THE IMPACT OF UNIT PROPERTIES ON MASONRY FLEXURAL STRENGTH USING THIN LAYER MORTAR.

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SUMMARY

This paper reports on a testing programme which uses the bond wrench and wallette specimens as used in Europe to evaluate the tensile flexural strength of masonry formed using thin layer mortars in combination with clay bricks, concrete bricks and aircrete units. The variables examined include the form of construction, the impact of elevated temperatures in early ages and the age at testing.

Findings from this programme of testing indicate the construction process affects bond, bond is significantly higher with clay and concrete units than the European and British codes allow for and raising the temperature of masonry in the early ages increases bond but maintaining this elevated temperature results in a decrease in the bond strength after a few days.

INTRODUCTION

Masonry construction is one of the oldest techniques used to build substantial structures. In ancient times even unbonded masonry units were used to form massive structures. Masonry units can be hewn rock of various types or formed from clay or mud either sun dried or fired in some manner. Recently natural aggregates, bonded together with cementious binders have been cast into regular shapes to form concrete blocks, the density of which depends on the type of aggregate used in them. Other developments in unit type, include the formation of concrete aircrete blocks. Cement, sand and pulverised fly ash (pfa) are formed into slurry into which aluminium powder is included. The powder enables the formation of many thousands of tiny discrete bubbles in the material, resulting in a lightweight building material suitable for modest buildings.

Alongside the various units available have been developments in the types of mortar used. Dry wall construction not requiring mortar has been used for millennia and is still used in some applications. But bonding units together has advantages and has also been employed for thousands of years. Using mud to enable irregularities in units to be absorbed and bonding masonry components together using bitumen has been employed throughout history. In more recent times, joining bricks or blocks using lime mortars has been employed. Cement mortars are a very recent innovation and have dominated masonry construction in developing countries for the past eighty or so years. A modification to cement mortars by including

polymers has resulted in mortar which has different properties to those of pure cement mortar. This mortar offers opportunities to expand masonry use.

Polymer modified mortar, when combined with bricks or blocks is sometimes termed thin layer masonry because it is possible to construct masonry with very thin joints. Flexural strength testing of masonry formed using polymer modified mortars has been undertaken on a variety of unit types, and over a range of ages, using bond wrench and wallette testing. In addition, two techniques for placing the mortar have been studied and the impact of heat curing on this form of masonry has been considered.

EXPERIMENTAL PROGRAMME

Masonry units

The properties of the masonry units used in this investigation are given in Table 1. The initial rate of absorption and coefficient of water absorption were determined in accordance with BS EN 772-11:2000, the compressive strength of units in accordance with BS EN 772 -1: 2000, and the density of specimens determined as required in BS EN 772 - 13 : 2000.

Table 1. Properties of masonry units. All units 215 x 103 x 65mm.

Unit type	Initial rate of absorption (kg/(m^2 x min)	Coefficient of water absorption (g/(m^2 x $s^{0.5}$)) [%]	Compressive strength (N/mm^2)	Dry density (kg/m^3)
Clay brick - Red smooth	1.02	-	64.6	1973
Clay brick - Red rough	0.32	-	-	1528
Concrete brick	-	98.77	30.7	2102
Aircrete brick	-	119.01	4.3	664

Mortar

Two mortars were used in the investigation. Celfix is a thin layer mortar specifically designed to bond Aircrete units and was used exclusively on the Aircrete material. Ardex was recommended as a polymer modified mortar suitable for use with solid concrete bricks and clay units. Both mortars came bagged and the user only needs to add the recommended quantity of water and mix to produce workable mortar.

Mortar workability

Mortar workability was determined using the flow table in accordance with BS EN 1015-3 : 1999, the plunger penetration in accordance with BS EN 1015-4 : 1999 and the dropping ball test in accordance with BS 4551-1 : 1998. To produce all the specimens, two mixes were needed. Table 2 gives the workability properties of each mix. Similar workabilities were obtained when specimens were constructed to ascertain the effect of construction technique on bond, although in this instance, B-wallette tests were undertaken in accordance with BS 5628 : Part 1 : 2005.

Table 2. Workability of mortar.

Mix	Flow table (mm)	Plunger penetration (mm)	Dropping ball (mm)
Air cured specimens	195	34	12.2
Oven cured specimens	196	34	11

Mortar compressive strength

Mortar compressive strength was determined in accordance with BS EN 1015-11 : 1999. This requires the broken ends of a 40 x 40 x 160mm long mortar prism, first tested and broken in flexure to then be re-tested in compression and the average of the strength from each end to be determined. In this programme of work, three prisms were made so six compressive strength tests were included in each result. Ardex was consistently stronger than the Celfix mortar. Both mortars exhibited erratic strength gains in the early ages. The mortar strength dipped with the Ardex mortar at day 6 and with the Celfix material at age 4 days but strength gain at a regular but decreasing rate continued from then until age 56 days. By age 8 days the Ardex had achieved 70% and the Celfix 68% of the 56 day strength. Figure 1 indicates the effect of age on the strength of mortar.

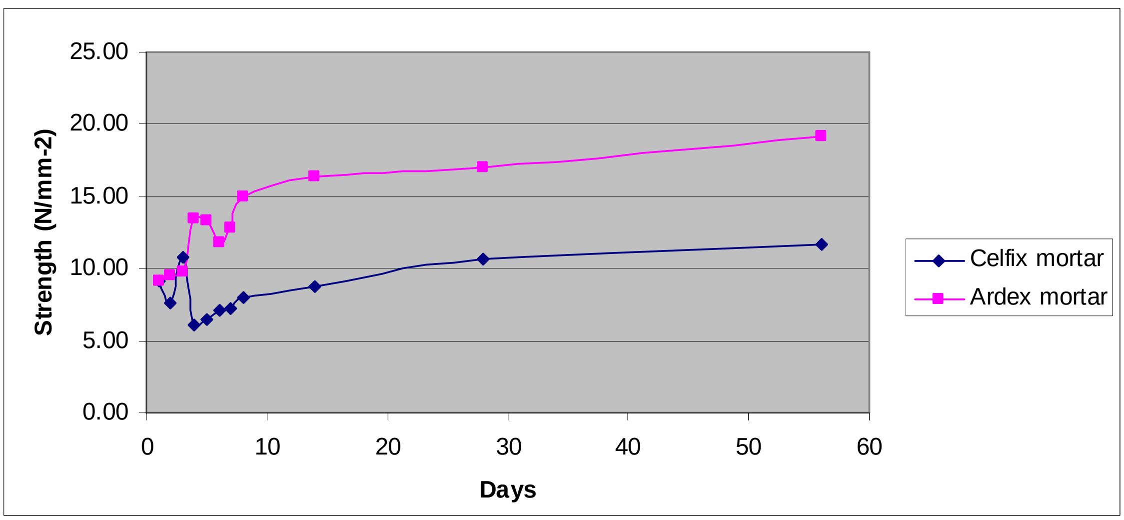

Figure 1. Effect of age on mortar compressive strength. 4 x 40 x +/- 80mm prism ends tested.

Mortar tensile strength

Mortar tensile strength was determined in accordance with BS EN 1015-11 : 1999. This requires a 40 x 40 x 160mm long mortar prism to be tested in flexure under a central point load over a 100mm span. In this research programme, three prisms were made and tested at each age. The Ardex generally had higher values than the Celfix mortar although at 28 days its strength dipped slightly below that of the Celfix mortar probably due to natural variations. The strength difference between the two materials was 46% at 14 days but only 24% at age 56 days. The proportional difference between flexural and compressive strengths was broadly similar for the two mortars except for the unusual 28 day result. See Figure 2.

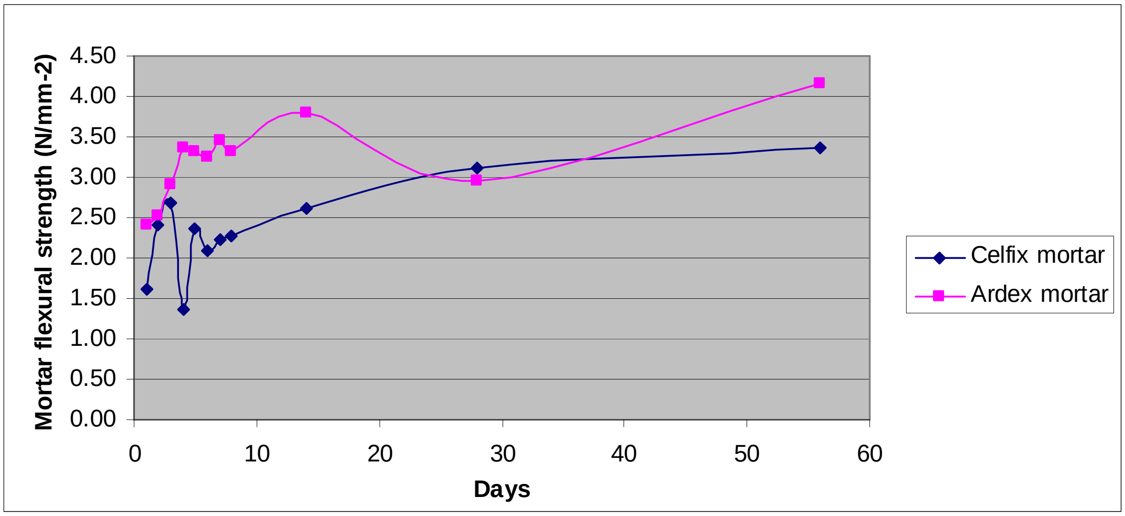

Figure 2. Effect of age on mortar flexural strength. 40 x 40 x 160mm prisms tested.

Figure 3 examines the relationship between the compressive and flexural strength of the two mortars. The overlap of the sets of data indicates they are from the same population, although each mortar has different strengths. Including logarithmic trend lines for the individual (shown) and combined (not shown) sets of data indicate that the trends are similar although the R^2 values (celfix = 0.54, ardex = 0.67) indicate some scatter of results.

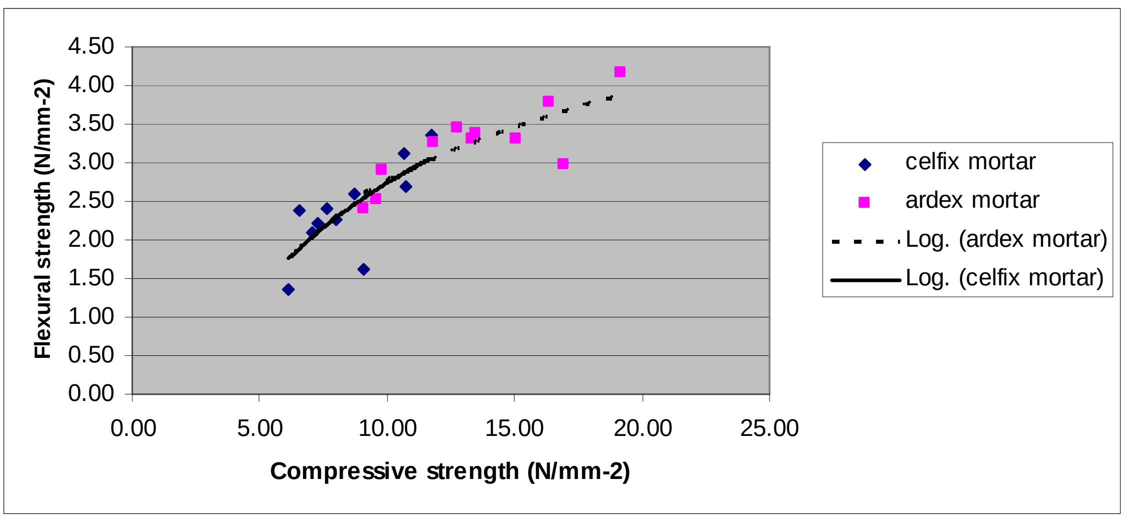

Figure 3. Relationship between compressive and flexural strength of mortar.

Masonry bond properties

The impact of construction technique on bond strength. A small programme of testing was initially undertaken to determine the optimum bond with polymer modified mortars. Traditionally, mortar is placed on the bed joint of the lower unit and a second unit is then placed directly onto that mortar bed, so bonding the two units together. With polymer modified mortars, a skin very rapidly forms over the mortar so it was thought that delay in placing the upper unit when building in the traditional manner could result in reduced bond at that interface. To overcome this a technique described as the scoop and trowel was used. A

3mm thin layer of mortar was laid on the lower unit as is common practice. Then a 1mm thick layer was trowelled onto the lower face of the upper unit just prior to laying. This meant that the final bond was formed between two mortar faces and represented the maximum or optimum bond strength possible. To verify this a set of B-wallettes were constructed traditionally and then using the scoop and trowel method and tested at 7 days age. The scoop and trowel method resulted in a 37% increase in tensile flexural strength. As a result all subsequent work was undertaken using the scoop and trowel method of construction.

The impact of early age heating and age on the bond strength of masonry formed using polymer modified mortars. The bond strength of the masonry was determined using the bond wrench test in accordance with BE EN 1052 – 5 : 2005 at a range of ages. Two test programmes of work were undertaken. In the first, two-high couplets were constructed and cured under polythene until testing. All specimens had three concrete units placed on top after being wrapped in polythene. With the second programme of testing two-high couplets were again constructed, then cured in an oven for variable numbers of days (x days – see figures 5 and 6) after which the specimens were removed and when cool wrapped in polythene, pre-loaded with three concrete units and tested at 28 days using the bond wrench. Concrete and aircrete units were heated to 70^{o}C and all others to 105^{o}C.

The effect of age on masonry strength

Figure 4 is a plot of bond strength vs. age for the specimens cured under polythene. With Aircrete the 8 day strength of the couplets was very nearly that achieved at 28 days. The strength increased at 56 days but this may be due to the natural variations that exist in masonry. The bond strength achieved from 8 days was equivalent to the tensile flexural strength of the unit material and further improvement in bond will not produce additional benefits. Observations indicated the failure mode of aircrete after 8 days was through the units. With clay and concrete bricks the bond increased up to 14 days but erratically with the concrete and rough red bricks and levelled off after that. With these bricks, mean bond strengths of between 2.0 and 2.5N/mm^2 were determined at 28 days. Table 3 shows the characteristic strengths at 14 and 28 days for all unit types together with the recommendations from the British and European codes.

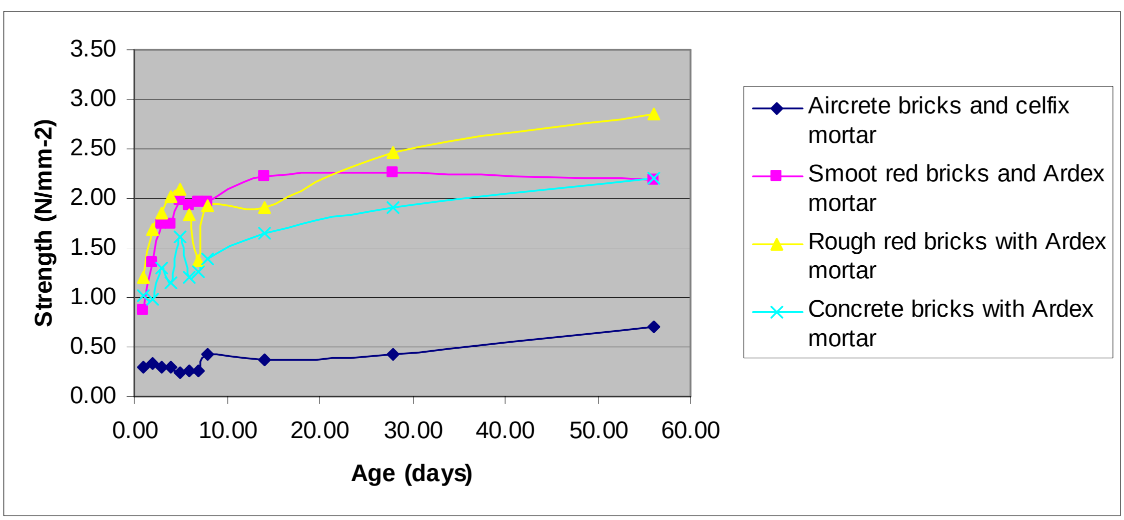

Figure 4. Effect of age on bond strength. (Specimens cured under polythene until testing)

Table 3. Characteristic bond strength of masonry by testing and British and European Standard recommendations.

	Characteristic test data Age (days)		EN 1996-1-1 : 2005		BS 5628 Part 1 : 2005 And National annex to BS EN 1996-1-1 : 2005	
Unit type	14	28	Conventional mortar	Thin layer mortar	Conventional mortar	Thin layer mortar
Aircrete	0.21	0.32	0.05	0.15	0.25	0.25
Smooth red brick	1.82	1.10	0.10	0.15	0.5	0.7
Rough red brick	1.23	1.46	0.10	0.15	0.4	0.5
Concrete brick	1.11	1.39	0.05	0.2	0.25	0.25

Aircrete results are broadly in agreement with code recommendations given in the UK and the UK annex to the European code but European recommendations are low compared to the test results. With the smooth and rough red clay units the characteristic bond strength of thin layer mortar as recommended by the British code and the British annex to the European code was 0.7 and 0.5N/mm^2 but test results gave value at 28 days of 1.1 and 1.46N/mm^2 respectively. Test results were 1.6 and 2.9 times the recommendations from the UK and using the UK annex to the European code for the two units. The recommendations from the European code are only 0.15N/mm^2 and may need to be revised in the light of British practice. A similar trend was noted for the concrete bricks, but with test results exceeding code values by 5.5 times.

Figure 5 indicates the effect of the oven treatment on bond strength for the four units examined and Figure 6 compares the bond of oven treated and polythene wrapped concrete and Aircrete specimens. In Figure 5, the clay units and concrete bricks maintain reasonable strengths when exposed to oven treatment for less than a week but thereafter the bond declines rapidly. In Figure 6 the strength of oven treated specimens exceeds that of the specimens under polythene until age 8 days. With the Aircrete the oven treated specimens show an increase in strength to 5 days but this is unlikely to increase as it is approaching the unit flexural strength.

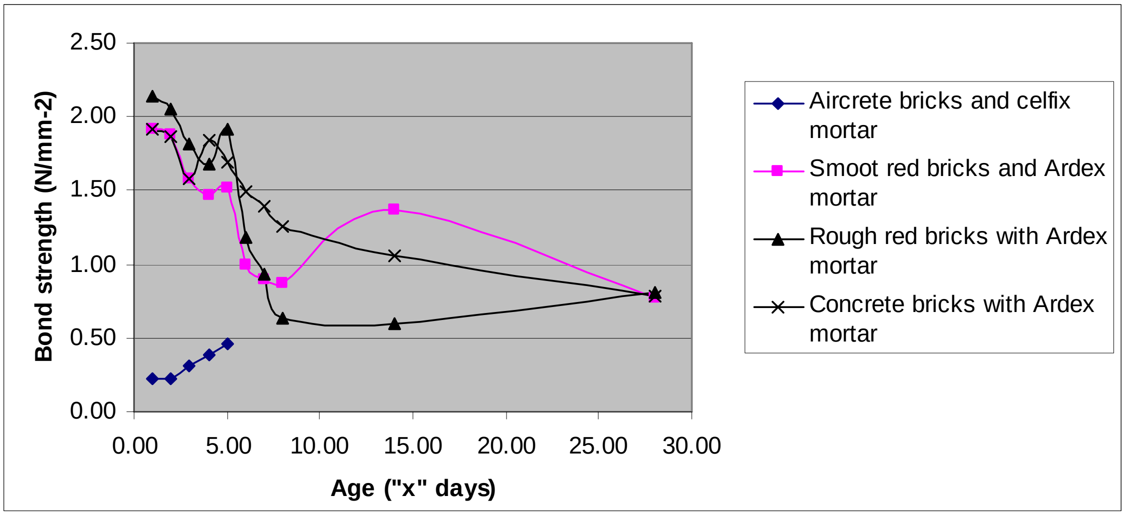

Figure 5. Effect of age on bond strength. (Specimens cured in oven for "x" days then under polythene until 28 days)

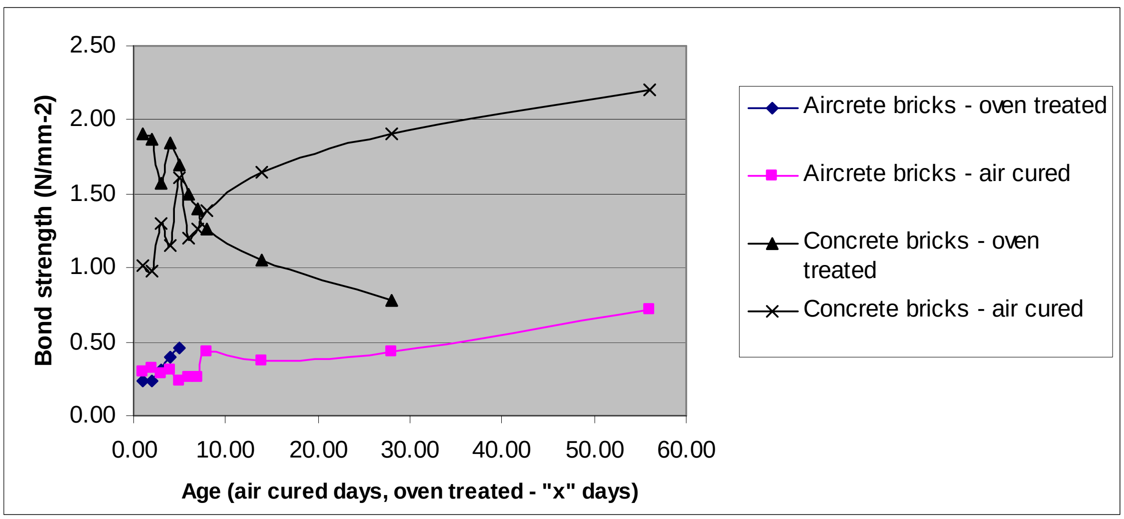

Figure 6. Comparison of bond strength of air and oven treated couplets. (Aircrete and concrete bricks)

Figure 7 indicates the impact of increased temperatures on the bond strength of masonry. Overall the findings can be summarised as follows. When clay specimens are heated at an early age for two or three days, the bond strength at 28 days is improved when compared to units cured at room temperature under polythene for the full 28 days. If these specimens are left in the oven for more than 3 days, the strength at 28 days is lower than for specimens cured under polythene at room temperature. With concrete units a similar trend occurs but the beneficial effect of the oven heating continues for up to 1 week. Unfortunately Aircrete specimens were only tested to 5 days but the oven treatment was beneficial at all stages.

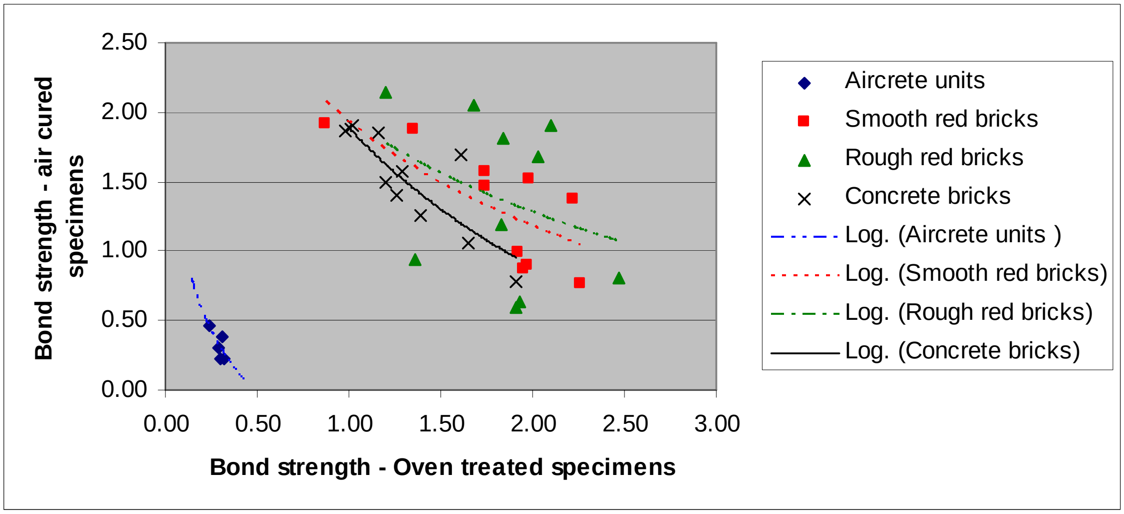

Figure 7. Effect of oven treatment on bond strength

CONCLUSIONS

1. Bond in thin layer masonry is improved by applying thin layers of mortar to each bedding face and forming the final joint between mortar and mortar, rather than bonding unit to mortar as is traditional.
2. Thin layer mortars exhibit erratic strength gain in both compression and flexure up to one week but thereafter, strength gain is at a steadily decreasing rate.
3. The seven day strength of both mortars in either compression or flexure was at least 67% of the 28 day strength.
4. A non linear logarithmic relationship appears to exist between the flexural and compressive strengths of thin layers mortars but with some scatter.
5. The characteristic bond strength of aircrete masonry formed with polymer modified mortars was nearly equivalent to that recommended in the UK National Annex to the Eurocode and those values given in BS 5628 : Part 1 : 2005.
6. The characteristic bond strength of clay units formed with polymer modified mortars was between 1.6 and 2.9 times the value recommended in the UK National Annex to the Eurocode and those values given in BS 5628 : Part 1 : 2005.
7. The characteristic bond strength of concrete units formed with polymer modified mortars was 5.5 times the value recommended in the UK National Annex to the Eurocde and those values given in BS 5628 : Part 1 : 2005.
8. Treating clay masonry built with thin layer mortar to elevated temperatures (105^{o}C) for the three days after building and then wrapping in polythene at room temperature until testing at 28 days increased the bond strength above that achieved when similar masonry was cured for the full 28 days under polythene. A similar increase in bond occurred with concrete units heated for up to seven days. Prolonged heating caused severe loss of bond with all unit types.

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REFERENCES

BS EN 772 – 1 : 2000, British Standards Institution. “Methods of test for masonry units – Part 1 : Determination of compressive strength.”

BS EN 772 – 11 : 2000, British Standards Institution. “Methods of test for masonry units – Part 11 : Determination of water absorption of aggregate concrete, autoclaved aerated concrete, manufactured stone, and natural stone masonry units due to capillary action and the initial rate of water absorption of clay masonry units, incorporating amendment 1”.

BS EN 772 – 13 : 2000, British Standards Institution. “Determination of net and gross dry density of masonry units (except natural stone)”.

BS EN 1015 – 3 : 1999, British Standards Institution. “Methods of test for mortar for masonry – Part 3. Determination of consistence of fresh mortar (by flow table)”.

BS EN 1015 – 4 : 1999, British Standards Institution. “Methods of test for mortar for masonry – Part 4. Determination of consistence of fresh mortar (by plunger penetration)”.

BS EN 1015 – 11 : 1999, British Standards Institution. “Methods of test for mortar for masonry – Part 11 : Determination of flexural and compressive strength of hardened mortar”.

BS EN 1052 – 5 : 2005, British Standards Institution. “Methods of test for masonry – Part 5 : Determination of bond strength by the bond wrench method”.

BS EN 1996 – 1 – 1 : 2005, British Standards Institution. “Eurocode 6 – Design of masonry structures – Part 1 – 1 : General rules for reinforced and unreinforced structures”.

BS 4551 – 1 : 1998, British Standards Institution. “Methods of testing mortars, screeds and plasters. Physical testing”.

BS 5628 – 1 : 2005, British Standards Institution. “Code of practice for the use of masonry – Part 1 : Structural use of unreinforced masonry”.

NA to BS EN 1996 – 1 – 1 : 2005, British Standards Institution. “UK National Annex to Eurocode 6 : Design of masonry structures – Part 1 – 1 : General rules fro reinforced and unreinforced structures”.