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BOND STRENGTH IN CALCIUM SILICATE FACING BRICK MASONRY

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Abstract

Bond strength in calcium silicate facing brick masonry may be affected by mason workmanship. The long term performance of bond strength in calcium silicate brick masonry was monitored over a 2 years period. Two types of calcium silicate brick were used, and 3 types of mortar. Bond strength was determined using a bond wrench machine.
Experimental results prove that the bond strength in calcium silicate facing brick masonry may decrease over period of time. In the case considered, even masonry with initial bond strength of 0,2 N/mm2 showed after some time a complete loss of bond.
It is stressed that present results refer to the considered types of facing brick and mortar only. No conclusions about other combinations of brick and mortar can be drawn.

Key words

Bond strength, calcium silicate brick, facing brick masonry

1 Introduction

Practical evidence shows that calcium silicate facing brick masonry may show minor bond. Simple pushing or drilling sometimes leads to sliding of bricks which can be removed afterwards with clean laying surfaces. Figure1 illustrates this phenomenon.
A poor bond strength in calcium silicate brick masonry is mostly considered to be a result of wrong application.
The calcium silicate bricks may be used while being to dry, which influences the bond strength development in a negative way. This leads to a limited initial bond strength. In the late 90s, however, some documented observations in Dutch building practice were reported [Boom 1998], obviously indicating that bond strength in calcium silicate facing brick masonry might be a transient phenomenon. In all cases, bond strength was considered to be sufficient initially, but decreased to unacceptable low levels within a few years period. This obvious evidence initiated a screening study, focussing on real time monitoring of bond strength as a function of some material characteristics of calcium silicate brick and mortar. The present paper concisely describes the findings of this research, thereby addressing the key question of bond strength evolution in time.

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1a

1b – Clean calcium silicate facing brick

1c- Small crack between calcium silicate brick and pointing

1d- Clean calcium silicate brick after removing a few bricks and mortar like a slice

Figure 1 –Calcium silicate brick with minor bond strength

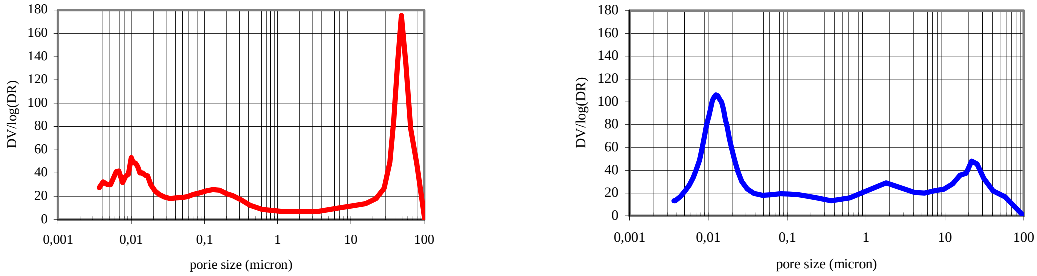
2 Material

A selection of mortars and bricks formed the starting point of the screening study.

2.1 Bricks

Two types of calcium silicate brick have been used (CSB 1 and CSB 2, common in The Netherlands) as well as a fired clay brick (FCB) for comparative purposes.

Density as well as porosity of silicate bricks are in the same range, being 1903 and 1932 kg/m^3 , and 28.2 and 27.1 % (vol by vol) for CSB1 and CSB 2, respectively. (Note: for the fired clay brick, values are 1876 kg/m^3 and 29 %). In both calcium silicate bricks, tobermorite is the binder. Differences occur both in the binder to sand ratio and grain characteristics. The binder to sand ratio is 1:6,6 and 1: 4,9, for CSB 1 and CSB 2, respectively; grains in CSB 1 are coarser than those in CSB 2. Both substantially influence the pore size distribution. According to mercury intrusion porosimetry, typical pore sizes of CSB 1 are in the range of 30-60μm, whereas CSB 2 shows a distinct pore size peak around 0,01μm (see Fig. 2b). This observation is in line with the fact that the water absorption rate of CSB 2 is smaller than that of CSB 1 or the fired clay brick (Table 1).



2a: Calcium silicate brick 1 (CSB 1)   *2b: Calcium silicate brick 2 (CSB 2)*

Figure 2 – Pore size distribution according to mercury intrusion porosimetry

Table 1 – Water uptake characteristics of the considered bricks.

Water uptake characteristic	CSB 1	CSB 2	FCB
Water absorption coefficient (kg/m^{2}s$^{1/2}$)	0,18	0,09	0,44
Initial rate of absorption (kg/m^2/min)	2,5	1,1	3,7

Water absorption is determined according to Dutch standard NEN 2871[5]. CBS = calcium silicate brick; FCB = fired clay brick.

Brick and mortar may be subjected to dimensional changes. Such transient behaviour can be expressed in response characteristics of the material. Swelling and shrinkage occur as a result of temperature and moisture content fluctuations, but apart from that, calcium silicate brick shows a typical structural change as a consequence of carbonation. Carbonation leads to shrinkage, which may be explained by reorientation, reshaping and repackaging of the material solid matrix [Mörtel 1998].
Differences are explicit. First of all, thermal and hygric responses are reversible, whereas carbonation leads to irreversible changes. Secondly, time scales highly differ: thermal and hygric shrinkage is a matter of days or weeks, determined by daily and seasonal fluctuations, whereas carbonation will usually take a few years.
Comparing both calcium silicate bricks shows that thermal and hygric characteristics are more or less the same, whereas the carbonation shrinkage is highly deviant.

Table 2 – Dimensional changes of the considered calcium silicate bricks

	CSB 1	CSB 2
Hygric shrinkage (10^{-3} m/m)	0,40	0,42
Thermal shrinkage (10^{-3} m/m)	0,55	0,55
Carbonation shrinkage (10^{-3} m/m)	0,51	0,75

A maximum change in temperature of 50^{o}C was used to calculate the maximum thermal shrinkage. Determined according to Dutch standard NEN 2871 [5]

2.2 Mortars

Three mortars have been used, primarily differing in types of binder (see Table 3). Two mortar types have been prepared according to defined mixtures. Mortar 1 consists of masonry cement and sand, whereas in mortar 2 ordinary Portland Cement (OPC) and

air lime is used, including an air entraining agent (AEA). Masonry cement is a combination of OPC and ground limestone (55% and 45% by mass, respectively) with air entraining agent (AEA). The third mortar is a common prefabricated mortar of which detailed information about composition is lacking. This manufactured mortar includes OPC, air entraining agents and some adhesion additives, and is specifically recommended for calcium silicate brickwork.

Table 3 – Mortar composition

Mortar type	Binder	Mixture ratio (v/v)	Additives
1	Masonry cement	1:3	AEA
2	OPC + Lime	C:L:S =1:1:6	AEA
3	OPC	Unknown	AEA + adhesion additives

AEA = air entraining agent; L = lime; OPC = ordinary Portland Cement

3 Methods

3.1 Specimen preparation

Column-like masonry specimens were composed of 6 bricks, without pointing. At lateral sides, including top and bottom, columns were covered with a polystyrene insulation foam. After an initial period of 7 days these specimens were placed outdoors, with the front side facing the West. Consequently, exposure to the outdoor climate should take place through one side only.
Figure 3 gives an impression of the specimens during exposure.

Figure 3 – Specimens during exposure

As was mentioned in the introduction, pre-wetting is usually considered to be a crucial factor to bonding. Consequently, the study included a variety of samples covering the issue of pre-wetting in relation to brick and mortar type combination. Pre-wetting was performed by submersion.
Table 4 gives an overview of the brick-mortar combinations considered.

Table 4 – Brick-mortar combinations

Nr	Type	Moisture content In brick	Mortar type
1	CSB 1	Pre-wetted 8%	1
2	CSB 2	Pre-wetted 8%	1
3	FCB	1%	1
4	CSB 1	3%*	1
5	CSB 2	4%*	1
6	CSB 1	Pre-wetted 8%	2
7	CSB 2	Pre-wetted 8%	2
8	CSB 1	Pre-wetted 8%	3
9	CSB 2	Pre-wetted 8%	3

* these brick were conditioned for three weeks at 20^0C/65%

3.2 Bond strength determination

Bond strength was determined according to the bond wrench test, prEN 1052-5 “Methods of test for masonry, Determination of bond strength by the Bond Wrench method” [prEN 2002]. This test was automated and performed using a home built bond wrench machine (Figure 4).

Figure 4 – Bond wrench machine

For each measurement two replicate specimens have been used in order to determine the bond strength in 10 joints, leading to a total of 110 specimens. Table 7 summarizes the test program, showing the intervals of assessment, covering a time period of 720 days. Only the calcium silicate brick and 1:3 masonry cement mortar combination completed the entire programme for both types of brick. All other combinations were assessed less frequently, i.e. 5 times only.

Table 5 – Test programme overview

Nr	Determination of bond strength (days)								
	5	7	14	28	56	90	180	365	720
1	x	x	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x	x	x
3		x		x		x		x	x
4		x		x		x		x	x
5		x		x		x		x	x
6		x		x		x		x	x
7		x		x		x		x	x
8		x		x		x		x	x
9		x		x		x		x	x

4 Results

The results are presented graphically in Figs 5-13 for each of the brick-mortar combination described in Table 6. Each graph includes all bond wrench data, i.e. 10 results at each distinct moment in time. The line in each graph is meant as a guide to the eye, showing the course of the arithmetic average value of bond strength.

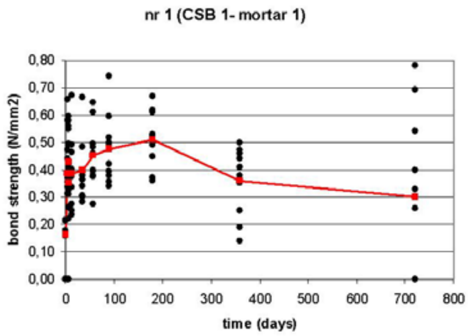


Figure 5 – CSB 1 with mortar 1

Within the first week period, a bond strength of ca. 0,4 N/mm^2 has developed. Between 180 and 720 days the average bond strength obviously decreases from 0,50 N/mm^2 to 0,30 N/mm^2.

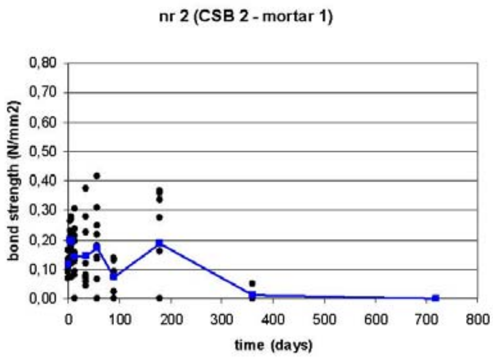


Figure 6 – CSB 2 with mortar 1

The average bond strength never exceeds 0,2 N/mm^2. At 180 days, the bond strength decreases substantially; at 365 days 8 out of 10 and after 720 all joints are broken.
Note: data at 90 days appear to deviate essentially. Scattering of data is remarkably small because climatic conditions during test differed essentially and were not fully representative compared to other replicate samples.

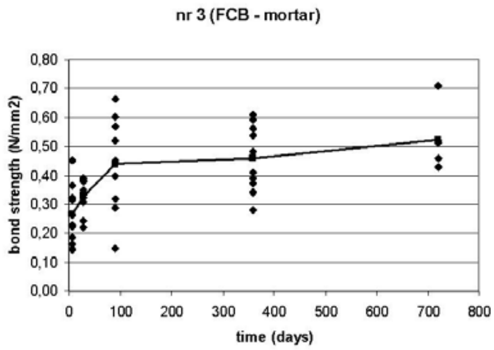


Figure 7- Fired clay brick with mortar 1

The fired clay brick showes a fast increase in bond strength up to 90 days. Hereafter, average bond strength increases slowly to 0,52 N/mm^2.

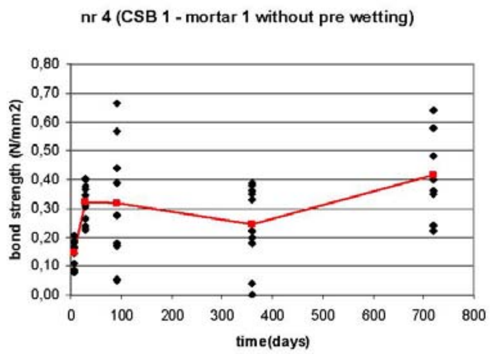


Figure 8 – CSB 1 with mortar 1, without pre wetting

The non-wetted CSB 1 with mortar 1 develops a bond strength of 0,33 N/mm^2 within a 28 days period. Thereafter, the average bond strength fluctuates slightly between 0,25 N/mm^2 at 365 days and 0,41 at 720 days.

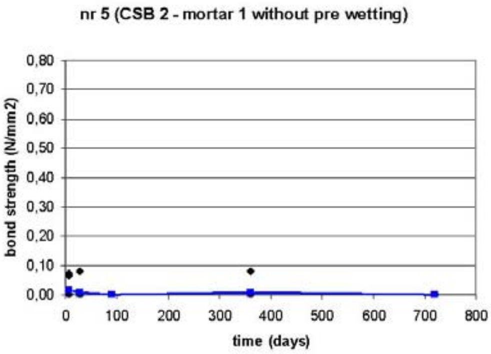


Figure 9 – CSB 2 with mortar 1 without pre wetting

The non-wetted CSB 2 develops hardly any bond strength with mortar 1. Only a few joints of every specimen column are not broken. The average bond strength never exceeds 0,01 N/mm^2.

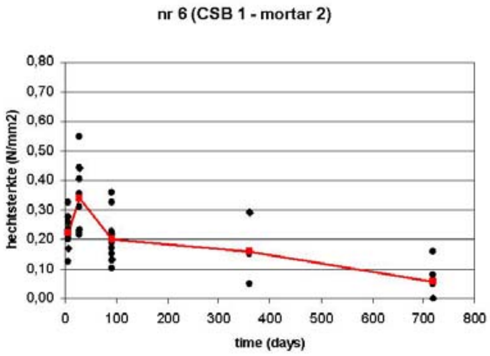


Figure 10 – CSB 1 with mortar 2

In combination with mortar 2, CSB 1 shows a maximum bond strength of 0,35 N/mm^2. A distinct decrease occurs thereafter. At 365 days the average bond strength is 0,18 N/mm^2 and 0,07 N/mm^2 at 720 days.

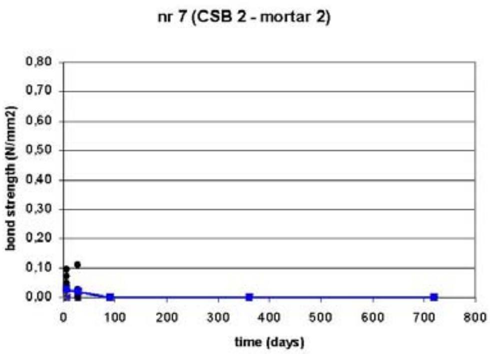


Figure 11 – CSB 2 with mortar 2

CSB 2 develops hardly any bond strength with mortar 2. Only a few joints of every specimen column are not broken. The average bond strength never exceeds 0,03 N/mm^2.

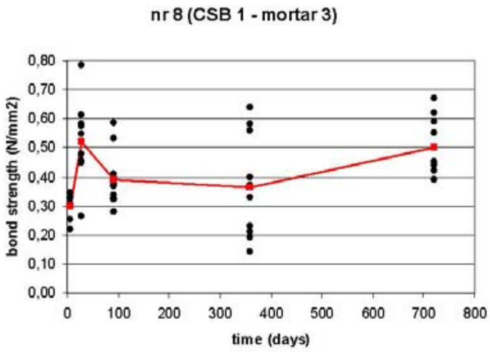


Figure 12 – CBS 1 with mortar 3

This combination develops an average an more or less stable bond strength of 0,52 N/mm^2.

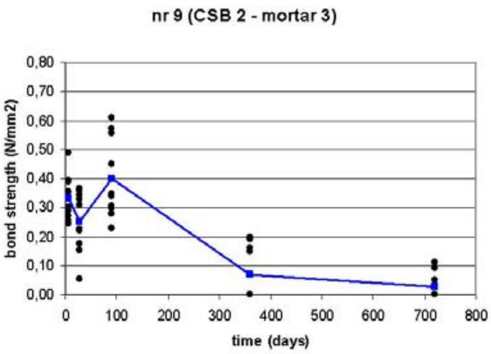


Figure 13 – CSB 2 with mortar 3

Until 90 days this combination shows a bond strength of about 0,40 N/mm^2. Hereafter, the average bond strength decreases to 0,07 N/mm^2 at 365 days and 0,03 at 720 days. At that time most of the joints are broken.

5 Discussion

5.1 Bond strength evolution

An explicit decrease of bond strength occurs for calcium silicate facing brick type 2 with all mortars considered. In all cases involved, no appreciable bond strength remains after a 2 years period, even though initial average values in the range of 0,2 to 0,4 N/mm^2 are observed This pronounced transient behaviour is not demonstrated in the calcium silicate brick type 1 and mortar combinations considered. Although in average terms, all CSB 1 cases apparently indicate some decrease in bond strength between 180 and 365 days, the remaining value at 2 years mostly is around the initial setting. The CSB 1 and mortar 2 combination clearly deviates and shows a distinct decrease comparable to that of the CSB 2 combinations.

The scattering of data is large, which is in line with the usual results of this type of experiment. Such scattering, however, may obscure profound interpretation of data, particularly if averaging is used only. Another presentation of the same data may give perspective to understanding of underlying processes. As an example, Figure 12

shows the data of Figure 4 in a more dimensional way. In Figure 4, apparently the average bond strength remains at a more or less steady-state level between 0,15 and 0,19 N/mm^2 in the period of 14 to 180 days. The detailed analysis of the scattered data in Figure 12 gives another picture of bond strength evolution . Classifying bond strength into 4 specific ranges (0-0,1; 0,1-0,2; 0,2-0,3 and 0,3-0,4 N/mm^2, respectively) shows an obvious 2-phase process. In phase 1, the number of moderate bond strength decreases in favour of the number of data with low or high bond strength. In other words: an increase in both weak and strong bonding. On the basis of averaging, however, no changes appear to be present. Phase 2 shows a major shift towards low values and finally after 720 days no bond strength is left.

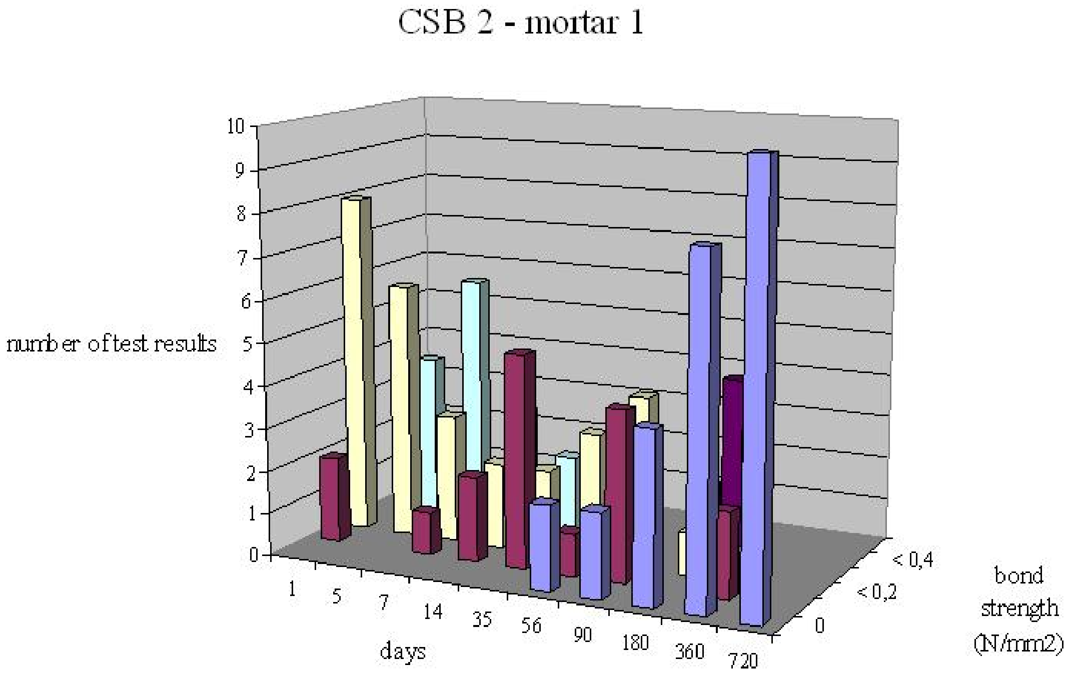


Figure 14: Number of test results in a specific range of bond strength as a function of time. Figure 14 gives another presentation of Figure 6 data.

Obviously, the present data indicate that calcium silicate brick characteristics affect bond strength evolution. As mentioned in the introduction, porosity and pore size distribution are generally accepted as a crucial factor in bond formation. CSB 2 is finer porous than CSB 1 (fig. 2), causing a higher suction of water from mortar, and shows a pronounced time dependent bond strength. According to Groot [Groot 1993], such transfer effects hamper *initial* bond strength formation between brick and mortar. Time dependency, however, has not been proven in relation to that yet.

A more obvious factor linked to bond strength evolution may be found in dimensional changes due to carbonation, considering the time scale of the observed phenomenon. Shrinkage of the calcium silicate brick may introduce a mechanical load on the brick mortar interface. CSB 2 shows a more pronounced shrinkage due to carbonation than CSB 1 (0,75 and 0,51 mm/m, respectively).

Elaborated work is needed to evaluate this hypothesis.

The fired clay brick-mortar combination exhibits bond strength evolution too, however, differing clearly from both calcium silicate bricks. In this case, bond strength shows a steady increase during the entire period of test, with a steep increase during an initial 90 days period, followed by a period of steady and slight growth.

5.2 Initial bond strength

Comparing the respective calcium silicate brick types shows a marked difference in initial bond strength. For all considered mortar combinations, the averaged initial value of CSB 2 is smaller than that of CSB 1. Type 2 even demonstrates 2 cases of negligible initial bond strength: the type 2 - mortar 2 combination, as well as the type 2-mortar 1 combination without pre-wetting.
The influence of pre-wetting appears to be considerable for both calcium silicate brick types, with the effect being most pronounced for CSB 2. Although pre-wetting has been determined for mortar 1 only, it clearly indicates a rise of the initial bond strength value. Taking the 28 days level as the initial value, pre-wetting led to an increases from 0,01 to 0,20 N/mm^2 for CSB 2, whereas CSB 1 showed a much smaller increase in the order of 0,07 N/mm^2

6 Conclusions

The present study delivers experimental evidence that bond strength in calcium silicate facing brick masonry may show transient behavior under normal West European outdoor conditions. According to the bond wrench test, prEN 1052-5, it has been demonstrated that bond strength in calcium silicate facing brick masonry may decrease substantially in time, depending on calcium silicate brick and mortar type combinations. In a two years period, even complete loss of bond strength may occur, which obviously is in line with previous documented observations in building practice [Boom 1998]. Consequently, it is suggested that the criterion of initial bond strength –i.e. 28 days values- might be reconsidered as performance criterion for calcium silicate brick masonry. No understanding of underlying processes is available yet.

Apart from that, it has been shown that pre-wetting of calcium silicate bricks plays a crucial role in initial bond strength formation for the material combinations concerned. Under the conditions in the present experimental work, pre-wetting led to a rise in initial bond strength compared to non-wetting.

The underlying mechanisms that cause the phenomena of transient bond strength in calcium silicate facing brick masonry are still not known. This means that time dependent behaviour of any other combination of calcium silicate brick and mortar can not be predicted and that the results of this research can not be generalised. Besides, it can not be answer yet how to tackle the problem of decreasing bond strength.
TNO Building and Construction Research will, in cooperation with the calicium silicate brick industry, give follow-up to the present findings and start to investigate the mechanism behind the described phenomena.

Acknowledgements

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