stage on the building site. Purpose designed tools and mortar provided by the Calcium-Silicate industry are used. The complete program developed to build load bearing walls in CaSi has automated unit production, i.e. computer aided drawing facilities, and machines for sawing units to size. CASIELs are shipped in packages per wall. A dedicated small crane to ease wall building is available. Building of a CASIEL wall starts with a kicker layer to create an optimal starting situation for the wall. The effect of kicker joint thickness on the load bearing capacity is discussed later in this paper.

Thin layer mortar is used for the subsequent layers. Tools for applying the thin layer mortar in both horizontal and vertical joints are available. The elements are hoisted individually into the proper position, controlled and guided by grooves. Directly after positioning, the CASIEL can be slided over the fresh thin layer mortar, by tapping it with a hammer, into its final position. Cord guiding is used to ensure a plumb and smooth wall. The fresh mortar is so workable that the surplus of mortar is squeezed out of the joint by the weight of the element. The speed of erecting walls is tremendously enhanced when building with CASIELs while labour costs are reduced. There is less physical stress for the bricklayers on site compared to traditional brick laying.

## COMPRESSIVE PROPERTIES

### Prism compressive strength.

For quality control purposes, the compressive strength ($f'_{d,EL}$) is determined from compression tests on cubes or prisms cut out of CASIELs at predetermined positions, according EN 771-2:2003. The prisms are either dried before testing or a correction for moisture content is applied afterwards. Table 1 gives general properties of the four qualities available, according to information given by manufacturers.

Compression tests on calcium silicate specimens of various sizes were performed by Vermelt-foort (2007) to obtain shape factors that would allow for the use of various specimen sizes. Various dimensions of the loaded areas in combination with various height over thickness ratios were used. Slender specimens showed vertical splitting cracks, squat specimens showed the well known hour glass fracture model, indicating the different effects of confinement by the loading platens and the effects of the material structure. The effect of size and shape of the specimens on compressive strength was established, (Vermeltfoort, 2007).

Table 1. Compressive properties of CASIELs and CASIEL masonry in N/mm$^2$.

| Code | $f'_{d,EL}$ | $f'_{wall}$ | E-modulus | |
|---|---|---|---|---|
| CS 12 | 16 | 8.4 | 6250 | |
| CS 20 | 20 | 10.2 | 9500 | |
| CS 28 | 28 | 13.6 | 12000 | values according |
| CS 36 | 36 | 16.8 | 14000 | to NEN 6790 |

## CASIEL wall strength

The strength of masonry walls made of CASIELs in combination with thin layer mortar can be established with:

$$f'_{wall} = 0.8\, f'^{\,0.85}_{d,EL} \qquad (1)$$

Equation (1) from EN 1996-1-1:2005 shows that the mortar quality has no effect on masonry strength. However, a certain minimum strength for the mortar used is prescribed.

To study the relationship between quality control test results and the real wall capacity, walls were tested in a specially built test set up with a capacity of 3 MN by Vermeltfoort and Ng'andu (2007). The averaged strength was 13.9 N/mm$^2$ (C.o.V. 5%), the E-value, 10.000 N/mm$^2$. Poisson's ratio depended on the load level. In another series, the averaged strength of five tests on specimens of 150 x 200 x 500 mm$^3$ was 12.34 N/mm$^2$, (C.o.V. 2%), the averaged E-value was 5290 N/mm$^2$ and the averaged Poisson's ratio was 0,15 (Vermeltfoort and Ng'andu, 2005).

Deformation measurements over the thin layer joints showed hardly any effect on deformation of the joint. This also may be explained by the fact that the joint (2-3 mm in thickness) is small compared to the CASIEL height of 600-650 mm.

In the 2D-compression tests of Vermeltfoort and Ng'andu (2005) some effect of confinement on strength was observed. The uni-axial compressive strength was 10.9 N/mm$^2$. The strength increased to 11.3 N/mm$^2$ (in average for two tests) for equal compression in two directions. Differently loaded in two directions, the 630 mm$^2$ square specimens failed at stresses of $\sigma 1 = 5.5$

N/mm$^2$ and σ2 = 13.8 N/mm$^2$ respectively. It may be assumed that the modulus of elasticity would increase with increasing lateral compression because the specimen can only expand in the third direction. However, this effect was not significantly measured. The averaged E-value equaled 8100 N/mm$^2$ with a maximum value of 10.000 N/mm$^2$ for σ1/σ2 = 1.

**Effect of moisture content**

In the project to establish the effect of kicker joint thickness also tests were performed to establish the effect of moisture content on compressive strength. For each type of CASIEL used, the compressive strength was established with prisms of 100 x 100 x 214 mm$^3$ (*h* x *l* x *b*). Prisms were dried in an oven or in open air. The specimens in the air dry condition were the weakest (Table 2). The values after correction for moisture content according to EN 772-1:2000 indicate that the result of the oven dried type A specimens is higher than expected compared to the dried ones.

Table 2. Compressive strength (N/mm$^2$) of CaSi prisms in oven and air dry conditions.

| | | Condition | test 1 | test 2 | test 3 | avg. | C.o.V. (%) |
|---|---|---|---|---|---|---|---|
| Type A | CS 12 | Oven | 21.4 | 21.7 | 21.4 | 21.5 (17.2*) | 0.8 |
| Type A | CS 12 | Air | 13.5 | 14.1 | 14.5 | 14.0 | 3.6 |
| Type B | CS 36 | Oven | 50.0 | 47.7 | 48.8 | 48.8 (39.0*) | 2.4 |
| Type B | CS 36 | Air | 36.6 | 37.7 | 39.8 | 38.0 | 4.3 |

*) value after correction for moisture content acc. EN 772-1:200, correction factor 0.8.

**Mortar properties for kicker joint tests**

Two types of mortar were used for the kicker joint specimens. A general purpose mortar was used to build the kicker joints and a thin layer mortar for the CASIELs. For both mortars, factory prepared, dry mortar, delivered in 25 kg bags was used.

Two batches were made from kicker joint mortar Type X and two from mortar Type Y. Three bags were used for batch X1 to which 6.4 liters of water were added. In batch X2, three liters of water were added to one bag of mortar. For both mortar mixes Y1 and Y2, 2.6 liters of water were added to one bag of mortar. Three mortar prisms (40 x 40 x 160 mm$^3$) were made of each mortar batch and tested according to EN 1015-11 [3].

One single batch of thin layer mortar was prepared using one bag of material to which six liters of water were added. From this batch three mortar prisms were made and stored under controlled conditions (20°C, RV 60%). All CASIELs were built using mortar of this single batch.

All mortar prisms were stored under controlled conditions (20°C, RV 60%) for curing. They were tested after 26, 33 and 61 days (end of testing program) according to EN 1015-11 to obtain an indication of strength development. The results, given in Table 1, show a clear difference between the three types of mortar used and relatively small differences between similar mortar batches. An increase in strength over time is observed.

Specimens, similar to mortar specimens were cut from street tiles. These tiles were used to simulate the concrete floor surface. The averaged bending strength (modulus of rupture) equaled 8.4 N/mm$^2$. The averaged compressive strength was 59.1 N/mm$^2$ (C.o.V. 4.1%).

Table 3. Mortar compressive strength (N/mm$^2$) at several ages.

| | Age | TL | X1 | X2 | Y1 | Y2 |
|---|---|---|---|---|---|---|
| | 26 | 26.1 | 11.1 | 9.0 | 33.3 | 29.1 |
| | 33 | 27.9 | 12.9 | 9.2 | 33.2 | 31.4 |
| | 61 | 28.6 | 18.2 | 12.0 | 44.4 | 35.9 |
| Avg | | 27.5 | 14.1 | 10.1 | 40.0 | 32.1 |

## SHEAR STRENGTH OF THIN LAYER JOINTS

For detailed numerical simulations of wall behaviour the mechanical properties of the joints under shear load are of importance. Specimens of 300 x 150 x 200 mm$^3$ were made, using blocks of 100 mm and 200 mm in length cut from CASIELs and tested in shear, Figure 2a.

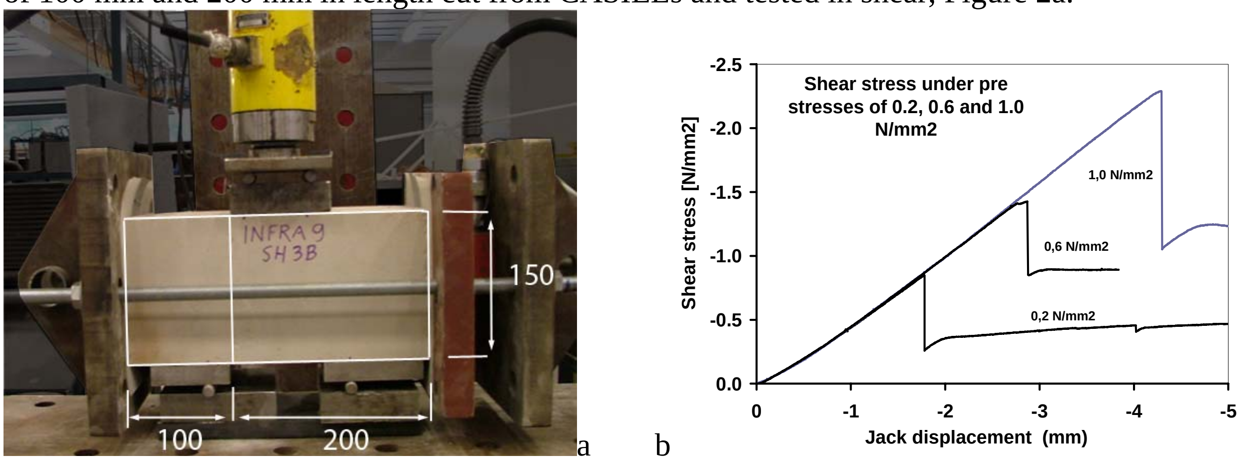


Figure 2. a) Shear test set-up, with shear in vertical and pre-compression in horizontal direction b) Shear stress versus displacement

Two shear tests were performed for each of the three levels of pre-compression (0.2, 0.6 and 1.0 N/mm$^2$) according to EN 1052-3:2001. Shear load and pre-stress load were measured via oil pressure in the system and a shear load displacement relationship was recorded (Figure 2b).

The shear load was increased gradually and the graph showed a linear relationship. After reaching ultimate load, the force dropped quite suddenly, accompanied by a loud bang. The load dropped considerably while large displacements occurred. However, after continuation of the test the load resumed at a residual level due to friction in the cracked surface. Form these measurements a shear coefficient can be established. Figure 2b shows schematically the shear strength displacement relationship for three pre-compression levels.

In Figure 3 the measured shear strength and the residual strength are plotted versus the applied pre-stress. The variation in residual shear strength results is smaller ($R^2$ = 0.93) than the variation in initial shear strength results ($R^2$ = 0.70). A clear relationship between pre-stress and shear strength is observed. The equations given in Figure 3 describe the relationship between shear strength (y) and pre-stress (x). The initial shear strength was 0.58 N/mm$^2$, the coefficient of friction 0.56 (pre-cracked phase) or 0.47 (post-cracked phase).

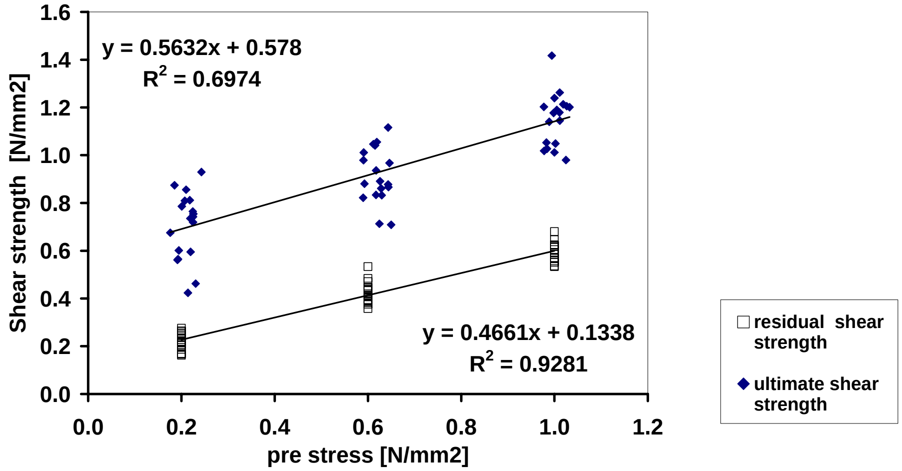


Figure 3. Shear strength versus pre stress for CASIEL thin layer mortar joints

## TENSILE PROPERTIES

### Tensile strength CaSi blocks

Four point bending tests were performed on specimens made from blocks glued together with Bolidt, a two component high strength glue. The glued joints were outside the constant moment area to assure fracture in the central part of the specimen in the calcium silicate and not in the joints. Figure 4b shows the loading scheme and dimensions of the 150 mm thick specimen and Figure 4a the load deflection diagram.

In the initial phase relatively large deformations occur due to the closing of "play' in the system. Then a more or less linear load deformation relationship develops. However, the accuracy is doubtful since not only deformation of the specimen but also that of some parts of the loading system is included in the measurements. The specimen fails suddenly. The averaged bending tensile strength (modulus of rupture) was 1.23 N/mm$^2$ (C.o.V. 12 %) based on a linear stress distribution over height.

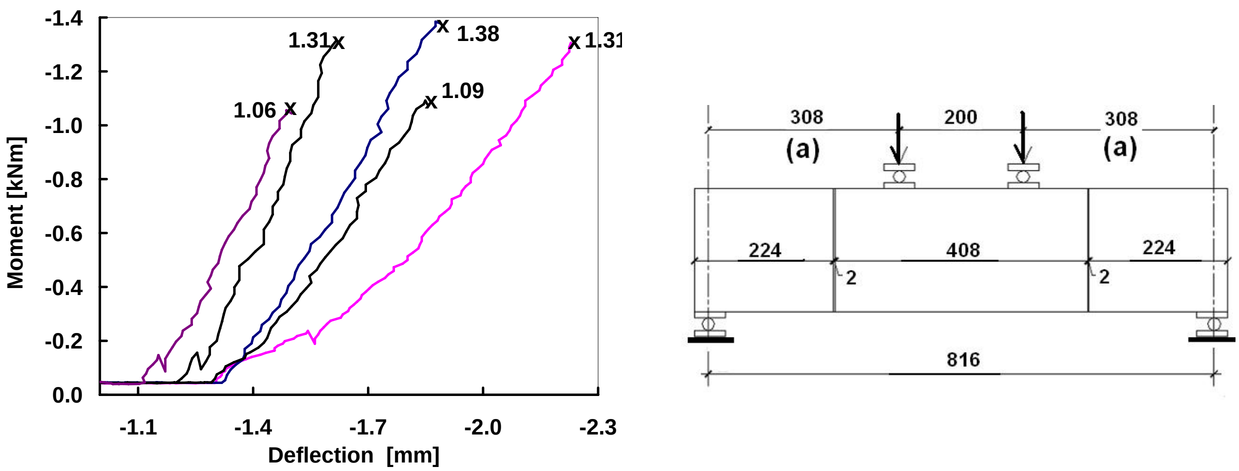


Figure 4. a) Load deflection diagram and b) dimensions bending tests

**Tensile properties of CaSi Elements (CASIELs)**

For numerical simulation of fracture, the tensile capacity is an important parameter. Therefore, splitting and bending tests were performed on specimens of various sizes, cut from CaSi blocks (CS 20). In the splitting tests some effect of size was observed by comparing results of series S-1with S-3 and S-2 with S-4. Splitting tests results were smaller than B3 and B4 bending test results.Table 4 gives an overview of the mean results of three and four point bending tests. Both in the three and four point bending tests, a larger span resulted in a smaller strength. The coefficient of variation (C.o.V.) in the three point bending tests was largest which is explained by the less uniform stress distribution in the central part of a 3-point bending test compared to the distribution in a four point bending test.

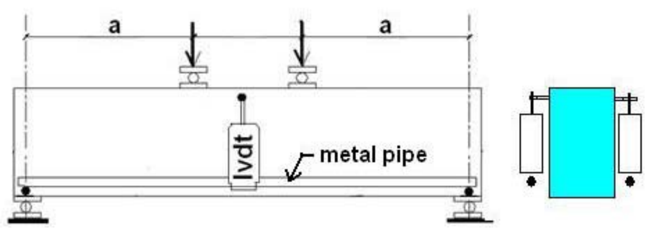


Figure 5. Scheme of deflection measurements in 3-point and 4-point bending tests with two LVDTs.

In four 3-point and six 4-point bending tests deformations were measured with an LVDT at either side at mid span of the specimen. The average of the measured deflection was used to control the speed of loading. A linear load deflection relationship with a sudden (brittle) fracture was found. This resulted in the values given in Table 4 showing higher values for the 3-point bending tests but still smaller than the other tests. The strength of these deformation controlled test are in contradiction with the other tests probably because they were performed more slowly. The mean E-values were 9400 N/mm$^2$ (C.oV. 4.5 %) and 8200 N/mm$^2$ (C.o.V. 18.6 %) for series B3-E and B4-E respectively.

Table 4. Bending test results (strength in N/mm$^2$)

| Type | l (mm) span | a (mm) (fig. 5) | w (mm) | h (mm) | # | strength | C.o.V. (%) |
|---|---|---|---|---|---|---|---|
| Three point bending tests | | | | | | | |
| B3 - 1 | 100 | | 58 | 58 | 12 | 4.12 | 41.0 |
| B3 - 2 | 160 | | 58 | 58 | 12 | 4.06 | 23.0 |
| B3 - 3 | 220 | | 58 | 58 | 8 | 3.93 | 49.0 |
| B3 - 4 | 160 | | 120 | 58 | 11 | 3.59 | 43.0 |
| B3 - 5 | 400 | | 58 | 58 | 8 | 3.36 | 7.7 |
| B3 - E | 360 | | 120 | 120 | 4 | 2.94 | 3.6 |
| Four point bending tests | | | | | | | |
| B4 - 1 | 400 | 60 | 58 | 58 | 6 | 2.46 | 4.8 |
| B4 - 2 | 400 | 60 | 58 | 58 | 16 | 3.00 | 11.3 |
| B4 - 3 | 400 | 50 | 58 | 58 | 4 | 1.92 | 42.0 |
| B4 - 4 | 450 | 50 | 58 | 58 | 6 | 2.28 | 9.7 |
| B4 - 5 | 300 | 50 | 57 | 57 | 4 | 2.30 | 4.4 |
| B4 - 6 | 260 | 50 | 60 | 57 | 6 | 2.43 | 15.0 |
| B4 - 7 | 160 | 50 | 59 | 57 | 7 | 2.61 | 14.7 |
| B4 - E | 360 | 240 | 120 | 120 | 6 | 2.09 | 11.2 |

## EFFECT OF KICKER JOINT THICKNESS ON COMPRESSIVE STRENGTH

CASIEL wall building starts with a kicker joint. With this joint, tolerances in floor level height are bridged, consequently, joint thickness will vary. A target thickness of 20 mm is advised. Practical values for thickness are between 10 and 50 mm. To study the possible negative effects of joint thickness on the load bearing capacity, tests were performed on specimens with joint thicknesses of 0, 20, 40 and 60 mm respectively (Table 5). The specimens were loaded concentrically to fracture. The top of the floor was imitated by a 50 mm thick concrete tile on which a kicker joint, a 100 mm high kicker block and a CASIEL were built, Figure 6. Two types of CASIELs and two types of kicker joint mortar were used. Material properties are given in Table 1 and Table 2.
The kicker joint mortar is confined by the floor and the CaSi block above. When loaded in compression, blocks and mortar will expand (differently) causing tension in one of both materials. In a thicker joint the confining effect is less and the kicker joint mortar will fail at smaller loads.


Figure 6. a) a specimen with concrete tile, kicker joint, kicker block and CASIEL. LVDTs used for deformation measurements are visible, b) a specimen after testing with cracks originating from the thin layer joint at mid height, and c) a specimen after testing with cracks that started at the kicker joint.

### Test program

Three brick-mortar combinations with four joint thicknesses were tested in duplicate (24 tests). The length of the specimens was approximately one third of the length of a CASIEL (330 mm). Four extra 495 mm wide specimens were tested with a joint thickness of 30 mm. All specimens were smooth and level at the top and bottom. However, to introduce the load smoothly, 2 mm cardboard was used to allow for dimensional tolerances of the specimen.

Figure 6a shows the position of the deformation measurement instruments. Deformation in loading direction was measured at mid height with LVDTs (150 mm gauge length) two at the front and two at the back. In some cases, two of these four LVDTs were positioned horizontally to measure lateral deformation.

Table 5. Specimen types

| Type | Number of tests | Joint thickness *) (mm) | CASIEL see Table 2 | Mortar see Table 3 | dimensions bxhxd **) (mm x mm x mm) |
|---|---|---|---|---|---|
| 1 | 4 x 2 | 0, 20, 40, 60 | Type A | Type X | 330 x 640 x 214 |
| 2 | 4 x 2 | 0, 20, 40, 60 | Type B | Type X | 330 x 640 x 214 |
| 3 | 4 x 2 | 0, 20, 40, 60 | Type B | Type Y | 330 x 640 x 214 |
| 4 | 4 | 30 | Type A | Type X | 500 x 640 x 214 |

* Each joint thickness was tested in duplicate for each brick mortar combination. A thin layer mortar joint of 2 à 3 mm was applied for the specimen with zero joint thickness.
** Target values of specimen’s dimensions, excluding tile and joint

## Results

Kicker joint thickness versus compressive strength is plotted in Figure 7 for each test specimen. In series 1, the difference between kicker joint mortar strength (12 N/mm²) and CASIEL strength (36 N/mm²) is largest and the effect of kicker joint thickness is significant. The compressive strength decreases as the joint becomes thicker. In series 2 and 3/4 the strength-joint thickness relationship is moderate. This also could be observed in the cracking pattern.

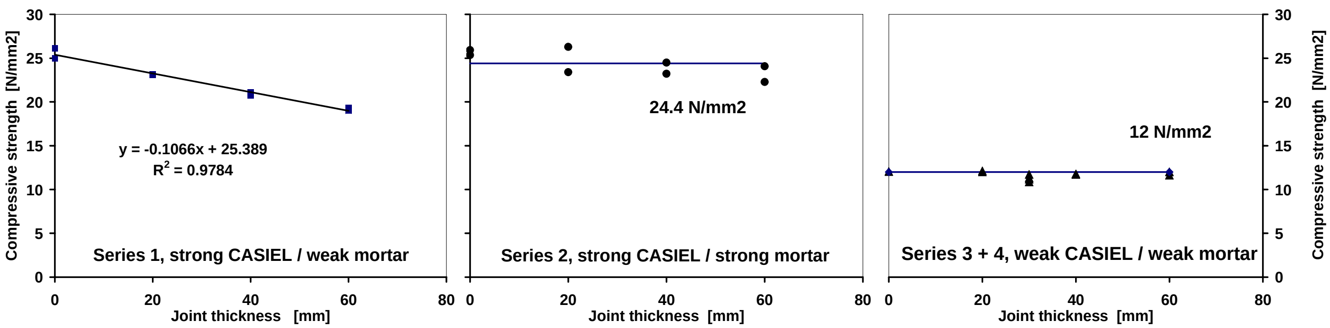


Figure 7. Compressive strength versus kicker joint thickness

The crack-patterns also indicate that in series 2, 3 and 4 the kicker joint thickness has only little effect on the compressive strength. Cracks developed near the thin layer mortar joint at mid height of the specimen and not below in the kicker joint.Two failure patterns are distinguished. The first is characterized by bulging of the kicker joint mortar (Series 1). The CASIELs crack vertically starting from the kicker joint. In the second pattern, (Series 2, 3 and 4) cracking mostly started around the thin layer mortar joint, the kicker joint hardly cracked or much later. Further, cracking started at the edges of the specimen at spots with less joint filling or openings. Cracks concentrated mainly in the larger front and back and less in the smaller side surfaces.

The modulus of elasticity was established with a linear ’best fit’ in the $\sigma$-$\varepsilon$-diagram for results between 10% en 75% of strength. Averaged E-values were 6368 N/mm$^2$ (C.o.V. 16%) for CaSi type A and 13 045 N/mm$^2$ (C.o.V. 6%) for CaSi type B. In some cases the results showed considerable differences, in the order of magnitude of two, between the results of different LVDTs.

Poisson's ratio followed from the results of lateral deformation measurements and showed that Poisson's ratio ($\upsilon$) varies with the load level. Poisson's ratio seems to be equal to 0.20 for CaSi type B and 0.30 for type A. It is emphasized that these values are obtained with measurements at the surface. Lateral deformation measurements 50 mm above the kicker joint indicate that the material is confined in that area while the lateral deformation is smaller than at mid height of the specimen.

## CONCLUSION

The Calcium Silicate industry offers a complete system for building walls: starting from the CAD drawing board to the finished wall. CASIEL construction is quick, relatively easy and ensures consistency in quality.

CASIELs have compressive strengths of up to 36 $N/mm^2$, and a modulus of elasticity of approximately 400 - 450 times cube compressive strength. C.o.V. values for compressive strength range from 4 - 10 %.

The tensile strength of CaSi CS 20-quality is approximately 2 $N/mm^2$ and their shear strength 0.57 $N/mm^2$. The bond strength is approximately 1.20 $N/mm^2$. C.o.V. values for tension range from 10 - 15 % (extreme values omitted).

Obviously, the kicker joints must correctly be made with care. A poor filling has a negative effect on the load bearing capacity of a wall. However, when mortar and CASIEL strength are tuned, joint thickness is not critical.

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