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# THE STRUCTURAL PROPERTIES AND OPTIMUM MIX PROPORTIONS OF PALMNUT FIBRE-REINFORCED MORTAR COMPOSITE

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## ABSTRACT

Thirty six cement mortar mixes of widely differing water/cement ratios were used to prepare fibre-mortar mixes with fibre volume fraction ranging from 0.5 to 4%. Relevant mechanical properties—compressive, tensile and flexural strengths of the composite were determined in order to study the effect of mix proportions on these properties. These properties were compared with those of corresponding plain mortar mixes. The results show that while palmnut fibre reduced the compressive and tensile strengths of mortar, the flexural strength of the composite is improved by up to 33%. A sand/cement ratio of 2.0, water/ cement ratio of 0.60 and fibre volume fraction of 2.0% were found to be the optimum mix proportions.

## Introduction

In a bid to finding acceptable solution to the increasing inadequacy of housing delivery in developing countries, various local vegetable fibre-reinforced cement mortar composites have been explored as alternative roofing materials (1-10) and an acronym, "Veficem" has been suggested (1) for easy reference to the vegetable fibre-cement mortar composite. These research findings have been collated (11) and have also led to the development of Veficem roofing tiles (12). It is concluded from these findings that vegetable fibre-reinforced mortar is indeed a promising roofing material. However, the failure which occurs in vegetable fibre-reinforced mortar roofing projects are traceable to lack of or improper know-how transfer, to missing knowledge concerning material properties, production techniques and installation methods (11).

There are several cottage factories in Nigeria which produce Veficem roofing tiles, using palmnut fibre, based on trial-and-error mix proportions. Moreover, there are hardly any published scientific data on the structural properties of this composite material inspite of the fact that they have been utilized in a number of housing projects. As a contribution towards filling this gap, this paper focuses attention on the relevant properties of palmnut fibre-reinforced cement mortar composite and the determination of the optimum mix proportion.

Palmnut Fibre: Processing and Characteristics. Palmnut fibre is the waste fibrous product obtained after the extraction of oil and kernel from the palm fruit. The palmnut fibres used were processed by washing in water with detergent to remove the oil coating after which they were sun-dried and stored. The processed palmnut fibre is light brown in colour. The

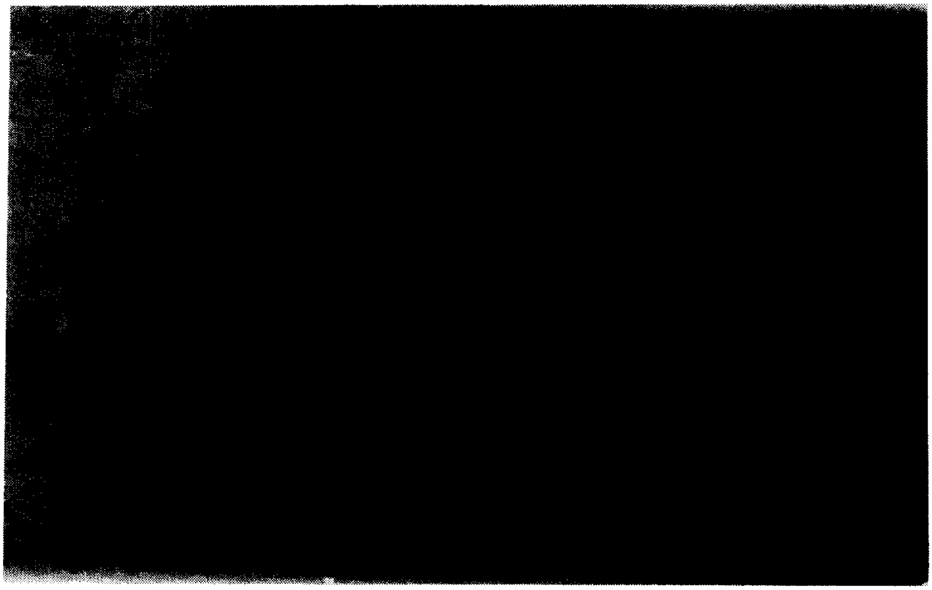

FIG. 1.
Sample of palm fruits and palmnut fibres.

palmnut fibre thickness varies from 0.10 mm to 0.29 mm with an average of 0.16 mm while the fibre length varies from 13 mm to 50 mm with an average of 35 mm. The palm fruits and palmnut fibres are shown in Figure 1.

The specific gravity, bulk density and water absorption of the palmnut fibre specimens were determined from nine different specimens by standard procedures as has been outlined in (13) and the results are summarized in Table 1.

The Hounsfield Tensometer was used in determining the tensile strength and elastic modulus of the fibre. Between 15 and 20 specimens of 15 mm gauge length were tested in each of the following three states:

(i) dry,
(ii) after 14 days-soaking in water,
(iii) after 14 days-soaking in calcium hydroxide (pH=10).

The purpose of these treatments is to assess the effects of such environments on the modulus and ultimate strength and hence the stability of the fibre. The calcium hydroxide, a hydration product of cement, simulates the alkaline environment resulting from the hydration of cement.

The results are also summarized in Table 1, while typical stress-strain curves for the fibre are shown in Figure 2.

The wet and alkaline environment appear not to have any significant effect on the elastic modulus and tensile strength of the fibre. However, it is observed from the results that there is wide variation in elastic modulus and tensile strength within each group and as such the effect of the different environment, if any, is not distinct.

TABLE 1
Summary of Physical and Mechanical Properties of Palmnut Fibre.
(values in parenthesis indicate range)

| | |
|---|---|
| Fibre length (mm) | 35 (13-50) |
| Fibre thickness, (mm) | 0.16 (0.10-0.29) |
| Specific gravity | 1.206 (1.192-1.290) |
| Bulk density, ($kg/m^3$) | 521 (494-583) |
| Water absorption in 24 hrs. at 26.2°C, (%) | 70.9 (68.6-73.8) |
| **Modulus of elasticity, (GPa):** | |
| (a) dry | 2.87 (2.22-3.66) |
| (b) soaked in water | 2.47 (1.93-3.10) |
| (c) soaked in Ca $(OH)_2$ | 2.68 (2.04-3.35) |
| **Ultimate tensile strength, ($N/mm^2$):** | |
| (a) dry | 118.74 (98.65-144.74) |
| (b) soaked in water | 106.24 (86.60-123.12) |
| (c) soaked in Ca $(OH)_2$ | 112.33 (99.60-125.44) |

## Structural Properties of Palmnut Fibre-Reinforced Mortar Composites

*Materials.* The cement used in the investigation is ordinary portland cement manufactured by Benue Cement Company Plc. The grading of the river sand used in the test conformed to Zone 3 of BS 882 (14).

*Strength Test Details.* Three types of tests were carried out for the purpose of assessing the structural properties of palmnut fibre reinforced mortar composite. Sand/cement ratios (s/c) of 1, 2, 3, 4, 5, 6 and water/cement ratios (w/c) of 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 were used to generate 36 different mixes of cement mortar. For each mortar mix fibre-mortar mixes were prepared with fibre volume fraction ($V_f$) of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0%. In all cases in thi work, mixing was done by hand. Sand and cement were first mixed properly to gether. The dry palmnut fibres were wetted by dipping in the mixing water and then added and mixed as evenly as possible with the dry sand-cement mixture before the remaining mixing water was added and further mixing done. It was observed that the above mixing procedure minimized the problem of balling of the fibres.

All test specimens were cured in water for 28 days at an average temperature of 27.6°C. The following properties of the fibre-mortar matrix were determined at 28 days:

(1) compressive strength on 100 mm cubes, three being tested for each mix;
(2) tensile strength on standard BS 12 (15) briquette specimens, three being tested for each mix;
(3) flexural strength on 300 mm × 75 mm × 10 mm specimens with central point loading, three being tested for each mix.

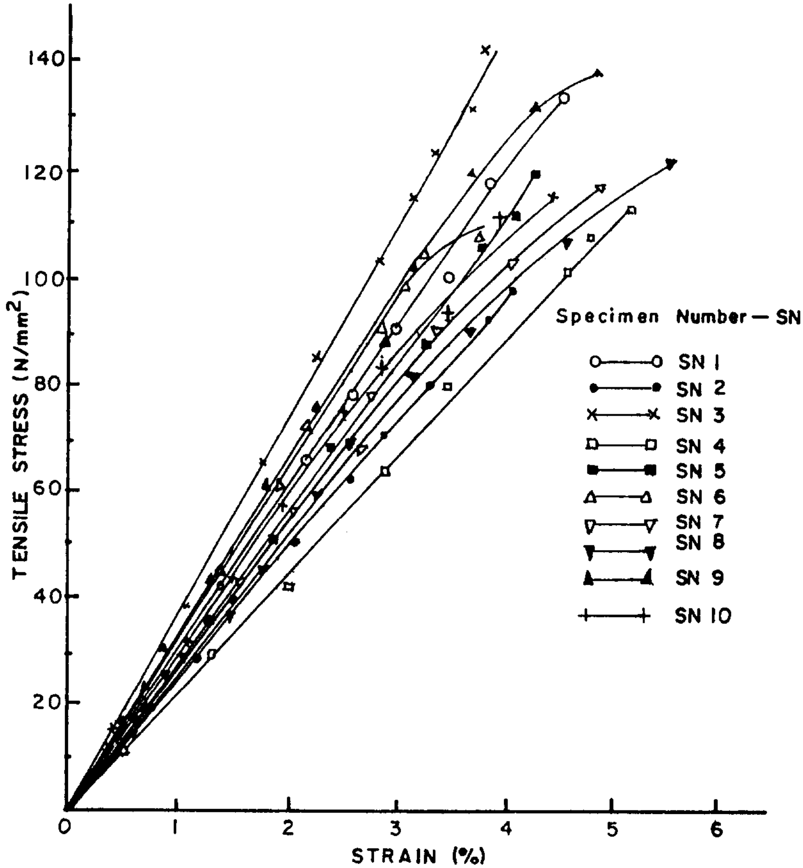


FIG. 2.
Stress-strain relationship for palmnut fibre.

## Results and Discussion

Compressive Strength. Typical results for the compressive strength of the fibre-mortar composites are presented in Figure 3. It is observed that the inclusion of palmnut fibre into mortar matrix reduces the compressive strength of the composite for all sand/cement ratios. This result is not surprising as the fibre in themselves can not resist axial compressive load and as such do not contribute to the compressive strength of the composite. Rather, under compressive type of loading the fibres may be viewed as a "filler" in the mortar matrix thus, introducing voids and discontinuity in the matrix with consequent reduction of strength. The reduction in compressive strength increases with increase in volume fraction of fibre and at 4% fibre volume fraction the strength reduction range is 37-65%.

Tensile Strength. Figure 4 shows typical results for the tensile strength of the fibre-mortar composites. In all cases, it is observed that the tensile strength of palmnut fibre reinforced

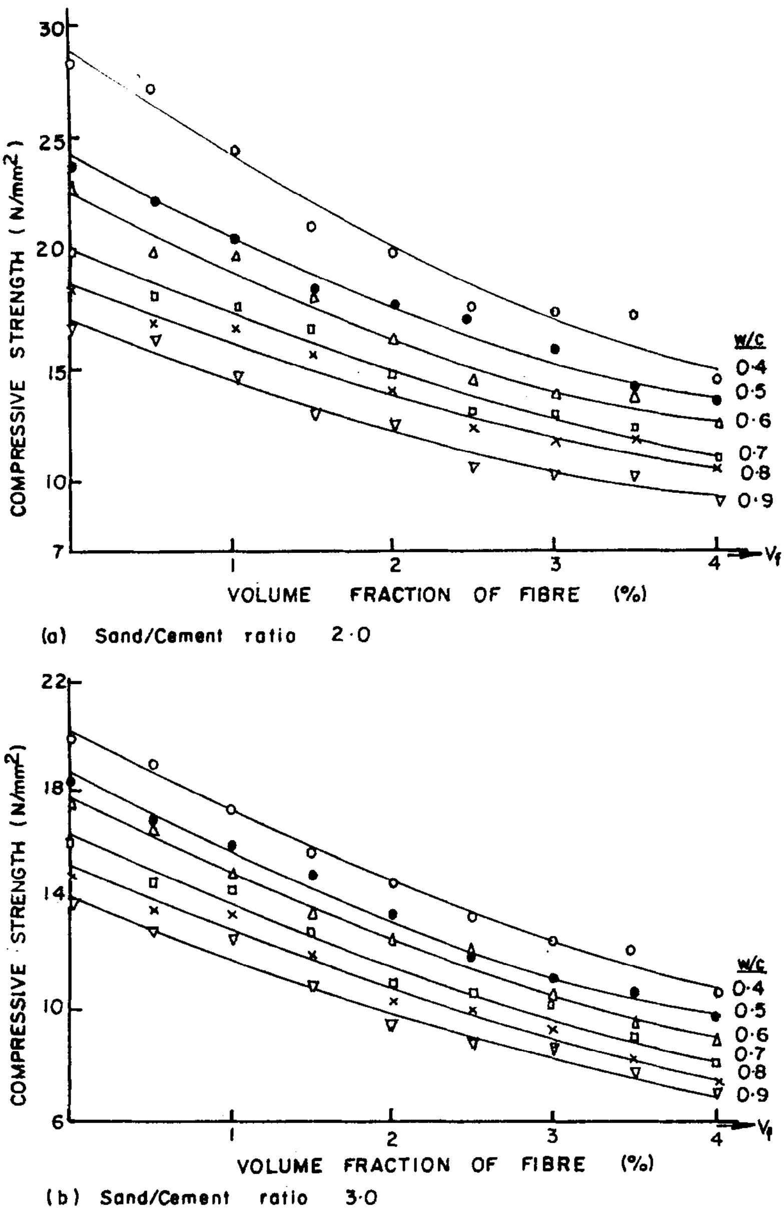


FIG. 3.
Relationship between compressive strength and volume fraction of fibre.

mortar decreases markedly with increase in the volume fraction of fibre. The reduction in tensile strength at 4% volume fraction of fibre is drastic ranging from 31 to 80% and appears to increase with increase in sand/cement ratio. The low tensile strength of the reinforced mortar may be attributed to the relatively low modulus of the fibres which has been

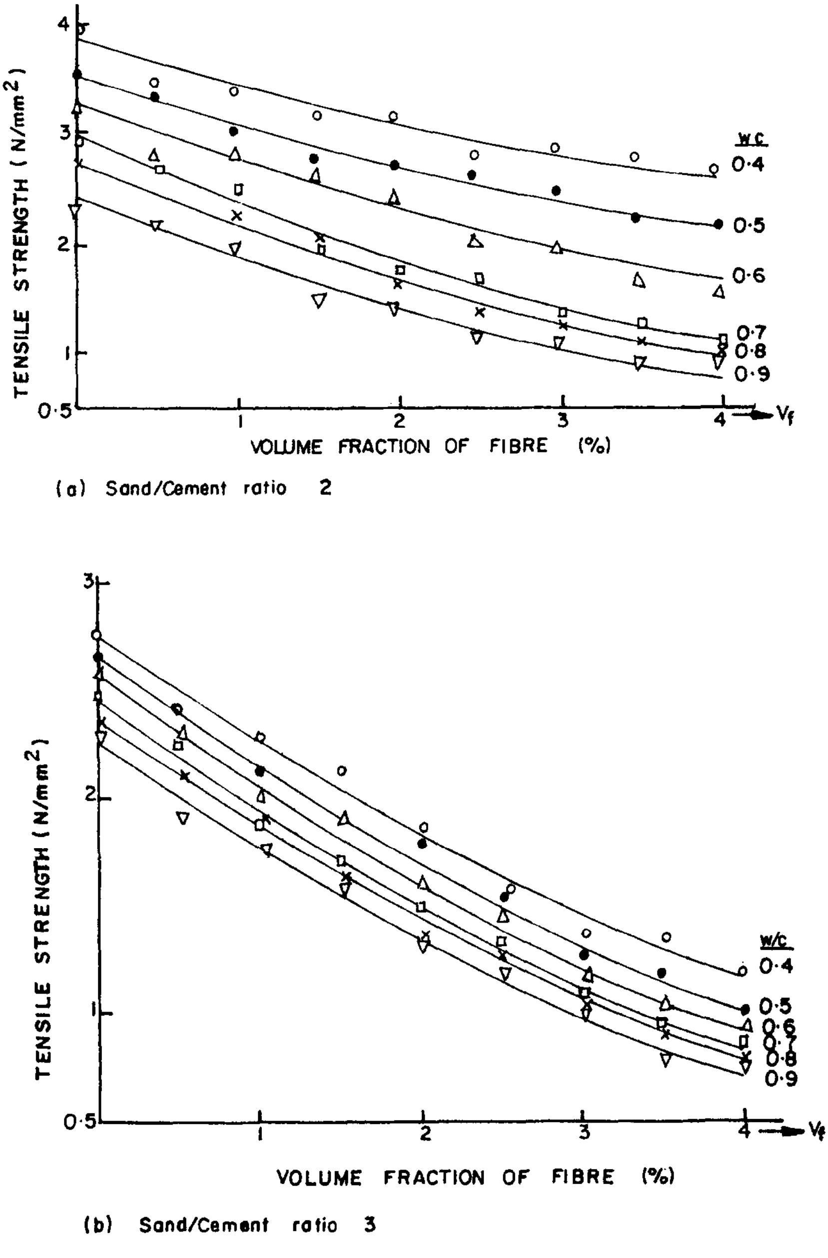


FIG. 4.
Relationship between tensile strength and volume fraction of fibre.

computed elsewhere (13) to be only about 1/8 that of the matrix. For the fibres to upgrade the tensile strength of the matrix, the fibre modulus needs to be appreciably higher than that of the matrix; otherwise, their inclusion into the matrix merely introduce voids and discontinuity in the matrix with consequent reduction in strength.

Flexural Strength. Typical results for the flexural strength tests of the fibre-mortar composites are presented in Figure 5. Unlike the compressive and tensile strengths, there is observed improvement in flexural strength by introducing palmnut fibre into mortar matrix. The improvement in flexural strength ranged up to 33%. This result is rather surprising because fibres with a low modulus, relative to the matrix, should not, from theoretical consideration of the structural mechanics (16), enhance the flexural strength of the composite as previous empirical studies (12,17-19) have confirmed. Taking cognisance of the service-

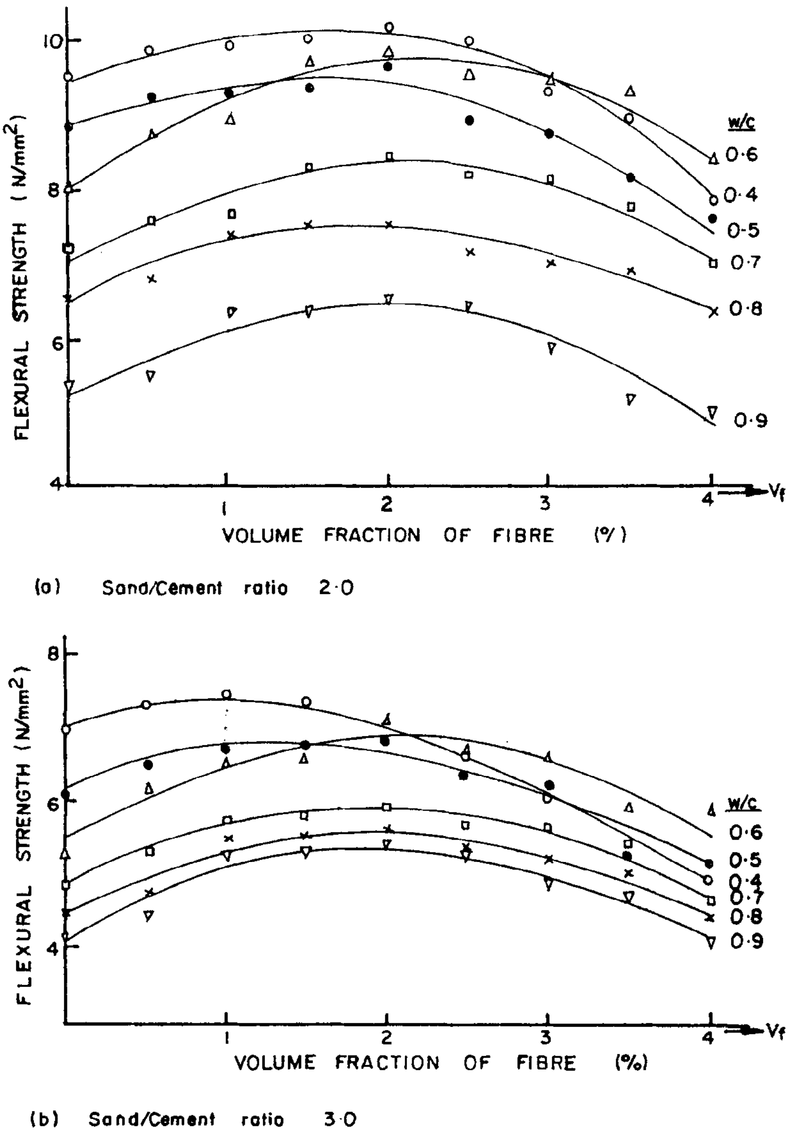


FIG. 5.
Relationship between flexural strength and volume fraction of fibre.

ability of Veficem roofing tiles, the standard definition of their modulus of rupture requires reconsideration in view of the results presented here and elsewhere (1,2). Nevertheless, it is a well established phenomenon that the post-crack load-deflection behaviour of such a composite is significantly different from that of the plain matrix. The fibre-reinforced composite has a post-crack load carrying capacity albeit of marginal consequence (19). Results from the present study are in conformity with this trend.

It was also observed that even where the composite had failed in flexure, the halves of the test specimens were still firmly held together by the fibres and that the crack formed at the failure surface closed upon release of the load. This observation is crucial in the performance characteristics of the composite as roofing element. The recorded improvement in flexural strength is pronounced up to sand/cement ratio of 4.0 after which fibre inclusion in the matrix appears to decrease the flexural strength of the composite. The decrease which is apparent at sand/cement ratio of 6.0 may be attributed to the weak bond that now exists between the fibres and the matrix as the relative quantity of binder is reduced by increasing the sand content. The fibres are no longer held firmly within the matrix and therefore cannot function effectively in resisting crack propagation as they are pulled out from the matrix. This fact was confirmed by separating the halves of the broken specimens where in this range of sand/cement ratio (s/c >4.0) the separation was quite easy and mainly by fibre pullout.

An optimum volume fraction of fibre of 2% was generally observed for the mixes with sand/cement ratio of 1.0 - 4.0. However, some mixes having sand/cement ratio of 3.0 and above and with low water/cement ratio showed optimum volume fraction of fibre range of 1.0 - 1.5% and is attributed to the very low workability of these mixes which reduced the degree of compaction as the volume fraction of fibre is increased.

## Optimum Mix Proportion

The optimum mix proportion was proposed by first determining the optimum proportion for the binary mixture (cement and sand). Nwokoye (20) has shown that the optimum properties of concrete mixes occur at the optimum coarse aggregate content and Powers (21) also observed a similar trend for mixtures of sand and cement.

Sand/Cement Ratio. The optimum sand/cement ratio was established by mixing the cement and sand in different proportions and determining the optimum sand content as that corresponding to the maximum compacted bulk density. To ensure uniform compaction effort, Proctor test mould was used and the mixes compacted dry in three layers, each layer being compacted with 25 blows of the Proctor rammer. The results of the test presented in Figure 6 indicate optimum sand/cement ratio of 2.0 for maximum compacted density.

Volume Fraction of Fibre. The optimum volume fraction of fibre was established by considering the effect of fibre inclusion into mortar matrix on the mechanical properties of the composite. The test results shown in Figure 5a for sand/cement ratio of 2.0 and for all water/cement ratios indicate that the optimum volume fraction of fibre for maximum flexural strength occurred at the fibre volume fraction of 2.0%.

Water/Cement Ratio. With the optimum sand/cement ratio and volume fraction of fibre established as 2.0 and 2.0% respectively, the workability of this mixture was assessed at

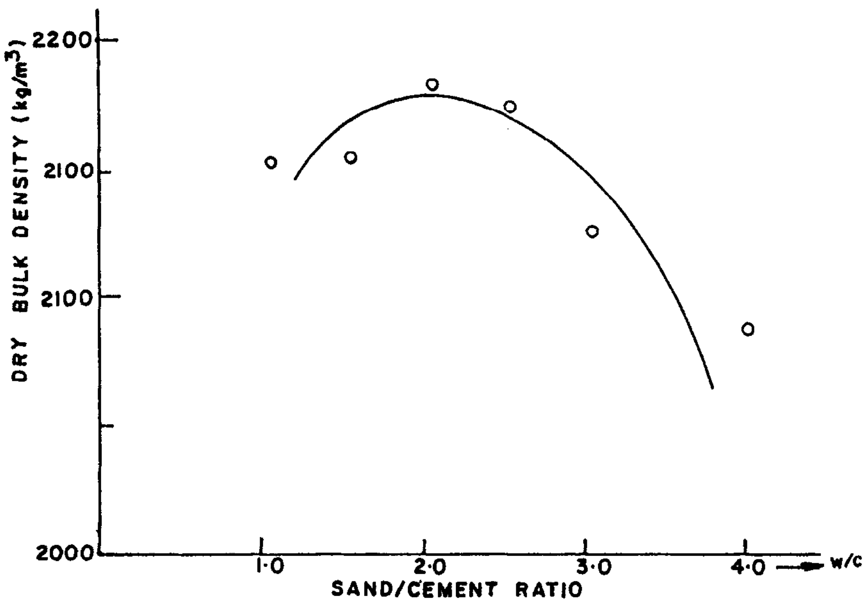


FIG. 6.
Relationship between compacted dry bulk density and sand/cement ratio.

different water/cement ratios for both plain and fibre-reinforced mortar. The compacting factor test was considered the most convenient basis for classifying the workability of the mixes and was carried out in accordance with BS: 1881 (22). The results are shown in Table 2. The compacting factor for all the fibre-reinforced mortar mixes was found to be lower than that of the corresponding plain mortar mixes. However, during the mixing and placing of the composite mortar it was observed that except at water/cement ratio of 0.40, the reduction in the workability of the fibre-reinforced mixes was not that much as was indicated by the reduction in the compacting factor. In fact, the composite mortar was observed to be more workable than the corresponding plain mortar mixes as the fibre helped to hold the matrix together and make it more cohesive. The best workability of the

TABLE 2
Workability Test Results (s/c = 2.0)

| Water/Cement Ratio | Compacting Factor | | % Reduction |
|---|---|---|---|
| | Plain mortar | Fibre mortar ($V_f$ = 2.0%) | |
| 0.40 | 0.865 | 0.802 | 7.3 |
| 0.50 | 0.948 | 0.890 | 6.1 |
| 0.60 | 0.991 | 0.961 | 3.0 |
| 0.70 | 1.000 | 0.993 | 0.7 |

composite mortar was obtained at a water/cement ratio of 0.60. The mix was cohesive, flowed satisfactorily, responded well to vibration and was easily placed with good finish. At water/cement ratio of 0.50, low plasticity was observed which resulted to shearing and cracking of the fresh fibre mortar composite during pilot production of tiles, while at water/cement ratio of 0.70 excessive bleeding and segregation of the mix were observed.

The optimum mix proportion is established thus:

| | | |
|---|---|---|
| Sand/cement ratio, (s/c) | = | 2.0 |
| Water/cement ratio, (w/c) | = | 0.60 |
| Volume fraction of fibre, ($V_f$) | = | 2.0% |

## Conclusions

The following main conclusions are drawn from the study:

(1) The modulus of elasticity and ultimate tensile strength of palmnut fibre used in this investigation range from 1.93 to 3.66 GPa and 86.6 to 144.74 N/mm$^2$ respectively.
(2) There is no significant effect of calcium hydroxide solution and thus the alkaline environment of cement on the stress-strain characteristics of palmnut fibre.
(3) Palmnut fibre-reinforced mortar has lower tensile strength and lower compressive strength than the unreinforced mortar.
(4) Palmnut fibre inclusion into mortar improved the flexural strength by up to 33%, and there was an optimum fibre volume fraction of 2%.
(5) For the brand of cement and type of sand used in this study, sand/cement ratio of 2.0, water/cement ratio of 0.6 and volume fraction of fibre of 2.0% were found to be the optimum mix proportions.

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