EFFECT OF FINES CONTENT OF SAND ON TENSILE BOND

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ABSTRACT. The paper deals with a project carried out at the Polytechnic of the South Bank involving the testing of two types of mortar, at two different consistencies, made with two types of sand both in their natural state and where the percentage of fines has been artificially increased.

Bond tests using some 320 wallettes and 350 couplets all made with a plain clay brick of medium strength and water absorption, are analysed and any relationship to the sand grading and mortar properties is examined.

1. OBJECT OF THE PROJECT

The fact that many traditionally used building sands do not conform with grading limits set by standards and that standards are under review, has led to an interest in the study of the effect of the grading and other characteristics of sand on the performance of masonry, with particular attention being paid to flexural strength and tensile bond.

The authors (1) carried out a programme of bond testing with a range of mortar mixes using four distinctly different sands and the results indicated that the higher the fines content the lower the bond strength. The results also showed that compressive strength of mortar was not a reliable indicator of tensile bond.

A further programme (the subject of this paper) has now been undertaken in which only two sands were used and variations in the fines content was obtained by adding various proportions of inert silica flour to give sands with 5, 7.5, 10, 12.5, and 15% fines below 75 micron particle size (by weight).

The paper shows the effect of these variations on the properties of the fresh and hardened mortar, i.e. density, consistency, workability, air entrainment, crushing strength and modulus of rupture. The bond strength studies show the results of tests on "bed joint" wallettes in accordance with BS 5628(2) and crossed brick couplets in accordance with ASTM C952(3). Only one brick type was used in the programme and this was selected as it was a medium strength clay brick without holes, cores or frogs.

2. MATERIALS USED AND TESTS CARRIED OUT.

2.1 Bricks

A lightly rusticated multi-red sand faced clay brick which was tested for compressive strength in accordance with BS 3921(5). Water absorption, 24 hour soak and 5 hour boil in accordance with BS 187(6). Suction rate in accordance with ASTM C 67-81(7).

2.2 Sands

A moderately coarse graded sand (Westwood), falling in the category S zone of the revised BS 1200(4) and a finer sand (Nutfield), falling in the category G zone. Particle size distribution was determined by sieving the washed sand in accordance with BS 812(9) and amendment to BS 1200(4). Clay and silt contents were obtained by the Field test and sedimentation (Andreason Pipette) methods - BS 812(Part 1), bulk density and bulking by BS 812(Part 2). Moisture content by the "Speedy" (calcium carbide) apparatus.

2.3 Cement & Lime

Purchased in standard 50 kg bags.

2.4 Silica Flour

Obtained in plastic bags from British Industrial Sand Ltd. and classified as HPF3 grade. The material consisted of 98.5% silica dioxide. 95% passed a 75 micron sieve and 40% passed a 20 micron sieve.

2.5 Mortars

Two cement, lime, sand mortars were used, one each of designation (i) & (iii) as specified in BS 4551(8) & BS 5628(2) namely 1:1/4:3 by volume and 1:1:6 by volume. Using the following densities, cement 1450 kg/m^3; lime 575 kg/m^3 and sand 1600 kg/m^3; the mix proportions by weight adopted were 1:0.1:3.31 and 1:0.4:6.62 respectively. This gave cement to dry mortar ratios of 22.7% and 12.5% respectively.

Sufficient water was added to give two consistencies of mortar, as measured by a dropping ball number of 10 $\pm$ 0.2mm and 13 $\pm$ 0.2mm.

2.6 Mortars with increased fines

Silica flour in quantities to give the desired percentage of fines in the 'adjusted' sand was added slowly to the sand in the pan mixer to give thorough distribution. The cement to dry mortar ratio was kept constant i.e. the dry sand weight was reduced by the amount of the added silica flour.

2.7 Tests on Fresh Mortar

The following tests were carried out in accordance with BS 4551(5) on every batch of mortar used. Consistence by both

dropping ball and flow table methods. Consistence retentivity and water retentivity. Air content by the pressure method. Stiffening rate. Density and water cement ratio.

2.8 Tests on Hardened Mortar

Specimens were prepared from every batch of mortar & cured in tap water at 20°C ± 2°C for 28 days and tested in accordance with BS 4551(5). 100mm cubes for compression tests. 100 x 25 x 25mm specimens for modulus of rupture and "equivalent" cube tests. 500x100x100 beams in accordance with BS 1881 (11). "Figure of eight" direct tension briquettes (as ASTM C190-82(10)).

2.9 Tensile Bond Tests

Sets of 10 bed joint wallettes were prepared in accordance with BS 5628 Part 1 (2) for each of the mortar mixes (i.e. both sands, both mix proportions with both consistencies, with the natural sand and with the fines passing 75μm sieve adjusted to give 7.5% 10% 12.5% and 15% fines. The 7.5% and 12.5% cases were omitted for DB10) The total number of wallette specimens was therefore 320. They were cured for 28 days in close fitting polythene covers in the laboratory and then tested in the standard test rig (span 650mm, 2 line loads at 390mm centres). Graphs of load against deflection were plotted for each wallette.

For each set of wallettes a corresponding set of couplets [in accordance with ASTM standard C952-1976 (3) as modified by the authors (1)] was made. They were cured under a polythene cover on a laboratory bench for 28 days and then tested in the couplet testing rig by a jack. Graphs of load against vertical deformation (from top face of upper brick to top face of lower brick) were plotted.

An additional 45 couplets, in sets of five using Nutfield sand, the 1:.1/4:3 mix at DB13 with 5%, 10% and 15% fines (<75μm) content and with bricks that had been preconditioned to have 0%, 3% and 6% moisture content were prepared. These were similarly cured and tested at 28 days. In order to eliminate as far as practicable, the effect of the time that the mortar had been standing on the spot board one couplet for each set was made in strict rotation.

3. TEST RESULTS AND DISCUSSION

3.1 Bricks

The results of tests to determine the brick properties are given below. The bricks were delivered in two consignments with a few months time interval, and results are given for both batches. Figure 1 shows the relationships between crushing strength and water absorption (24 hour soak) and Figure 2 shows the mean suction rate for dry bricks and for bricks with a controlled moisture content. Figure 1 indicates clearly that the greater the strength of these bricks the lower the water absorption.

	1st Batch	2nd Batch
Crushing stress. N/mm^2 (mean of 12)	58.6	44.5
Water absorption 24 hour soak	6.7%	9.1%
Water absorption 5 hour boil	11.3%	13.6%
Suction rate $kg/m^2/min$	0.71	0.47
Dry density kg/m^3	1980	1940

3.2 Sands

Figure 3 shows the sand densities and bulking properties which indicate that the Westwood sand is denser than the Nutfield sand. The results of the particle size distribution for both sands as well as the sands modified to contain 10% and 15% fines are given in Figures 4 and 5 with the Type G and S envelopes from BS 1200 (1983 amendment). These show that the N15% (Nutfield 15% fines) and W15% (Westwood 15% fines) fall outside the Type G envelope. N10% and W10% fall inside the Type G and outside the Type S envelopes and Nutfield (natural) falls within Type G and just on the extremity of the Type S envelope. Westwood (natural) falls well within both Type G and S envelopes. Figure 6 shows the proportion of fines obtained from the Andreason Pipette test (BS 812) which is usually assumed to represent particles 20 μm in size. The results of the Field settling test on Figure 7 show the same trends as Figure 6, although the authors have found this method unreliable in previous work (1).

In calculating the quantities of added silica flour required the natural fines (<75 μm) was taken as 5% for the Nutfield and 2% for the Westwood sand.

3.3 Fresh Mortar

The water cement ratio results are given in Figure 8 and as one would expect show a slight fall as the fines content increase. ie. for the same consistency and cement content less water is required as the fines content increases.

Figure 9 shows the air content of the mortar plotted against the fines. Again as one would expect there is a falling off of air content with increased fines but it is interesting to note that the mixes form groups not by designation (i) or (iii), but by consistency, the stiffer mortars (DB 10) having a much greater air content than the DB 13 mortars.

3.4 Hardened Mortar

Figures 10 and 11 show the compressive strength of the mortars plotted against fines, each point representing the mean of 12 cubes (3 each from four mixes). Figures 12 and 13 show the flexural strength of the hardened mortar using 500 x 100 x 100mm beams and 75 x 25 x 25mm prisms respectively. The points in Figure 12 represent the means from 3 beams and those on Figure 13 means from 12 prisms. Figure 14 shows the direct tensile stress measured with figure of eight briquettes and the points represent means of six briquettes.

The graphs generally show that the mortar strength properties increase with an increase in the fines content and this is particularly marked for compressive strength. Figure 15 shows

the hardened (wet) density of the mortar against the fines content and here again there is a marked increase in density with increase in fines. It also shows that the Westwood mortars are denser than the Nutfield and that DB 13 mixes are denser than the DB 10 which is consistent with the air content results.

The increase in compressive strength can be explained partly by the increase in density (Figure 15) and partly by the decrease in water/cement ratio (Figure 8).

3.5 Tensile Bond

Figures 16 to 19 show the wallette flexural strengths plotted against fines and Figures 20 to 23 show the couplet tensile bond strength also plotted against fines, for both sands, both mixes and both consistencies. Regression lines for both the means of 10 specimens and the 95% log-normal characteristic strength are given and the marked decrease in bond strength can be clearly seen and is particularly pronounced for the wallettes. The couplet strengths decrease with increase in fines, in all cases except one (the Nutfield 1:1:6 characteristic strength DB 13). Figures 16-23 show (with Fig.16 being the one exception) that the mortars with the wetter consistencies (DB 13) give higher bond than the DB 10 mixes.

Figures 16 to 19 also show the BS 5628 Table 3 characteristic strengths for W.A>12% and 7%<W.A<12% as the W.A of the bricks is around the 12% value. With one exception (Nutfield 1:1/4:3, DB 13) the values for the 15% fines all fall below the Table 3 strengths. The Westwood DB 10 1:1/4:3 results for both 2% and 10% fall below the Table 3 values. The same applies to Westwood 1:1:6 DB 13 for 7.5%, 10% and 12.5% fines. With the exception of Westwood DB10 designation (i) mortar, the wallette results for both natural sands give characteristic strengths higher than the BS 5628 Table 3 values.

These results combined with those in paragraph 3.4 above show clearly that while the mortar compressive and tensile strength increases with the percentage of fines in the sand, for a given consistency, the bond strength decreases, and therefore that the compressive strength of a mortar is not an indicator of its tensile bond strength.

Figure 24 shows the couplet bond strength for bricks with controlled moisture contents for three mortars (5%, 10% and 15% fines) and clearly demonstrates the increase in strength with increase in moisture in the bricks up to 6%. Each point on the graph represents 5 couplets only but despite the scatter the three regression lines are close.

3.6 General

Space does not permit inclusion of all the results of the test programme but Figure 25 is included to show the relationship between mortar compressive strength (from cubes) and flexural strength (from prisms) and Figure 26 to show the relationship between mortar prism flexural strength and the direct tension in briquettes. Figure 27 shows the relationship between wallette and couplet results for the means of all the results.

4. CONCLUSIONS

The results of this research programme have shown that the percentage of fines in a sand has a marked effect on the properties of mortar and the tensile bond strength of bricks to mortar.

Compressive, tensile and flexural strength of mortars increase with the percentage of fines in the sand for a constant consistency of the mortar. Tensile bond strength decreases with an increase of fines.

Tensile bond strength does however increase with an increase in the water content of the clay bricks for the mortars used in the tests.

It is clear that the mortar compressive strength does not give a guide as to the bond strength to be expected. The need for bond testing as a method of construction control is thus demonstrated.

Many of the results, particularly 15% fines (which lie outside the Type G envelope of BS 1200) gave wallette characteristic strengths lower than specified in Table 3 in BS 5628 but the results for the natural sands exceeded the BS values (with the one exception of Westwood DB10 designation (i) mortar).

It is demonstrated however that both the mortar consistency and the moisture in the brick has a considerable effect on tensile bond with the "wetter" consistency (DB 13) generally giving higher results, and the bricks with 6% moisture giving greater bond than for dryer bricks.

Relationships between compressive stress and flexural stress, between flexural stress and direct tension and between wallette and couplet strengths are established.

5. ACKNOWLEDGEMENTS.

The support and assistance of the Property Services Agency in sponsoring this work and the Sand and Gravel Association in arranging for the supply of sand is appreciated and acknowledged. The excellent work carried out by the technicians and other supporting staff at the Polytechnic is gratefully acknowledged.

6. REFERENCES.

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6. BS 187 Specification for calcium silicate bricks. British Standards Institution. London 1978.

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8. BS 4551 Methods of testing mortars, screeds and plasters. British Standards Institution. London 1980.

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11. BS 1881 Part 3. Methods of making and curing test specimens. British Standards Institution. London 1980.

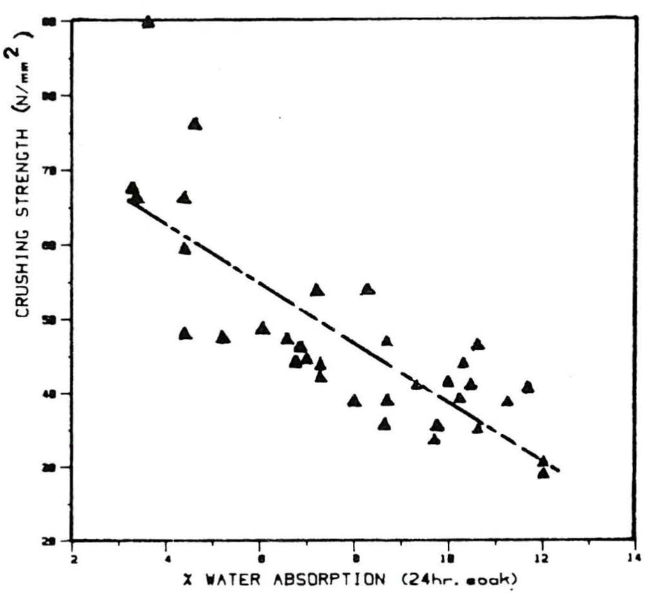

Fig.1 CRUSHING STRENGTH v WATER ABSORPTION

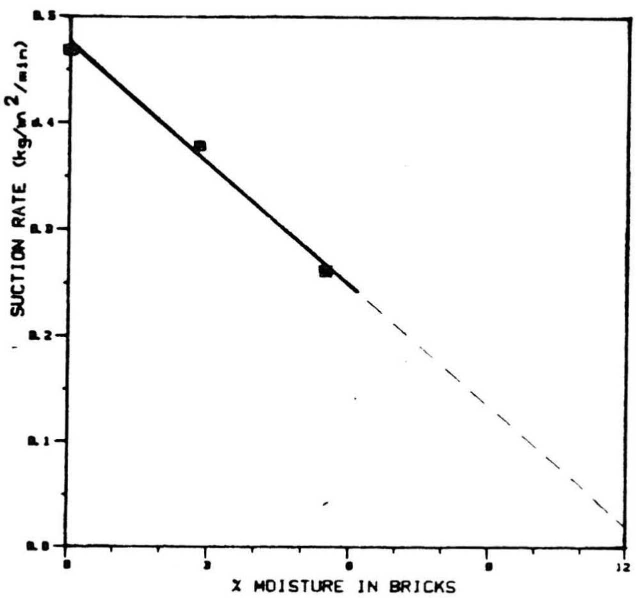

Fig.2 SUCTION RATE AT VARYING MOISTURE CONTENTS

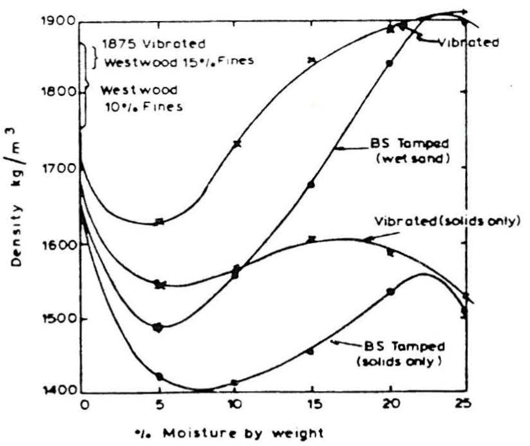

Fig.3a.Westwood Sand Density & Bulking

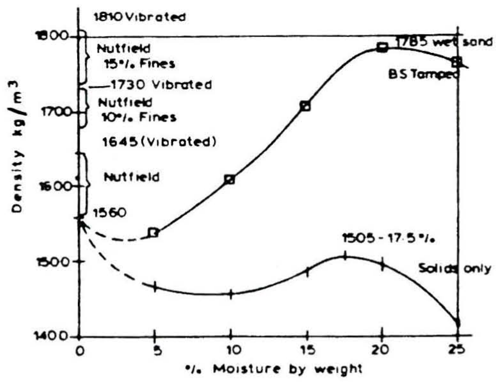

Fig.3b.Nutfield Sand Density & Bulking

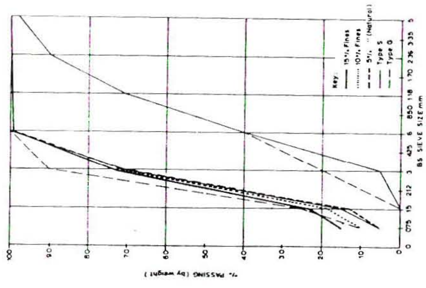

Fig. 4 Sand Grading Curves
NUTFIELD SAND WITH 5%, 10%, & 15% FINES

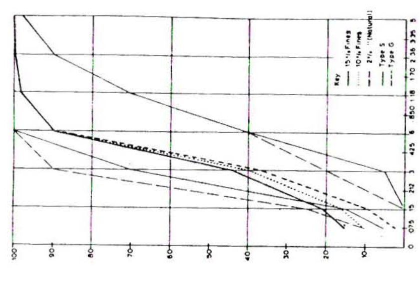

Fig. 5 Sand Grading Curves
WESTWOOD SAND WITH 2%, 10%, & 15% FINES

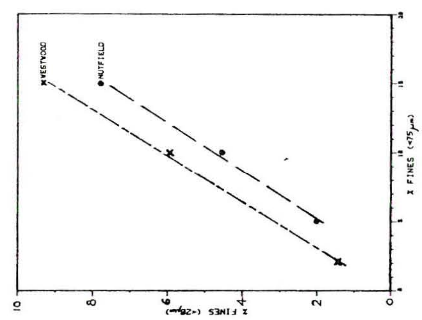

Fig.6 ANDREASON PIPETTE TEST ON SANDS

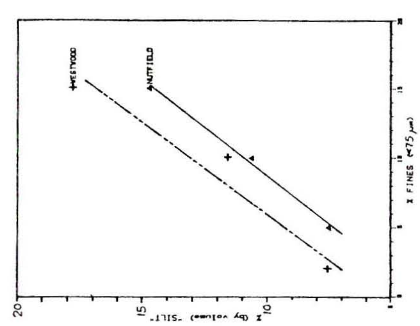

Fig. 7 FIELD SETTLING TEST ON SANDS

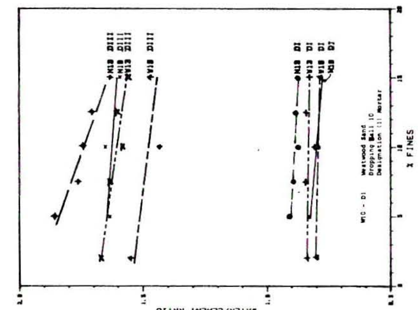

Fig.8 WATER/CEMENT RATIO v FINES IN SAND

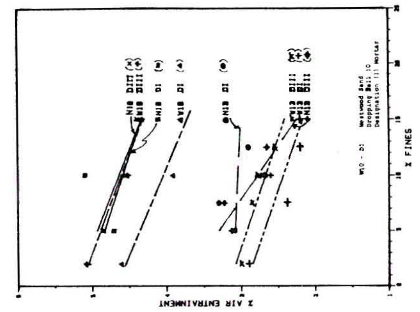

Fig.9 AIR ENTRAINMENT v FINES IN SAND

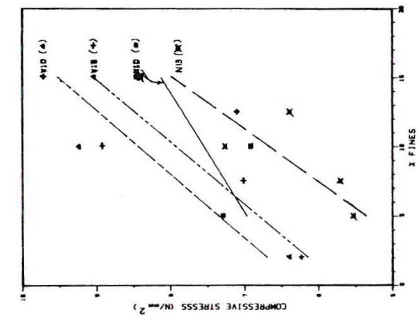

Fig.10 COMPRESSIVE STRENGTH v FINES IN SAND
Designation (iii) Mortars

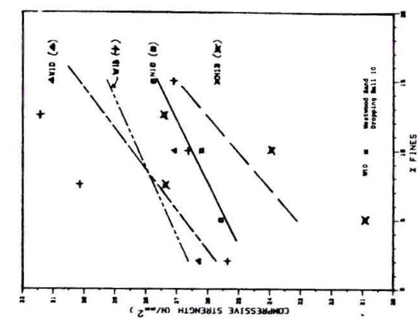

Fig.11 COMPRESSIVE STRENGTH v FINES IN SAND
Designation (i) Mortars

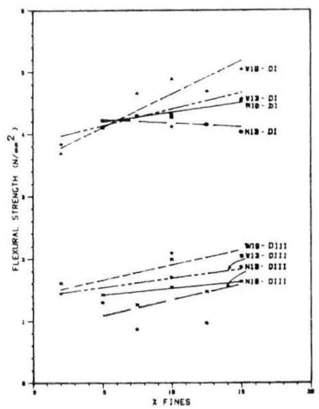

Fig.12 Flexural strength of beams (500 x 100 x 100) v Fines in sand

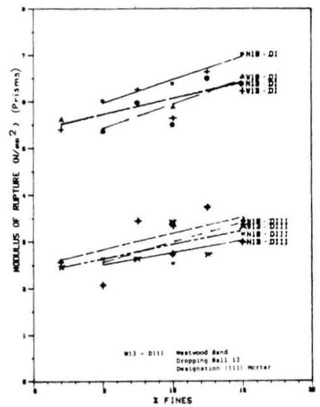

Fig.13 Modulus of rupture v Fines in sand

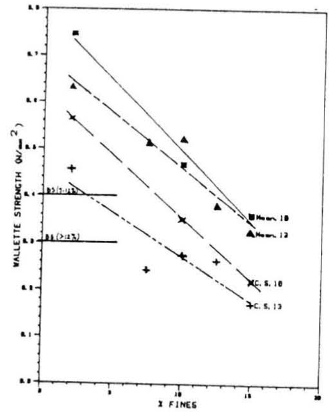

Fig.16
VALLETTE STRENGTH (WESTWOOD 1:1:6) v % FINES

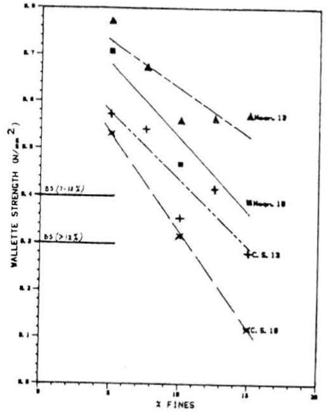

Fig.17
VALLETTE STRENGTH (NUTFIELD 1:1:6) v % FINES

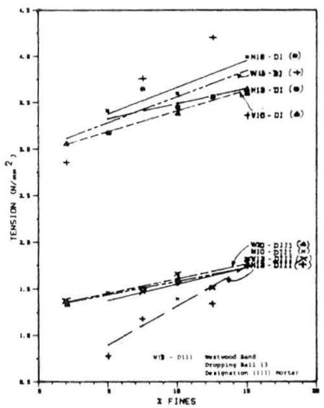

Fig.14 Direct Tension in Briquettes v Fines in Sand

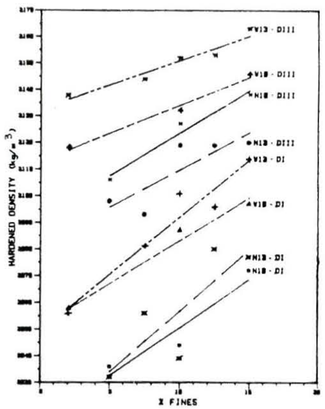

Fig.15 Hardened (Wet)Density v Fines in Sand

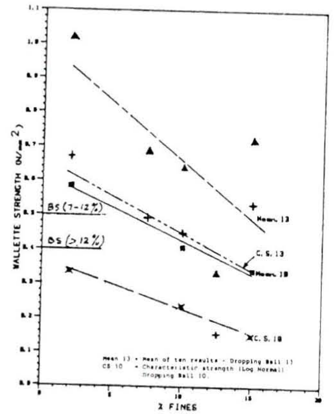

Fig.18
VALLETTE STRENGTH (WESTWOOD 1:1/4:3) v % FINES

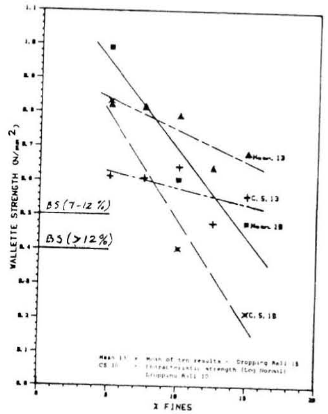

Fig.19
VALLETTE STRENGTH (NUTFIELD 1:1/4:3) v % FINES

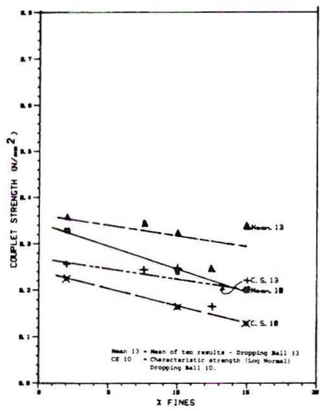

Fig.20
COUPLET STRENGTH (WESTWOOD 1:1:6) v X FINES

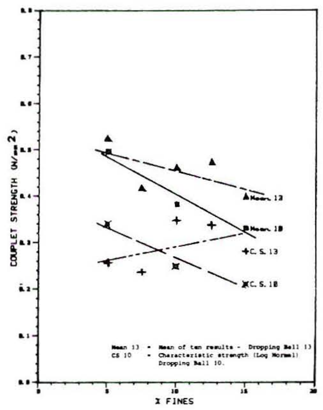

Fig.21
COUPLET STRENGTH (NUTFIELD 1:1:6) v X FINES

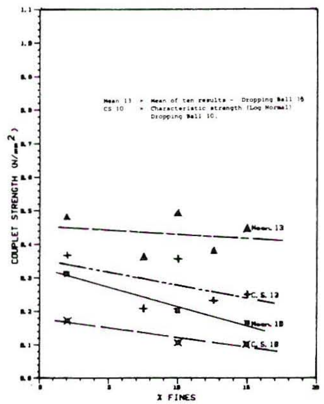

Fig.22
COUPLET STRENGTH (WESTWOOD 1:1/4:3) v X FINES

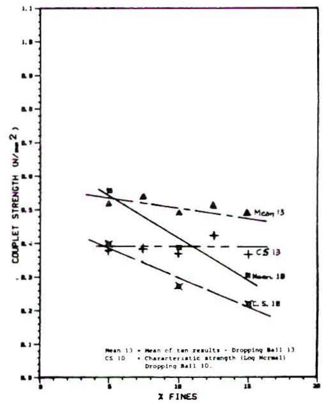

Fig.23
COUPLET STRENGTH (NUTFIELD 1:1/4:3) v X FINES

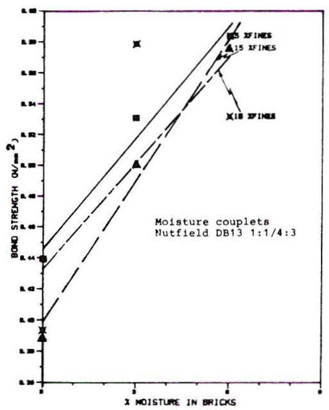

Fig 24 COUPLET BOND STRENGTH v MOISTURE IN BRICKS

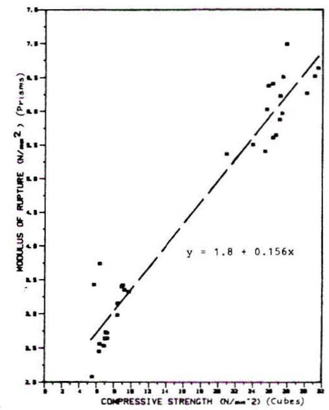

Fig.25 MORTAR FLEXURAL v COMPRESSIVE STRENGTH

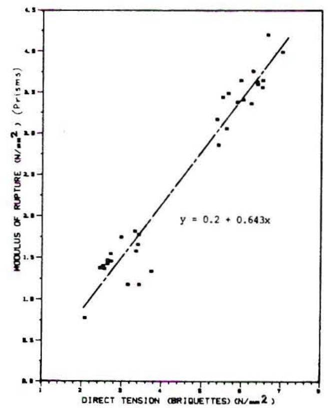

Fig.26 Modulus of Rupture v Tension

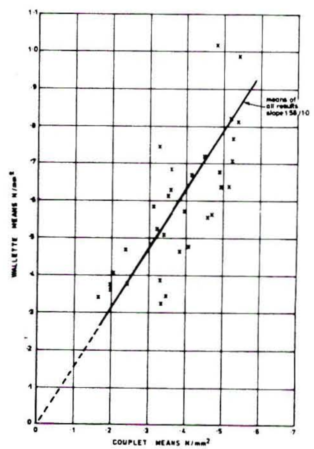

Fig.27 Couplet v Wallette strength