CEMENT MORTAR ROOFING SHEETS REINFORCED WITH COIR FIBRE

by

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Synopsis

A cement:sand matrix reinforced with short chopped coir (coconut) fibre was investigated as a possible material for manufacturing corrugated roofing sheets. Optimum values for the cement:sand mix, water/cement ratio, fibre volume percentage and fibre length were arrived at for sheets compacted by hand tamping as well as vibration.

Considerations of costs were also taken into account in the above optimization.

Background

Sisal, jute and coir are some of the natural fibres that have been used for reinforcing roofing sheets made with a cement:sand mortar mix (1). Although these fibres have lower tensile strengths than steel or polypropylene fibres, they do in fact increase the flexural strength and toughness of the mortar matrix considerably. The pull-out of these fibres at failure increases the work of fracture, giving rise to greater energy absorption upon impact failure and a degree of post-yield plasticity in flexure.

The use of these fibrous mortars in the form of corrugated roofing sheets is of particular relevance to many developing countries because of their relative cheapness and the ready availability of the fibres concerned. The increasing reluctance for using asbestos, due to the potential health hazard it poses, also creates the need to find an alternative roofing material. This paper reports results of tests on cement mortar sheets reinforced with coir (coconut) fibre, which is found in abundance in Sri Lanka.

Identification of Parameters

The purpose of these tests was to optimize the various parameters involved in manufacturing the sheets. The following parameters were identified:

(i) Cement:sand mix
(ii) Water/cement ratio
(iii) Fibre volume percentage
(iv) Fibre length
(v) Method of fibre incorporation - i.e. whether as oriented long fibres or chopped short fibres.
(vi) Method of compaction - i.e. whether hand tamped or vibrated.

The first two parameters are matrix properties, while the next two are fibre properties; the last two parameters are concerned with the fabrication procedure.

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The decision to use sand as a filler, as opposed to using a pure cement paste matrix, was made primarily in order to reduce the cost of the sheets. Furthermore, the drying shrinkage of the matrix will also be reduced by using sand combined with the cement paste.

There are two methods of incorporating the fibres into these sheets. One method is to lay fibres of length 200 mm or longer in a prescribed direction in between two layers of the matrix. The other method is to chop the fibres into lengths of 13 mm to 63 mm and mix these into the cement mortar prior to spreading. The first method tends to give better strength properties in the direction of fibre orientation. However, the fabrication procedure is more difficult; futhermore, if fibre volume percentages are too high, the intermediate layer of fibre can impair the integrity of the sheet due to separation of the mortar layers. The second method, which gives a uniform distribution and random orientation of fibre in the matrix, results in sheets which lack the directional strength obtained from tne first method; however, this method has the advantage of a relatively easy fabrication technique. Hence, the present investigation was confined to this second method of fibre incorporation.

Two methods of compaction were investigated. Some of the tests were carried out on full scale corrugated roofing sheets made by hand tamping the mortar mixture with a trowel on a flexible membrane and then gradually sliding this onto a corrugated former. Other tests were performed on smaller samples of flat sheets which were compacted by vibration.

Given that the methods of fibre incorporation and compaction were chosen as above, the test programme was devised so as to arrive at optimum values for parameters (i) to (iv).

Experimental Details

The cement used was Ordinary Portland Cement, while the sand was well graded and passed through a 1.6 mm sieve. The volume percentage of fibre required was incorporated into the mix based on its saturated surface dry weight.

Six kinds of tests were performed on five types of specimens. The experimental details are summarized in Table 1 and described in more detail elsewhere (2, 3).

Optimization of Matrix Properties

The cement:sand mix, water/cement ratio, fibre volume percentage and fibre length have to be regarded as coupled parameters - i.e. a variation in one of them could cause a change in the optimum values of the others. One way of approaching such a problem is a full or partial factorial experimental design. However, this method was not used because it involved a considerable amount of testing; instead, an attempt was made to arrive at the optimum values for the above parameters in a rational, step-by-step fashion.

The first parameter considered was the cement:sand mix. It was felt that the optimum w/c ratio would be a function of the above, especially in the context of the chopped fibres in the mix causing reduced workability and poor compaction. In order to investigate this interaction between cement:sand mix and w/c ratio, a series of tensile briquette tests were performed, varying the cement:sand mix from 1:0.5 to 1:2 and the w/c ratio from 0.3 to 0.4. The fibre volume percentage was kept constant at 4.5%, as was the fibre length at 25 mm. The briquettes were compacted by hand tamping, which was the method used in the full scale sheet tests as well. The tensile test results are shown in Figure 1. This indicates that, for the w/c range investiaged, all the mixes apart from the richest are affected by strength loss due to poor workability at a low w/c ratio. Hence, the optimum w/c ratios were chosen as 0.3, 0.35, 0.4 and 0.4 for the cement:sand mixes 1:0.5, 1:1, 1:1.5 and 1:2 respectively.

Although it was attempted to fabricate the full scale corrugated sheets using the above w/c ratios, workability constraints resulted in these ratios having to be increased for the 1:0.5 and 1:2 mixes, as seen in Table 2. The breaking loads per unit width for the sheets, tested in three point flexure, are shown in Figure 2. It is seen that very adequate repeatability is obtained, despite the brittle nature of the material. It can also be noticed that although there is a monotonic gain in average strength from leaner to richer mixes, the strength gain from the 1:1 to 1:0.5 mix is small. This suggested that the advantage of increasing the richness of the mix from 1:1 to 1:0.5 was minimal, and that the 1:1 mix was the best choice.

The above line of reasoning was confirmed on the basis of a cost evaluation (Appendix 1), which enabled the performance of the sheets to be compared on the basis of a strength/ cost index. This comparison (Figure 3) clearly established the 1:1 cement: sand mix (w/c = 0.3 and V_f = 4.5%) as an optimum one for hand tamped sheets. In this context, it is of interest to note that a 1:1 cement mortar is reported to have shown better mechanical properties than either a neat cement paste or a 1:2 mortar, when these matrices were reinforced with 2% jute fibre (1).

Optimization of Fibre Properties

The optimization of fibre properties was done using flat sheet specimens which were compacted using a vibrating table. As this method of compacting improved the workability, it was possible to keep the w/c ratio constant at 0.3. The cement:sand mix was also kept constant at 1:1. A series of compression tests was performed to ascertain the point at which the reduction of w/c ratio resulted in low workability and hence poor compactability and thus reduced strength. The results of these tests (Figure 4) show that a w/c ratio of 0.3 does not cause workability problems except in the 6% fibre volume percentage mix. However, the w/c ratio employed in all the subsequent testing was standarized at 0.3. Thus, the tests to optimize fibre properties were all carried out by incorporating them into an identical matrix of cement:sand mix 1:1 and w/c ratio 0.3.

The fibre length was optimized first, with the volume percentage fixed at 4%. Lengths of fibre from 13 mm to 63 mm were investigated. The lower limit was imposed by the chopping procedure, and the upper limit by the tendency for fibres to "ball up" during mixing, thus reducing compactability.

The four point flexural tests (Figure 5) showed that the modulus of rupture was around the same for all fibre lengths investigated; however, the maximum deflection at failure (which would be an index of toughness) was greatest for the 38 mm fibre length. The impact test results (Figure 6) indicate that 50 mm is the optimum fibre length. It is unfortunate, however, that the results for the 38 mm fibre length sheets were not reliable (and therefore omitted from Figure 6).

The above evidence indicates that a fibre length of 38-50 mm would be the optimum length with regard to both flexural and impact behaviour. This is probably the length at which fibre rupture and pull-out occur simultaneously, giving rise to the maximum work of fracture and hence maximum energy absorption. Other investigators have arrived at a similar optimum length, based on fibre pull-out tests (1).

In the next series of tests, the fibre length was maintained at 50 mm, while the volume percentage was varied from 2% to 6%. Both the three point flexure tests (Figure 7) and the impact tests (Figure 8) indicated an optimum volume percentage of 4%. This figure is around the same value obtained for other fibre-matrix systems as well (1). It should be appreciated that the use of a w/c ratio of 0.35 for the 6% fibre volume percentage mix may have improved the performance of the resulting sheets (see Figure 4). However, other investigators have found that an increase in fibre volume percentage over 3% for 1:0.5 cement:sand sheets with w/c = 0.35 causes a reduction in modulus of rupture (4).

It may also be possible to increase the above optimum percentage by pressing the sheets after casting. However, excessive fibre volume percentages have been found to increase the permeability and hence reduce the waterproofing qualities of these sheets (5). It should be mentioned that the full scale sheets tested in this investigation, having a fibre volume percentage of 4.5%, gave excellent performance with regard to the permeability test specified in the ISO standard (2, 6).

Feasibility for use as a Corrugated Roofing Sheet

The ISO standard for asbestos cement corrugated sheets (6) specifies four classes for roofing sheets and a possible fifth class. The specified breaking loads for sheets with a clear span of 1.1 m loaded at mid span with a line load are 1.50 kg/cm and 1.06 kg/cm for the two lowest classes. The breaking loads for the full scale sheets tested here (Table 2) have been obtained for a clear span of only 0.68 m. Therefore, the corresponding breaking load for the 1:1 cement:sand sheet is 1.25 kg/cm for a clear span of 1.1 m. This classifies the sheet as the lowest class of sheet according to ISO/R 393 (6). However, it does show that the use of this sheet as a roofing material is in fact feasible.

Another test of feasibility is to determine the uniformly distributed load that can be carried by this sheet. For a clear span of 1.1 m, this value works out to be 2.23 kN/m², which is well in excess of the uniformly distributed load of 0.75 kN/m² required in CP:3Ch.V:Part 1 (7) for a flat or mildly inclined roof. It is difficult to estimate the point load (or more accurately, the load over an area of 300 mm x 300 mm) that could be sustained by this sheet, without actually performing an experiment - the requirement in the above code of practice is 0.9 kN (7).

It should also be borne in mind that the full scale sheets tested here were compacted by hand tamping. Vibrational compaction would have enabled better compaction and also a reduction in the w/c ration from 0.35 to 0.3, both of which would have contributed to higher strength. Casting pressure has also been found to improve the strength of similar sheets (1). The above techniques would improve the feasibility for using this material as a corrugated roofing sheet. Furthermore, savings of over 50% in cost can be achieved, compared to using asbestos sheets, as indicated in Appendix 1.

Closure

The series of tests reported in this paper have suggested the following optimum parameters for cement mortar sheets reinforced with chopped short fibres :-

Optimum cement:sand mix	1.1
Optimum fibre volume percentage	4%
Optimum fibre length	39-50 mm
Optimum w/c ratio (vibrated)	0.3
(hand tamped)	0.35

The limited full scale testing reported here has shown that there is considerable promise for using this fibrous mortar for corrugated roofing sheets. However, the properties of full scale corrugated sheets compacted by vibration and/or pressing should be investigated. Furthermore, given the fact that coir fibre may be attacked by the alkaline mortar matrix, the long term performance of these roofing sheets should also be investigated.

Acknowledgements

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Appendix 1

Specimen cost analysis for 1:1 cement : sand sheet with V_f=4.5%
Dimension of sheet = 1016mm x 853mm x 6mm
Cost given in Sri Lanka Rupees at 1986 retail prices

Material Cost

Cement -	8.17Kg	17.96
Sand -	8.17Kg	0.33
Fibre -	8.17Kg	1.58
		19.87
Add 10% for transport and water		1.99
		21.86

Labour Cost

No. of sheets per day - 20 sheets by 2 trained workers

Labour cost per sheet = 75x2/20	7.50
Total Cost	29.36

Note:- Cost of asbestos sheet of similar size 60.11
Saving compared to asbestos sheet is 51%
Saving (without labour) compared to asbestos sheet is 64%

Specimen type	Dimensions	Method of compacting	Method of curing	Method of testing
Briquettes	Cross section of 25mm x 25mm	Hand tamped	Immersed in water for 7 days	Direct tention in standard briquette tester.
Cubes	70.7mmx70.7mmx70.7mm	Vibrated	Immersed in water for 14 days	Standard compression testing mechines
Flat sheet specimens	381mmx152mmx9.5mm 356mmx64mmx9.5mm	Vibrated	Immersed in water for 7 days	4 point flexural tests 3 point flexural tests Impact tests using impact hammer in standard timber testing machines.
Full scale corrugated sheets	1016mmx853mmx6mm	Hand tamped	Kept moist for 28 days	3 point flexural tests (line loading)

TABLE 1 - Experimental Details

Mix Proportions ct: Sand (w/w)	Water/Cement ratio	Maximum Central Deflection (mm)	Breaking Load per Unit width (Kg/cm)
1:2	0.45	1.58	1.06
1:2	0.45	1.19	0.95
1:2	0.45	2.92	1.05
1:2	0.50	1.78	1.11
1:1½	0.40	1.24	1.82
1:1½	0.40	1.17	1.51
1:1	0.35	2.21	1.91
1:1	0.35	2.11	2.05
1:1	0.35	2.84	2.14
1:½	0.35	2.84	1.96
1:½	0.32	6.10	2.24

TABLE 2 - Results of 3 point flexural tests on full scale corrugated sheets

FIGURE 1 - TENSILE STRENGTH OF BRIQUETTES FOR VARYING CT:SAND MIXES AND W/C RATIOS

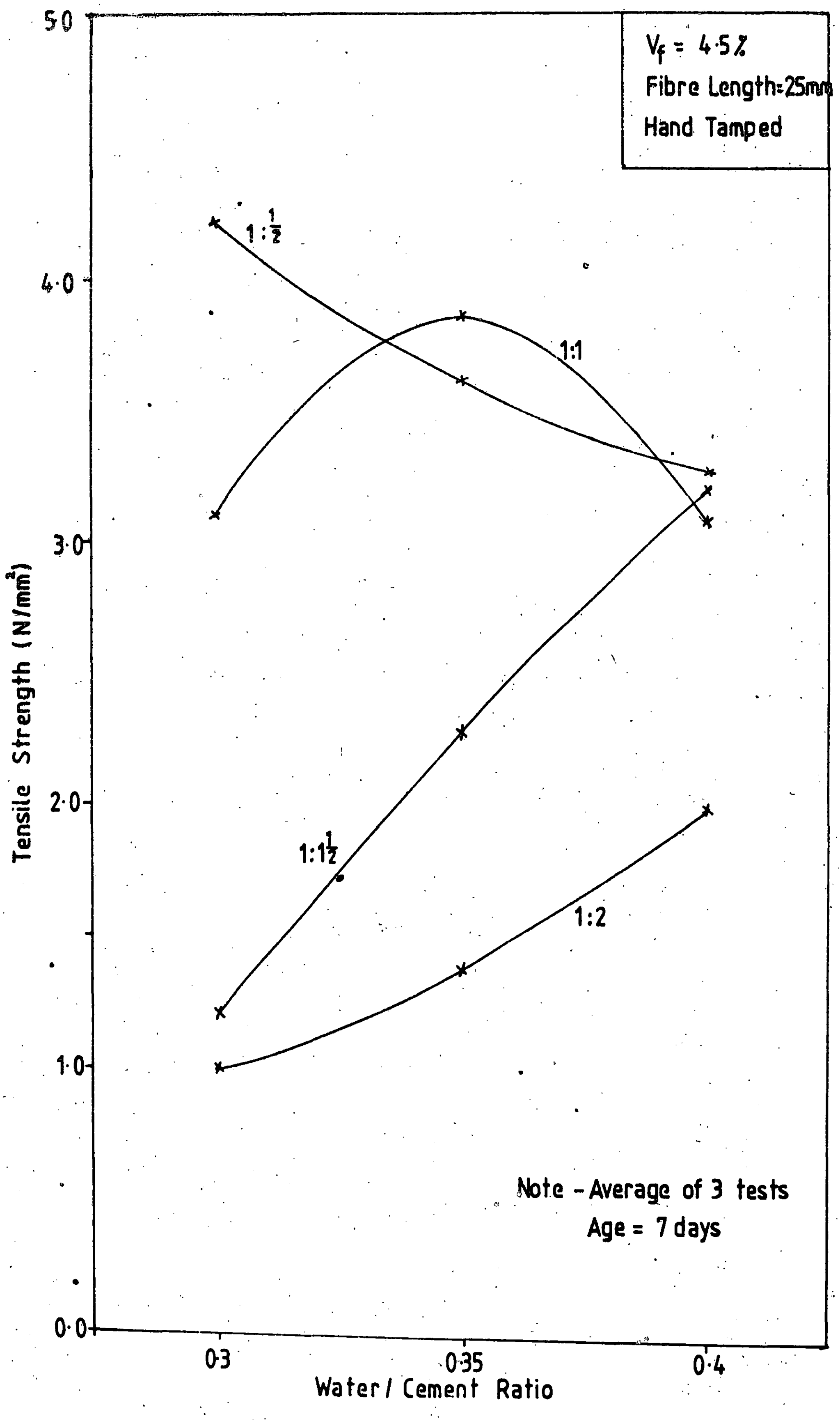

FIGURE 2 - FULL SCALE FLEXURAL TEST RESULTS FOR CORRUGATED SHEETS WITH VARYING MORTAR MIX

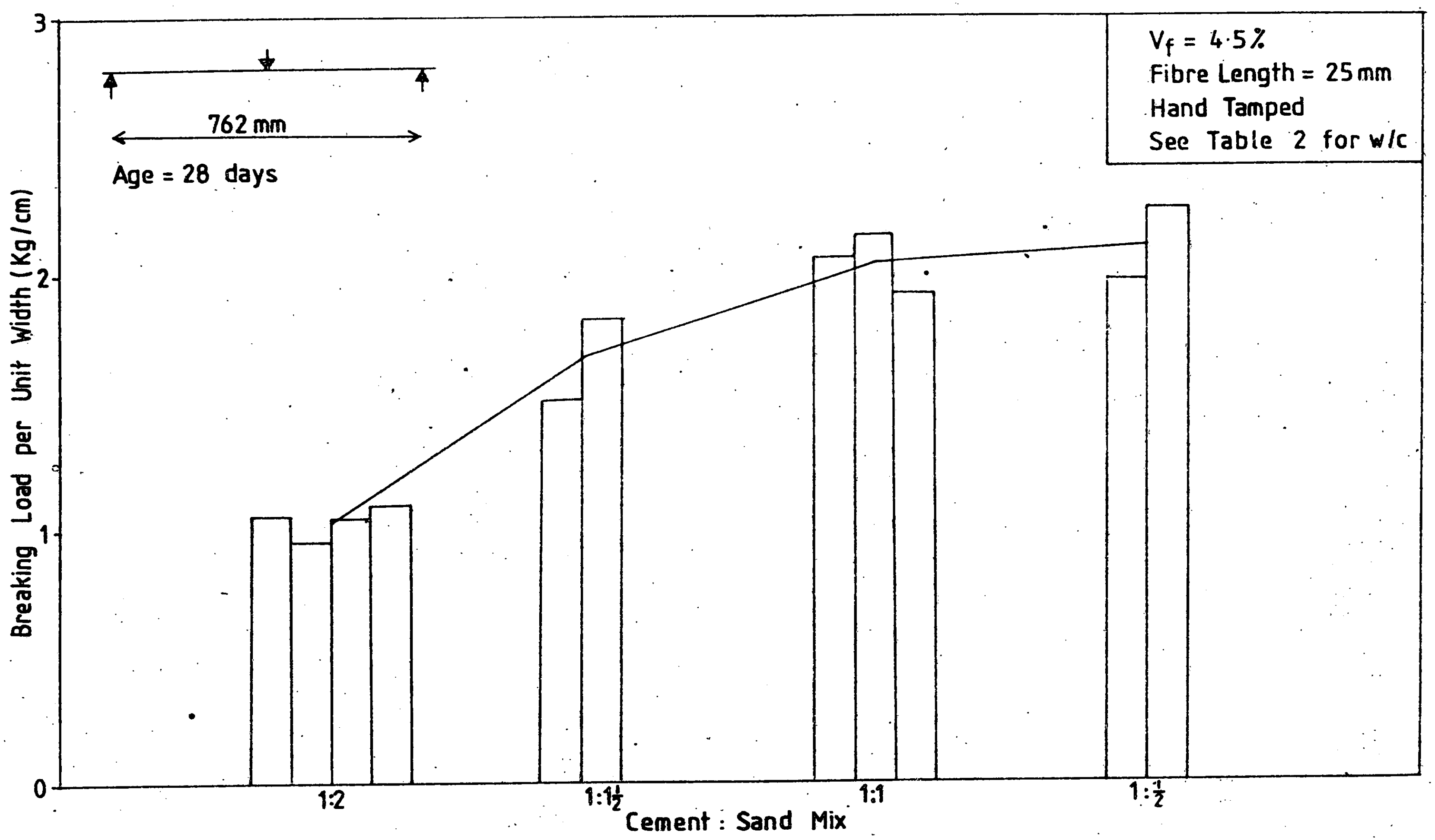

FIGURE 3 · VARIATION OF STRENGTH / COST INDEX WITH MORTAR MIX PROPORTIONS

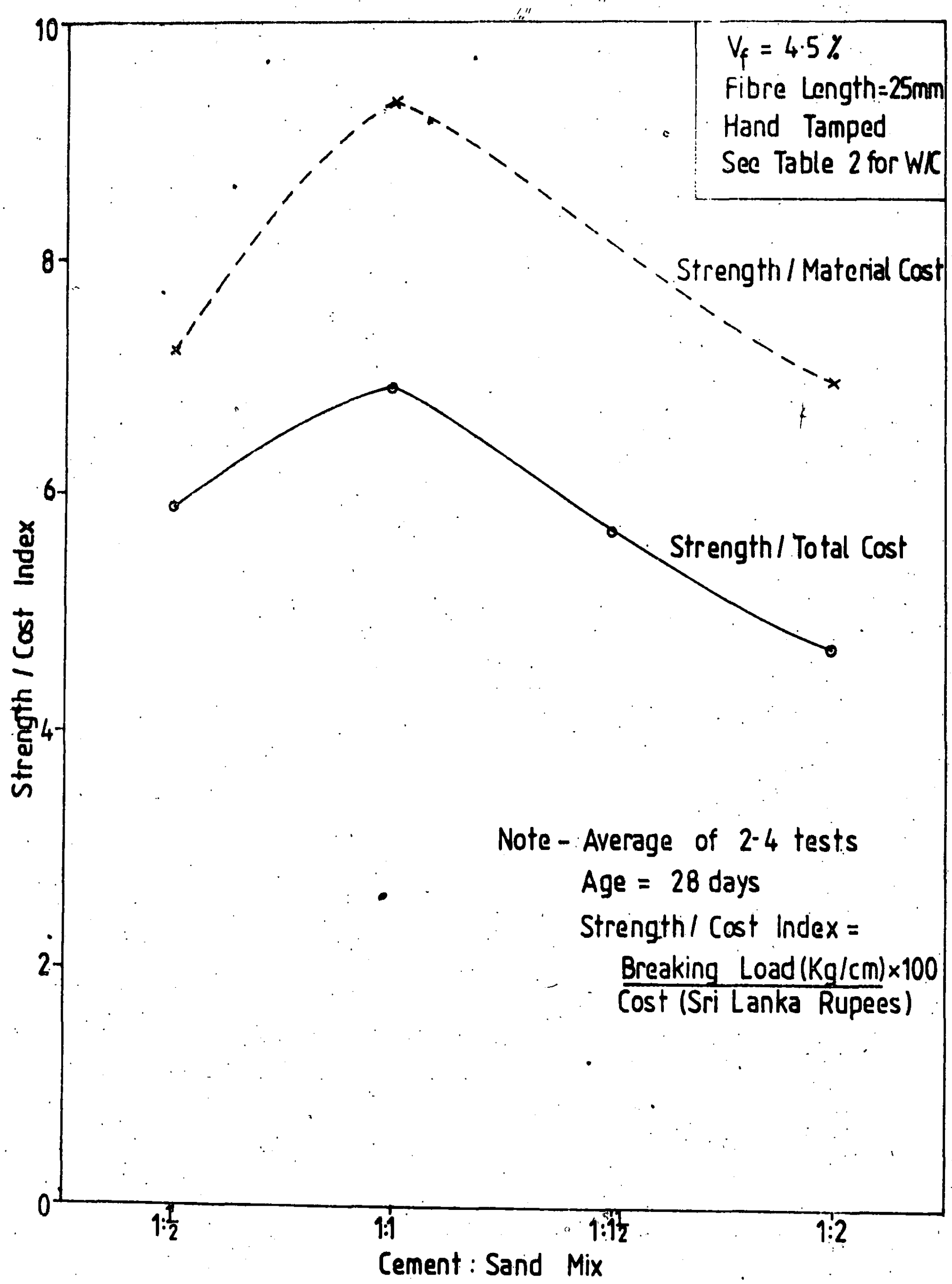

FIGURE 4 - COMPRESSIVE STRENGTH OF CUBES FOR VARYING W/C RATIOS AND FIBRE VOLUME PERCENTAGES

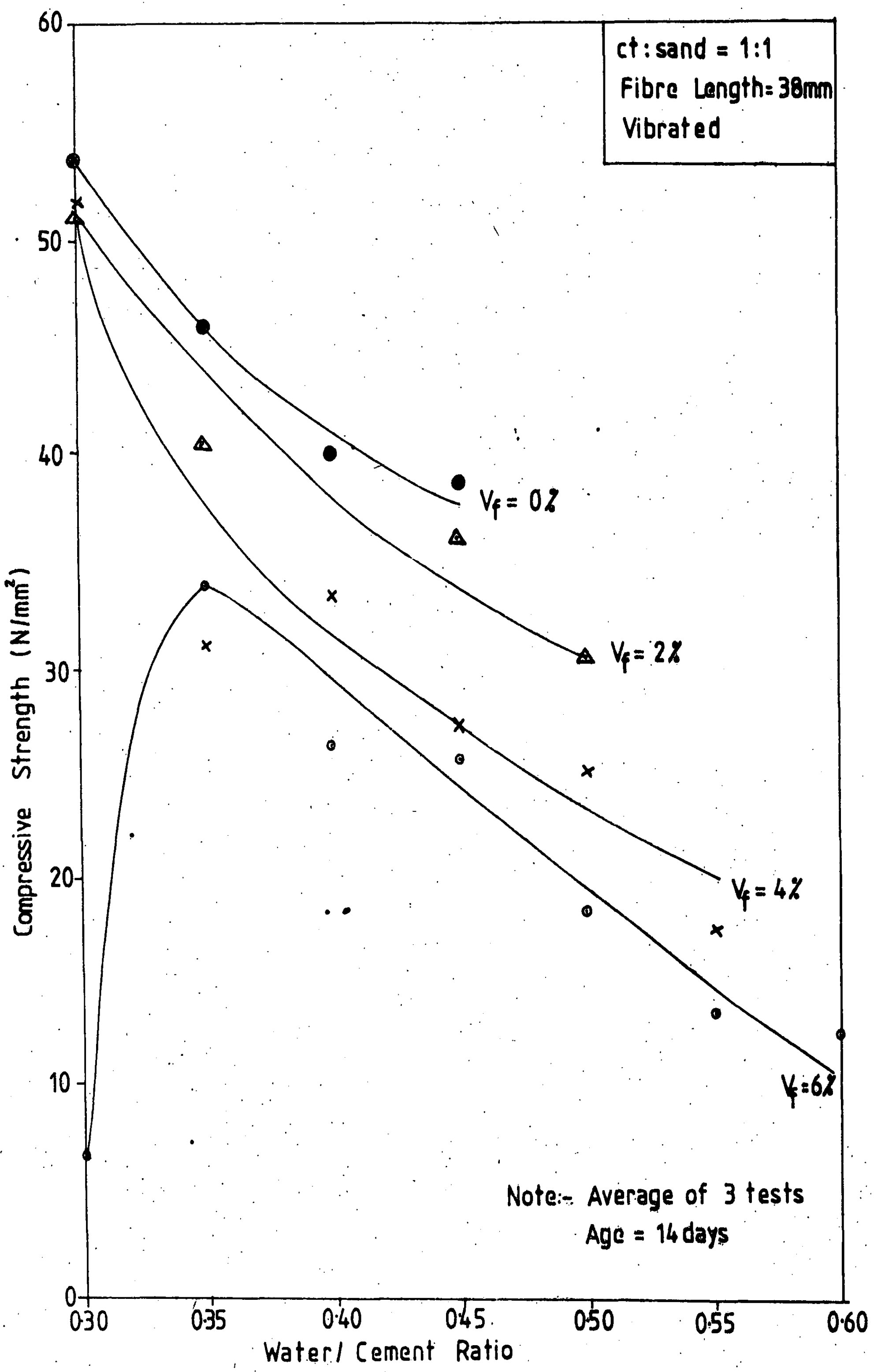

FIGURE 5 - FLEXURAL TEST RESULTS FOR VARYING FIBRE LENGTHS

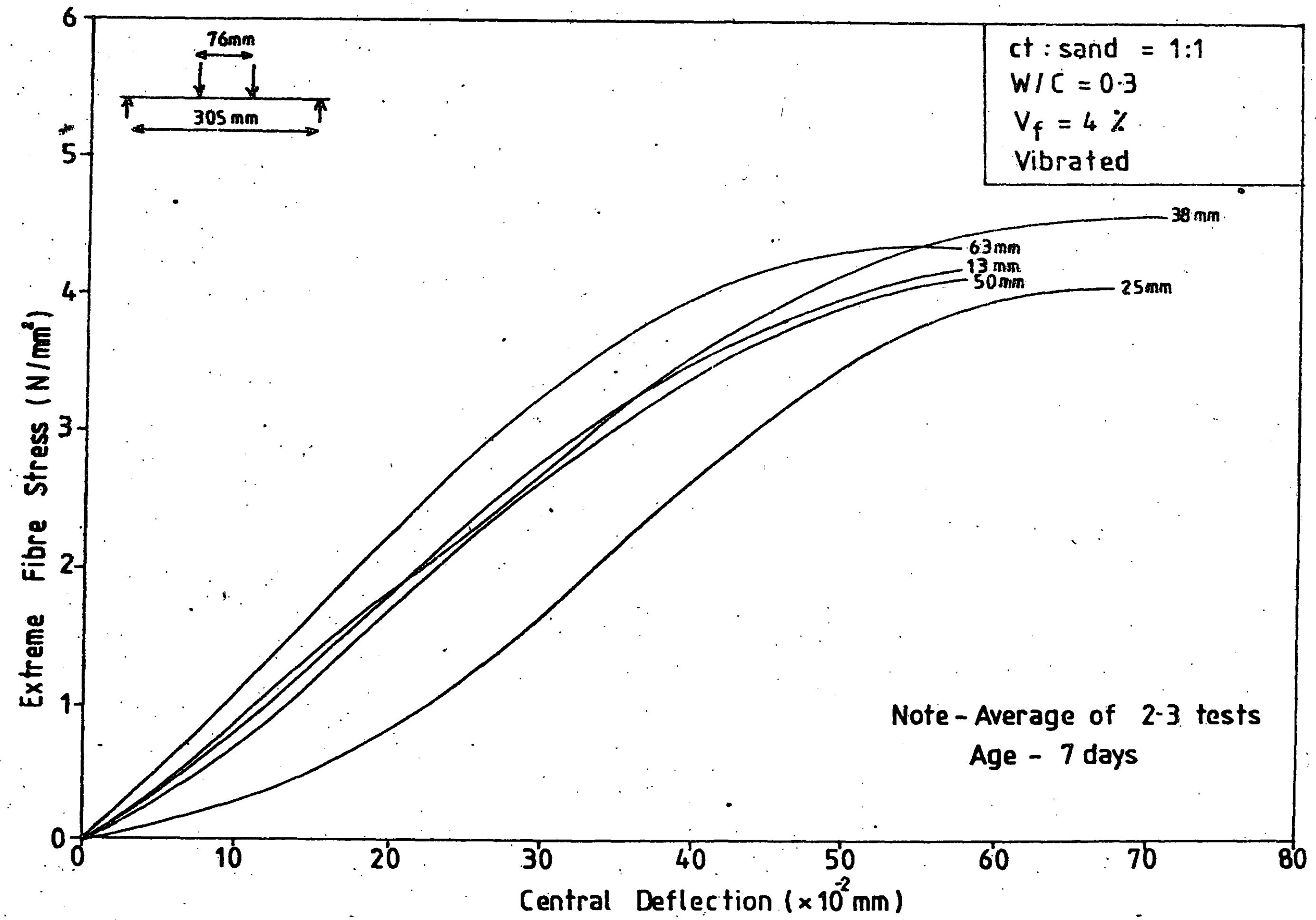

FIGURE 6 - IMPACT TEST RESULTS FOR VARYING FIBRE LENGTHS

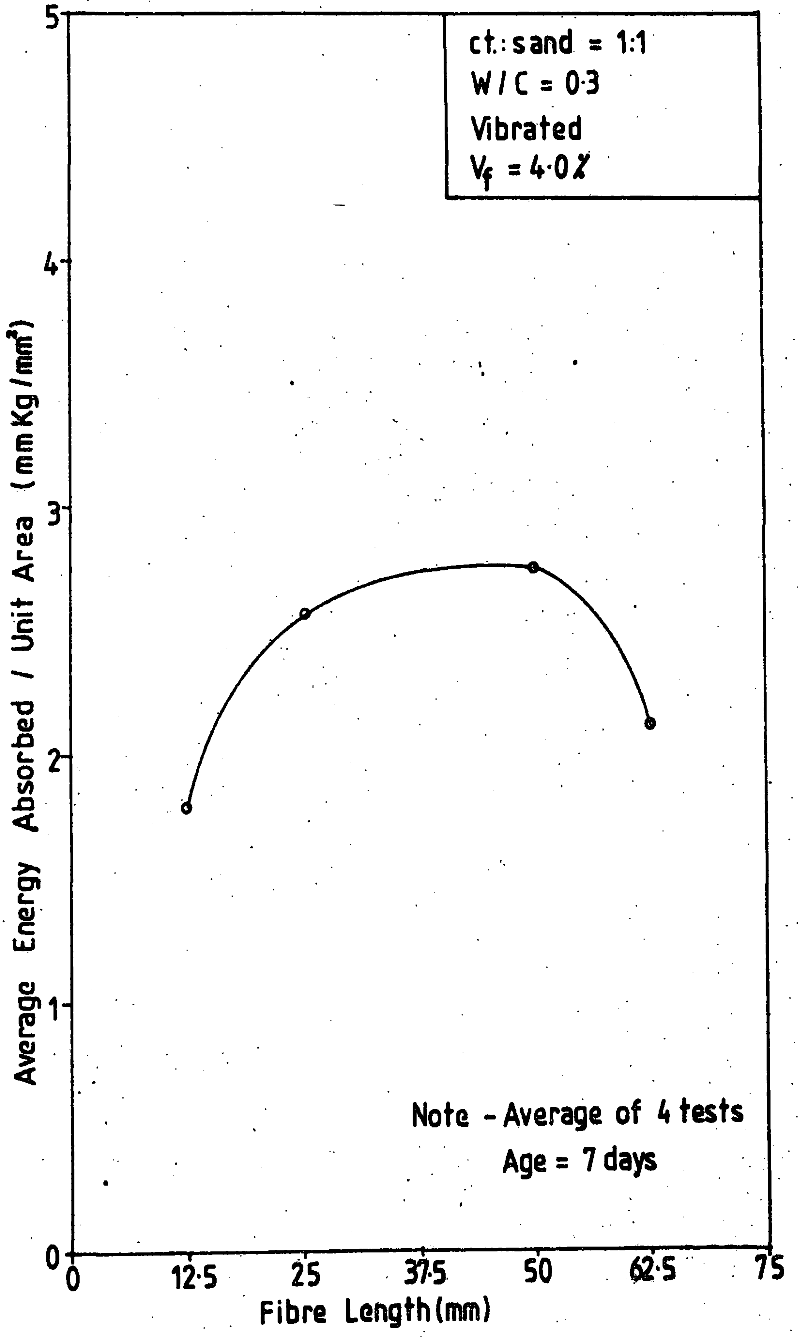

FIGURE 7 - FLEXURAL TEST RESULTS FOR VARYING FIBRE PERCENTAGES

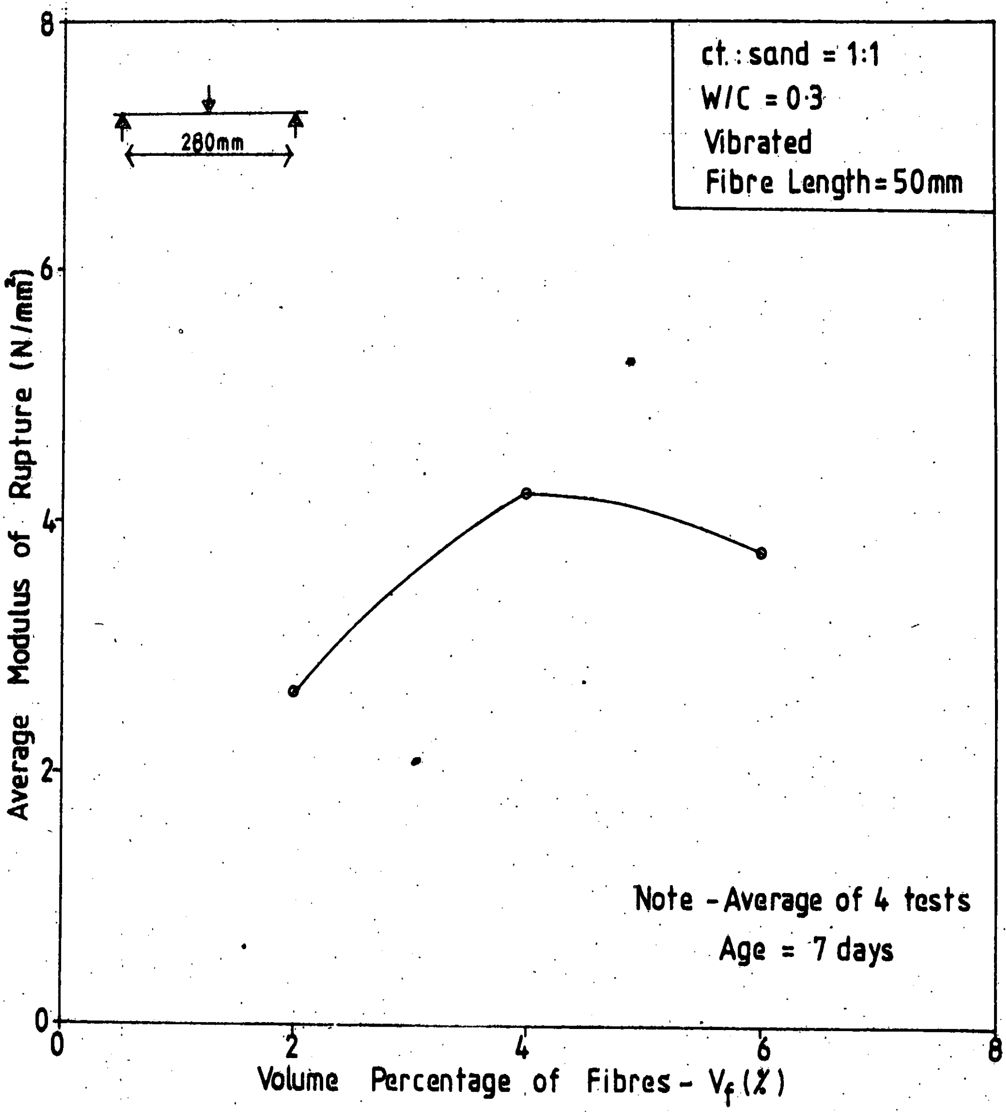

FIGURE 8 - IMPACT TEST RESULTS FOR VARYING FIBRE PERCENTAGES