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A TENSILE BOND STRENGTH TEST FOR COMPOSITE MASONRY/CONCRETE

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ABSTRACT

A simple test for measuring the tensile bond strength of the interface of composite masonry/concrete construction is described. The results of tests on sixty seven cores taken from four reinforced brickwork beams are reported and the test method is reviewed. Although originally developed as part of a research project, it is suggested that the test could be used for quality control purposes on site particularly where it is important to ensure the adequacy of the bond between masonry and concrete.

INTRODUCTION

Many forms of construction are designed where in-situ concrete or grout and masonry are assumed to act compositely. Typical examples include grouted hollow concrete, calcium silicate or clay block construction as used in low to medium rise building works in many parts of the world. Concrete is also used to repair or strengthen a variety of existing masonry structures ranging from historic monuments and arch bridges (Page et al. 1991) to modern buildings damaged by excessive ground movements, terrorist attack or seismic activity. In addition concrete and masonry act compositely in many forms of reinforced masonry construction, notably reinforced grouted cavity, reinforced pocket-type and reinforced cellular walling (Garrity 1993).

Concrete/masonry bond

Unless steel ties are used, which is not always desirable, the shear connection between masonry and concrete necessary for composite action is dependent on the bond between the two materials. In a review of the literature on brick/mortar bond (Goodwin and West 1980), the rate at which the masonry units absorb moisture from the mortar was found to have the greatest influence on the bond strength. More recently, (Lawrence and Cao

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1987, 1988) found that the bond between clay bricks and modern cementitious mortars is derived mainly from the mechanical interlocking of the cement hydration products growing on the surface and in the pores of the bricks. In particular, the brick/mortar bond was found to be influenced by the distribution, continuity and degree of microcracking of the hydration products which is dependent on several factors such as the water:cement ratio, free lime content, aggregate grading and curing of the mortar. The size and distribution of surface pores in the bricks and their moisture content at the time of construction can also have a significant effect. Similar factors are also likely to influence the bond between concrete and masonry in composite construction, as are macroscopic defects such as shrinkage cracking and voids in the concrete caused by inadequate compaction.

The importance of achieving good bond between masonry and in-situ concrete has been demonstrated in large-scale testing of reinforced brickwork beams where shear failure was immediately preceded by longitudinal cracking at the brickwork/concrete interface (Tellet & Edgell 1983). The premature vertical splitting failure of two laterally loaded full-scale reinforced brickwork walls due, possibly, to the inadequate shear connection between the concrete and the brickwork, has also been reported (Maurenbrecher et al 1976, Fisher et al. 1989). More recently, in full-scale tests on masonry arch bridges, premature failure occurred as a result of arch ring separation caused by lack of bond (Melbourne & Gilbert 1993). Similar problems can occur with certain types of repair to masonry arch bridges, in particular, where shotcrete linings are cast onto the intrados (or soffit) or when a concrete saddle is cast directly onto the extrados of the arch barrel.

Durability

In reinforced masonry construction, the reinforcing steel is passivated against corrosion by a continuous coating of alkaline cement paste provided by the surrounding mortar or concrete. Research has shown that where concrete is cast against masonry, the wet concrete can be de-watered by the porous masonry leading to plastic shrinkage cracking (Kingsley et al. 1985, de Vekey 1988, El-Saie et al. 1994). Plastic settlement of the wet concrete, that can lead to cracking and reduced bond between the concrete and the steel reinforcement, has also been reported (Garrity 1992). Although there are no reports of corrosion of the steel reinforcement in reinforced masonry structures arising from plastic cracking, there is a concern that plastic shrinkage and plastic settlement effects may reduce the corrosion protection, particularly where exposure to chloride ions from seawater or de-icing salts is likely.

Testing of composite concrete/masonry

Judging from the above, the quality of the masonry/concrete interface is likely to influence the structural performance and, possibly, the durability of composite masonry/concrete construction. It is also clear that the bond between concrete and masonry is highly complex and that testing masonry and concrete as the separate components of composite construction will not reflect how the two materials interact in practice.

Where reinforced masonry construction has been used for many years, as in the seismically active Western United States of America, engineers have devised test procedures that take into account the de-watering of wet concrete (or grout) by porous masonry (Dickey 1987). A typical example of such a test used to determine the compressive strength of the grout used in reinforced grouted concrete block walls is described in a review of current specifications, practice and experience of the grouting of reinforced brickwork and blockwork construction (Edgell and de Vekey 1987). The test is very similar to the conventional cube test used in the UK to determine the compressive strength of mortar and concrete except that, instead of using steel moulds to form the specimen, the grout is cast in moulds formed from concrete blocks similar to those used in the actual wall. The surfaces of the blocks are covered with absorbent paper which allows water to pass through it but prevents the grout from bonding to the blocks.

Almost all of the tests that have been developed for monitoring the quality of masonry construction are compressive, flexural or masonry unit/mortar bond strength tests. Although the bond strength of composite masonry/concrete construction has been measured in the laboratory (Sinha and Foster 1979), as far as the author is aware, no test has been developed that is suitable for multi-specimen testing in the laboratory or routine quality monitoring on site.

As part of a laboratory-based study of composite masonry/reinforced concrete walls, the author devised a simple tensile test which was used to measure the bond strength of the masonry/concrete interface. A further requirement of the test was that it should permit the identification of any defects within the interfacial zone that might influence structural behaviour and durability such as plastic cracking, cracking due to drying shrinkage or the effects of poor compaction. As the test involved the use of small specimens that could be easily handled and transported to a testing house, it is considered suitable as a site-based quality control test for composite masonry/concrete construction. The main aims of this paper, therefore, are to:-

a) describe the tensile bond strength test for composite masonry/concrete.

b) review the sampling and testing methods.

c) describe how the test might be used in practice.

THE TENSILE BOND STRENGTH TEST

In the study referred to above, short lengths of reinforced cellular brickwork wall were constructed; each wall consisted of brickwork built in a cellular bonding pattern around vertical steel reinforcing bars that had been previously cast into a reinforced concrete foundation. The voids or cells in the brickwork were then filled with insitu concrete to form a reinforced masonry wall. When the concrete had gained sufficient strength, each length of wall was rotated into a horizontal position and tested to failure as a beam in four point bending (Garrity 1992).

In order to investigate the bond between the brickwork and the concrete it was decided to carry out direct tensile testing of samples of the brickwork/concrete interface taken from four of the beams tested in the study, hereafter referred to as beams W, X, Y and Z. The method of sampling and testing is described below. The properties of the materials used in the construction of the four beams are summarised in Table 1.

Table 1. Summary of Material Properties

Beam	**Bricks**			**Mortar**	**Infill Concrete**	
	Compressive Strength [MPa]	**Water Absorption [%]**	**Initial Rate of Suction [kg/mm²/min]**	**28 Day Compressive Strength [MPa]**	**Slump [mm]**	**28 Day Compressive Strength [MPa]**
W	95.5	6.3	0.46	26.0	> 150	41.3
X	95.5	6.3	0.46	21.0	> 150	41.2
Y	127.0	2.9	0.24	18.1	10	37.0
Z	127.0	2.9	0.24	15.7	10	37.5

Notes

a) 1 : ¼ : 3 (opc:lime:sand) mortar used throughout.

b) All tests on clay bricks conducted in accordance with BS 3921 : 1985.

c) Conversion factors : 1 MPa = 145 psi; 1mm = 0.03937 in.;
1kg/mm²/min. = 19.42 g/30in²/min.

Sampling and preparation of test specimens

On completion of the bending tests, 44 mm (1.73 in.) diameter cylindrical specimens were cored from the undamaged regions of the beams using electrically powered rotary coring equipment. In each case, full depth cores yielding two test specimens were taken from each beam. Each full depth core was cut in half and the ends of each half were trimmed with a rotating blade saw to produce a 50 mm (1.97 in.) long test specimen with the brickwork /concrete interface located at its centre as shown in Fig. 1. The end faces of each cylindrical specimen were ground parallel to within ± 0.25 mm (0.0098in.). Two different types of specimen were obtained from the beams, namely those containing a mortar joint, hereafter referred to as *type A* specimens, and those without a mortar joint, referred to as *type B* specimens.

Test details

Each cylindrical specimen was tested in direct tension in an Instron 4206 universal testing machine at the University of Bradford. The arrangement used for gripping each end of the specimen and locating it in the jaws of the test machine is shown in Figure 1. A double universal joint arrangement comprising a screw-fitted steel end-plate was used to align the specimen in the jaws of the test machine and to ensure that any applied load was purely axial. Any minor variations in the ends of the specimen were accommodated in the thin layer of epoxy-based adhesive that was used to connect the test piece to the steel end-plates. Once set up in the test machine, the specimen was subjected to an increasing tensile force until failure occurred. The force was applied to the specimen via a crosshead which moved at a constant rate of 0.5 mm/min (0.02 in./min).

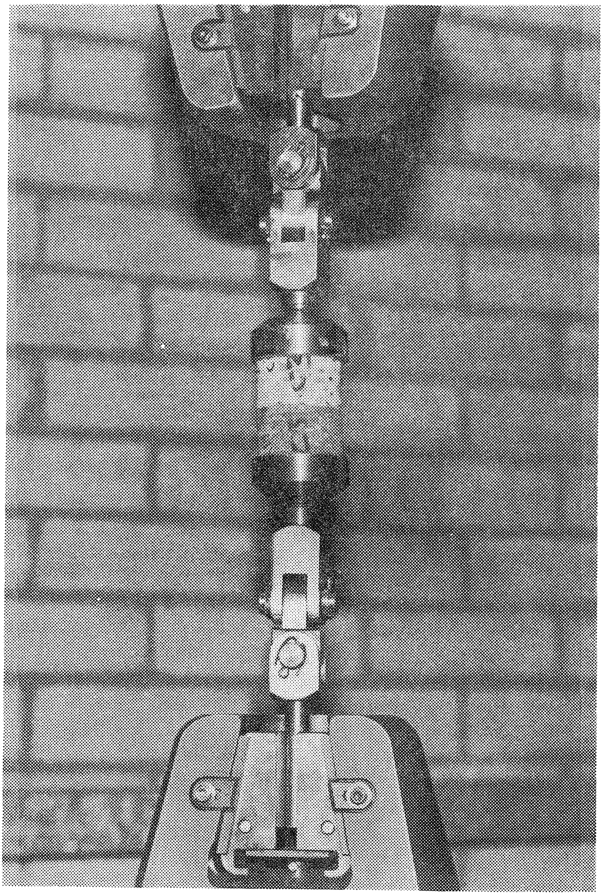

Fig. 1. Test Arrangement

Test results

The results of tensile bond strength tests carried out on sixty seven cores taken from the four reinforced brickwork beams referred to earlier are presented in Table 2.

Table 2. Tensile Bond Strength Test Results (Conversion Factor : 1 MPa = 145 psi)

BEAM W		
Core Type & Number	**Bond Strength [MPa]**	**Failure Mode**
A1	1.39	4
A2	2.74	2
A3	2.14	3
A4	1.13	4
A5	1.50	1
A6	2.06	4
A7	0.71	4
A8	2.09	4
Mean strength = 1.72 MPa		
B1	2.24	2
B2	1.22	1
B3	1.21	1
B4	2.64	2
B5	2.14	1
B6	1.21	1
B7	2.84	2
B8	1.98	2
B9	1.37	1
B10	2.60	1
Mean strength = 1.95 MPa		

BEAM X		
Core Type & Number	**Bond Strength [MPa]**	**Failure Mode**
A9	0.54	4
A10	0.59	4
A11	1.23	4
A12	2.80	4
Mean strength = 1.29 MPa		
B11	1.59	1
B12	2.53	2
B13	2.02	1
B14	2.35	3
B15	1.47	1
B16	2.38	1
B17	2.25	1
B18	0.98	1
B19	1.46	1
B20	2.01	1
B21	1.52	1
B22	1.14	1
Mean strength = 1.81 MPa		

BEAM Y		
Core Type & Number	**Bond Strength [MPa]**	**Failure Mode**
A13	1.73	4
A14	0.84	4
A15	---	5
A16	---	5
A17	0.49	1
A18	0.62	4
A19	1.57	4
Mean strength = 1.05 MPa		
B23	1.98	1
B24	1.93	1
B25	0.71	1
B26	1.56	1
B27	---	5
B28	1.13	1
B29	0.69	1
B30	0.97	1
B31	2.27	2
B32	1.82	1
Mean strength = 1.45 MPa		

BEAM Z		
Core Type & Number	**Bond Strength [MPa]**	**Failure Mode**
A20	0.55	4
A21	1.38	4
A22	1.01	4
A23	0.64	4
A24	---	5
A25	1.08	4
Mean strength = 0.93 MPa		
B33	2.13	1
B34	2.02	1
B35	0.96	1
B36	0.87	1
B37	1.00	1
B38	2.32	1
B39	0.62	1
B40	0.70	1
B41	1.11	1
B42	0.98	1
Mean strength = 1.27 MPa		

Failure modes: 1 - Failure at brick/concrete interface; 2 - Tensile failure of concrete; 3 - Tensile failure of brick;
4 - Failure plane passing through brick/mortar interface and along mortar joint; 5 - Failed during sample preparation.

DISCUSSION

Review of the sampling and testing

Coring equipment of various sizes can be readily hired at low cost from most plant hire firms and many civil engineering laboratories specialising in concrete or rock testing will be equipped with such machinery. Furthermore, many engineers will be familiar with the equipment as it is a commonly used method of sampling hardened concrete from existing structures for compressive strength testing.

Obtaining composite brickwork/concrete cores from the reinforced brickwork beams proved to be quick and simple. The main problem encountered during drilling was the wear of the cutting tool caused by steel reinforcing bars. In addition, a small number of cores snapped when the drill bit hit a steel reinforcing bar. In practice, it is not always possible to avoid cutting through some of the reinforcement even when a covermeter is used to identify its likely position prior to drilling. Although four of the sixty seven cores broke during trimming, no other problems were encountered during the preparation of the test specimens.

The use of 100 mm (3.94 in.) and 150 mm (5.9 in.) diameter cores was investigated in trials, however, the lighter 44 mm (1.73 in.) diameter samples proved to be easier to handle during trimming and when manoeuvring the specimen into the jaws of the testing machine. A common problem when testing comparatively large, low strength specimens in tension is the creation of undesirable torsional and flexural effects by specimen misalignment. Such effects are reduced when using small diameter specimens. Indeed, the use of 44 mm (1.73 in.) diameter cores together with the measures described earlier to ensure axial loading appear to have been successful as none of the specimens tested showed any signs of torsional or flexural failure.

On site, the use of comparatively small cores is preferred for the following reasons:-

i) There is less chance of coring through any steel.

ii) Less material is removed from the structure, an important consideration when thin structural members are being investigated.

iii)There will be less damage to the exposed surface of the structure.

iv)Small samples are easier to transport to a testing house.

v) It is less costly to obtain a representative number of samples for testing.

The test results

The bond strengths of the cores taken from beams Y and Z are generally lower than those taken from beams W and X. This may be because beams Y and Z were made using lower porosity bricks and lower strength infill concrete and mortar resulting in reduced mechanical interlock between the hydration products and the surface of the fired clay.

The variation in the results presented in Table 2 are very typical of tests on inherently variable materials such as masonry and concrete. The results do, however, yield two important points with practical implications. In the first instance, it is clear that the average tensile bond strength of the *type A* test specimens, that is those containing mortar joints, was less than that of the *type B* specimens. Hence, when coring samples for testing from composite masonry/concrete construction, it is important to ensure that some of the cores contain mortar joints in order to obtain a representative sample.

The second point demonstrates a possible disadvantage of using small diameter cores, namely that the effects of any minor defects will be magnified. An example of this is seen with seven of the cores where failure occurred in the concrete rather than at the brick/concrete interface; in each case, it is very likely that failure was caused by the presence of a large piece of aggregate in the core. Also, with two of the cores, failure occurred in the brick. This is almost certainly due to the presence of intermittent horizontal planes of weakness in the brick due to the extrusion process which was used to form the "green" clay into the required shape prior to firing. Both defects are likely to act as stress raisers in the cores leading to premature failure and underestimates of the interface bond strength. It is not yet known whether cracking would initiate at such locations in a full-scale structure. To draw attention to these potential problems when testing masonry/concrete cores of this type, it is suggested that the mode of failure and location of the failure plane should be recorded in addition to the tensile bond strength.

PRACTICAL APPLICATIONS OF THE TEST

Bond strength testing before starting construction on site

With reinforced concrete construction in the U.K. it is common practice for the concrete supplier to produce trial batches of the proposed concrete mixes before starting construction on site. This helps the engineer responsible for the supervision of construction to judge if the materials are suitable for the proposed works and gives adequate time to change the mix proportions if necessary. Using the same philosophy, it is suggested that *trial panels* of unreinforced composite masonry/concrete that are representative of the proposed forms of construction, are built before starting work on site. The trial panels should be constructed from the bricks or blocks specified by the architect or engineer and two or three alternative concrete mixes. Cores would be taken from each panel after three, seven and twenty eight days and tested in the manner described in this paper. This approach is recommended for the following reasons:-

i) It gives the engineer or architect on site an opportunity to judge the standard of workmanship of the bricklayers or masons before work is started.

ii) It gives the contractor the opportunity to try different methods of construction.

iii) It shows which of the concrete mixes is likely to suffer from defects such as poor compaction or plastic cracking due to the de-watering effects of the masonry.

iv) It shows which concrete mix is likely to be most compatible with the specified masonry and, in particular, which mix achieves the greatest bond.

v) It allows the engineer to assess the influence of any shrinkage-compensating or plasticising admixtures, proposed by the contractor, on the masonry/concrete bond.

vi) It provides the engineer and contractor with useful information regarding the rate of gain of tensile bond strength. This may influence the rate of construction on site.

vii)It gives *reference tensile bond strengths* when the construction is three, seven and twenty eight days old. These can be used in the quality control process, as described below.

Quality control testing of composite masonry/concrete on site

The following procedure is suggested as a means of assessing the quality of composite masonry/concrete during construction :-

a. As described above, *trial panels* of unreinforced composite concrete/masonry should be built before starting construction of the main works on site. The most compatible concrete mix should be identified and the *reference tensile bond strengths* for that mix should be agreed and recorded. Construction of the specified works can then start on site.

b. During construction, when instructed by the supervisory staff, each bricklayer or mason must build a short length of unreinforced wall. This *control wall* must be representative of the actual construction and should be built using the same masonry units, mortar, insitu concrete and masonry bonding pattern as in the specified works. Additional control walls may be built, at the request of the engineer's or architect's representative.

c. Each control wall should be built in similar exposure conditions and be cured in a similar manner to the actual construction.

d. After seven days have elapsed, the control wall should be carefully rotated and lowered onto a flat part of the site. At least ten cores should be drilled from the wall, each core penetrating through the masonry into at least 50 mm (1.97 in.) of the insitu concrete. In order to obtain a representative sample, the cores should be taken from all parts of the control wall.

e. Each core should be carefully inspected for any signs of cracking or poor compaction and the results of the inspection should be given to the supervising engineer or architect. Any premature failures occurring during coring or afterwards must be recorded.

f. The masonry/concrete interface of each core should be indelibly marked with the date of construction and any identifying number. Each core should then be placed in its own polyethylene bag and sealed then taken to a testing house for testing in the manner described in this paper.

g. The results of the tests, including the mode and plane of failure and the age of the specimen when tested, should be reported to the supervising engineer or architect without delay for comparison with the *reference tensile bond strengths*.

Testing of masonry strengthened using in-situ concrete

There are many examples of existing masonry structures that have been repaired or strengthened using insitu concrete. If the engineer or architect needs to measure the bond between the two materials, cores can be taken and tested in direct tension as described earlier. A problem that could arise with historic or listed masonry structures is the need to disguise the core locations. If the end of the core that was originally the exposed face of the masonry structure is retained when the core is prepared for testing, it can be fixed back in its original position with an epoxy resin adhesive once the rest of the void has been filled with mortar or any other suitable material.

SUMMARY

The quality of the masonry/concrete interface is likely to influence the structural performance and, possibly, the durability of composite masonry/concrete construction. Testing the masonry and concrete as the separate components of composite construction will not, however, reflect how the two materials interact in practice.

It is proposed to measure the bond strength of the masonry/concrete interface using a simple tensile test. The test is considered suitable for most forms of composite masonry/concrete construction such as new reinforced masonry or insitu concrete repairs to existing masonry structures. A suggested quality control procedure for composite masonry/concrete construction, in which the tensile bond strength test is a key part, is also presented.

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