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MORTAR-BRICK BOND STRENGTH OF GLUED MASONRY FOR VENEER WALLS

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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 informations 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.
An experimental comparison of available test methods characterizing the bond strength was performed. The first part of the paper (1/2) presents the determination of all the material properties together with mechanical test results on combinations mortar-brick.
These results give some information on the advantages and inconveniences of the discussed test methods.

Key Words

Glued masonry, bond strength, durability

1 Introduction – Technique of "gluing"

The last years have shown that the masonry sector was not inactive for innovative aspects. This dynamism is directed as much on the development of new execution techniques (gluing, pistol and pump, rolling device, manutentionary robots for big units, prefabricated masonry (Vekemans and Ruben 2002), as on the development of new materials (format and properties of the masonry units, adhesive mortar, cover up mortar (Zeus and Popp 2000) (Valluzzi et al 2002) , ancillary components).
The technique of 'gluing' masonry units for veneer walls with use of a pistol is explained in different papers (Martens 2001) (Van der Pluijm 1999). It refers to the setting up of an adhesive mortar in +/- 2 to 7 mm thickness. It's important to remark that the resins content of the used mortar (that gives particular properties like water retention , adhesion properties,…) is low and the binding agent remains cement ; that's why this terminology ('adhesive mortar') is used in this paper. Assuming that, we point out the inaccurate but used terminology 'gluing'. Under the impulsion of producers, the

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technical possibility was first studied in the Netherlands (Van der Pluijm 1991) (de Kroon 1998) (Martens 2002), what resulted in execution directives (BKB 1999) and mortar certification guidance (IKOB 1999) (BMC/IKOB 2001). The technique appeared in 1995 in Belgium with the edification of the Roi Baudouin Stadion. The number of buildings has increased since then as well for the particular residential sector as for banks, public buildings (libraries,…). (TI-KVIV, COBOMEDIA, WTCB 2002) gives the vision on the subject seen from the different 'partners' of the building sector.

2 'Sufficient adhesion'

Adhesion between brick and (general purpose) mortar is usually not subjected to specifications. In a 'normal' masonry (not loadbearing masonry), it has got little importance according to (Febelcem 2002). However, after a research program at BBRI concerning the durability of masonry mortar (with clay units) following a great number of in situ damages (winter 81-82) in Belgium (Not published Research Report), consecutive publications by BBRI proposed prescriptions (in terms of composition and thanks to microscopic analyses) to have durable combinations (BBRI 1993) and mentioned that "the bond strength must not be lower than *0.02 N/mm² (measured according to the 'cross couplet test'* (NBN B14-221)*. That bond strength may not be used in stability calculations"* (Construction 1991)*.* During this research, we were forced to remark that often lab-prepared specimens showed no adhesion and that this property was very heterogeneous*.* Eurocode 6-part 2 also mentions that the bond strength has to be 'sufficient' to the intended use. This document refers to the mortar product standard NBN EN 998-2 (2003). For masonry to be used with structural aims, the bond strength of the mortar to certain types of masonry units has to be declared in terms of initial shear strength according to EN 1052-3 (as long as no direct tensile test is available and recognized). The normative Annex C mentions as minimal lower value 0.15 N/mm² for general purpose mortar and lightweight mortar and 0.3 N/mm² for thin layer mortar without any further explanations on the type and characteristics of the masonry units.

Note that the veneer wall is mainly submitted to hygrothermal and wind loading (and foundation settlement); the behaviour under these loadings is influenced by the wall-ties (permitting the transfer of sudden wind loadings to the loadbearing wall), the boundary conditions and the building typology. In these cases, the bond strength (and also the mode of failure) plays a role. It has also got an influence on the behaviour of self-loadbearing lintels for short span (< 1m), not recommended in Belgium by BBRI but often realised according to 'empirical experience'.

3 Research project at BBRI – Scope of this paper

A 2 x 2 years research project (partly financed by the Belgian Ministry of Economical Affairs) began in 2001 at BBRI in order to evaluate a very large number of aspect of the technique (Grégoire and de Barquin 2001). The main objective is to provide useful and adequate information (via a NIT – Technical Information Note) to the masonry sector (building companies, designers, public authorities).

The scope of this paper is only directed to the 'adhesion aspects'. Adhesion is one of the main important provided chararacteristics. Three problems appear: how can we measure this adhesion in this particular period of evolution to European Standards? What is a sufficient adhesion for this kind of masonry? Is the adhesion function of time and/or external influences (durability) ?

This last point is of primordial importance for safety aspects because, once the reference documents will be accepted, the designers will use more systematically the improved mechanical properties (self-loadbearing lintels,…).

After having given the determined individual material properties of the studied range of samples, the used test methods and results on assemblage are given and discussed.

4 Material properties

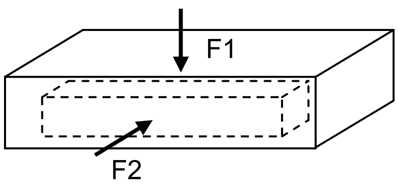
4.0 Brick properties

Table 1 shows the main results of the determined unit properties. The range of samples was constituted in order to cover a large range of brick Initial Rate of Absorption (IRA); amongst the chosen ten types of units, 4 types are extruded into which 2 are perforated with different IRA (S1, S3) and the two others are characterised by their surface texture (rough-S2 or smooth-S4). Amongst the 6 ‘pressed’ bricks, 2 have a frog (H1, H2) and the others are sanded on their surface (H4, H5, 527-6) or not (H3) ; these types cover the higher IRA’s. Moreover, the ten bricks cover a large range of mechanical strengths.

Table 1 : overview of the characteristics of the selected bricks

properties	brick	H1	H2	H3	H4	H5	527-6	S1	S2	S3	S4
F : frog ; E : extruded ;	S : sanded; P : perforated (percentage)	F	F		S	S	S	E P (22%)	E	E P (19%)	E
IRA	[g/dm²min]	29	33	50	45	40	56	⊥:1; // : 4	22	⊥:9; //:23	28
A	[kg/m²s$^{1/2}$]	0.434	0.379	0.584	0.585	0.575	0.631	0.011	0.138	0.199	0.348
Capillary Absorp-tion	[% mass]	14.7	13.2	15.6	15.4	16.7	15.7	2.8	7.1	9.0	16.2
Absorp-tion under vacuum	vol. mass [g/cm³]	1.75	1.77	1.66	1.69	1.67	1.82	2.26	2.16	1.98	1.76
	Porosity [Vol %]	34.4	33.1	38.3	37.0	36.7	28.6	11.2	19.3	25.0	34.9
Compres-sive strength [N/mm²]	mean	21.1	24.8	28.6	31.8	27.4	40.2	105.2	70.6	58.0	76.7
	Normalised f_b	16.4	19.8	23.2	25.2	21.6	30.2	94.4	57.2	46.9	60.4
Flexural strength [N/mm²]	E_{dyn}	5400	6200	5000	5300	8600	4000	29300	24900	6500	11800
	f1	3.6	4.0	4.1	4.2	5.3	2.9	17.6	13.4	1.6	8.9
	f2	3.7	4.3	3.9	4.0	4.7	2.5	16.1	13.4	8.1	9.7

The compressive strength was determined according to the NBN EN 772-1. Due to the necessity for some types of brick to grind their surface with mortar for planearity aspect, the same preparation was realised for all the 10 types after drying at 105°C. 5 replica were used per type. According to the dimensions of the specimens, the correction factor is applied on the mean value in order to determine the normalised compressive strength. Note that some further works have shown that the preparation (grinding, rectification, 2 superposed samples) can influence the results.



In order to characterise the tensile behaviour of the units, the dynamical modulus (E_{dyn}) by means of the fundamental resonance frequency and the bending strength were determined on cut and dried at 105°C prisms. The bending strength was determined according to two perpendicular direction in order to evaluate the extrusion’s influence for extruded bricks (F1 is // and F2 is ⊥ to the extrusion direction). 3 replica are used to determine the mean value.

The suction of the brick (IRA – g/dm².min) was determined according to the NBN B24-202 after drying at 105°C. This property involves at the present day the choice of the mortar. For two types of perforated units (extruded), the IRA was also determined on the lateral faces perpendicularly to the extrusion direction (IRA ⊥).

According to the Belgian standard NBN B27-010, the total porosity (waterabsorption under vacuum), the capillary absorption and the capillary absorption speed A ($kg/m^2s^{1/2}$) were determined.

4.1 Mortar properties

The range of adhesive mortar samples (LM1 to LM7) comes from three different manufacturers (see table 2); they offer moreover several types according to the suction power of the brick (IRA). Identification test results are also summarized in this table. Different tests were performed on the powder. The granulometry was analysed according to NBN B 11-013. Adhesive mortars LM1 to 3 (from the same manufacturer X) do not show filler with dimension greater than 1 mm. LM4 and LM5 (manufacturer Y) show a high quantity of fillers (+/- 12 %) with dimensions between 1 and 2 mm. The two other adhesive mortars LM6 and 7 show a +/- 4 % content of filler with this range of dimensions. The content of ashes was determined in order to provide information on the component. In particular, calcinations at 450°C show the adjuvant content in simple (molecular weight not to high, not cyclic,..) and organic additives giving particular behaviour to the mortar like adhesion, water retention. We can observe, for example, that LM6 and LM7 show 4 times lower content in these constituents than the other samples. The water retention power was also determined. Lower values indicate a mortar with a higher water retention power.

Table 2 : Overview of the characteristics of the selected adhesive mortars.

	Adhesive mortar :	**LM1**	**LM2**	**LM3**	**LM4**	**LM5**	**LM6**	**LM7**
	Manufacturer :	X	X	X	Y	Y	Z	Z
	Use	Gluing of bricks		Gluing of bricks and natural stones	Gluing of masonry units		Gluing of bricks, concrete blocks,…	
Technical information from the manufacturer	Prescribed brick's IRA [g/dm².min]	IRA > 30 high IRA	5<IRA<40 mid IRA	IRA < 15 low IRA	- mid to high IRA	- low IRA	IRA > 5 mid to high IRA	IRA < 15 low IRA
	Execution	pump/pistol			pump/ pistol or Tank + agitator / trowel		Preferably adapted pump/pistol	
Mix [l / 25 kg]	Prescribed	5 – 5.5	5 – 5.5	5 – 5.5	+/- 4.5	+/- 4.5	+/- 3.5	+/- 3.75
	Realised at BBRI	5.2	5.2	5.2	4.5	4.5	(agitator) 4.0	(agitator) 3.9
setting up	Open time [min]	4	4	4	7	7	20	15
Granulometry	> 1	0.1	0.1	0.0	11.9	12.6	3.8	3.9
Sieves sizes [mm]	1 > … > 0.5	34.6	34.2	33.1	14.6	24.3	17.0	17.3
	0.5 > … > 0.25	21.2	21.5	20.8	18.1	22.6	34.4	34.2
	< 0.25	18.2	18.3	18.2	27.2	17.8	22.4	19.6
Water retention	Waterloss [% mass]	0.19	0.44	0.33	0.32	0.37	0.23	0.97
Content of ashes [% mass]	loss at 450°C	1.37	1.36	1.38	2.65	1.76	0.31	0.26
	loss at 625°C	3.15	3.12	2.90	7.61	4.36	4.28	4.06
	loss at 900°C	3.25	3.36	3.23	9.09	8.30	7.19	7.15

Prisms were prepared for three types of mortar (LM2, LM4, LM6) in order to determine the dynamical modulus (Edyn) by measuring the fundamental resonance frequency and the bending / compressive strength (see table 2).

Table 3 : Adhesive mortars LM2, LM4, LM6: mechanical properties

	LM2	LM4	LM6
E_{dyn} [N/mm²]	14500	18000	16000
Volume masse [kg/m³]	1727	1824	1724
Bending strength [N/mm²]	7.2	8.6	5.7
Compressive strength [N/mm²]	23.7	31.0	20.0

5 Characteristics of the assembled specimens

After a description of the tested combinations, of the preparation of the samples and the realised tests, results are presented and discussed. First, some explanations on the terminology, used to characterise the bond brick/mortar are necessary. The 'constructive strength' is issued from the test results by a conversion factor (depending on the geometry) in order to remove the influence of the setting up in lab when different from the setting up in practice (for example : uncompleted gluing on the brick's length). The intrinsic strength is issued from the constructive strength by a conversion factor in order to remove the influence of the technique (for example : mortar set back from the brick's visible face). We have thus : test result ≤ constructive strength ≤ intrinsic strength.

5.0 Tested combinations

Several combinations were tested according to all the 5 presented test-methods (see 5.2) ; 2 types of bricks (H4 and S2 – with different physical and mechanical properties see table 1) combined with 3 mortars amongst which 1 general purpose mortar (MT1) and 2 adhesive mortars (LM2 and LM4).

5.1 Samples preparation

In this first part, only the intrinsic strength is considered. Samples were prepared with a trowel by the BBRI staff. The mixing is realised by a lab-mixer. All the bricks were dried at 105°C and brushed to remove particles before setting up. Adhesive mortars were set up with a prescribed joint thickness of 4 mm on 2 types of bricks characterised by a different IRA.
In all the cases, the fresh specimen was not loaded (like in practice).

5.2 Test methods – Mechanical tests

Different kinds of tests were performed in order to evaluate the bond strength ; this one can be evaluated by means of bending tests, tensile tests and shear tests.
The four-point bending test (F4P) adapted from NBN EN 1052-2 consists in the testing of a specimen with 7 assembled brick units in a horizontal position. The inner span (constant moment) contains 2 joints (see figure 1). The force is applied thanks to 2 cylinders on the upper surface of the specimen. If break occurs outside the inner span, a new test is performed with the resulting specimen (minimum of 5 assembled units). Results of the first test give in this case a down-boundary value of the strength. Because the prisms are tested in horizontal position, the dead weight is taken into account calculation of the strength. 3 replica are tested.
The Bond wrench test (BWT) constitutes a particular bending test (prEN 1052-5). The moment is applied on the joint thanks to an eccentric load and a lever arm clamped on the upper brick of the prism. After the first test, a second one can be performed on the following joint of the same prism. 5 replica were tested for these comparisons.
The cross couplet test (X) according to the Belgian test-method NBN B 14-221 concerns the testing of two perpendicularly assembled brick units in a compressive way resulting in a tensile action on the tested joint (see figure 2). Five replica were used.
The fourth type of test is adapted from methods (for example : NBN B 14 210) to test the adhesion strength (H) of materials set up on substrates (plaster, render, repair

mortar,..) but also a kind of masonry 'mortar': gypsum based adhesives for gypsum block (according to NBN EN 12860). It consists in the gluing of a cylindrical steel plate (Ø 50 mm) on the 'finishing' material (here, the mortar) and after cutting the surrounding of the plate on top of the substrate (the brick), the load is applied perpendicularly to the substrate until break (see figure 3). The break occurs within +/- 5 seconds.
The preparation of the specimen has been done in the following way. The fresh mortar is set on a wood hydrophobic layer preliminary (lightly) moistened with oil (the excess is removed). After having brushed the brick, it is pressed on the mortar. The excess of mortar is then removed. After 4 days, the specimen is removed from the mould and conserved in curing conditions 20+/-2°C and 50+/-5% RH. 3 replica were tested at 2 mortar ages (at 7 days, at > 28 days).
The shear strength (CIS) is determined according to EN 1052-3. For every combination 9 triplets are necessary ; 3 for each of the three precompression levels (fpi = 0.2 N/mm², 0.6 N/mm² and 1.0 N/mm²). A regression line of the individual results (fvoi) permits the determination of the initial shear strength (fvo) and the friction angle (α). Note the following difference in comparison with the standard: no disposition was taken to maintain a constant precompression load during every single test.

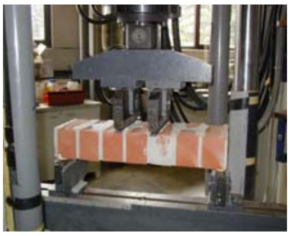


Figure 1: Test arrangement 4 point bending test (F4P)

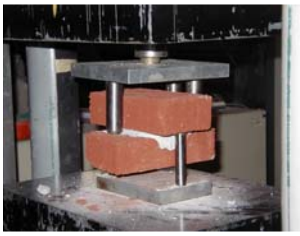


Figure 2: Test arrangement Cross couplet test (X)

Figure 3: Test arrangement Adhesion test (H)

5.3 Results – Comparison between test methods

Table 4 shows the obtained mean values. The influences of the material properties (brick and mortar) is clear for all the test-methods.

Table 4 : correlation between intrinsic strength [N/mm²] determined according to 5 test-methods for 2 bricks and 3 mortars : LMi = adhesive mortars ; MT1 = general purpose mortar.

	Brick :	H4			S2		
	Mortar :	LM4	LM2	MT1	LM4	LM2	MT1
Bending tests	F4P	**1,7**	**1,4**	**0,2**	**3,0**	**-**	**0,5**
	BWT	**0,9**	**0,9**	**0,2**	**2,5**	**1,9**	**0,3**
Tensile tests	Adhesion (H)	**1,0**	**1,5**	**-**	**4,0**	**4,0**	**-**
	Cross couplet test (X)	**0,4**	**>0,5**	**0,1**	**1,0**	**1,0**	**0,3**
Shear tests	Initial strength (CIS)	**0.8**	**1.0**	**0.6**	**1.8**	**2.4**	**0.8**
	friction angle	**51°**	**53°**	**28°**	**47°**	**44°**	**42°**

According to the bending tests, the same characteristic is theoretically determined. However, the differences are in these cases notable; the 4-point bending test gives higher mean values than the bond wrench test from 0% higher for H4-MT1 to +/- 80% higher for H4-LM4. The regression line of the five points (intercepting the origin) has got the following equation : BWT = 0.74 x F4P with R^2 = 0.9314. According to the tensile tests, differences also appear. The regression line of the 4 points has got the following equation : X = 0.26 H with R^2 = 0.8865. The correlation between the bond

wrench test and the adhesion test is given by the following equation: H = 1.73 x BWT with R^2 = 0.8794; what is a surprising correlation between a direct tensile test and a bending test.
The correlation between the bond wrench test and the shear strength test is given by the following equation (intercepting the origin) : CIS = 0.95 x BWT with R^2 = 0.5456 and for the line not intercepting the origin : CIS = 0.67 x BWT + 0.48 with R^2 = 0.7431.
The shear strength test gives thus a better 'adequation' (but far from being good) with the bond strength test with a line not intercepting the point (0,0); what is not adequate for a parameter characterizing the bond strength.
The four-point bending was proposed for its easy methodology. Several disadvantages exist: the necessity to join steel laths with egalisation mortar in order to obtain linear applied forces, a 7 assembled brick sample generates only 1 result and the possible break outside the inner span.
One of the advantage of the bond wrench test is that every joint of a prism can be tested and generate 1 test result ; the number of brick to be tested is thus limited. A lot of dispersion occurred in the results and the clamp has sometimes influenced the break. Moreover the observed dispersion of individual results is relatively high (up to 60 %).
According to (Van der Pluijm 2003), the cross couplet test induces non-uniform stress repartition and shear stress. Moreover, the kind of break with weaker brick can be inappropriate and not representative of a tensile break (see figure 4).
The adhesion test is relatively easy to perform and gives useful information on the bond strength, intrinsic and comparative characteristic (see figure 5). High obtained values can be justified by the quick increase of the applied load (break occurs within +/- 5 seconds) but the exact influence of this test-parameter was not further studied until now.

Figure 4 Inaccurate break during a cross couplet test on combination H4-LM2.

Figure 5 Adhesion test on H4-LM2. Break in the brick

The particular setting up of the sample has shown a certain influence on the mortar : that gives a little higher W/C_{obs} and hydration (see part 2/2 point 5.2.F). A possible improvement is the realisation of a 'doublet' (1 mortar joint between 2 bricks) and a later cutting at one interface permitting the gluing of the steel plates and the testing of the second interface.
The disadvantage of the shear strength test is the necessity to have 9 specimens each comprising 3 bricks if precompression is used. The precompression load (not kept constant during every single test) has varied in a large range during every test. Note that the values mentioned in NBN EN 998-2 (see point 2) are verified, and that, also with the general purpose mortar MT1 showing quite often loss of adhesion during handling before.

6 Conclusions

After having determined the material properties from a representative range of samples (brick and mortar), different kind of mechanical tests on assemblages were performed. Consequence of these results was the use of the bond wrench test for the following tests aimed to evaluate more precisely the influence of the material properties and the influence of aging test (see part 2/2). Due to the dispersion of results, it appeared necessary to also test some combinations according to more than one test-method. We have chosen the 4-point bending test and the adhesion test; this one, used for different kind of finishing products, rendering and plastering materials, seemed to be more accurate and easy to perform and moreover it is also used for Gypsum based adhesives for gypsum blocks. The results can also give correlation for different kinds of material properties. We exclude the cross couplet test because of the inaccurate kind of break for weaker bricks and the shear strength test because, to our opinion it is not able to be of great utility to detect the loss of bond strength after accelerated aging.

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