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EVALUATION OF DURABILITY OF NATURAL FIBRE REINFORCED CEMENT MORTAR COMPOSITE- A NEW APPROACH

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ABSTRACT

'Toughness' of a composite generally based on the 'toughness indices' evaluated by flexural tests as contemplated in several codes (ASTM, ACI, JCI-SF4/JSCE-SF4) may not be appropriate / realistic for natural fibre cement composites containing low modulus fibres like sisal, coir etc., due to several reasons. Further, durability of natural fibre cement composite can be evaluated on the basis of flexural toughness (FT) and it has a special significance. Toughness of a natural fibre composite can also be evaluated by impact tests, which helps in realistic assessment of ductility of the above composite. Evaluation of durability of a natural fibre composite by residual impact strength (I_{rs}) and flexural toughness index (I_T) and their comparison are presented and discussed. I_{rs} values could be used to assess the durability of natural fibre composites, than, the conventional 'toughness indices' used for composites, in general.

Keywords: durability, toughness, residual impact strength, flexural toughness index, fibre content, sisal fibre, cement mortar.

1. INTRODUCTION

Durability of a material, in general in defined as the service life of a material under given environmental conditions. The above definition holds good for all concrete and cementitious composites (reinforced with artificial fibres like steel etc.). However, in the case of natural fibre composite, not only the (external) environment, but also the internal environment in the matrix (i.e. alkaline medium), play a combined role in determining its durability. Several investigators have studied the durability of various natural fibres, such as, sisal, coir, jute etc., in various mediums and exposure conditions which has been summarized in Table-1[1-15].

Table-1. Overview of durability of natural fibres investigated.

Fibre type	Aging/exposure conditions											Ref. /(s)
	1	2	3	4	5	6	7	8	9	10	11	
Agava	•	•							•	•	•	1
Akwara		•										2
Bamboo	•	•										3
Coir	•	•	•	•	•	•	•	•				5,6,7,8,9
Date palm		•										10
Elephant grass	•	•										11
Hemp	•											6
Jute	•	•	•									4,6,7,12
Musamba	•	•										11
Remie		•										12
Sisal	•			•								5,13,6,14
Plantain	•	•										6,11
Water reed	•	•										15,11

Note: (i) Description of codes in aging/exposure conditions are as follows; 1- Alkaline medium (continuous/alternate wetting and drying under room/elevated temperature); 2- Alternate wetting and drying; 3- Tap water (over varying periods); 4- Cement saturated water; 5- Seawater; 6- H_2SO_4 solution (1%); 7- One year old mortar and water cured; 8- One year old mortar (air-cured); 9- Na_2SO_4 solution (10%); 10- Alternate freezer and water curing; 11- Alternate elevated and normal water temperature. (ii) Criterion to evaluate the durability of fibres after exposure in the various test conditions can be summarized as: Tensile strength; Changes in length/diameter/ weight.

The durability of natural fibre composites exposed to various environments has also been investigated, based on the changes in a chosen strength criterion (Table-2).

Table-2. Overview of durability of natural fibre composites investigated.

A	B				C										
	F	T	S	I	1	2	3	4	5	6	7	8	9	10	11
Agava-mortar	√					•	•		•	•	•	•			
Banana-mortar	√						•	•							
Cellulose-cement sheet			√										•	•	
	√	√													•
	√				•										
Coir-mortar, concrete	√	√			•	•	•	•							
	√				•		•	•							
	√						•								
		√													
	√						•	•							
Date palm-mortar	√				•										
Jute-mortar	√						•	•							
	√							•							
Ramie-mortar	√						•	•							
	√							•							
Sisal-mortar, concrete	√	√			•	•	•	•							
	√				•		•	•							
	√						•	•							
	√						•								
Wood fibre-cement sheet	√	√		√	•		•								

Note: (A) type of fibre and composite (B) Criterion for evaluating durability (C) aging/exposure condition
(i) F-Flexural strength- Toughness; S- (Compression) Shear; I - Impact strength**;** (ii) Description of codes for aging/exposure conditions are as under 1-Tap water; 2-Alkaline medium; 3- outdoor environment; 4- Alternate wetting and drying; 5- Na_2SO_4 solution (10%); 6-Alternate elevated and near zero temperature; 7-Alternate elevated and curing in normal water temperature; 8-Alternate freezer and curing in normal water temperature; 9-Cyclic freeze-thaw; 10-Accelerater carbonation and 11- Hot water soak test (ASTM C 1185).

In reality, durability of natural fiber composites cannot be determined solely on the deterioration characteristics of natural fibres, as fibre-debonding from the cement matrix and the reduction of strength of cement matrix in the alkaline medium, and other environments would have cumulatively contributed to the deterioration of the composite and hence may have to be considered for obtaining better insight into the actual deterioration process. Generally, post-crack behaviour of the cement composite is a measure of ductility and it is an important parameter used to evaluate the durability of fibre composites. This is measured by 'toughness' of a composite structural member, in an indirect manner by carrying out tests involving direct tension, compression or flexure. However, flexural tests are generally preferred in view of their simplicity [4]. The test procedures for the measurement of 'toughness indices' given in the various codes of practice are summarized in Table-3.

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Table-3. Measurement of toughness of the composites by various codes of practice.

Type of standard and Ref. Nos.	Toughness indices considered	Evaluation of toughness of the composite
ASTM C-1018 [24]	I_5, I_{10}, I_{30}	• Ratio of area under the load - deflection curve up to deflection of 3, 5.5, 15.5 times the first - crack deflection of the curve. • The indices I_5, I_{10}, I_{30} have a minimum value of unity (i.e. elastic - brittle behaviour) and values of 5, 10, 30 respectively for ideal elastic - plastic behaviour.
JCI–SF4 and JSCE- SF4 [25-31]	T_{JCI}	• Energy required to deflect to a mid - point deflection of 1/150 of its span. • In addition to the absolute toughness value, a flexural toughness factor (or average flexural strength-f_e) is also used as one of the toughness parameter i.e. $f_e = (T_{JCI} / d_t) * (s / bd^2)$ Where, s,b,d are the span, breadth and depth of the specimen; d_t - specified deflection and T_{JCI} - area under the load - deflection curve upto the deflection ‘ d_t’.
Ward and Li method [32]	T_{max}, T_{50} and T_{10}	• T_{max}’ is defined as the beam deflection at maximum load divided by the deflection at first crack and is somewhat analogous to the ‘ductility ratio’ used with reinforced concrete beams. • The above index gives an idea of the ‘inelastic deformation’ and ‘multiple cracking’ that occurs before the ultimate load is reached. • ‘T_{50}’ is defined as the deflection when load drops to 50% of the maximum value divided by the deflection, which would be observed at a similar load on the ascending part of the load - deflection, if the beam behaved linearly - elastic, up to this point. • It reflects the ability of a beam to absorb energy by ‘inelastic deformation’ relative to the rate at which it stores or releases elastic energy. • ‘T_{10}’ is defined as the total area under the load - deflection curve upto the point, where, the load drops to 10% of the maximum value, divided by the beam cross - sectional area. It correlates approximately to the total energy - adsorption capacity of the beam.

‘Toughness indices’ of the composites as summarized in Table-3 are based on the flexural tests conducted on the composite beam specimens. Moreover, they have been used to understand the behaviour of various composites and also to evaluate the relative performance of different composites. As an extension of the above approach ‘toughness’ of natural fiber composites have so far been evaluated based on flexural tests. However, in the case of natural fiber composites, evaluation of ‘flexural toughness’ (F_T) has a special significance. Not only the durability of a composite as such, but also, the relative improvement/ loss in the durability of such composites, due to various methods of enhancing/ improving durability, can be evaluated. During the service life of fibre reinforced composites, they are not only subjected to flexural static, dynamic and fatigue loads, but also, subjected to impact loads. It is therefore necessary to evaluate the toughness of a composite subjected to impact loads and compare it with the result from other F_T tests commonly adopted. Incidentally, impact strengths characteristics are much simpler to evaluate than the ‘F_T’ and its indices as stated in Table-3.

In view of the above, durability of a natural fiber (i.e., sisal) reinforced cement mortar is evaluated using an impact test [35] and the results obtained are compared with that of flexural toughness evaluated for identical specimens, to highlight the usefulness of the new approach.

2. MATERIALS AND METHODS

2.1 Materials used

OPC-53 grade; fine aggregate; potable water; and sisal fibres, were the various materials used for the various investigations of the composite. The salient properties of the materials evaluated adopting standard test methods [32, 33] are presented in Tables 4 to 6.

Table-4. Physical properties of cement (OPC-53 grade).

Property	Value	IS 12269-1987 requirements
Standard consistency (%)	29%	--
Initial setting time (min.)	55 min	30 mts (min.)
Final setting time (min.)	175 min	600 mts (max.)
Soundness	1mm	10mm (max.)
Specific gravity	3.14	--
Compressive strength @		
(i) 3 days	28 MPa	27 MPa (min.)
(ii) 7 days	38 MPa	37 MPa (min.)
(iii) 28 days	56.7 MPa	53 MPa (min.)

Note: Sand conforming to the gradation stipulated in I.S. specification for 'standard sand' was prepared in the laboratory and used for determining the compressive strength of cement.

Table-5. Physical properties of fine aggregate.

Property	Value/ description
Specific gravity	2.48
Water absorption	1.4%
Rodded bulk density	1.737 gm/cc
Fineness modulus	2.5

Note: Procedure is based on IS: 383 - 1997 [33]

Table-6. Physical properties of sisal fibres.

Fibre type	Sisal
Fibre length (mm)	180-160
Fibre diameter (mm)	0.1-0.5
Tensile strength(N/mm^2)	31-221
Elongation (%)	14.8
Specific gravity	1.4
Elastic -modulus (GPa)	7.83

2.2 Preparation and testing of specimens

Flexural and impact strengths of sisal reinforced cement composites were evaluated by testing slab specimens (size: 300x300x20 mm; 1:3 mix) adopting W/B corresponding to a constant flow value (=112%) and at four ages of normal curing (i.e. at 28, 56, 90 and 120 days). Six fiber contents ranging from 0% - 2.0% (0.25%, 0.50%, 0.75, 1.0%, 1.5% and 2.0 - by wt. of cement) were used in the cement mortar composites. W/B ratio corresponding to a flow value of 112.5% (i.e.0.47) was determined by flow Table test for 1:3 mix. At the end of the above curing period, the slab specimens were tested by the projectile impact test [34]. Flexural strength of mortar slab specimens was determined by a four-point loading system and using the 5kN capacity universal tensile testing machine. A computerized data-logging system was interfaced to the above test set-up for acquiring data and processing them, through software exclusively developed for the above purpose. For the above test, slab specimens of size 120x90x20 mm were cut and removed from the fractured slab specimens obtained from the impact test of slab specimens of size 300x300x18 mm. For each slab specimen, the load versus deflection values were obtained through LVDT and logged on to a computer and a plot of load vs. deflection obtained using the specially developed software, wherein the load is measured at the loading position of the specimen used in the test. Along with the above plot, the maximum load and deflection at failure are also displayed in the system and logged on to the computer. After the specified period of normal curing, i.e., in this case, after 120 days, the slab specimens were kept immersed in NaOH solution (prepared at 0.1N) for (another) 28 days. After 28 days of immersion in the above alkaline medium, the slab specimens were tested for their impact and flexural strength using the identical procedure and experimental set-up as for the case of normal-cured specimens. The results from the above tests were used to understand the behaviour of slab specimens in an alkaline environment and to evaluate the durability of the composite. Details of projectile test, calibration between energy and blows imparted and comparison between the three-point and four point flexural testing tests are discussed and available elsewhere [35,36].

2.3 Durability evaluation of the composite

During the impact test on each slab specimen, the numbers of blows required for the appearance of the first crack and at the failure were noted. The impact energy absorbed by the mortar slab specimens were computed based on the number of blows required to initiate the first crack and the number of blows required to cause ultimate failure using simple projectile test set-up [34,35]. From the above two energies, the residual impact strength (I_{rs}) is computed using equation (1)

$$\text{Residual impact Strength Ratio} - (I_{rs}) = \left[\frac{\text{Energy absorbed upto ultimate failure}}{\text{Energy absorbed at initiation of first crack}}\right] \quad \text{--- (1)}$$

'I_{rs}' as defined was evaluated before and after exposure in NaOH medium. Similarly flexural toughness (F_T) of the composite before and after exposure in NaOH medium was determined.

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Deviation in 'I_{rs}' and 'F_T' values expressed as percentage of values before exposure in alkaline medium, were computed, critically assessed for evaluating the durability of the composite.

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of durability based on 'I_{rs}'

Impact strength and I_{rs} values of cement mortar slabs and cement mortar composite slabs before and after exposing them in NaOH medium are given in Table-7 for various fibre contents.

From the critical evaluation of the above experimental data, following observations are obtained.

(i) I_{rs} values of cement mortar slabs decreases after exposure in NaOH, due to interaction between the matrix and the medium, leading to strength - loss of the matrix after exposure, which is reflected in the I_{rs} values of the slabs.

Table-7. Impact strength of sisal fibre cement mortar composite slabs before and after exposure in NaOH (1:3; constant flow value = 112%; aspect ratio of sisal fibres = 200).

Fibre content (%)	Impact strength/ residual impact strength ratio						Deviation in I_{rs}
	Before exposure			After exposure			
	A	B	C	A	B	C	
0	13.84	18.0	1.30	8.91	10.89	1.22	-6.15
0.25	16.91	22.5	1.33	9.9	16.83	1.70	+27.81
0.50	17.35	29.5	1.7	10.89	21.78	2.0	+22.35
0.75	17.76	35	1.97	11.88	26.73	2.25	+14.21
1.00	18.18	40.0	2.20	12.87	32.67	2.53	+20.00
1.50	19.39	45.0	2.32	15.84	42.57	2.68	+18.96
2.00	21.34	54.0	2.53	16.83	48.51	2.88	+13.83

Note: (i) Energy for one blow = 0.99J (Height of fall = 21cm); (ii) A- Impact strength at initiation of crack (in Joules); B-Impact strength at final crack (in Joules); C- Residual impact strength (I_{rs})

(ii) I_{rs} values of cement mortar composite slabs decreases with increase in fibre content, after exposure in the alkaline medium, when compared to the I_{rs} value before exposure and it is found to be independent of the fibre content.

(iii) As the matrix fails early, i.e. it has lesser impact strength after exposure in the alkaline medium, 'I_{rs}' values of the slabs after exposure are higher, as the denominator in I_{rs} (as defined in eqn.1) is lesser (than the value before exposure) and hence I_{rs} values are higher for composite slabs after exposure in the alkaline medium.

(iv) Deviation in I_{rs} values after exposure in the alkaline medium have also been computed and expressed as a percentage of relative change in values (eqn 2.) with respect to the I_{rs} values obtained before exposure in the alkaline medium, for all types of slabs considered.

$$Deviation\ in\ I_{rs} = \left[\frac{(R_2 - R_1)}{R_1}\right] X\ 100 \quad \ldots (2)$$

From the results it is found that the deviation in I_{rs} value of the plain mortar slab is negative, indicating nearly failure of matrix due to exposure in the alkaline medium. The deviation in I_{rs} values of all composite mortar slabs are all positive as I_{rs} values of composite slabs after exposure are higher than the corresponding values before exposure [35].

Fractured specimens after evaluating the durability of the composite, by the impact test are shown in Figure-1. It is found that the failure patterns are also found to be similar to the patterns observed, before the specimens are subjected to the durability test, and evaluated by the impact test [35].

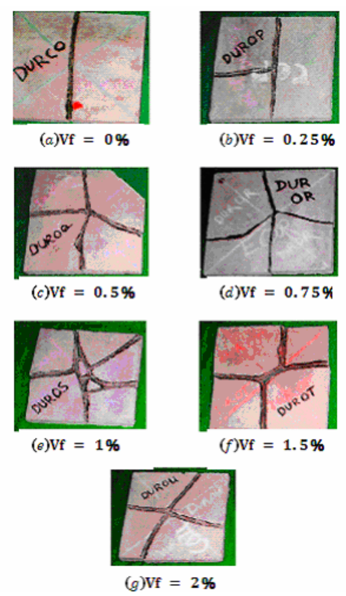

Figure-1. Fractured specimens after evaluating the durability of the composite by the impact test.

3.2 Evaluation of durability based on flexural toughness index (I_T)

Flexural toughness of cement mortar slabs and cement mortar composite slabs, before and after exposure in NaOH medium are presented in Table-8, for various fibre contents.

Table-8. Flexural toughness index of sisal fibre cement mortar composite slabs (1:3; Constant flow value = 112%; aspect ratio of sisal fibres = 200).

Fibre content (%)	Toughness index = {$A_2/(A_1+A_2)$}						Deviation in I_T
	Before exposure			After exposure			
	A	B	C	A	B	C	
0	1322	700	0.34	1006	368	0.26	-22.54
0.25	1557	432	0.21	790	701	0.47	+116.58
0.50	998	434	0.30	198	846	0.81	+168.21
0.75	1361	2388	0.63	629	1887	0.75	+17.73
1.00	1319	471	0.26	848	498	0.37	+40.68
1.50	2413	1788	0.42	885	2392	0.73	+71.76
2.00	1347	1846	0.57	325	1084	0.77	+33.21

Note: (i (A) - Area of the load-displacement diagram upto the pre-cracking stage- (A_1)N-mm; (B)- Area of the load-displacement diagram after the post-cracking stage-(A_2) N-mm; (C)- Flexural toughness index -(I_T)= {A_2/ (A_1+A_2)}

Deviation in I_T values after exposure in the alkaline medium have also been computed. From the results it shows that the I_T values of cement mortar and cement mortar composites exhibit the same trend as that of 'I_{rs}' values [35].

4. CONCLUSIONS

Residual impact strength (I_{rs}) and flexural toughness (evaluated using four-point loading) (I_T) values could reflect the changes in the strength due to the interaction between the matrix and any medium considered (NaOH in the present case) and hence can be used with confidence to evaluate the durability of natural fiber reinforced mortar composites and also the relative performance of composites.

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