8TH
CANADIAN
MASONRY
SYMPOSIUM

Jasper, Alberta
May 31 - June 3, 1998

INFLUENCE OF THE TYPE OF MORTAR JOINT ON THE TIME DEPENDENT BEHAVIOUR OF MASONRY

Rob van der Pluijm and Ad Vermeltfoort
TNO Building and Construction Research
PO Box 49, NL-2600 AA Delft

Eindhoven University of Technology
PO Box 513, NL-5600 MB Eindhoven

ABSTRACT

In the Netherlands thin layer mortars are usually applied in calcium silicate blockwork, but there is a tendency to use thin layer mortars also for concrete and clay brickwork. The paper describes an experimental research into the influence of the type mortar (thin layer and general purpose) on creep and shrinkage of masonry. Concrete, clay brick and calcium silicate units were used. The ratio between joint thickness and unit height was also a parameter for calcium silicate masonry. Detailed measurements, carried out for a period of 300 days, were performed perpendicular and parallel to the bed joint. Furthermore the mass of the shrinkage specimens was recorded.
The experiments strongly indicate that shrinkage mainly depends on the unit-type, where creep is also influenced by the joint type. Strange enough, the tests on calcium silicate masonry showed that the type of mortar joint was more important than the ratio between joint thickness and unit height.

Keywords: General Purpose mortar, Thin layer mortar, Clay brick, Concrete brick, Calcium silicate unit, Shrinkage, Creep

INTRODUCTION

The influence of different types of joints on the time dependant behaviour of masonry is hardly known. As the importance of thin layer mortars is increasing in the Netherlands, the reported research (Van der Pluijm, 1997) was focused on the difference between thin layer joints (3 mm thick, indicated with TLM) and joints with general purpose masonry mortars (12 mm thick, indicated with GPM) for clay, concrete and calcium silicate masonry. Furthermore, the height of the units was a parameter for the calcium silicate masonry because the height of calcium silicate units varies between 50 and 600 mm in the Netherlands.

MATERIALS AND SPECIMENS

Mortar and Units

Four types of units were used: calcium silicate bricks[1], parts of large calcium silicate blocks[2], wire cut extrusion clay bricks and normal density concrete bricks. Factory made mortars normally used in practice with these units were applied. An overview of brick and mortar properties is presented in Table 1 and Table 2.

Table 1 Compressive strength of units

	compressive strength [N/mm^2]	
unit type	according Dutch standards	Normalized to 100mm height acc. prEN 772-1
Calcium silicate block	26	26
Calcium silicate brick	34	26
wire cut extrusion clay brick	69	52
normal density concrete brick	61	46

Table 2 Compressive strength of mortars f_c^{mortar} according to NEN 3835 and prEN 1015-11

mortar	used with unit type	f_c^{mortar} *) [N/mm^2]
thin layer mortar Calsifix	calcium silicate bricks	18,4
laboratory made mortar 1:1:4	and blocks	15,2
thin layer mortar Ankerplast	clay brick	20,3
masonry mortar Beamix 316		7,1
thin layer mortar C62	concrete brick	17,0
masonry mortar Beamix 312		9,1

*) 40 mm cubes

Specimens

The calcium silicate units were pre-wetted resulting in a moisture content of 6.5% (m/m). The clay and concrete bricks were used right away. The age of the concrete bricks was 5 weeks at time of preparation. One batch of mortar was prepared for each mortar type. Specimens consisting of brick-type units were made using cord guiding. After preparation all specimens were close covered in polyethylene to avoid shrinkage prior to the start of the creep tests.

The dimensions of specimen were chosen as small as possible according the guidance given by Schubert (1991) and preliminary tests carried out at the Eindhoven University of

---

[1] a unit with dimensions of approximately lxhxt = 210x50x100

[2] a verly large block (denoted with 'element' in the Netherlands) with dimensions lxhxt = 900x600x100

Technology (Raijmakers, 1996). In the latter research a comparison was made between wallette size specimens (1200×1000×100 mm^3) and small specimens corresponding with the specimens described in this paper. In agreement with the recommendations of Schubert, it could be concluded that the small specimens are representative for the behaviour.
The length and height of the shrinkage specimens were taken almost equal because horizontal and vertical deformations were recorded. The length of the creep specimens was approximately half the length of the shrinkage specimens as only vertical deformations in the direction of the load were recorded. The thickness of all specimens corresponded with the width of the units (100 mm). (see Fig. 1). Every test was carried out in duplicate.

After the end of the creep and shrinkage measurements, the creep specimens were tested in compression until failure to get a good impression of the masonry compressive strength f_c^{masonry} (see Table 3). Also included are stiffness values E determined in the creep test set-up and in the compressive test set-up both determined at the same stress level. The main difference between the values determined for E is that the load in the creep test set-up was applied in two steps in a period of half an hour. The time effect is visible for the calcium silicate and concrete specimens.

Table 3 Strength and stiffness of creep-specimen (mean of two)

masonry type	E (in compressive test) [N/mm^2]	Eo (initial stiffness in creep-frame) [N/mm^2]	compressive strength [N/mm^2]
calcium silicate block	11540	9210	22,6
calcium silicate block + TLM	12930	8600	17,0
calcium silicate + GPM	10300	8170	20,5
calcium silicate brick + TLM	13570	11690	18,5
calcium silicate brick +GPM	9650	7930	18,5
clay brick + GPM	12890	14390	23,9
clay brick + TLM	13160	13140	37,8
concrete brick + GPM	28600	26790	26,4
concrete brick + TLM	28890	26030	26,1

E determined at 2,5 N/mm^2 as secansmodulus

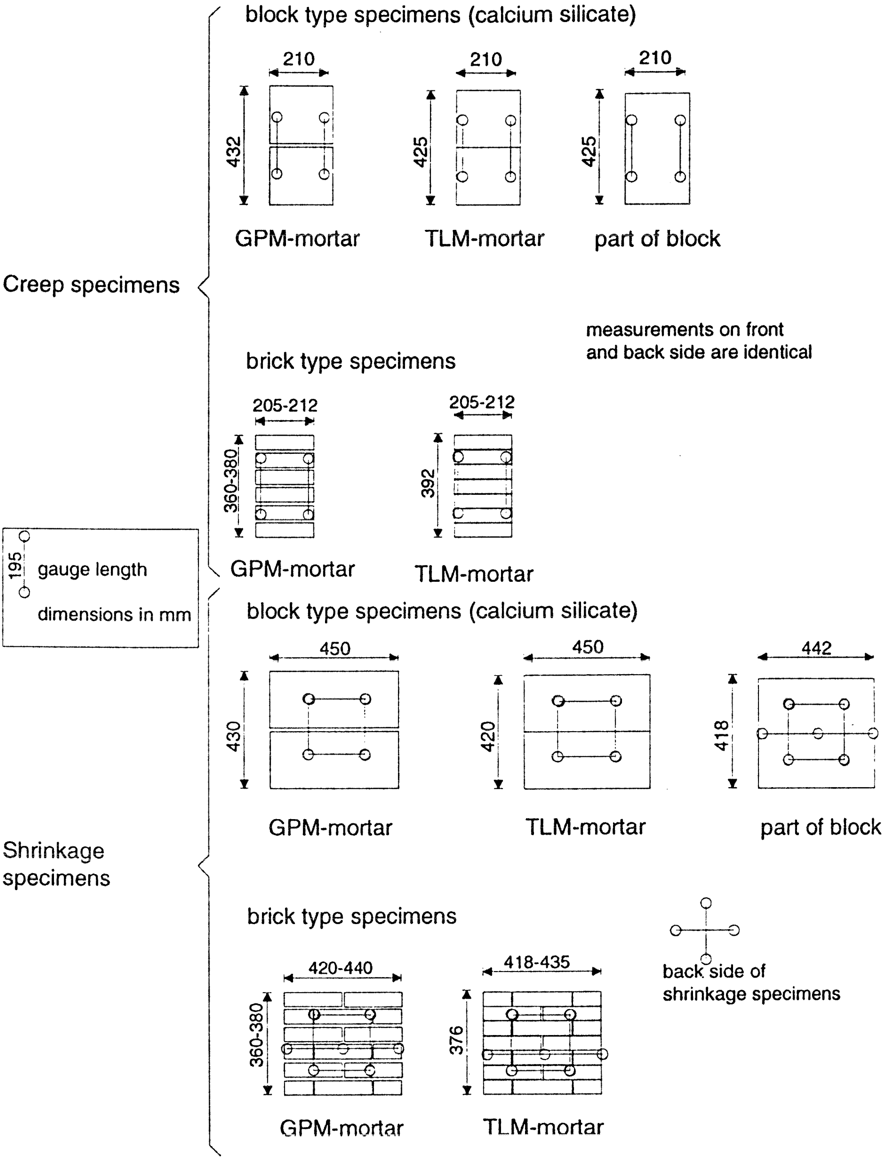

Fig. 1 Specimens

EXPERIMENTAL SET-UP

The experiments were carried out in an environmental test chamber at (20 ± 2) °C and (50 ± 2)% RH. The specimens were also prepared and stored in this room prior to the creep tests. One week after preparation, shrinkage measurements were taken and the weight of the shrinkage specimens was recorded. During these measurements the specimens were temporarily taken out of the plastic. After three weeks of hardening all 18 creep specimens were placed in six frames. In each frame three specimens were placed on top of each other. At the top and bottom each specimen was capped with gypsum in plastic bags and provided with 10mm tick steel platens. The load was applied in two phases up to a level of 2,5 N/mm^2. At this moment all shrinkage specimens were taken out of their plastic coverage. After that, the sides of the specimens were covered with a bituminous layer in order to simulate the normal evaporation process for walls as close as possible. The measurements on creep and shrinkage specimens taken after applying the load were taken as the zero-values for the time dependant behaviour. From these measurements and those taken in the first three weeks, it could be concluded that the moisture loss of the shrinkage specimens during the first three weeks was negligible.

Measurement were taken with a demec gauge with a length of 195 mm. All measurements are indicated in Fig. 1. Measurements were taken after 8 hours, 1, 2, 4, 7, 14, 28, 42, 70 en 98, 121, 153, 184, 225 and 295 days. After each measurement, the weight of the shrinkage specimens was recorded. Afterwards all shrinkage specimen were dried to a constant mass.

EXPERIMETAL RESULTS

On the next pages, the following data for each specimen type, is presented per type of masonry unit:

- loss of mass of the shrinkage specimen, expressed as an percentage of the dry mass established afterwards;
- the vertical shrinkage (perpendicular to the bed joint)[3];
- the horizontal shrinkage;
- the creep factor calculated with:

$$\phi(t) = \frac{\varepsilon_t(t) - \varepsilon_e - \varepsilon_{sh}(t)}{\varepsilon_e} \qquad (1)$$

in which:

$\varepsilon_t(t)$ is the mean total strain in the creep specimen:

ε_e is the mean elastic strain established immediately after applying the load;

$\varepsilon_{sh}(t)$ is the mean vertical shrinkage of the two corresponding shrinkage specimens.

---

[3] although the word shrinkage already indicates shortening, values for shrinkage are always presented as negative numbers and values for expansion with positive numbers

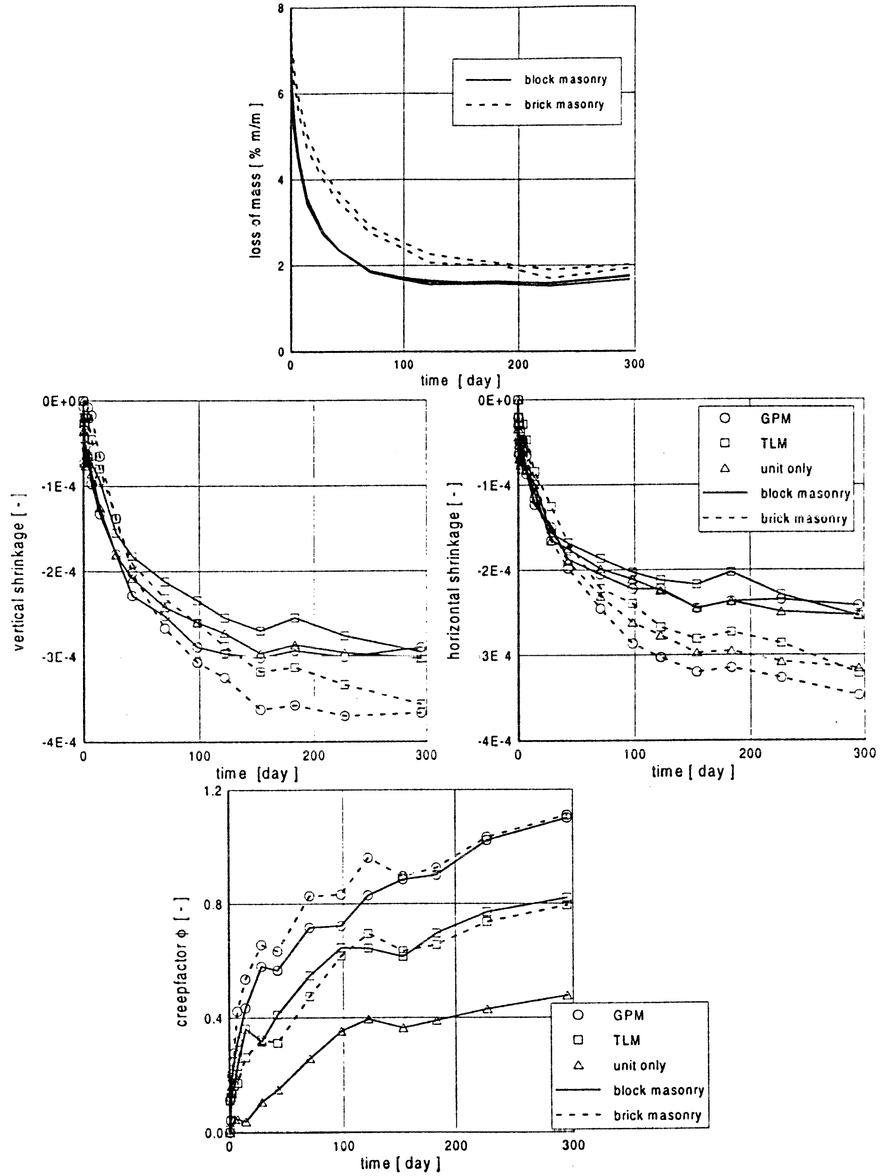

Fig. 2 Overview of time dependant behaviour of specimens made with calcium silicate bricks and blocks.

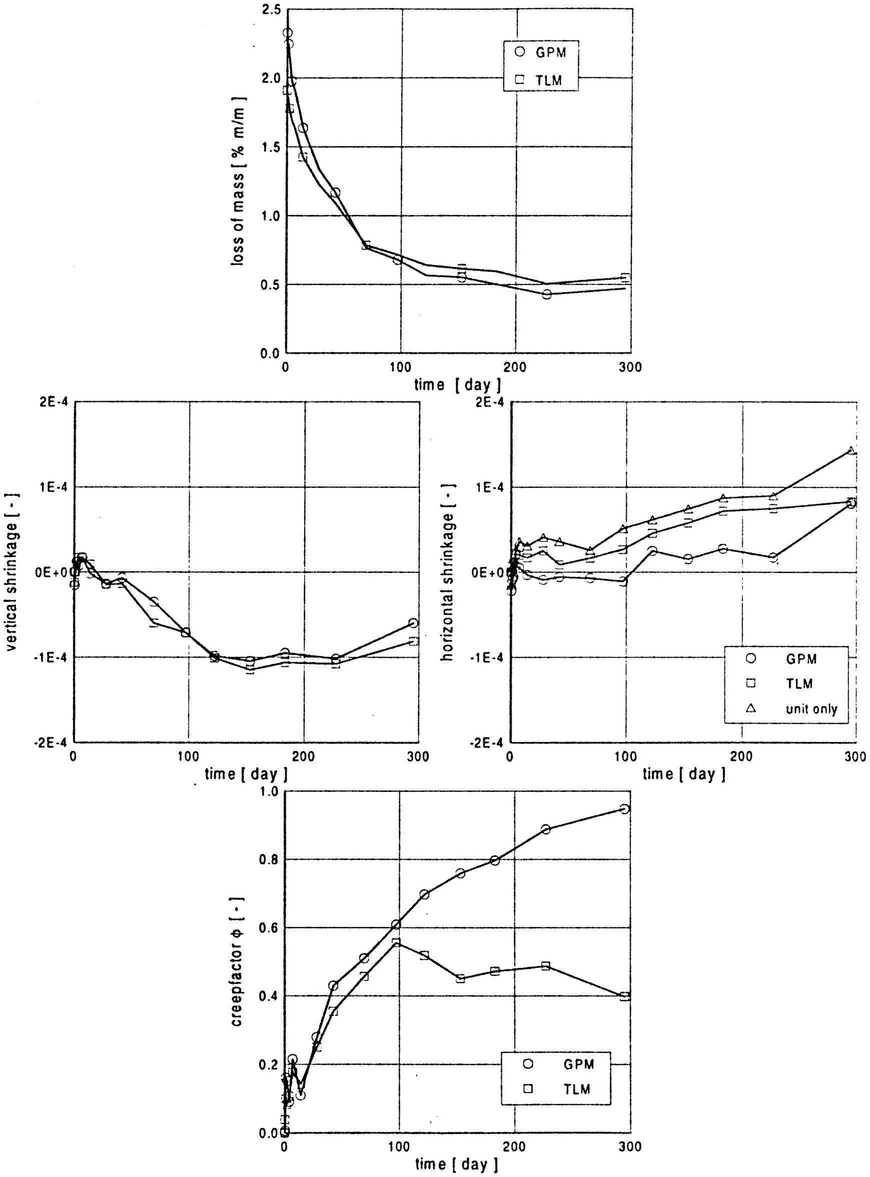

Fig. 3 Overview of time dependant behaviour of specimens made with wire cut extrusion clay bricks.

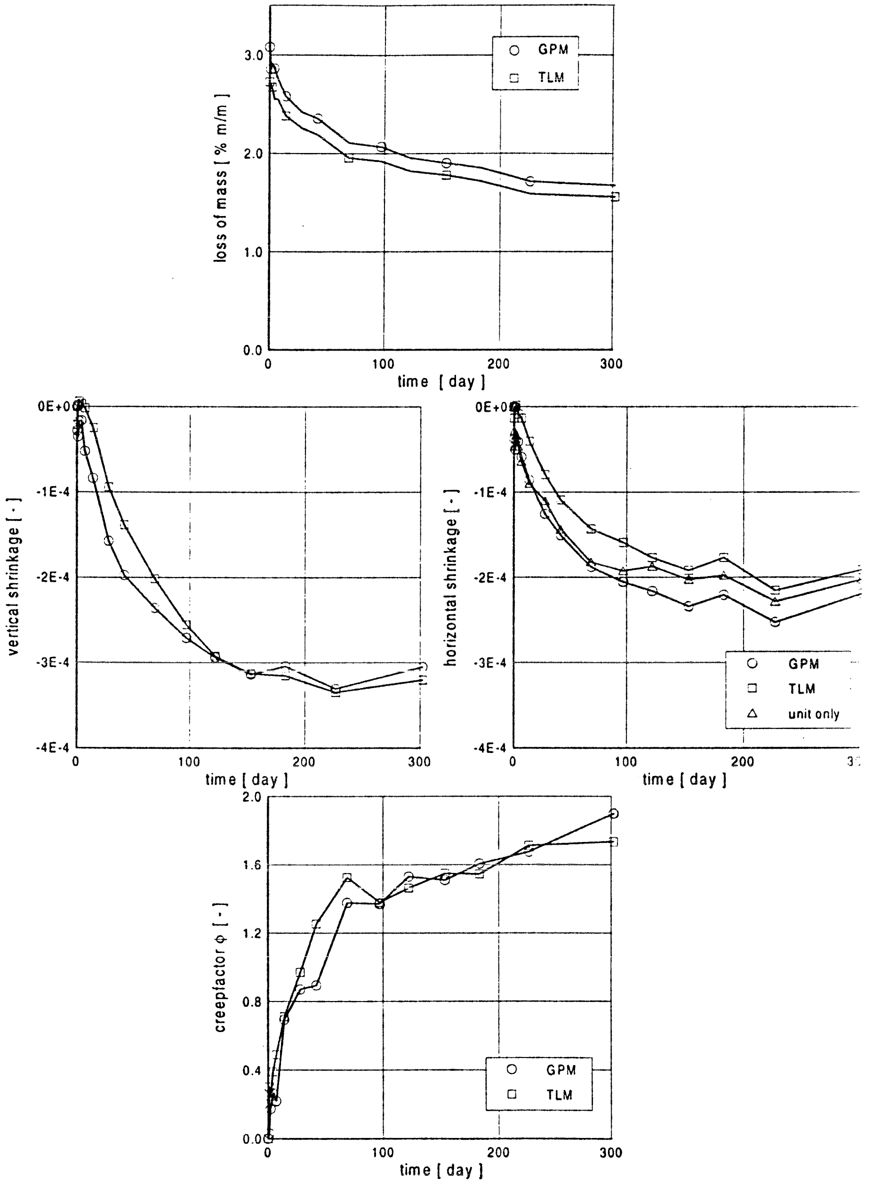

Fig. 4 Overview of time dependant behaviour of specimens made with concrete bricks.

Numerical simulation

Creep can be considered as visco-elastic behaviour and can be simulated with chain-models consisting of feathers and dampers (see Fig. 5).

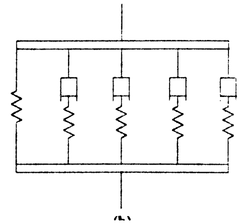

Fig. 5 Maxwell-chain used to simulate visco-elastic behaviour

Shrinkage is simulated by increasing an imposed strain field as a function of time. Within the finite element-method program DIANA, the material properties for the parts of the chains are determined automatically on the basis of a table of the total deformation (elastic + creep) against the time (the so-called creepfunction *J*). The average vertical creep and shrinkage for all calcium silicate masonry were determined and simulated in a one-element test calculation with a plane stress membrane element. The results of the calculation including test-data is presented in Fig. 6.

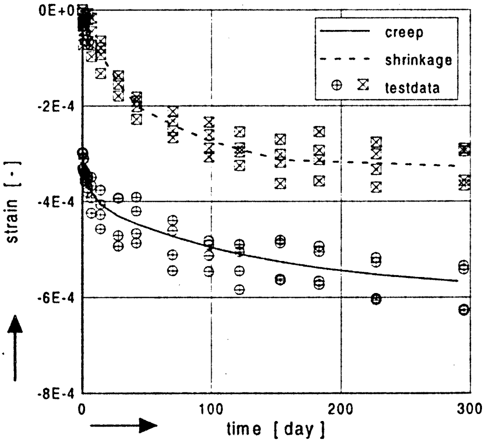

Fig. 6 Strains caused by creep and shrinkage of calcium silicate masonry, experimental and numerical results

From Fig. 6 it can be observed that the behaviour in the experiments can be simulated satisfactory.

DISCUSSION OF EXPERIMENTAL RESULTS

The weight of the clay brick and calcium silicate shrinkage specimens increased in last period between 225 en 295 days. In this period the RH increased from 50 to 52% for three days due to a small problem with the equipment. This might be a cause for the increase in weight due to increase of moisture content of the specimens. The decrease in shrinkage of the clay brick specimens (Fig. 3) confirms this hypothesis, but the behaviour of the calcium silicate specimens does not conform this. Furthermore the concrete brick specimens did not show an increase in mass, but they did show a decrease in shrinkage. An other cause of the increase in mass can be carbonation. This is especially the case for calcium silicate specimens.

Looking to all results together it may be concluded that small deviations in RH cause the fluctuations in the shrinkage behaviour.

The graphs of the experiments show that the values measured after 295 days will approximate the 'end' values for creep and shrinkage.

An overview of the last measured values for creep and shrinkage is presented in Table 4, Table 5 and Table 6 for each unit-type.

Table 4 Creep and shrinkage values of calcium silicate masonry after 295 days (initial moisture content of units at time of laying = 6,5%)

	block	block + TLM	block + GPM	brick	brick + TLM	brick + GPM
shrinkage vertical (‰)	-0,30	-0,30	-0,29	-	-0,36	-0,37
shrinkage horizontal (‰)	-0,25	-0,25	-0,24	-0,32	-0,32	-0,35
creep factor ϕ (-) (σ = -2,5 N/mm^2)	0,48	0,82	1,10	-	0,79	1,11

The average horizontal shrinkage of the calcium silicate masonry was 13% smaller than its vertical shrinkage. No influence of the joint could be seen for the block-specimens. More remarkable is the fact that the same is true for the masonry made with bricks. For both calcium silicate unit types, there is no difference between the specimens with thin layer joints and the normal joints and the units themselves. It must be concluded that the difference between the behaviour of specimens made with bricks and blocks is mainly caused by the units themselves. Joints hardly have an influence on the shrinkage behaviour of calcium silicate masonry.

The creep of the calcium silicate specimens was strongly influenced by the presence of joints and the type of joints. The type of joint seems to be more important than the number of joints. Specimens made with blocks and one joint showed the same creep behaviour as brick specimens with four joints of the same type within the gauge length. This was not only valid for the creep-factor but also for the total creep deformation. An explanation for this phenomenon is not known. Perhaps that a difference in behaviour of the unit type (brick versus block) nearly exactly compensated a difference caused by the different number of joints. The authors have to admit that this is only a guess.

Raijmakers (1996) found nearly the same creepfactor for calcium silicate masonry made with another type of calcium silicate blocks (438 × 198 × 100 mm^3) and thin layer mortar.

Table 5 Creep and shrinkage values of clay brick masonry after 295 days
(units processed directly from the stock)

	brick	brick + GPM	brick + TLM
shrinkage vertical (‰)	-	-0,06	-0,08
shrinkage horizontal (‰)	+0,14	+0,08	+0,08
creep factor ϕ (-) (σ = -2,5 N/mm^2)	-	0,95	0,40

If loss of mass is associated with loss of moisture for the clay brick specimens, no difference of the hygroscopic behaviour can be observed between specimens made with GPM mortar and made with TLM mortar. The shrinkage in vertical direction and the expansion in horizontal direction are nearly the same for both type of clay brick masonry. When the horizontal expansion of the clay brick itself is taken into account, it must be concluded that shrinkage of head joints partly compensated the expansion of the bricks. In vertical direction the shrinkage of the joints resulted in shrinkage of the specimen. It is assumed that the change in length can be calculated with:

$$\varepsilon_{\mathrm{sh;total}} \cdot l_{\mathrm{gauge}} = \varepsilon_{\mathrm{sh;unit}} \cdot l_{\mathrm{gauge;unit}} + \varepsilon_{\mathrm{sh;joint}} \cdot l_{\mathrm{gauge;joint}} \qquad (2)$$

in which:

$l_{\mathrm{gauge}}, l_{\mathrm{gauge;unit}}, l_{\mathrm{gauge;joint}}$ are respectively the total gauge length, the total length of units within in gauge length and the total length of joints within the gauge length and

$\varepsilon_{\mathrm{sh;total}}, \varepsilon_{\mathrm{sh;unit}}, \varepsilon_{\mathrm{sh;joint}}$ are respectively the shrinkage of the specimen, the uniform shrinkage of the unit and the uniform shrinkage of the joints.

When eqation (2) is applied in both directions, the expansion and the shrinkage of specimen are mathematically not is accordance with each other.

It is suggested that the orientation of particles in the clay unit causes a difference in hygroscopic behaviour in different directions. When the resemblance between masonry with thin layer joints and normal joints is considered, it could be concluded that the joint thickness is not an important factor for the shrinkage of the joints themselves. It could be suggested that the brick mortar interface plays an (unknown) role. With this assumption, equation (2) could be modified using the number of joints instead of the length of the joints within the gauge length. However, this cannot bring the horizontal and vertical measurements in correspondence with each other. The conclusion was drawn that the behaviour of the clay brick is not isotropic.

As with calcium silicate masonry, the creep of the clay brick masonry was strongly influenced by the type of joints. The creep of the masonry made with TLM is remarkable low compared with the clay brick masonry made with GPM.

Table 6 Creep and shrinkage values of concrete brick masonry after 295 days (units processed directly from the stock, with an age of five weeks)

	brick	brick + GPM	brick + TLM
shrinkage vertical (‰)	-	-0,31	-0,32
shrinkage horizontal (‰)	-0,20	-0,22	-0,19
creep factor ϕ (-) ($\sigma = -2{,}5$ N/mm^2)	-	1,90	1,73

For the concrete brick masonry, no real difference could be observed between shrinkage of specimens made with GPM and TLM. The shrinkage in horizontal direction was smaller than in vertical direction. The influence of the head joint on the shrinkage in horizontal direction seems to be negligible.
The resemblance between the shrinkage behaviour of masonry with TLM and GPM in horizontal and vertical direction suggests again that the thickness of the joints is not very important.
The difference between the creep factors of both types of concrete masonry was relatively small, but again the masonry with thin layer joints showed the smallest creep. The creep factors were large compared with the other types of masonry. Obviously, the unit itself played an important role, making the effect of the joint type less apparent.

CONCLUSION

Shrinkage is mainly dependent on the type of unit. From the difference between the horizontal and vertical shrinkage, it must be concluded that joints play a role, but the type of joint or its thickness is not important. In the calcium silicate masonry even the ratio between joint thickness and unit height did not play a role. The calcium silicate unit itself dominated the shrinkage behaviour.
Creep of calcium silicate masonry mainly depends on the type of joint, and not on the ratio between joint thickness and unit height. Creep of clay brick masonry is also influenced strongly by the type of joint. The effect is smaller for the concrete brick masonry, due to the relative large influence on the creep of the concrete bricks themselves.

ACKNOWLEDGEMENTS

The research was financed by the Dutch masonry industries and the Dutch governement, via the Centre for Civil Engineering Research and Codes (CUR) as a part of the Dutch national masonry research program.

REFERENCES

Raijmakers, T.M.J., 1996; Research into shrinkage and creep behaviour of masonry, TUE report TUE/BKO/96.03, in Dutch

Van der Pluijm, R. A.J. Wubs, 1997, Time dependant deformation behaviour of masonry, TNO Building and Constructio report 96-CON-R0901-03, in Dutch

Schubert, P., 1994, Test Methods for the Determination of Creep and Shrinkage in Masonry, Proceedings of the 10th IBMaC, ed. Shrive and Huizer, Calgary, 1994, pp 777-786