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論 文

[1198] Study of the Properties of Coir Fiber Mortar and Concrete

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1. INTRODUCTION

Cement based products reinforced with natural fibers in appropriate field of applications is very significant from economic and technical point of view. Its low-cost and easy replenishability are some of its many distinct advantages, which when fully harnessed can lead to energy and scarce resources conservation. Technical merits of natural fibers in cement matrices like delaying of tensile cracking, improvement of post-cracking strength, and toughness have been reported [1]. One hindering factor to the extensive use of natural fiber is its inherent low-modulus of elasticity, and low-durability in an alkaline medium[1]. However, appropriate short ranged application like pre-cast formworks, and piling shells-cap can adopt such kind of fiber as a support or main reinforcement. If these are the intended applications of the fiber composite, then it is necessary to study exhaustively the properties of this kind of material. This paper describes the results of comprehensive experimental evaluation of the fresh and mechanical properties of a particular natural fiber cement composite, namely a cement mortar/concrete reinforced with short randomly oriented coir fiber.

2. EXPERIMENTAL PROGRAMME

A comprehensive experimental program was carried out to determine the influence of fiber reinforcing parameters, i.e., fiber volume fraction (Vf by volume) and aspect ratio (L/d) in combination with different types of matrices to the fresh and mechanical properties of coir fiber cement composite. The program is divided into two subseries, namely: (1) Investigation of the effect of major parameters to the properties of the composite with mortar, and (2) with gravel-concrete as the matrix phase. Test detail and series coding are outlined in Table 1.

2.1 MATERIAL AND METHOD OF TEST

The properties of portland cement, fine and coarse aggregates used in this study are shown in Table 2. The natural fiber used in this experiment came from a matured air-dried coconut (Cocos Nucifera Linn) fruit harvested for copra in Laguna, Philippines. The coir fiber has an average tensile strength, initial modulus of elasticity and elongation of 1100 kgf/cm^2, 29000 kgf/cm^2 and 25% respectively. Structure of fiber surface and section in Fig.1 reveals its inherent durability potential against decomposition. The chopped fibers are gradually dispensed into the fluid mixture while mixing. Fresh properties of concrete mixture like slump, inverted slump time, and air content were measured in accordance with ASTM C-143, C-995, and C-231, respectively. Behaviour of the properties like the modulus of elasticity, stress and strain at the

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onset of first crack, at ultimate, and at post cracking stages under compression (ASTM C-39), flexure (ASTM C-1013), and direct tension (insert method [2]) were measured from the respective stress-strain diagram.

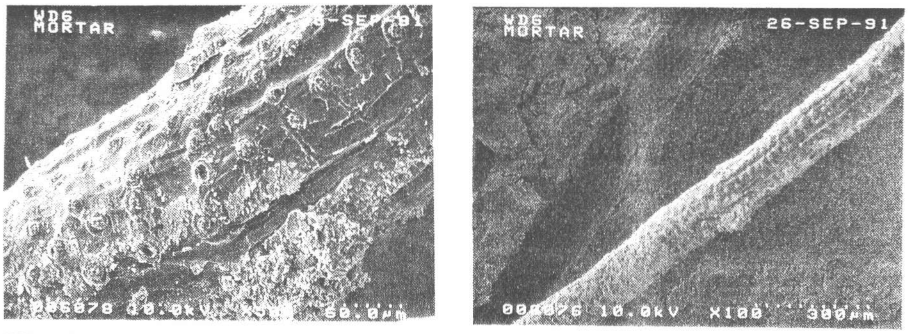

FIG.1 SEM micrograph of coir fiber surface and replicated topography in matrix

TABLE 1 DETAIL OF TEST

MIX CODE SERIES	TYPICAL PROP. C:S:G:W/C	FIBER LENGTH (cm)	FIBER VOLUME (%)
MORTAR			
_M40_	1:1.0:0.0:40	3, 6, 9	0.8, 1.5, 2.5, 3.5, 4.5
_M70_	1:3.0:0.0:70	3 - -	0.8, 1.5, 2.5, 3.5 -
CONCRETE			
_C40_	1:1.8:1.0:40	3 - -	0.5, 1.0, 1.5, 2.5
_C50_	1:2.3:1.5:50	1, 3, 6	0.5, 1.0, 1.5, 2.5, 3.5
_C60_	1:3.0:2.0:60	3 - -	0.5, 1.0, 1.5, 2.5

Table 2 PROPERTIES OF CONSTITUENTS MATERIAL

MATERIAL	SPECIFIC GRAVITY	DESCRIPTION
CEMENT	3.15	FINENESS:3260 cm^2/g CONSISTENCY:28.1%
SAND	2.60	FUJI RIVER SAND, ABS:1.60% MAX SIZE:2.5mm,FM:2.41
GRAVEL	2.62	KINU RIVER GRAVEL,ABS:1.40% MAX SIZE:20mm,FM:6.26

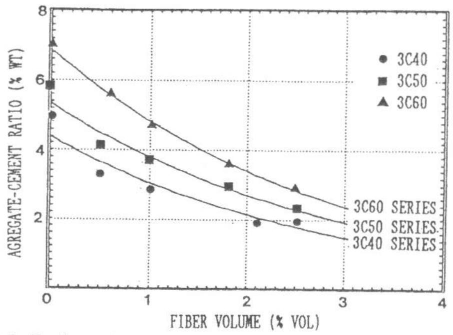

FIG.2 Reduction of Aggregate/cement ratio

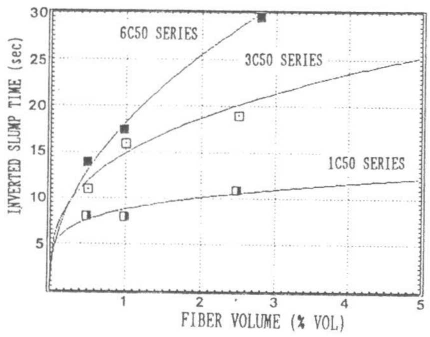

FIG.3 Effect of fiber length to inv slump

3. DISCUSSION OF RESULTS

3.1 FRESH PROPERTIES

Inclusion of coir fiber in fresh concrete or mortar significantly altered the rheological behaviour of the mixture in terms of stability and mobility. The coir fiber stiffened the mixture resulting to an increased stability and cohesion. Effect of fiber addition to the mix proportion and fresh properties of concrete are summarized in Table 3. In Fig.2 the reduction of the aggregate-cement (A/C by weight) ratio that is necessary in order to meet the required workability of 10-14 seconds inverted slump time in a concrete mixture is clearly shown. For this particular method of mixing, fiber balling was observed to occur at $V_f \geq$ 1.5% for concrete and 2.5% for mortar having a typical fiber length of 3 cm (approximate L/d=100). As expected, loss of workability with an increase in fiber content and aspect ratio occurred, as shown in Fig 3. Such loss are primarily due to the bundling of fibers, particle interference between fiber and aggregate, and the overall proportioning of the constituents.

TABLE 3 - Mix proportion and Fresh Properties

MIX SERIES	QUANTITIES (per cu.m.) VF (%)	CEMENT (kg)	WATER (kg)	SAND (kg)	GRAVEL (kg)	FIBER (kg)	FRESH PROPERTIES SLUMP (cm)	INV.SLUMP (sec.)	AIR (%)	DENSITY (kg/m3)
BASE C40	0	450	180	1215	810	0	19.0	----	3.5	2656
FRC 3C40	0.5	627	251	1063	709	10	17.5	12.3	3.8	2660
	1.0	613	245	1134	643	20	11.5	13.8	3.9	2656
	2.5	715	286	1092	470	37	11.4	16.5	3.9	2603
BASE C50	0	438	219	1183	832	0	17.0	----	4.5	2674
FRC 3C50	0.5	456	228	1122	828	8	12.0	11.0	3.9	2642
	1.0	572	286	1095	617	28	9.5	17.8	4.1	2597
	2.5	625	313	938	625	40	16.0	19.0	3.0	2540
BASE C60	0	321	193	1252	834	0	11.0	----	3.5	2600
FRC 3C60	0.5	372	224	1191	840	11	9.0	10.2	3.1	2637
	1.0	395	237	1164	760	17	11.0	10.0	4.2	2574
	2.5	485	291	1161	632	32	12.5	25.5	2.8	2550

3.2 MECHANICAL PROPERTIES OF COIR FIBRE COMPOSITE

3.2.1 Compressive Properties

It was observed that the failure of specimen was gradual, and in spite of the presence of excessive vertical cracks the specimen retained its structural integrity. The experimental stress-strain curve showed: (1) changes in the slope of the elastic portion, (2) the peak strain, (3) shallow slope of the post-cracking portion, and (4) increased area under the stress-strain diagram. These experimentally observed properties were correlated with the fiber and matrix parameters in order to derive a simple prediction equations which can be used in calculating the basic compressive properties. In Fig.4 the effect of fiber addition to compressive strength of a fiber-mortar or concrete is found to be minimal. It was also observed that a marked decrease in strength occurred for a $Vf \geq 2.0\%$. This may be due to the increased porosity brought about by the reduced efficiency in compaction of a high Vf mixture. Also, at high fiber content it was necessary to reduce the amount of the aggregate to meet the workability requirement. This may have caused a weakening of the fiber-matrix bond due to the lack of sufficient matrix necessary for efficient fiber embedment. As for the effect of length, variation in strength at different aspect ratio never differs by more than 10% especially at a low Vf. However, at high fiber volume the reduction in strength is more pronounced for longer fibers, which may be brought about by fiber bundling and ineffective compaction. The compressive strength (σc_c) was correlated with parameters,

fiber concrete: $\sigma c_c = 1.0701 \ \sigma c_m(1-Vf) - 1.77 \ Vf(L/d)$ (R=0.980) (1a)

fiber mortar: $\sigma c_c = 1.1210 \ \sigma c_m(1-Vf) - 23.31 \ Vf(L/d)$ (R=0.961) (1b)

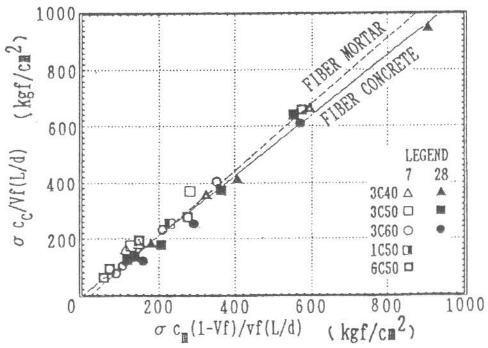

FIG.4 Correlation of compresive strength with major parameters

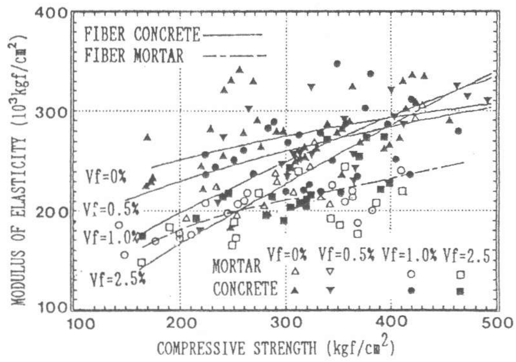

FIG.5 Compressive strength-Elasticity Relationship

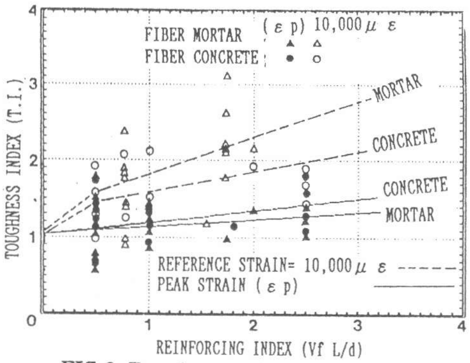

FIG.6 Toughness index in compression

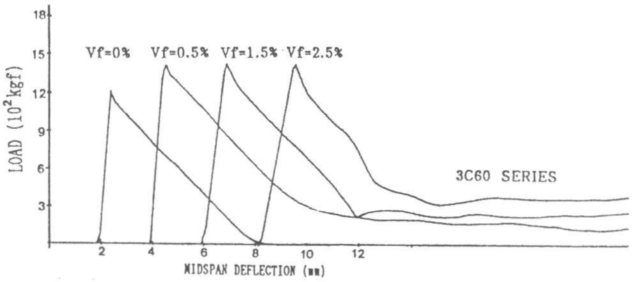

FIG.7 Typical Load-deflection diagram

Modulus of Elasticity (Ec_c) - A slight reduction in the secant modulus of elasticity (at 45% of the compressive strength) can be seen in Fig 5. This may be due to increased porosity, elasticity mismatch, low modulus and high Poisson ratio of the reinforcing fiber. Also, the secant modulus of fiber mortar is about 20-40% less than that of fiber concrete, which may be due to the absence of coarse aggregates. Curves shown in Fig.5 are summarize into a single expression relating the modulus of elasticity with the fiber parameters (Vf, L/d) and matrix strength by the method of least square, and the equation is given as

fiber concrete: $Ec_c = 766\sigma c_c + 18721\ Vf(L/d)$ (R=0.958) (2)

Degree of Toughness in compression - Enhanced ductility was clearly seen from the shallow slope in the post cracking portion of the stress-strain diagram. Measured peak strain (εp) of fiber mortar and concrete are 10-30% greater than that of the base matrix. These enhancements resulted to a higher degree of toughness due to the increased area under the stress-strain diagram. Toughness index (T.I.) in compression was calculated as the ratio of the area of the stress-strain diagram of fiber composite and that of the base matrix measured from a reference strain, ie. εp and $10{,}000\mu\varepsilon$. These reference strains were chosen to measure the energy absorbing capability of the composite prior and after the cracking stage. In Fig.6, more than twofold increased in toughness occurred, and it was observed that this was most pronounced in a ductile matrix series (eg. W/C=60).

3.2.2 Flexural Properties

Typical flexural load-deflection curves shown in Fig. 7 shows the different responses of composite at different fiber volume fraction. Higher fiber dosage improved the post-cracking strength without significantly affecting the first crack strength. It was observed that the coir fibers were very effective in controlling the growth of major cracks which prevented the sudden failure and collapse of the specimen. In Fig. 8 a nominal increase proportional to the fiber reinforcing index in flexural strength of about 8-12% occurred. This trend is comparable to the results obtained with similar low-modulus synthetic fibers (eg. polypropylene). Effect of aspect ratio seems negligible since the variation in strength is around 10% only. The flexural strength of mortar and concrete reinforced with short-randomly oriented fibers is given as,

fiber concrete: $\sigma b_c = 1.1090\ \sigma b_m(1-Vf) + 0.65\ Vf(L/d)$ (R=0.994) (3a)

fiber mortar: $\sigma b_c = 0.9542\ \sigma b_m(1-Vf) + 2.210\ Vf(L/d)$ (R=0.992) (3b)

Swamy et.al.[3]: $\sigma b_c = \sigma b_m(1-Vf) + 0.82\tau\ Vf(L/d)$ (4)

Comparing eq.3 to eq.4, the average interfacial shear stress (τ) between fiber and matrix during this peak stage can be calculated, where τ is equal to 2.7 and 0.8 kgf/cm² for mortar and concrete, respectively. The reduction in the value of τ as the matrix changes from mortar to concrete is in agreement with the result obtained from the works of Swamy et al. with steel fiber concrete[2]. Also this value of τ confirms the notion that the stress level at the pullout stage is well below the stress level required to cause the yielding of fiber, which is about 500 kgf/cm^2. Hence, the ability of coir fiber to impart toughness thru gradual fiber pullout does not diminish in spite of its low tensile strength.

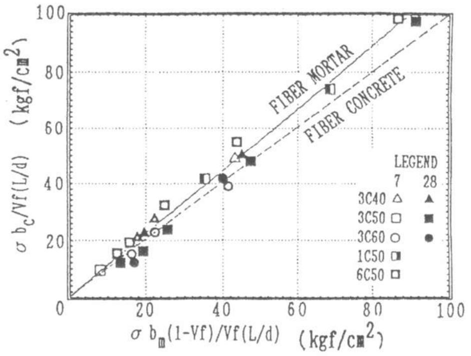

FIG.8 Correlation of flexural strength

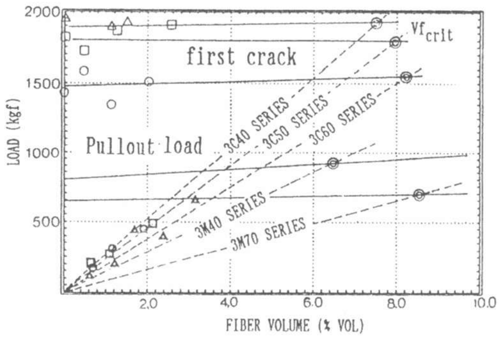

FIG.9 Location of Vf critical

Strain at ultimate and at onset of first crack - The onset of first crack was measured from a point in the flexural stress-strain where the curve started to deviate from linearity. This designates the stage when the microcracks concentrate and localize in the direction of the principal strain [3]. Effect of the reinforcing index to both flexural stress and strain at onset of first crack is limited to less than 10% only. As for the strain at the peak or ultimate, significant improvement occurred in the coir fiber cement composite. The measured maximum strain in the tensile zone ranged between 200-400$\mu\varepsilon$ compared to the 150$\mu\varepsilon$ of the plain concrete. This ability to sustain additional strain without collapse is a special attribute of fiber concrete, and this is also visible with this kind of low-modulus fiber cement composite. The maximum tensile strain (εb_c) is summarized as follows,

fiber concrete: $\varepsilon b_c = 4.32\ \sigma b_c + 30.0\ Vf(L/d)$ (R=0.946) (5)

Flexural modulus of elasticity (Eb_c)- The secant modulus of elasticity measured from the linear portion [3] of the experimental stress-strain curve up to the first crack varied between 250000 to 355000 kgf/cm^2. Theoretically, a low modulus fiber will yield a composite modulus of elasticity slightly lower than that of the matrix. From the experimental results, it was found out that no reduction and in fact a slightly increasing trend of the modulus of elasticity proportional to Vf(L/d) index occurred. The prediction equation is given as,

fiber concrete: $Eb_c = 6030\ \sigma b_c + 7038\ Vf(L/d)$ (R=0.990) (6)

Post cracking strength and Location of Vf critical - Sudden failure was prevented due to the presence of fibers spanning the cracks in the beam specimen. This is reflected from the presence of the residual load in the load-deflection diagram in Fig. 7. In Fig.9, the negligible difference in the post-cracking trend for W/C ratio ranging from 40 to 60% (fiber length of 30 mm) can be seen. This indicates the relative similarities in the interfacial shearing stresses for this range of W/C ratio. The significant effect of (L/d) to the post-cracking strength was observed. Remarkable improvement was seen for the composite containing lower aspect ratio fiber, which may be attributed to the larger surface area of fiber and its higher incidence of passing a vertical crack.

The graphical method of Vf critical determination as suggested by Hannant[4] was adopted in this study. In Fig.9, the Vf critical for concrete with W/C ratio ranging from 40-60% (3C40, 3C50, 3C60) is roughly at 7-8%. For mortar with W/C ratio of 40% (3M40) its around 6%. The increase in the value of Vf critical can be attributed to the post cracking strength and to the decrease in the interfacial shear stress (τ) as the matrix changed from mortar to concrete. Likewise the use of a weak matrix may decrease the interfacial shear stress which can result to a higher Vf critical, as seen from the value of 8% of the 3M70 series.

Energy absorbing capability of coir-fiber concrete - The first crack toughness in flexure was computed based on the definition of ASTM C-1018. The toughness index (T.I.) was calculated up to 5.5 times the deflection at the first crack. It is evident from Fig. 10 that the addition of fiber increased the toughness by more than 100% for fiber volume of 1% only, and it increases in proportion to the value of the index VfL/d. This toughness enhancements not only implies ductility and energy absorbing capabilities but also assurance of safety and integrity of a structural element prior to failure.

3.2.3 Tensile Properties

Results of split tensile tests showed negligible improvement in the first crack strength even with the addition of coir fibers. As for the direct tension, relationship between fiber index and tensile strength in Fig.11 indicates an increase of about 18% proportional to the fiber reinforcing index. Likewise a slight increased in the first crack strength of the order of 10% was observed. The secant modulus of elasticity calculated from the stress-strain curve in direct tension showed that a slight improvement proportional to the Vf(L/d) occurred. A simple prediction equation is given as,

$$Et_C = 8672\ \sigma t_C + 1159\ \ Vf(L/d) \qquad (R=0.963) \qquad (7)$$

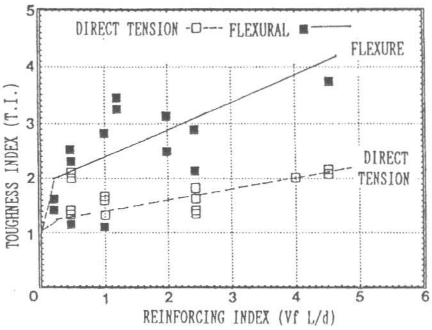

FIG.10 Toughness index in flexure

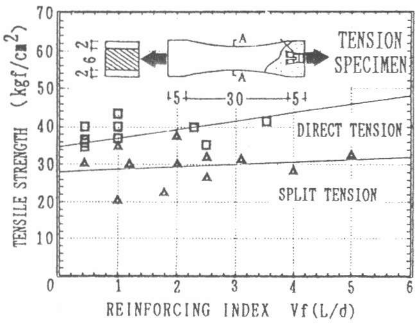

FIG.11 Trend of tensile strength

4. CONCLUSION

This study indicates that the utilization of coir fiber derived from the residues of coconut husks can provide solutions to two significant problems, namely, elimination of solid wastes and the provision of a valuable construction material. Based from this experiment the feasibility of using the coir fiber in construction is very significant, and from these improved understanding of the structure-property of the coir fiber cement composite it may be possible to find new ways to apply such kind of material as reinforcement not only to cement matrices but also to other kinds of materials.

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