THE INFLUENCE OF HARDENING CONDITIONS ON THE PROPERTIES OF CALCIUM SILICATE TL-MORTAR

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ABSTRACT

One aspect of our investigation into the spacing of movement joints in masonry walls involved the short and long term deformation of mortar embedded in masonry. In this research the influence of hardening conditions on the physical and mechanical properties of thin layer mortar for Calcium Silicate Elements were studied, with a focus on the shrinkage by hardening.

Mortar prisms made in steel moulds (according to European Standards) under seven different moisture conditions during hardening were compared to mortar prisms made in a mould made of Calcium Silicate bricks to evaluate the influence of water suction. During the test period the weight, deformation and strength of the specimens were determined. The results were also compared with similar tests on masonry mortar for clay bricks and thin layer mortar for clay bricks and concrete bricks.

In the experimental research a significant influence of the hardening conditions on the final material characteristics of the mortar was found. In some cases material properties were reduced by a factor 2. The values of the strength and strain of mortar hardened in steel moulds do not give correct results for calculating the spacing of movement joints in Calcium Silicate masonry.

KEYWORDS: mortar, hardening conditions, movement joints, crack control

INTRODUCTION

In the Netherlands, due to a lot of regulations [1], many movement joints are used in masonry walls (Figure 1). Architects, owners and contractors are less enthusiastic about these movement joints, because they seldom have a positive influence on the appearance, they are expensive, they have to be maintained and they have a negative influence on the structural coherence of the wall.

That is why, some years ago, at Eindhoven University of Technology, an investigation concerning façade engineering and the spacing of movement joints was started [2, 3]. The project aims at answering the question: "When, where and at what spacing should movement joints be used to prevent cracking, and when cracks occur, what crack width is acceptable?".

Figure 1: Movement joint in an office building

For the spacing of movement joints as well as for the crack width, design rules should be based on information about the detailing of the veneer walls (geometry, restrained deformation) and on the physical and mechanical characteristics of the masonry used (shrinkage, creep, relaxation, tensile strength).

One aspect to reach this goal was to get a better understanding of the influence of hardening conditions on the behaviour of masonry. This paper will describe some time-dependent parameters that influence the occurrence of cracks: shrinkage (hardening and drying) and thermal deformations for Calcium Silicate Thin Layer (TL) mortar. The experimental research in this project was started with experiments on mortar prisms hardened in steel moulds at different humidity conditions, followed by tests on mortar prisms hardened in Calcium Silicate brick moulds.

HARDENING CONDITIONS - PRISMS

This section presents a year's investigation into the material properties of Calcium Silicate TL-mortar (M12.5) at different humidity conditions. The mortar prisms (6 specimens per humidity condition), with a nominal size of 160 x 40 x 40 mm^3, were made in a steel mould [1] and stored on wooden strips (see Figure 2), similar to the investigations presented in papers [3], [4] and [5].

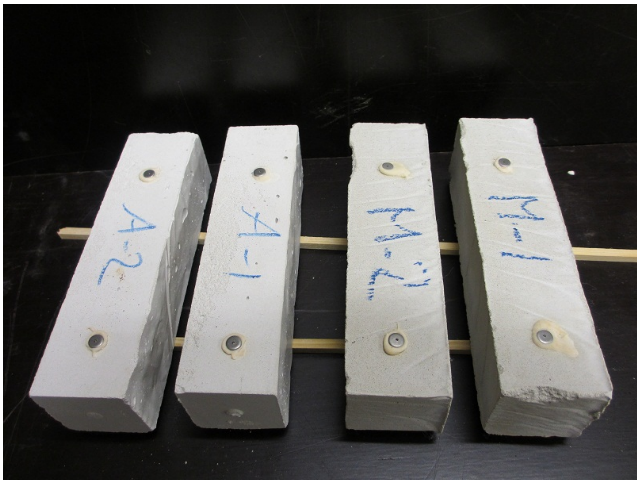

Figure 2: Calcium Silicate TL Mortar prisms

The mortar hardened at 20 °C under one of the following seven different relative hardening conditions, whereby the initial period of higher relative humidity varied: dry, 7 days humid, 90 days humid, humid, 7 days wet, 90 days wet, and wet (see Figure 3).

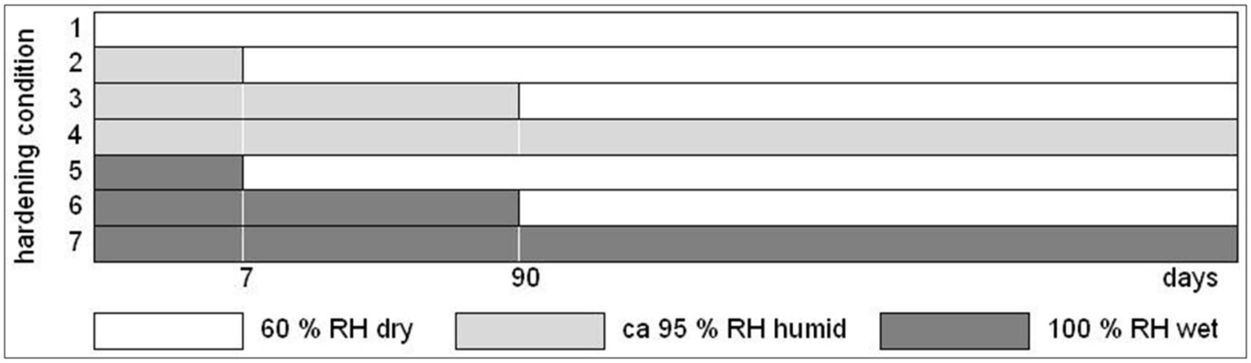

Figure 3: 7 Types of relative humidity conditions (all 20 °C)

All the mortar prisms were stored in a climate room (20 °C / 60 % RH), under the following conditions:
- Dry: on wooden strips (see Figure 2 and Figure 4 left);
- Humid: on wooden strips, in a plastic bag, with small container of water and damp cloth (90-95 % RH) (Figure 4 middle);
- Wet: submerged in a water container (100 % RH), on wooden strips (Figure 4 right).

Figure 4: Relative humidity conditions set up

HARDENING CONDITIONS - TEST RESULTS

During the test period the following measurements were carried out:
- The (change of) weight of the mortar prisms at specified times;
- The (change of) length or strain of the mortar prisms at specified times;
- The dimensions and the density, of the mortar prisms at 28, 205 and 319 days;
- The flexural strength of the mortar prisms at 28, 205 and 319 days;
- The compressive strength of the mortar prisms at 28, 205 and 319 days.

Figure 5 shows the average test results for the change of weight at specified times for the different relative humidity conditions (6 specimens per hardening condition).
Table 1 shows the total average change of weight (6 specimens per hardening condition) and the density in (1 specimen per hardening condition), at the end of the test period (319 days).

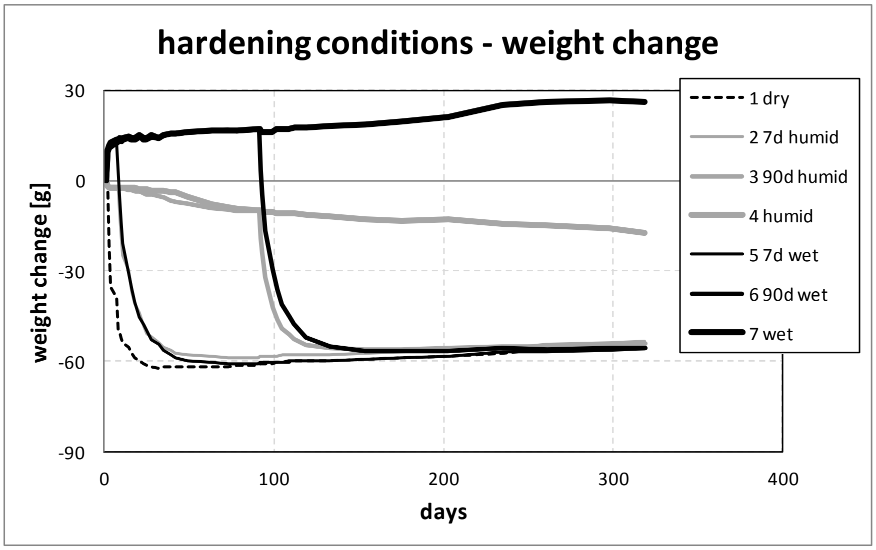

Figure 5: Results of the change of weight

Table 1: Density and total average change of weight at 319 days

Results / Hardening condition	Test Number	density	average change of weight	
		[kg/m^3]	[g]	[%]
		319d	319d	
dry	1	1485	-54	-12
7d humid	2	1500	-53	-11
90d humid	3	1515	-54	-12
humid*	4	1635	-17	-4
7d wet	5	1505	-56	-12
90d wet	6	1485	-56	-12
wet*	7	1760	+26	+6

* still humid /wet

It was found that the weight variation for the different humidity conditions gives the following picture (Figure 5 and Table 1):

- Wet specimens show a weight increase (no. 7, start no. 5 and 6).
- Humid specimens show a slight weight decrease (no. 4, start no. 2 and 3).
- Dry specimens show a large weight decrease (no. 1, end no. 2,3,5 and 6).
- When wet and humid specimens are placed in a dry environment, after 7 or 90 days (no. 2,3,5 and 6) they show a sharp weight decrease, to approximately the same decrease as the dry specimens.

Figure 6 shows the average test results for the change of length or strain at specified times for the different relative humidity conditions (6 specimens per hardening condition).

Table 2 shows the total average strain (6 specimens per hardening condition) at the end of the test period (319 days).

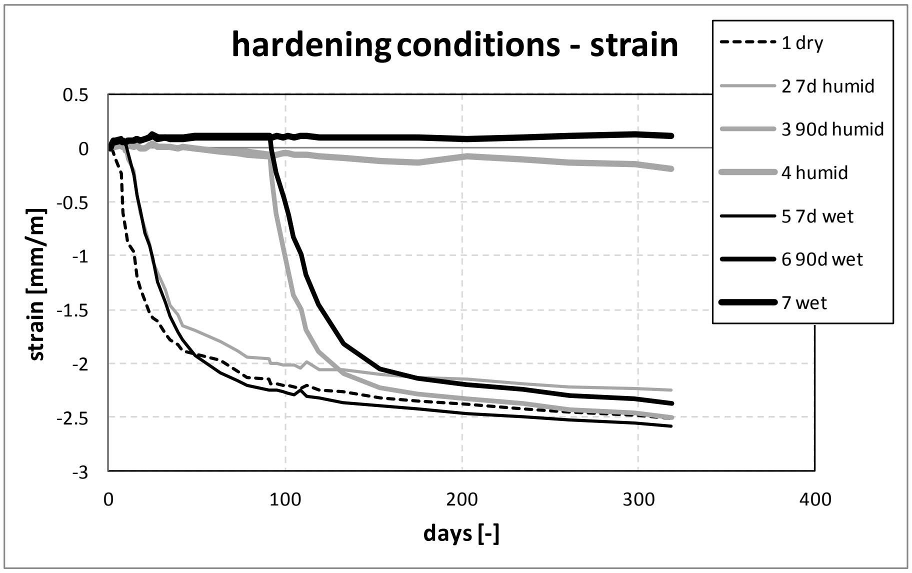

Figure 6: Results of the change of length or strain

Table 2: Total average strain at 319 days

Results / Hardening condition	Test Number	density	average strain
		[kg/m^3]	[mm/m]
		319d	319d
dry	1	1485	-2.5
7d humid	2	1500	-2.2
90d humid	3	1515	-2.5
humid*	4	1635	-0.2
7d wet	5	1505	-2.6
90d wet	6	1485	-2.4
wet*	7	1760	+0.1

* still humid /wet

It was found that the strain variation for the different humidity conditions gives the following picture (Figure 6 and Table 2):

- Wet specimens show a slight swelling (no. 7, start no. 5 and 6).
- Humid specimens show a slight shrinkage (no. 4, start no. 2 and 3).
- Dry specimens show a higher shrinkage (no. 1, end no. 2,3,5 and 6).
- When wet and humid specimens are placed in a dry environment, after 7 or 90 days (no. 2, 3, 5 and 6), they show a sharp length decrease, to approximately the same shrinkage as the dry specimens.

Table 3 and Figure 7 give the test results (1 specimen per hardening condition and date) for the density, flexural and compressive strength at 28, 205 and 319 days for the 7 different relative humidity conditions.

Table 3: Mechanical properties at 28, 205 and 319 days

Results / Hardening condition	Test Number	Density [kg/m^3]			Flexural strength [N/mm^2]			Compressive strength [N/mm^2]		
		28d	205d	319d	28d	205d	319d	28d	205d	319d
dry	1	1585	1615	1485	5.8	4.2	2.8	11.3	15.0	11.5
7d humid	2	1630	1625	1500	5.3	3.9	5.4	14.4	17.3	14.1
90d humid[#]	3	1810	1630	1515	3.7	5.2	4.4	10.5	21.8	15.5
humid[*]	4	1820	1815	1635	3.7	4.0	4.9	10.0	16.3	13.5
7d wet	5	1625	1625	1505	4.4	4.1	4.2	13.6	14.8	11.5
90d wet[#]	6	1845	1465	1485	3.4	3.8	4.1	8.8	11.1	12.4
wet[*]	7	1760	1755	1760	-	3.4	3.4	7.4	10.2	10.6

[#] still humid/wet at 28 days, [*] still humid /wet
- no measurement

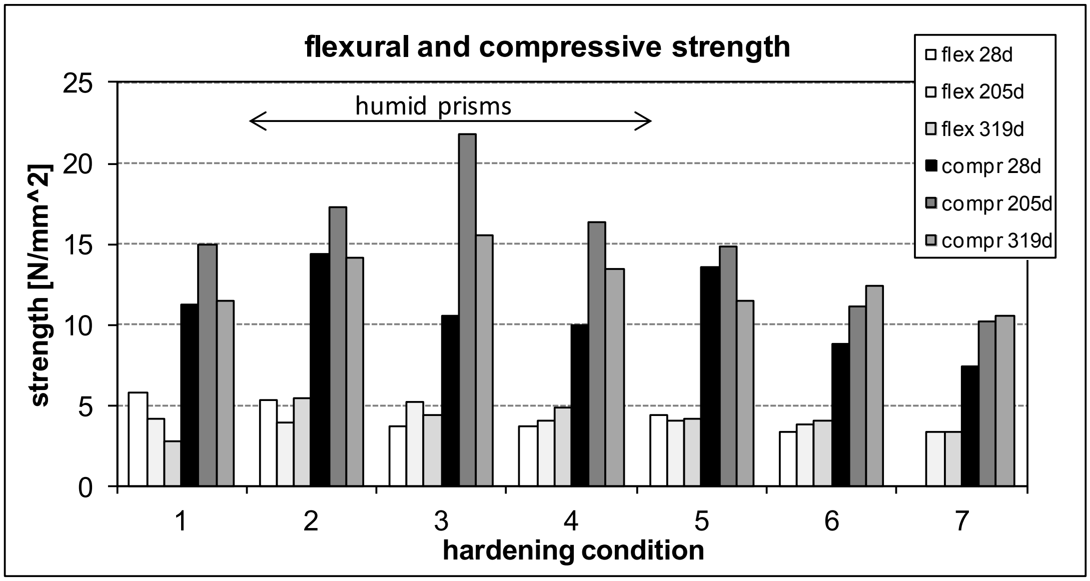

Figure 7: Flexural and compressive strength at 28, 205 and 319 days

As expected, the results indicate that the hardening conditions influence the final material properties of the mortar. When the prisms were stored in a humid environment, higher final density, compressive strength and flexural strength of the mortar were found (at 319 days, this is one batch of mortar). The difference in flexural strength between dry and humid specimens was up to a factor 1.9 (at 319 days) and in compressive strength up to a factor 1.5 (at 205 days). This calls for a right balance in curing masonry. Ideal curing conditions and curing time should optimize the strength and shrinkage of the mortar, leading to optimization of the spacing of movement joints. It is important to note that only one specimen was tested for each curing condition and date, and that mortar has a natural variability. But as shown in the next paragraph, these differences between curing conditions were found also in former investigations.

HARDENING CONDITIONS - DISCUSSION

In Table 4, 5 and 6 the total average weight change, strain and compressive strength are given for 5 different mortar types in 6 series from former investigations [3, 4 and 5].

Table 4: Total average change of weight for 5 types of mortar

Hardening condition	no	Weight change [g]					
		TL-mortar CaSi	TL-mortar Concrete [3]	TL-mortar Brick [3]	Masonry mortar 1a [4]	Masonry mortar 1b [3,4]	Masonry mortar 2 [5]
		319d	424d	423d	350d	360d	639d
dry	1	-54	-25	-44	-43	-50	-30
7d humid	2	-53	-32	-49	-38	-43	-34
90d humid	3	-54	-30	-47	-	-32	-32
humid*	4	-17	-3	**+9**	-15	-5	-4
7d wet	5	-56	-32	-53	-	-46	-36
90d wet	6	-56	-34	-51	-	-39	-38
wet*	7	+26	+32	+11	+25	+10	+28

* still humid /wet

Table 5: Total average strain for 5 types of mortar

Hardening condition	no	Strain [mm/m]					
		TL-mortar CaSi	TL-mortar Concrete [3]	TL-mortar Brick [3]	Masonry mortar 1a [4]	Masonry mortar 1b [3,4]	Masonry mortar 2 [5]
		319d	424d	423d	350d	360d	639d
dry	1	-2.5	-0.81	-1.44	-0.50	-0.50	-0.40
7d humid	2	-2.2	-0.91	-1.58	-0.70	-0.75	-0.62
90d humid	3	-2.5	-0.98	-1.49	-	-0.90	-0.71
humid*	4	-0.2	+0.03	**+0.32**	-0.15	**+0.05**	-0.11
7d wet	5	-2.6	-1.05	-1.75	-	-0.45	-0.69
90d wet	6	-2.4	-1.05	-1.32	-	-1.10	-0.86
wet*	7	+0.1	+0.07	+0.08	+0.05	+0.05	+0.07

* still humid /wet

Table 6: Total average compressive strength for 5 types of mortar

Hardening condition	no	Compressive strength [N/mm^2]					
		TL-mortar CaSi	TL-mortar Concrete [3]	TL-mortar Brick [3]	Masonry mortar 1a [4]	Masonry mortar 1b [3,4]	Masonry mortar 2 [5]
		319d	305d	305d	350d	360d	682d
dry	1	11.5	15.1	14.8	4.8	4.3	2.8
7d humid	2	14.1	18.5	14.0	10.9	10.3	5.1
90d humid	3	15.5	26.1	18.0	-	18.0	6.9
humid*	4	13.5	15.1	11.3	16.5	19.4	7.1
7d wet	5	11.5	17.2	11.4	-	7.8	4.4
90d wet	6	12.4	25.9	16.2	-	16.5	5.0
wet*	7	10.6	11.3	8.8	14.8	13.6	4.5

* still humid /wet

All measurements have 6 specimens per hardening condition, except Masonry Mortar 1b (3 specimens) and TL-mortar CaSi for compressive strength (2 specimens).

All the results show the same trends as seen in the previous investigations, but the amount of the total average weight decrease, shrinkage and compressive strength of the 5 different mortar types was not the same:

- Wet specimens show a slight weight increase and swelling;
- Humid specimens show a slight weight decrease and shrinkage;
- All the other specimens show a larger weight decrease and shrinkage;
- In all mortar types the highest compressive strength was found for 7 days and 90 days humid specimens.

Exceptions are indicated in bold: for humid brick TL-mortar and brick masonry mortar (series 1b), weight increase and swelling is seen.

The TL-mortars give a more extreme behaviour:

- The total weight decrease was smallest in masonry mortar and concrete TL-mortar;
- The total shrinkage was smallest in masonry mortar and highest in Calcium Silicate TL-mortar;
- The compressive strength was highest for concrete TL-mortar and smallest for masonry mortar no. 2.

INTERACTION WITH CALCIUM SLILICATE

Mortar hardened in steel moulds differs from mortar hardened between bricks [6, 7 and 8]. That is why the interaction between this TL- mortar and Calcium Silicate bricks (IRA = 10 g/dm^2/min) was investigated.

In this section an investigation into the influence of the type of mould, for the evaluation of the influence of water suction, on the material properties of the mortar prisms is presented. Two types of mortar prisms were made (4 specimens per type):

1. Mortar prisms, with a nominal size of 160 x 40 x 40 mm made in a steel mould (Figure 8 left).
2. Mortar prisms, with a size of approximately 160 x 40 x 40 mm made in a mould of Calcium Silicate bricks and filters (Figure 8 right).

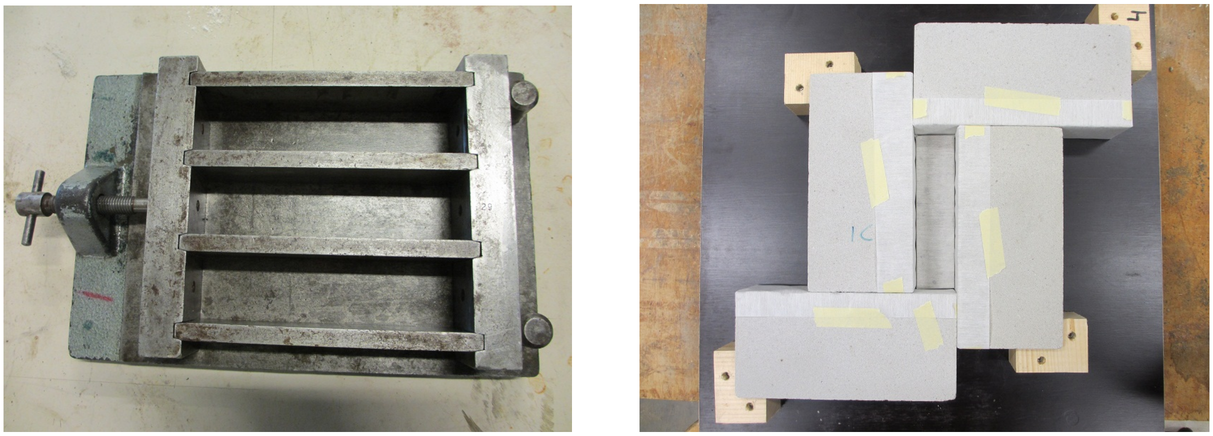

Figure 8: Steel mould and Calcium silicate mould

The prisms were stored in a climate room (20 ^{o}C / 60 % RH) on wooden strips (Figure 2). The time dependant properties of the prisms (weight and deformations) were monitored at specified times. The dimensions, density, flexural and compressive strength of the mortar prisms were measured at 28, 205 and 319 days;

Figure 9 shows the average test results for the change of weight (Figure 9 left) and the change of length or strain (Figure 9 right) at specified times for the different prism types. Table 7 gives the test results for the density, flexural and compressive strength at 28, 205 and 319 days for the different prism types (1 specimen per type and date).

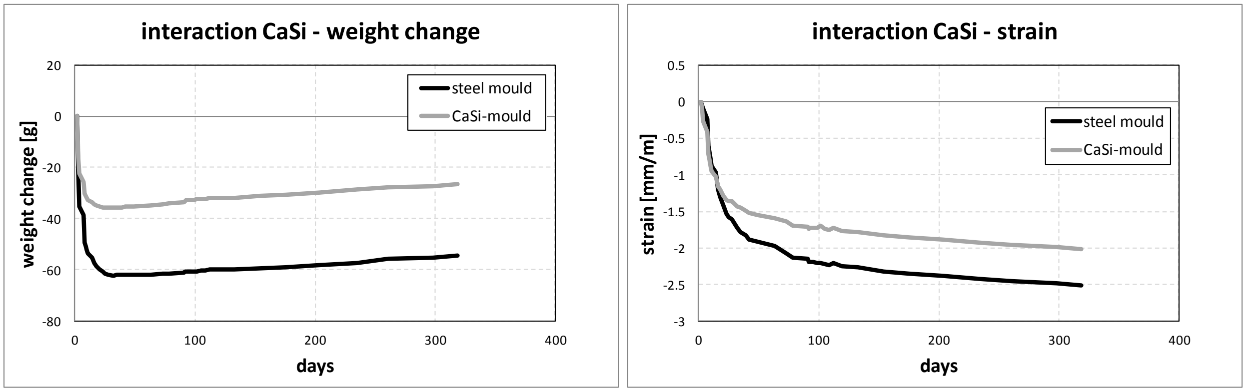

Figure 8: Results interaction (weight change and strain)

Table 7: Mechanical properties at 28, 205 and 319 days

Results Type mould	Density			Flexural strength			Compressive strength		
	[kg/m^3]			[N/mm^2]			[N/mm^2]		
	28d	205d	319d	28d	205d	319d	28d	205d	319d
dry steel mould	1585	1615	1485	5.8	4.2	2.8	11.3	15.0	11.5
dry CaSi-mould	1495	1540	1525	5.1	5.9	5.4	8.9	11.4	12.1

From the results it is concluded that:

- The weight loss after the first day was less for mortar prisms made in Calcium Silicate moulds (30 g at 319 days), than for mortar prisms made in steel moulds (55 g at 319 days) (factor 2). The CaSi-mould prisms already lost water to the Calcium Silicate bricks in the mould.
- The total shrinkage for CaSi-mould prisms was less (2.0 mm/m at 319 days) than for steel mould prisms (2.5 mm/m at 120 days).
- The initial flexural and compressive strength at 28 days was higher for steel mould prisms, but the end flexural and compressive strength at 319 days was higher for Calcium Silicate mould prisms. This means that for calculating spacing of movement joints in Calcium Silicate masonry, the values of the flexural strength of mortar hardened in steel moulds does not give correct results.

INTERACTION - DISCUSSION

The results for Calcium Silicate TL-mortar interaction with Calcium Silicate bricks show the same trends as seen in the previous investigations for masonry mortar and fired clay bricks

(Figure 9 and Table 8) [5]: Steel mould prisms show a higher weight decrease and shrinkage and a lower strength.

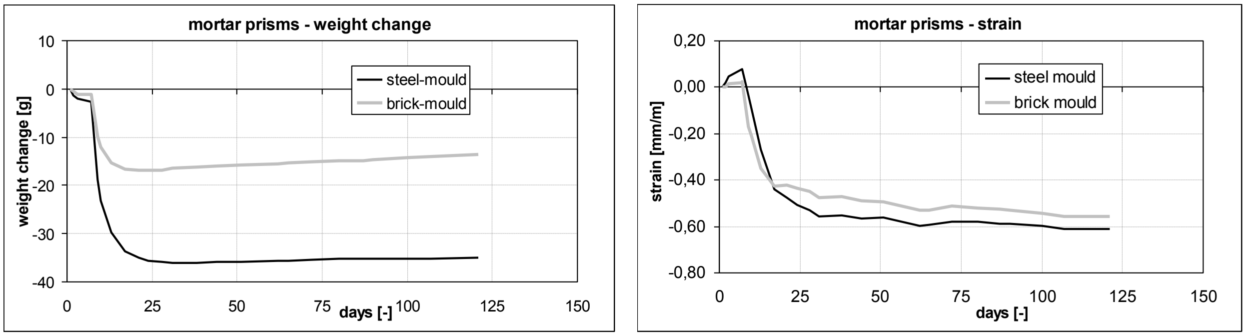

Figure 9: results brick masonry mortar interaction (weight change and strain)

Table 8: Mechanical properties brick masonry mortar interaction

Results	Flexural strength			Compressive strength		
	[N/mm^2]			[N/mm^2]		
Type mould	28d	90d	240d	28d	90d	240d
steel mould	2.5	2.3	2.3	6.1	5.6	5.6
brick-mould	3.7	4.1	5.1	4.2	5.7	7.4

CONCLUSIONS

The results showed that the hardening conditions influence the final material properties of the mortar.

Ideal curing conditions and curing time should optimize the strength and shrinkage of the mortar and leading to optimization of the spacing of movement joints.

The end strength is higher for Calcium Silicate TL-mortar hardened between Calcium Silicate bricks than for Calcium Silicate TL-mortar hardened in steel moulds. The values of the flexural strength of mortar hardened in steel moulds give incorrect results for calculating spacing of movement joints in Calcium Silicate masonry.

All the results show the same trends as seen in the previous investigations, but the amount of total average weight decrease, shrinkage and compressive strength of the 5 different mortar types is not. The TL-mortars give a more extreme behaviour.

Steel mould prisms show a higher weight decrease and shrinkage and a lower strength, than brick mould prisms.

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