INFLUENCE OF MORTAR PROPERTIES ON THE TENSILE BOND STRENGTH OF BRICK MASONRY

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ABSTRACT: This paper reports on a parametric study comprising over 1100 tests to determine the influence of mortar properties on the flexural tensile bond strength of brick masonry. The results show that there can be considerable effects of sand gradation, different combinations of Portland Cement and Lime or Masonry Cement, flow of the mortar, and age. In addition water retentivity, air content, and strength of the mortars were measured as were the absorption and strength properties of the bricks. While certain influences were quite apparent, it does not seem possible to advance beyond qualitative guidelines for the effects of these factors on flexural tensile bond strength.

1. INTRODUCTION

Modern day practices regarding flexural tensile bond strength of brick masonry contain many inconsistencies. Conclusions from various research projects are also often contradictory. It is from this confused and confusing background that proposals have linked tensile bond strength to properties such as; compressive strength of prisms, mortar types or compressive strengths, initial rates of absorption and other characteristics of the bricks, water retentivity of mortars, and type of construction supervision. In some cases the solution simply has been to adopt very low design strengths. This complex situation has been further complicated by the high variability of tensile bond, by the fact that standard beam type tests have not provided a representative statistical sample, and by attempts to arbitrarily calibrate tensile bond strengths with experience on the flexural strength of walls.

This paper uses the results from a current parametric test program as background for preparation of proposals for different solutions to this problem.

2. EXPERIMENTAL PROGRAM

2.1 Range of Tests

A limited parametric study was carried out to gain additional direct experience and insight into factors affecting flexural tensile bond strength. The aims were to identify trends or relationships associated with tensile bond and to further document findings from the forerunner of this program (1). Two types of bricks having fairly similar properties were tested in combination with a much greater range of mortars. In addition to different combinations of Portland Cement (PC), Masonry Cement (MC), Lime (L), Sieved Sand (SS), and Masonry Sand (MS), water content was varied to obtain different levels of mortar flow. The age of testing was also included as a variable.

2.2 Fabrication of Specimens

The test specimen was a seven brick high prism constructed in a stack pattern. All joints were tooled using a 5/8 in. (15 mm) cylindrical jointer. Mortar was batched by weight to assure consistent mix properties. The dry weight of each batch was limited to 30 kg since mortar left over after 30 minutes was thrown out. After the water content had been adjusted to obtain the desired flow, no retempering of the mortar was permitted. Because flow was very sensitive to moisture content, individual batches were said to have the desired flow when the

measured value was within 3%. Three 2 in. (51 mm) cubes of mortar were prepared from each mortar batch. In addition water retentivity and air content tests were performed on each mortar type.

2.3 Properties of the Mortars and Mortar Materials

2.3.1 Proportions. Table 1 lists the mix proportions. For the Type S mortars it was intended to document the influence of Lime versus Masonry Cement and Sieved Sand versus Masonry Sand for flows of 110, 120 and 130%. However in the case of the sieved sand, the 130% flow did not provide a usable mortar. For the Type N mortars only flows of 120% were prepared.

2.3.2 Cementitious Materials. Normal Portland Cement corresponding to Type 10 in CSA Standard A5 was used. The Masonry Cement was a popular brand which satisfied CSA Standard A8. Hydrated lime was used in the dry form.

2.3.3 Fine Aggregate (Sand). Figure 1 shows the gradation limits for sand appropriate for use in mortars. However most commercially available masonry sands tend toward the fine boundary or in some cases fall outside this limit. The dashed line in Figure 1 is the gradation for the usual Masonry Sand (MS) available in Hamilton, Ontario. In order to produce a sand which fit mid way between the gradation limits, it was necessary to sieve the larger size particles from an available concrete sand. The dashed-dot line is gradation for this Sieved Sand (SS).

2.3.4 Properties of the Mortars. Initially larger ranges of flows were to be incorporated. However, flows less than 110% were not sufficiently workable for good brick laying and flows of 130 were an upper limit for sufficient stiffness to support the bricks. As shown in Table 1, mortars made with Masonry Cement had higher air contents than those made with Portland Cement and Lime. (Note: The mortar was mixed by hand which probably minimizes the air content.) Mortars made with finer Masonry Sand tended to have slightly higher air contents than corresponding mortars using the coarse Sieved Sand. Within each type of mortar there was some flow which tended to produce water retentivity near the preferred 70 to 75% range. However, since flow was very sensitive to small adjustments in water content large variations in water retentivity within each category of mortar were not surprising.

The 28 day compressive strengths of mortar cubes indicate that mortars made using Sieved Sand are stronger than similar mixes made using Masonry Sand. Also, mortars made with Masonry Cement tended to have lower strengths than similar mortars made with Portland Cement and Lime.

2.4 Properties of the Bricks

Table 2 contains the properties of the two types of bricks used in this study. They have the standard nominal 90mm x 190mm bed joint area and 57mm height. Three circular holes reduce the cross section by 15 percent. The bricks were very similar with the only significant differences being colour and initial rate of absorption (IRA).

2.5 Compressive Strength of Prisms

Table 3 contains the results of compression tests of 4 brick high prisms at 28 days age. Comparisons show that higher prism strengths correlate with higher mortar strengths. Also the prisms made with the Brown Brick tended to be slightly stronger.

TABLE 1
MORTAR

Designation	Mix Proportions[a]					Properties			
	Portland Cement	Masonry Cement	Lime	Sieved Sand[c]	Masonry Sand[c]	Flow[b] (%)	Air Content (%)	Water Retentivity (%)	28-day Cube Strength(MPa)[d]
S_1	1.0		0.5		4.0	110	9.0	69.2	12.45
			(0.2)		(4.81)	120	8.2	67.8	12.12
						130	7.1	55.8	10.57
S_2	1.0	2.0			8.0	110	13.0	64.5	12.50
		(1.45)			(9.58)	120	12.0	59.5	9.67
						130	12.0	69.0	11.03
S_3	1.0	2.0		6.34		110	11.0	65.1	17.21
		(1.45)		(8.0)		120	12.0	70.7	20.19
S_4	1.0		0.5	3.36		110	6.0	63.6	20.76
			(0.2)	(4.2)		120	4.5	75.6	19.15
N_1	1.0		1.0		6.0	120	7.5	56.3	5.13
			(0.39)		(7.22)				
N_2		1.0			3.0	120	11.0	63.8	2.78
					(4.96)				
N_3		1.0		3.0		120	12.0	65.0	5.10
				(5.20)					
N_4	1.0		1.35	5.68		120	6.4	59.3	9.05
			(0.54)	(7.16)					

[a] Values are given as volumes and bracketed terms are weights, which were used for better quality control. All weights are relative weights with respect to the Portland Cement (PC) [or Masonry Cement (MC) where applicable].

[b] Flows were ± 3% for all the mortars.

[c] Sand proportions were adjusted to give better workability where possible.

[d] Average of 8 to 12 tests.

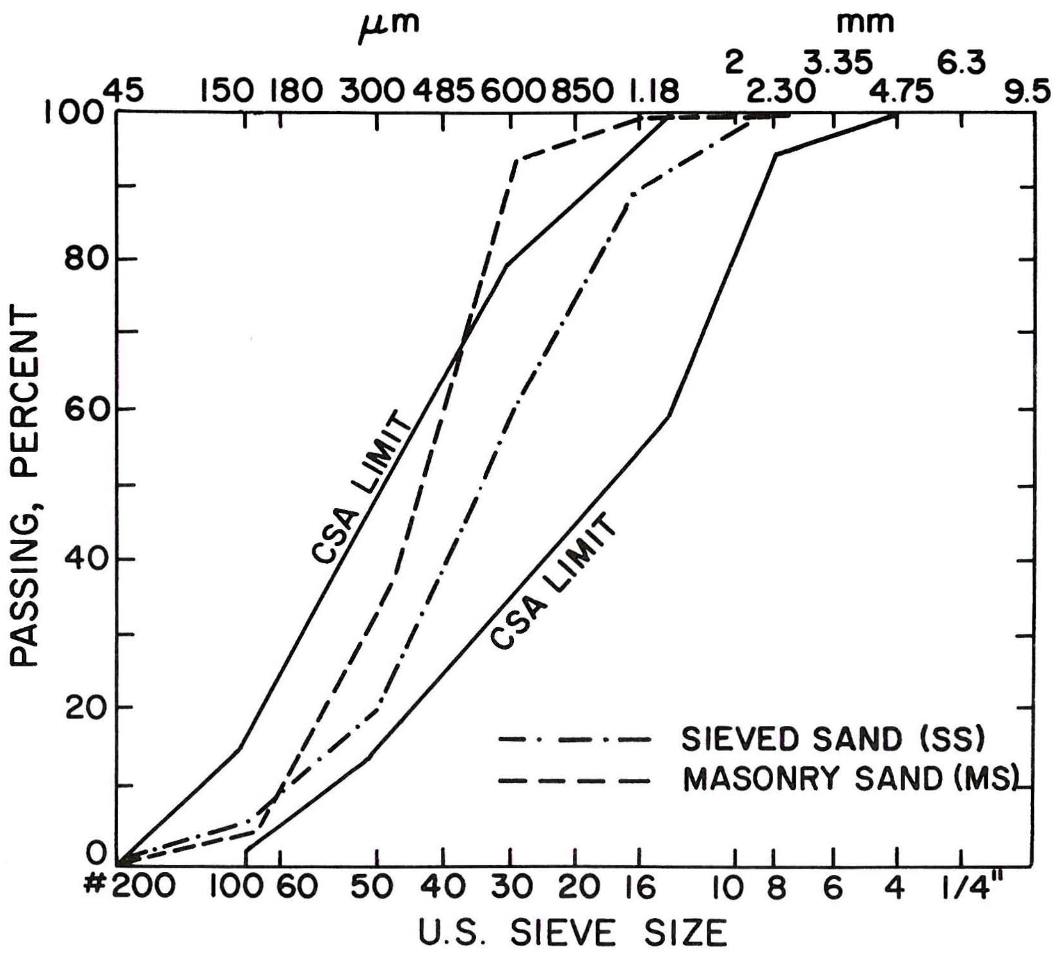

Figure 1 **GRADATION OF MORTAR SANDS**

TABLE 2

BRICK PROPERTIES

Brick	Symbol	IRA[b] (kg/m²/min)	Oven Dry Density[b] (kg/m³)	Compressive Strength[a,b] (MPa)
Brown Brick	N	0.33	2058	118.9
Red Brick	0	0.28	2097	118.4

[a] Compressive test performed on half bricks.

[b] Area of brick used was net area (nominal area less the area of the three holes).

TABLE 3

BRICK PRISM DATA

Mortar	Flow	Brick Type	28-day Prism Compression Strength (MPa)[a]	Mean Bond Strength in MPa at Age Shown[b] (Coefficients of Variation are in Brackets) 2 Days	28 Days	90 Days	1 Year
	110	N	26.8	-	1.19 (17)	-	0.93 (36)
		O	23.6	-	0.63 (25)	-	0.60 (45)
S_1	120	N	30.2	0.92 (30)	0.97 (21)	1.35 (27)	1.14 (38)
		O	27.5	0.57 (30)	0.63 (15)	0.81 (16)	0.87 (41)
	130	N	24.5	-	0.89 (21)	-	1.54 (26)
		O	24.8	-	0.51 (16)	-	0.91 (25)
	110	N	25.5	-	0.73 (23)	-	0.80 (26)
		O	29.4	-	0.45 (26)	-	0.39 (29)
S_2	120	N	27.5	0.51 (28)	0.69 (10)	0.96 (46)	1.09 (28)
		O	26.2	0.57 (28)	0.65 (19)	0.78 (22)	0.91 (30)
	130	N	26.5	-	0.83 (11)	-	1.01 (20)
		O	30.4	-	0.81 (14)		1.09 (34)
	110	N	32.7	-	0.59 (22)	-	0.60 (23)
		O	32.6	-	0.43 (20)	-	0.35 (12)
S_3	120	N	36.2	0.73 (13)	0.60 (18)	0.71 (29)	0.86 (16)
		O	30.1	0.60 (14)	0.42 (24)	0.68 (41)	0.42 (14)
	110	N	35.9	-	0.60 (27)	-	0.90 (31)
		O	29.2	-	0.56 (15)	-	0.60 (16)
S_4	120	N	37.3	0.76 (34)	0.55 (31)	0.91 (22)	0.92 (22)
		O	33.7	0.47 (21)	0.59 (10)	0.87 (22)	0.95 (19)
N_1	120	N	21.8	-	0.94 (20)	-	1.28 (32)
		O	21.0	-	0.82 (26)	-	0.81 (30)
N^2	120	N	19.2	-	0.72 (15)	-	0.92 (25)
		O	18.0	-	0.62 (34)	-	1.05 (41)
N_3	120	N	18.9	-	0.55 (16)	-	0.76 (33)
		O	18.1	-	0.55 (17)	-	0.68 (34)
N_4	120	N	27.2	0.43 (36)	0.74 (24)	-	1.10 (27)
		O	25.5	0.72 (16)	0.59 (27)	-	1.41 (28)

a Prism strength is based on nominal area of 90 mm x 190 mm and 2 to 4 tests.
b Bond strength is the mean of 12 to 15 results.

2.6 Flexural Tensile Bond Strengths

The use of the Bond Wrench (2) was adopted. This method provides an unbiased statistical sample since all joints are tested (3,4). The bond wrench had a lever arm of 1838mm from the centre of the brick. The length of time for loading each joint to failure was in the order of 1 minute as sand was gradually poured into a pail suspended from the end of the bond wrench. Table 3 contains the mean flexural tensile bond strengths and the corresponding coefficients of variation for each series. In almost all cases 15 joints were tested for each result in the table. The brick prisms were constructed in late summer of 1983 and have been stored at nearly contant temperatures near 20 C but with relative humidities ranging from as low as 20% at times during the winter up to 80% during humid periods in the summer. Practical considerations resulted in 2 day and 90 day tests being limited to 120% flows for the Type S Mortars.

3. DISCUSSION OF TEST RESULTS

3.1 Basis for Interpretation

To quantify observations, it was decided that the T-test for paired data provided the most appropriate form of statistical comparison. This procedure eliminates the effect of test to test variations and reduces the influence of any bias in the selection of the combinations of test parameters. However lack of pairing in some cases eliminated results from this evaluation. As a check on the effect of including all data, a normal distribution with a coefficient of variation of 30% was used to establish the confidence interval for comparison of effects of varying individual parameters. This analysis gave essentially the same results as the T-test for paired data except that it indicated more significance of mortar flow.

3.2 Effect of Flow

The 28 day and 1 year data in Table 3 was reproduced in Figure 2 for Type S mortars. Statistical analyses shown that strengths for 120% flow are better than for 110% flow at the 95% confidence level. At the 90% confidence level, no significant difference was found for 130% versus 120% flow but there was a significant improvement in strength for the 130% versus 110% flow.

3.3 Effects of Materials and Mortar Proportions

3.3.1 Masonry Cement Versus Lime. Figure 3 contains a bar chart of the 28 day and 1 year strengths for the Type S mortars. Figure 4 is a similar presentation for the Type N mortars which had been limited to the 120% flow. The results have been plotted for mortars arranged in decreasing sequence of flexural tensile bond strength. The analysis indicated that use of lime provides significantly better bond than Masonry Cement at the 99.9% confidence level.

3.3.2 Masonry Sand Versus Sieved Sand. In a similar manner to that above, comparison of S_1 to S_4, S_2 to S_3, N_1 to N_4, and N_2 to N_3 shows that at the 99% confidence level, Masonry Sand would be expected to provide higher flexural tensile bond strengths than Sieved Sand.

3.3.3 Brown Versus Red Brick (N versus O). The T-test for paired data showed that the flexural tensile bond strength would be expected to be significantly better for the brown brick than for the red brick at a 99.9% confidence level.

3.3.4 Type N versus Type S Mortar. Analysis of the data indicates that no significant difference in strength exists between Types N and S mortar at the 90% confidence level.

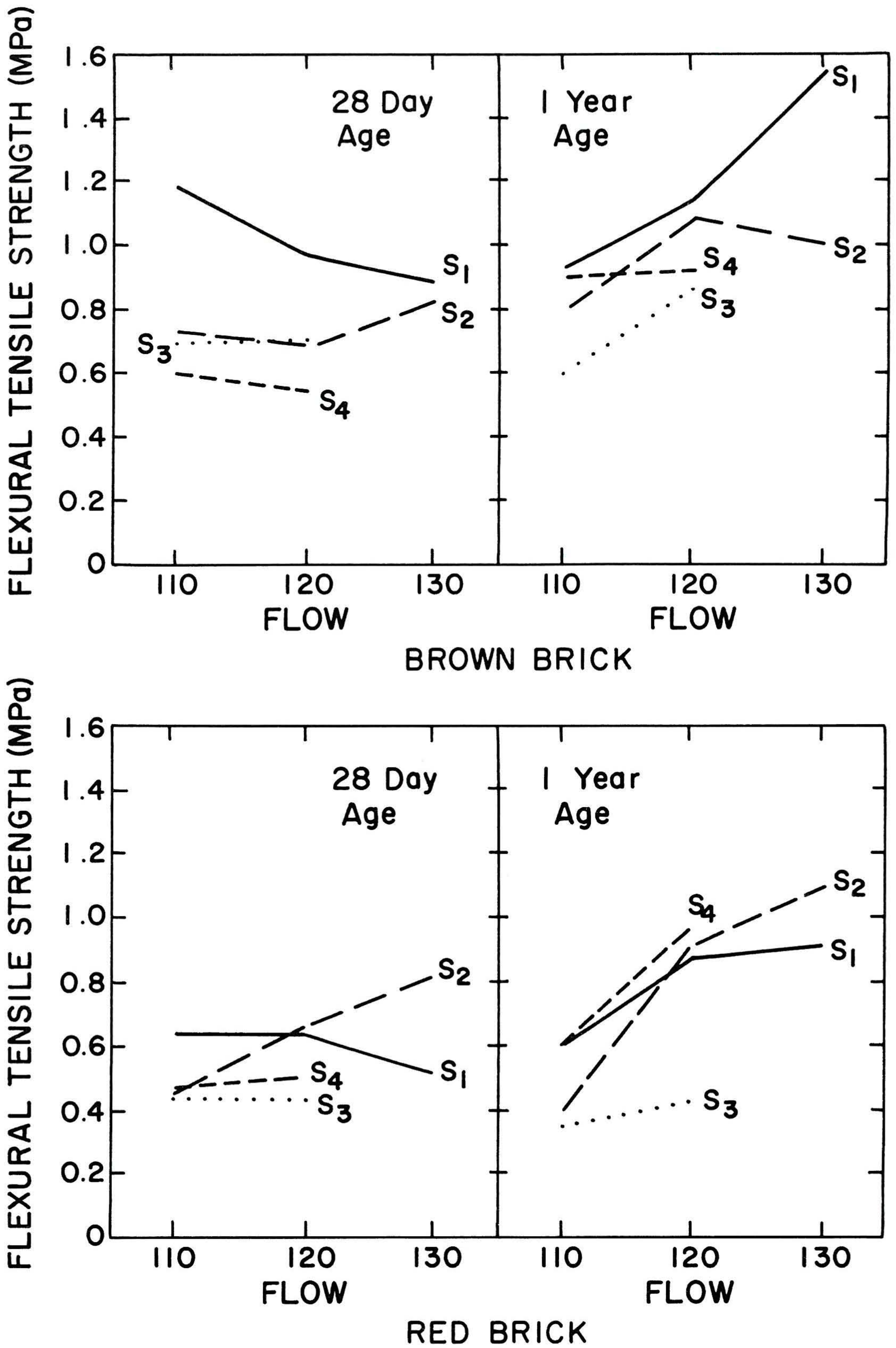

Figure 2 **STRENGTH VERSUS FLOW FOR TYPE S MORTARS**

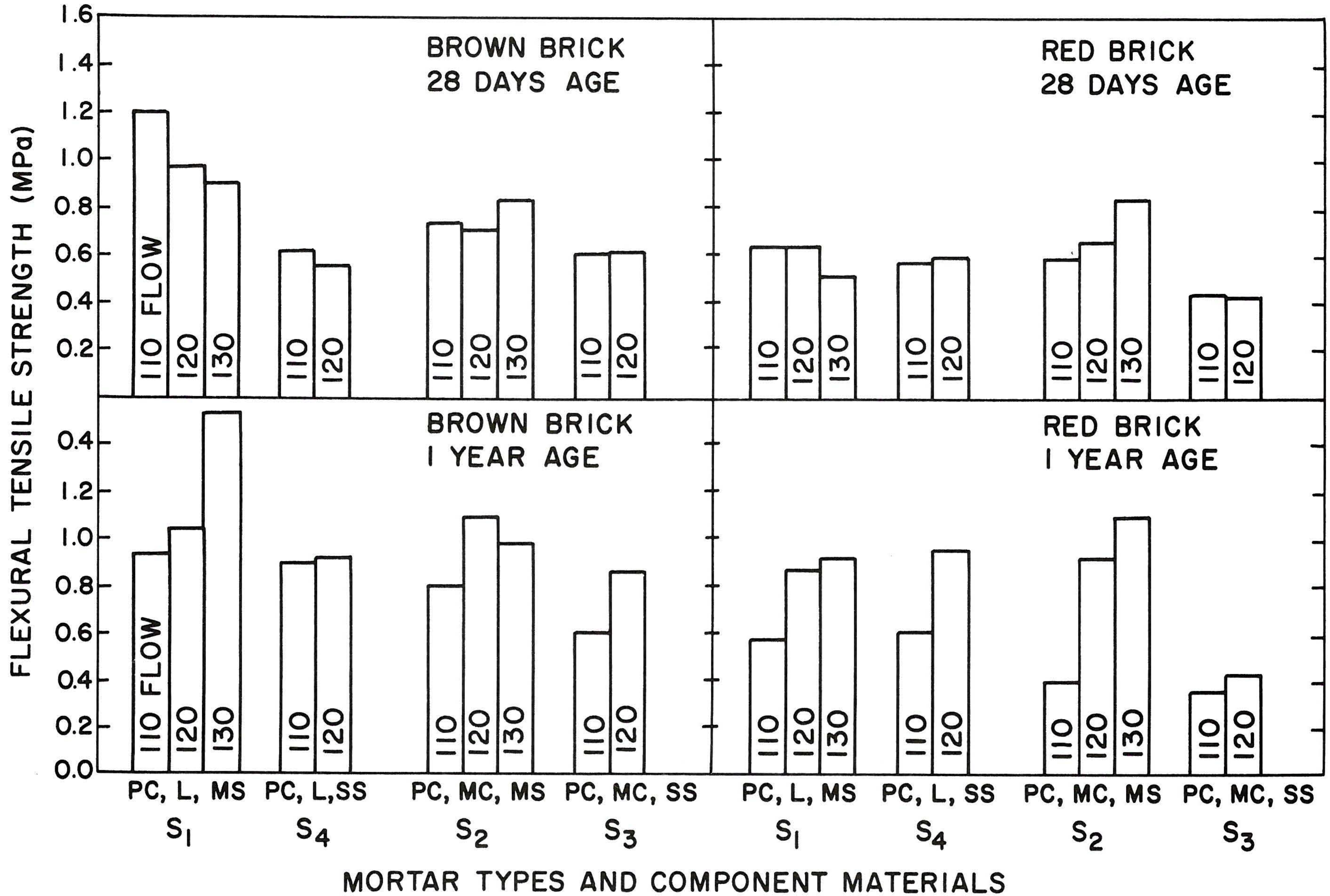

Figure 3 INFLUENCE OF MORTAR MATERIALS ON BOND STRENGTH

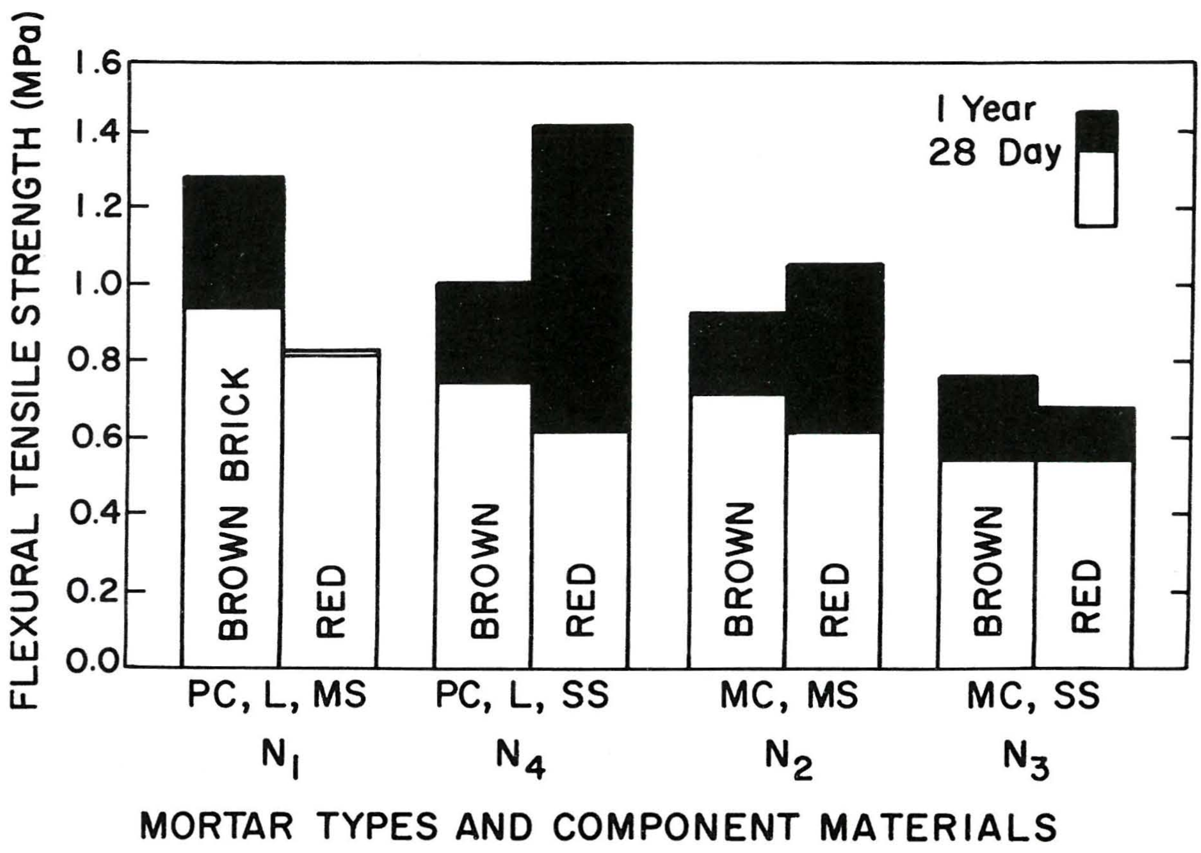

Figure 4 **INFLUENCE OF MORTAR MATERIALS ON BOND STRENGTH**

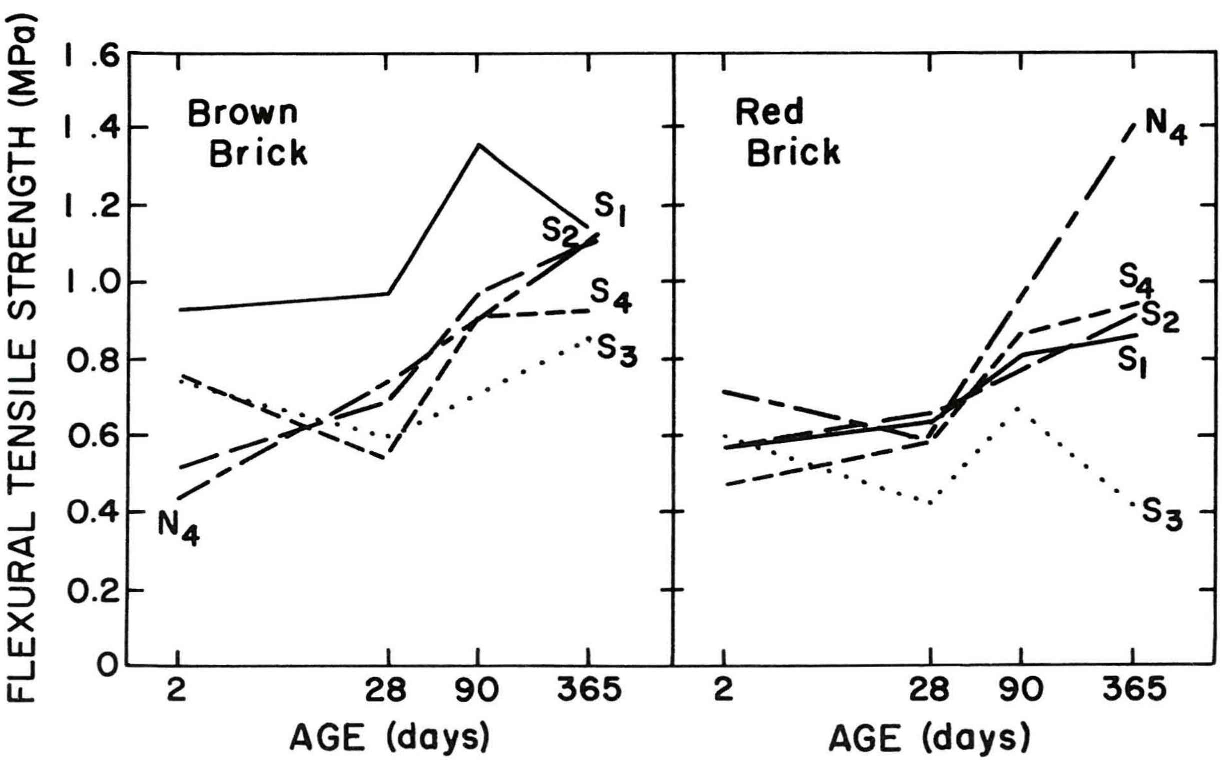

Figure 5 **STRENGTH VERSUS AGE FOR 120% FLOW MORTARS**

3.4 Effect of Age

Figure 5 contains the data for specimens tested at 2 days, 28 days, and 1 year. Tests were also performed at 90 days for the Type S mortars shown. The results show that at the 99.9% confidence level there is a significant difference in bond at 365 days compared to 28 days. Analysis of the data indicates that at the 90% confidence level, there is no significant difference between the 2 day and the 28 day strengths.

4. CONCLUSION

4.1 General Discussion

The great differences in allowable design stresses for flexural tension normal to the bed are typified by the 0.07 MPa value in the Australian Code (5) and the 0.25 MPa or 0.19 MPa values for S and N mortars respectively in the Canadian Code (6). The large differences in observed strengths (7,8) and the high variability seem to be an unavoidable characteristic. Review of available data indicates that there is no solid basis for relating tensile bond strength to compressive strengths of mortar cubes or brick prisms. Similarly, while certain trends can be identified, it seems unlikely that unique relationships exist to quantify the effects of other properties of the mortars or masonry units. Therefore it seems sensible that writers of building codes should seek a different solution to this complicated problem.

4.2 Conclusions and Recommendations

4.2.1 Allowable Stresses. If characteristic strength is defined as the mean minus 1.5 standard deviations, the characteristic flexural tensile bond strengths for many combinations of bricks and mortars are of the same order of magnitude as currently specified allowable working stresses in North America. Alternately, the extremely low design stresses specified in some other parts of the world result in very conservative designs for many cases. It is suggested that neither approach is in the best interest of both the competitiveness of the brick industry and public safety or investment.

An alternative approach is to require testing to be undertaken to qualify combinations of bricks and mortars to use certain levels of design stresses. This approach would remove the need to accommodate the least appropriate combinations of materials within a single design stress. In addition it would focus the attention of manufacturers, designers and builders on the property which generally should be the principal concern. In this context experience will quickly accumulate to guide designers toward choosing the appropriate materials to satisfy particular design requirements for flexural tensile bond.

4.2.2 Quality Control During Construction. Compressive strengths of mortar cubes or control of batch proportions are standard methods of quality control for masonry. In many situations both of these may be waived if specified compressive strengths of prisms are satisfied. While compressive strength may be the controlling factor for some situations, it is known that the compressive strength of brick prisms is not highly sensitive to the compressive strength of the mortar. Therefore in most cases the content of cementitious material required for workability of the fresh mortar and durability of the hardened mortar will be more than adequate for compressive strength requirements. Hence confirmation of compressive strength by prism tests may only be necessary in relatively few cases.

It is suggested that the Bond Wrench be adopted as the standard field control test. Use of a 1.2m lever arm would permit on site testing with manageable requirements for loading mass. In addition, tests indicate that flexural tensile strengths at 2 days age can provide a good indication of the strength at later ages. Therefore field testing could be conducted in time to permit faulty construction to be replaced with a minimum of disruption.

4.2.3 Guidelines for Mortar Mix Materials and Proportions. Although qualification testing would in itself lead to preference for certain materials, some general guidelines can be provided. These are:

a) Sand gradations near the coarse limits are not suitable either for workability or bond strength. As long as the percentages passing the finest sieves are not increased, finer sands have been shown to be satisfactory.

b) Higher flows will normally result in better mortar bond.

c) While good bond can be achieved with Masonry Cement, tests indicate that Portland Cement and Lime mortars are likely to have better flexural tensile bond properties. In addition the influence of higher air contents on permeability and durability of mortars needs more investigation. Therefore, while it would be premature to attempt to provide a definitive statement on the relative merits of cementitious materials, it is recommended that more research be conducted on this topic.

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