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TESTS ON GLUED MASONRY FOR VENEER WALLS MORTAR-BRICK BOND STRENGTH

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Abstract

BBRI is performing a research program in order to evaluate the technique of the 'gluing' of units for veneer walls. Final aims are to provide a full range of necessary and accurate information to the sector via a Technical Report and to give a basis for a suitable guideline for certification. This two-parts paper presents only the results in relation with the bond strength.
After having discussed the available test methods characterizing the bond strength in the first part of the paper (1/2), part (2/2) presents the results of mechanical tests on clay units/adhesive mortars combinations performed on a wide range of material properties. Moreover, microscopic analyses were performed. The evaluation of the durability was done by means of frost resistance tests. The influences of the material properties are discussed. In general, we can conclude that on all the tested combinations, no important problem related to performance has been detected (initial bond strength, frost resistance).

Key Words

Glued masonry, bond strength, durability.

1 Scope of the second part

The determined individual material properties of the studied range of samples is given in part (1/2) in which the mechanical test methods to characterize the bond strength were also discussed. In the second part, we focused more precisely on the 'adhesion aspects' in function of the material properties and in function of the aging (durability). Mechanical test-results on assemblages (in a wide range of material properties) before and after freeze/thaw cycli are given and discussed. Microscopic analyses also attribute to the discussion.

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2 Characteristics of the assembled specimen

After a description of the different preparations of the samples, of the tested combinations and of the realised tests, results are presented and discussed.

2.0 Samples preparation – series

A first preparation of samples with pump and pistol was realised in may 2002 by a building company proposed by the Belgian mortar manufacturers federation (FeMO). It concerns Series 1 and 2. Because of the high external temperatures of that month, some mortar particles blocked the pump quite often during the confection of the specimens. Moreover, we were unable to set up adhesive mortars LM6 and LM7 with the pistol; nor the performed granulometry analyses, nor the information concerning the open time of these mortars helped to explain the phenomenon. Later bond strength problems occurred also with LM4 while testing series 1 (see 2.2.1). That is the reason why a second preparation was realised later and series 3 was scheduled.

Figure 1 Preparation of specimens

This second preparation of samples with pump and pistol was realised in December 2002 by manufacturer demonstrators. It concerns Series 3. Only the adhesive mortar 'LM4' was set up with the pistol and with a prescribed joint thickness of 4 mm on 8 types of bricks characterised by a different IRA. All the bricks were dried at 105°C and brushed to remove particles before setting up.

For several intrinsic characterizations, samples were prepared with the trowel by the BBRI staff. It concerns Series T, H and X. The mixing is realised by a lab-mixer. All the bricks were dried and brushed before the setting up. In all the cases, the fresh specimen wasn't loaded (like in practice).

2.1 Test methods

2.1.1 Frost resistance tests

The retained test method is adapted from the Belgian test method for clay bricks (NBN B 27-009 (1983) + add. 2 (1995)). It consists in a preliminary immersion of the sample in water during 6 days before the submission to 20 cycli to – 15°C. Thaw occurs by introduction of water in the freezing chamber. Samples are set horizontally in a tank with sand ; the visible face is upward and is the only one without sand contact (see figure 2). Already present degradation are marked before water impregnation. After the cycli, eventual new degradations are noted and then, mechanical tests are performed in order to evaluate eventual loss of strength.

Figure 2 Freeze/thaw test arrangement

2.1.2 Mechanical tests

For the investigation on the influence of the material properties, the bond wrench test and the adhesion test were principally performed. However, some 4-point bending tests

were also performed for comparison purpose. The methodology of these test-methods is explained in first part (1/2).

2.1.3 Microscopic analyses

The technique of the thin sections was used to investigate the quality of the bond and the mortar characteristics. After preparation of the sample (resin impregnation, cutting) the thickness of the section is reduced to 30 µm. Without any reference concerning this type of mortar, the reference thin sections used to determine the observed water to cement ratio (W/C_{obs}) are thin sections coming from concrete references. The analyses were directed to several criterions : cement hydration, W/C_{obs}, capillary porosity, macropores, cracks along the interface brick/mortar and in the mortar (shrinkage). W/C_{obs} is given by the fluorescence ; the higher is W/C_{obs}, the more important is the capillary porosity, more fluorescent is the image given by the microscope (in cementpasta zone). Hydration of the cement is evaluated observing the presence of klinker or not hydrated cement particles.

2.2 Results

2.2.1 Series 1 : no test results

We are giving this explanation to be rigorous. When we were beginning the mechanical tests for this series (about one month after preparation of the prisms), we noticed that a great number of prims from this series showed no adhesion. We assume that this was for the following reason. These assemblages were the very first that were build therefore, there was a waiting time between the laying of the mortar and the pressing of the brick. This time was too long due to the combination of a) the difficulty to prepare small samples by people not familiar with that kind of work and b) the warm weather, accelerating the dessication and the hardening of the mortar (see also the results of the microscopic analyses). No test results from this series were thus retained. Very important to say is that series 3 concerns the same combinations and the test results were high without this kind of loss of adhesion.

2.2.2 BWT on series 2 – figure 3

This series concerns the combinations of 3 types of bricks with different IRA - S1 (4 g/dm².min), S4 (28 g/dm².min) and H3 (50 g/dm².min) - with 6 different adhesive mortars, thus 18 combinations with 8 replica by combinations. This series shows loss of adhesion for only one combination corresponding to a combination that is not prescribed by the manufacturer: brick H3 (50 g/dm².min) set up with adhesive mortar LM7 (for brick with IRA < 15 g/dm².min) set up with the trowel. The results of this series were thus retained.

F4P was performed on the combinations with brick H3 with all the mortars ; because the results are quantitatively (F4P = 1,1 x BWT with R^2 = 0,8557) and qualitatively (break surface) of the same order than those obtained with the bond wrench test, we spoke here only in term of this last. The shown results concern the constructive strength. The intrinsic strength is from 0 to +/-30% higher.

The dispersion of the individual test results was important ; the coefficient of variation is comprised between +/- 10 and 60 %. Figure 1 shows the mean values of all these tests results. In order to clarify the explanations, mean results are first discussed brick by brick and then mortar by mortar with regard to the result value but also the break surface. Remind that LM6 and LM7 were set up with the trowel and the other ones with the pistol.

With the most resistant brick (S1 with also the lower IRA), the lower obtained results concern the adhesive mortar LM6 (0.8 N/mm² - not-prescribed by the manufacturer combination). The others results reach higher mean values up to 1.6 N/mm² also for 2 not-prescribed combinations. Plane of fracture occurs at the brick/mortar interface (with mortar tracks on the brick for LM6 and LM7).

Both prescribed combinations with S4 (IRA = 28 g/dm².min) - S4-LM2 and S4-LM6 – show different results as well with regard to the values (respectively 1.7 and 0.8 N/mm²) as the plane of fracture (in the mortar, at the interface with mortar tracks on the brick and brick tracks on the mortar). For the not-prescribed combinations, results vary from 0.4 N/mm² for S4-LM7 to 1.9 N/mm² for S4-LM1. Break occurs either at the interface or under a thin brick layer. For the other adhesive mortars, the plane of fracture are partly situated at the interface and under a bricklayer (tracks on the mortar).
Prescribed combinations H3-LM6 shows very low results (0.2 N/mm²) in comparison with the prescribed combination H3-LM1 (0.8 N/mm²).
LM1 – prescribed for bricks with a high IRA (> 30 g/dm².min) and LM2 - prescribed for bricks with a mid IRA (5 < IRA < 40 g/dm².min) – show good results for the 3 different considered IRAs. LM3 and LM5 prescribed for bricks with a low IRA (< 15 g/dm².min) give a mean value lower than for LM1 and LM2 in the case of this type of bricks. However results are satisfactory. LM6 – prescribed for bricks with mid to high IRA (> 5 g/dm².min) – gives low results for the brick with a high IRA and lower than the other prescribed combinations for the brick with a mid IRA. LM7 – prescribed for brick with a low IRA (< 15 g/dm².min) shows good results only for this combination.

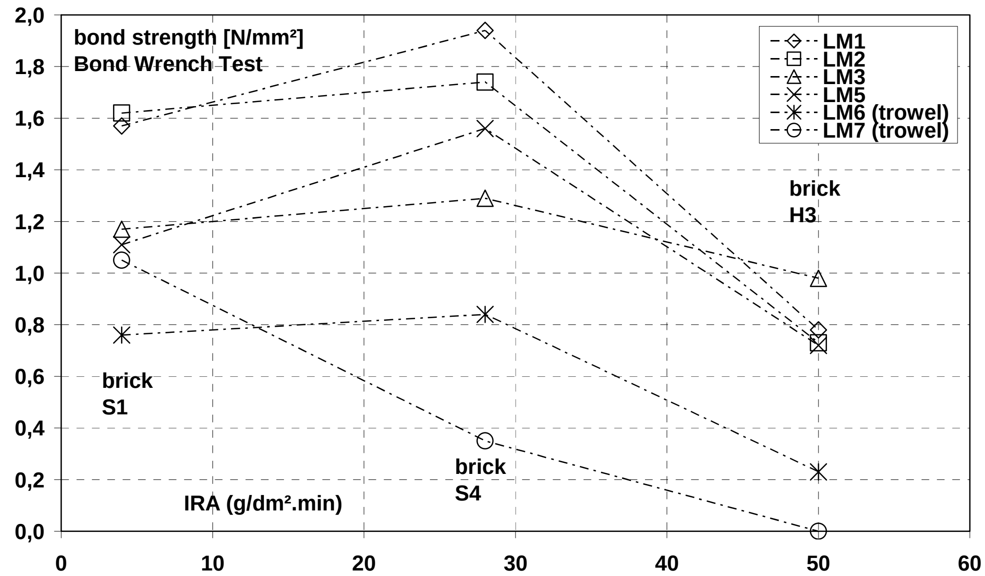

Figure 3 Constructive bending strength according to the bond wrench test – series 2

2.2.3 Adhesion test on series H - figure 4

12 different IRAs were tested covering the full range ; tested surfaces comprise the bed surfaces of 10 different types of bricks and the lateral surfaces of 2 types of extruded bricks (showing a different IRA in this direction 'IRA ⊥') combined to 3 adhesive mortars, thus 30 combinations with 3 replica. 3 individual tests are realised at 2 mortar ages : 7 and > 28 days. As well the values as the plane of fracture are taken into account. For the perforated bricks (S1 and S3), it's interesting to remark that the results on the perforated surfaces are higher than on the lateral surfaces ; firstly because the cohesion of the brick perpendicularly to the direction of the extrusion (the case for S3) is lower, secondly because the penetration of the mortar inside the perforations gives a supplementary strength due to the adhesion on the surfaces of the perforation (the case for S1). This last phenomenon is not to be generalized because it depends on the quantity of set up mortar.

With LM2, break occurs for 7 of the 10 types of bricks (S3, H1, H2, H5, H4, H3, 527-6 – strength lower) entirely in the brick and that also for not-prescribed by the manufacturer combinations with values from 0.7 to 1.7 N/mm². With 2 stronger bricks (S2, S4), we observed mixed plane of fracture (superficially in the brick and at the brick/mortar interfaces) with high values (3.0 to 4.6 N/mm²). The combination with the strongest brick (S1 – not-prescribed with this mortar because of a very low IRA) show intermediate results (1.9 to 2.9 N/mm²) with mixed break (superficially in the brick or in the mortar very close to the interface). The mortar age when tested show an influence only for these last 3 bricks for which at 7 days, the results are a little lower than at > 28 days and the plane of fracture situated mainly in the mortar (close to the interface) for S2 and S4.
With LM4, the same observations appear with the strongest bricks (S1, S2, S4). For the other bricks, more mixed breaks were observed accompanying lightly but systematically lower values than with LM2. Some lower values at > 28 days than at 7 days occurred but are due more to a heterogeneity in the results than to a trend. The following prescribed combinations have shown low mean values at > 28 days because of some very low individual test results : H1-LM4 (0.4 N/mm²) and H3-LM4 (0.5 N/mm²). Moreover we observed that for S4 and H2 with a IRA very close to the brick H1's one, the results are satisfactory.
With LM6, the strongest bricks show a different behaviour than with LM2 and LM4 ; as well for the not-prescribed combination S1-LM6 as for the prescribed combinations S2-LM6 and S4-LM6, plane of fracture occurred mainly in the mortar very close to the interface (mortar pellicle on the brick) with values significantly lower. With the other bricks, the same kind of plane of fracture appeared with mean values from 0.1 to 0.9 N/mm². The prescribed combinations H1-LM6 (0.1 N/mm²) and 527-6-LM6 (0.6 N/mm²) have shown low mean values at > 28 days. Moreover, we observed that with S4 and H2 with a IRA very close to the brick H1's one, the results are higher.

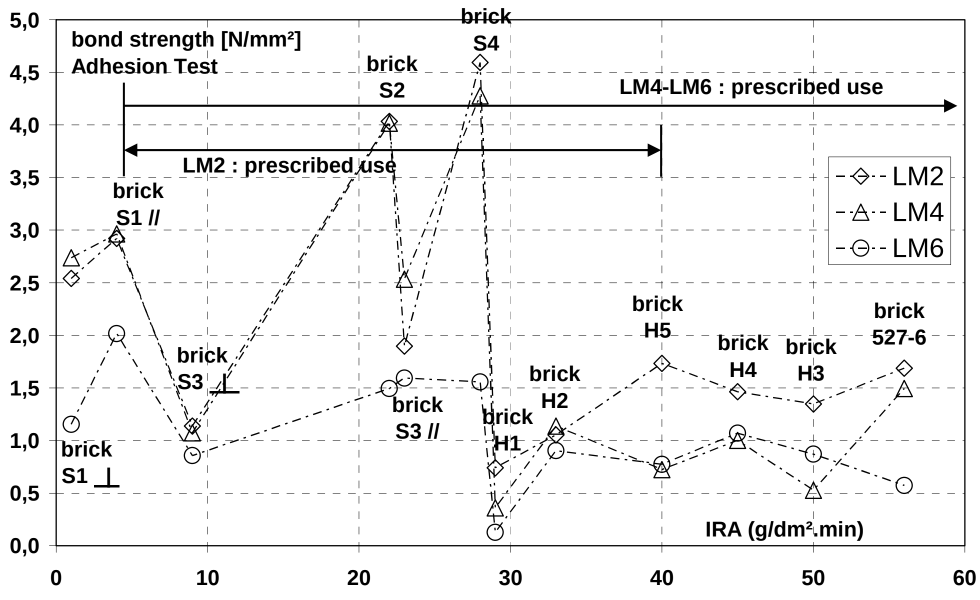

Figure 4 Series H: Intrinsic bond strength according to the adhesion test (at > 28 days)

2.2.4 Mechanical tests before and after freeze/thaw cycli – figures 5, 6, 7 and 8

As shown in the mentioned figures, we haven't observed degradation or adhesion perturbation due to the freeze/thaw cycli for the tested combinations ; the observed variations during the mechanical tests are mainly due to the dispersion of the results.

The conclusions are the same for the combinations tested after and before the freeze/thaw cycli according to the Bond wrench test and to the adhesion test.
According to the adhesion test (see figure 8), the mode of failure (in the brick) is the same before and after freeze/thaw cycli for combination H2-LM4. For combinations H1 and H5 – LM4, the dispersed modes of failure (mortar tracks at the interface and in the brick) is present before and after the cycli and have generated for example this apparent strength increase for combination H5-LM4.

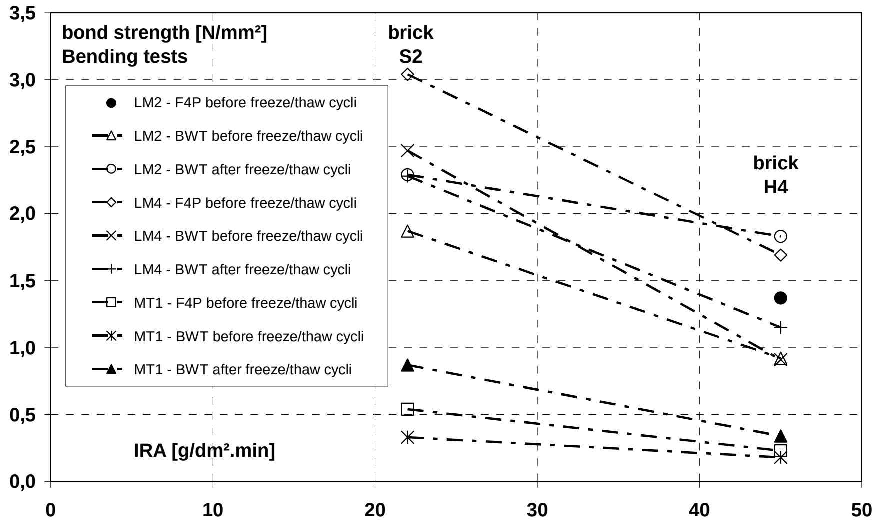

Figure 5 Series T : Intrinsic bond strength according to the bending tests (4point bending test –F4P and bond wrench test – BWT) before and after freeze/thaw cycli

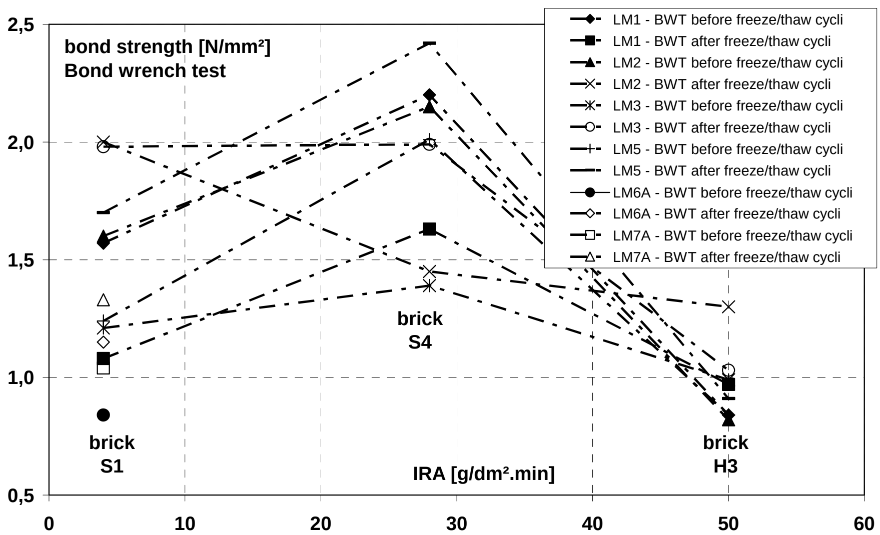

Figure 6 Series 2 : Intrinsic bond strength according to the bond wrench test (BWT) (intrinsic value deducted from the constructive values) before and after freeze/thaw cycli

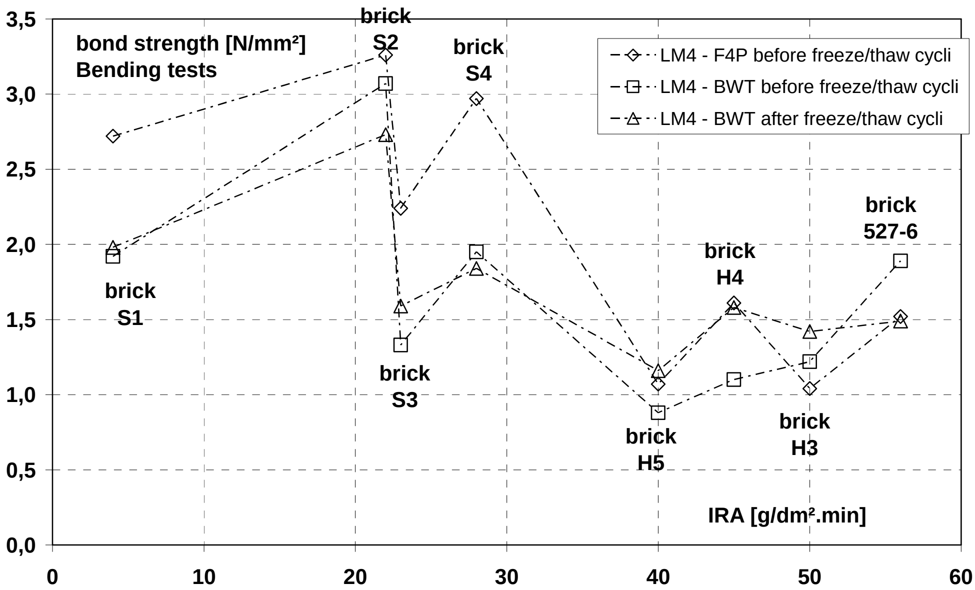

Figure 7 Series 3 : Intrinsic bond strength according to the bending tests (four point bending test –F4P and bond wrench test – BWT) (intrinsic value deducted from the constructive values) of the bending tests before and after freeze/thaw cycli

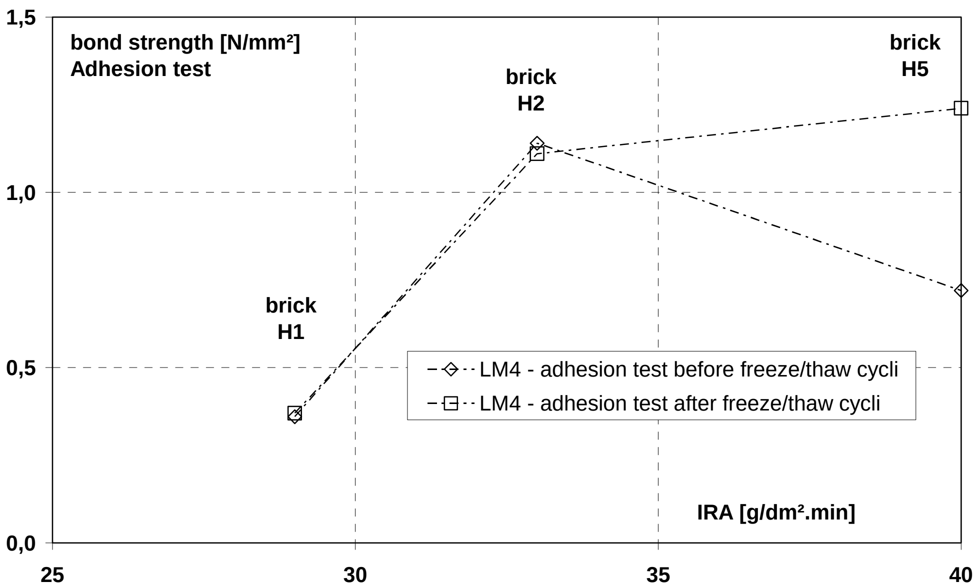

Figure 8 Series H : Intrinsic bond strength according to the adhesion test before and after freeze/thaw cycli

2.2.5 Microscopic analyses - results

On all the analysed brick/mortar combinations, we observed that the hydration degree (DH) was low to medium ; the eventual influences of a later hydration on the mechanical strength in case of humidification necessitate further works. The W/C_{obs} is comprised between 0,50 and 0,65. These ratios belong to the range of the W/C_{obs} of the frost resistant mortar according to (BBRI 1993). Indeed, this range was between 0,40 et 0,70.

LM4 from series 1 set up by warm weather and with a waiting time that was too long doesn't distinguish itself in comparison with when it was set up in 'good conditions'. The LM6's lower mechanical strengths are not justifiable according to the degree of hydration or according to the W/C_{obs} but finally rather in reason of a lower resin content. We can observe in table 1 that W/C_{obs} decrease with the increase of the IRA except for LM2 from series H.

Table 1: overview of some microscopic analyses results (Series 2 and Series H)

	Mortar :	LM1	LM2	LM2	LM3	LM4	LM6
	Prescription :	IRA > 30	5<IRA<40	5<IRA<40	IRA <15	IRA > 5	IRA > 5
	water retention (% loss) :	0.19	0.44	0.44	0.33	0.32	0.23
	ashes content (450°C-% mass) :	1.37	1.36	1.36	1.38	2.65	0.31
Brick / IRA (g/dm^2.min)		Series 2 BWT	Series 2 BWT	Series H Adhesion	Series 2 BWT	Series H Adhesion	Series H Adhesion
S1/ 4	**W/C_{obs}**	0.60-0.65	0.60-0.65	0.55	0.60-0.65	0.65	0.55-0.60
	DH	Low to very low	Low to very low	medium to low	Low to very low	Low	Low to very low
	Mech. test	1.6 N/mm^2	1.6 N/mm^2	2.5 N/mm^2	1.2 N/mm^2	2.7 N/mm^2	1.2 N/mm^2
S4/ 28	**W/C_{obs}**	0.50	0.50-0.55	0.55	0.50-0.55	0.58-0.60	0.53-0.55
	DH	Low	Low	Medium to high	Low	Low	Low
	Mech. test	1.9 N/mm^2	1.7 N/mm^2	4.6 N/mm^2	1.3 N/mm^2	4.3 N/mm^2	1.6 N/mm^2
H5/ 40	**W/C_{obs}**			0.50-0.55		0.58	0.53
	DH	-	-	Medium to high	-	Low	Low
	Mech. test			1.7 N/mm^2		0.7 N/mm^2	0.8 N/mm^2
H3/ 50	**W/C_{obs}**	0.50	0.50	0.55	0.50	0.50-0.55	0.50
	DH	Low	Low	Medium to low	Low	Low	Low
	Mech. test	0.8 N/mm^2	0.7 N/mm^2	1.4 N/mm^2	1.0 N/mm^2	0.5 N/mm^2	0.9 N/mm^2

2.3 Discussion

On the compatibility between brick and mortar, the mechanical tests have shown that bricks with similar IRA can generate different strengths with the same mortar. We observed also prescribed 'combinations' giving low strength and different behaviour between mortars containing a different resin content.

The first preparation of samples has given lower resistances than foreseen because of the hot weather conditions (also confirmed by the bricklayers) and the difficulty to use this technique in laboratory conditions (on relatively small specimens).

We noted also fracture in the brick in case of very high IRA, but this is explained by the correlation between mechanical strength and porosity. Even for the recommended combinations LM6 mortar has shown lower resistances (due to the lower resin content than the other adhesive mortars).

In a general way, we can say that on all the tested combinations, no great performance problem were detected (initial adhesion, durability).

At this time, we can suggest at least the following criterion :

- each combination must show minimal performance in terms of initial bond strength (mean value and plane of fracture). A criterion on the mortar's resin content can also help the user. That minimal value should according to us
    - o Either be > 1 N/mm^2 (when tested according to the adhesion test). Only combination LM6-S4 (cf figure 2) appeared to have a lower bond strength.

- Or generate a break clearly in the brick (and not at the interface or in the adhesive mortar). This possibility must be retained in the case of bricks with high porosity (and thus lower mechanical strength) for which we have observed failure in the brick with values lower than 1N/mm².
- An estimated criterion on the resin content should be > 1%, because there is an evident correlation between the resin content and the bond strength. The LM6 mortar (characterised by a resin content of 0.31%) has shown the lowest values for adhesion.

- each combination brick-mortar must conserve minimal adhesion strength after aging tests. The recommended aging tests are the exposition to freeze/thaw and to thermal action. The freeze/thaw tests presented in this article did not generate any problems. The aging under thermal influences has to be studied in further works. A residual minimal value of 0.5N/mm² is recommended.
- each adhesive mortar has to have a sufficient open time allowing the setting up in determined climatical conditions ; the setting up by warm weather appears unfavourable (see series 1 point 2.2.1).

It is hoped that recognised and verified criterion of this kind will ensure the use of this technique towards designers and users.

3 Further work

Further works concerning the bond strength are performed to study the following possible influences: influence of the brick's water content and the quantity of water for the mix, the external weather conditions during execution and the thermal solicitation. The latter influences greatly the behaviour of adhesive mortar as known from experiences with for example adhesives for tiles.

4 Conclusions

After having determined the material properties from a representative range of samples, different kind of mechanical tests on assemblages were performed before and after freeze/thaw cycli. The study is supported with microscopic analyses of the bond brick/adhesive mortar.

The obtained results allow us to elaborate general criteria for a sound selection of the materials but need to be further investigated on the influence of the climatic conditions during the working out of the masonry.

Actually, this influence has been pointed out to be crucial for the quality of the bond between mortar and brick. Particular attention must also be given to the open time of the mortar, to the elimination of non adherent particles on the bricks (dust, sand, …) as well as to specific measures in the case of 'gluing' in hot weather conditions (direct sunshine) which increase the risk of technical problems with pumps and pistols.

Despite the fact that we have observed bricks with similar IRA to be able to generate with the same mortar different mechanical behaviours, and that recommended combinations can sometimes give a poor mechanical resistance, we can state that, considering the whole set of tested specimens, no dangerous lack of performance has been detected (initial adhesion and durability).

Further works are still needed for safety reason; when 'structural' behaviour will be benefited, the behaviour in time (durability) will be of primary importance.

The evaluation of the durability of a recent technique necessitates years. Because it's to early to confront theory and laboratories experience to the 'in-situ' experience, the aging of already existing buildings in Belgium and in the Netherlands is still ongoing.

Acknowledgements

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