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STRENGTH OF CORRUGATIONS OF A ROOFING SHEETS REINFORCED WITH SISAL FIBRES

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ABSTRACT

Most of the corrugated roofing sheets have damaged due to tearing out at its corrugations by high wind loads and impact loads. The strength of these corrugations can be improved with fibre reinforcement, as the fibres are the crack arresters and absorbs energy. In this paper natural fibre namely sisal fibres are used as reinforcement in cement matrices for producing corrugated roofing sheets has been investigated and reported. Flyash- based sisal fibre roofing sheets were cast manually and the strength of the corrugations of the above composite sheets in terms of splitting, due to direct and impact loads, were experimentally evaluated. It is found that the strength towards splitting of corrugations of the flyash based sisal fibre corrugated roofing sheets due to direct and impact loads was improved as compared to the corrugated sheets without sisal fibres. Also it is observed that flyash based sisal fibre reinforced sheets are comparable to the splitting of corrugations due to direct and impact loads of a commercial roofing sheet, available in India.

Keywords: corrugated roofing sheet, sisal fibre, flyash content, fibre content, flexural load, impact load, splitting.

1. INTRODUCTION

Emphasis on the development of new materials and technology has been there for the past few decades, especially in developing countries like India, so that the ‘overall cost’ of construction becomes affordable by the people. Further, countries like India have a social obligation of providing shelter to all, which they strive very hard to fulfill within a reasonable time. If overall economy in the construction of shelter especially to economically weaker sections of society is to be achieved, then, economy in each major component of shelter, to the extent possible has to be realized. Roof, is one of the main building element, consumes about 20% of the total cost of construction. Asbestos cement based roofing and other light roofing materials are very commonly used in the construction of houses and industrial buildings, not only in India, but in all other developing countries of the World. In spite of the fact that asbestos-based roofing elements and products pose health hazards, ban on their use has not been effectively enforced. However, there exist alternate fibres, which have the potential for use in roofing materials. For example, fibres from plants, such as, sisal, having several advantages like abundant availability, less - costly and does not pose health hazard, and hence, can be used to develop various building products like roofing element etc. Of the various pozzolanas, flyash, is abundantly available in several countries and also in India. In spite of the above fact, it has use, especially, in cement-based system for the production of building materials and for other beneficial uses. In India, sisal fibres are also abundantly available. Hence, there is scope and a necessity to investigate the role of flyash in influencing the characteristics of natural fibre composites and products. Such studies have not been done extensively and reported. Overview of studies carried out so far on natural fibre composite products/ components in cement/cementitious systems are summarized in Table-1.

Table-1. Overview of products / components developed and investigated based on natural fibre composites.

S.No.	A	B	C	D	E	F	G	H	I	J	K	Ref. No.
1	Coir	●	●	●		●	●	●			●	1 to 20,21,22
2	Sisal	●	●	●		●	●				●	2,4,5,6,9,11,12,14,17,20,23,24,25,26, 27
3	Jute	●										6,17,28
4	Cellulose	●			●							29,30,31,32
5	Sun hemp	●	●									33,34
6	Sugarcane bagasse	●		●		●						35,36
7	Reed		●						●	●	●	37,38,39,40
8	Natural Agave										●	41
9	Hibiscus Cannebinus										●	17
10	San fibre										●	42
11	Bamboo fibre	●										43

Note: (A) type of fibre (B) roofing tiles/thin sheets (C) wall panels/panel products (D) kitchen sinks (E) pipes (F) flumes (G) adobe blocks (H) lost form work (I) embankment (J) soil reinforcement (K) slabs/beams.

Based on the above, it can be inferred that the, focus of the investigations so far reported has been on developing roofing sheets/ tiles using natural fibre composites. But the studies on the splitting of corrugations of a corrugated roofing sheet due to direct and impact load were not investigated so far. The improvement in the strength to split the corrugations will minimize the damages due to the wind and impact loads acts on these corrugated roofing sheets. Hence, in the present study, splitting due to direct and impact loads on corrugations of a sisal fibre reinforced corrugated sheets using cementitious mortar (1:3) have been investigated and compared with the splitting performance of corrugations of a commercially available corrugated roofing sheet. The usefulness of flyash based corrugated roofing sheet has also been highlighted.

2. MATERIALS AND METHODS

2.1 Materials

Ordinary Portland cement (OPC - 53 grade); graded river sand conforming to IS: 383[44]; potable water and sisal fibres (0.25%, 0.5%, 0.75%, 1.0%, 1.5%, and 2.0%- by weight of cement); and fibre length ranges from 20 to 30mm) were the various material used. Flyash was obtained from the nearest thermal power plant of Neyveli Lignite Corporation (NLC) at Neyveli, Tamilnadu, India. The above flyash is from a 'lignite source'. The salient physical properties of the flyash were determined adopting various Indian standard procedures. The chemical composition of the flyash sample, were determined and provided by the 'Center for Applied Research and Development' (CARD), a research and development centre at Neyveli, Tamilnadu, India. The basic properties of the above materials are given in Tables 2 to 6. It can be seen that the flyash used falls under Type C and hence it is expected to possess both the 'pozzolanic and binding properties'.

Table-2. Physical properties of cement (OPC-53 grade).

S. No.	Property	Value
1	Standard consistency (%)	29%
2	Initial setting time (min.)	55 min
3	Final setting time (min.)	175 min
4	Soundness	1mm
5	Specific gravity	3.14
6	Compressive strength @ i) 3 days ii) 7 days iii) 28 days	 28 MPa 38 MPa 56.7 MPa

Note: (1) 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; (2) The sample conforms to the specifications of 53 grade as per IS: 12269-1987 [45].

Table-3. Physical properties of flyash.

S. No.	Property	Value
1.	Specific gravity	2.47
2.	Initial setting time	30 min.
3.	Final setting time	125 min.
4.	Standard consistency	60 %
5.	Soundness	0
6.	Compressive Strength @ (i) 3 days (ii) 7days (iii) 28 days	 15.2 MPa 16.3 MPa 23.1 MPa

Note: (1) The properties were evaluated as per standard procedures prescribed in IS: 1727 - 1999 [46] and IS: 4031 (Part 8) – 1988 [47].

Table-4. Chemical characteristics of flyash.

S. No.	Chemical composition	Value (% by wt.)	IS: 3812 requirements
1.	Loss of ignition	3.74	12% (max)
2.	Silica as SiO_2	35.87	35% (min)
3.	Iron as Fe_2O_3	4.00	-
4.	Alumina as Al_2O_3	34.14	-
5.	Calcium as CaO	14.25	
6.	Magnesium as MgO	3.64	5% (max)
7.	Sulphate as SO_3	3.40	2.75 (max)
8.	Sodium as Na_2O	0.90	1.5%
9.	Potassium as K_2O	0.06	1.5%
10.	Chloride	-	-
11.	Silica+alumina+iron	-	70% (min)

Note: (1) Flyash is from a lignite source located in Neyveli, South India;
(2) IS: 3812 - 2003, (part-1), "Pulverizes Fuel Ash - Specification [48];
(3) Chemical composition as determined and furnished by CARD, Neyveli.

Table-5. Physical properties of fine aggregate.

S. No.	Property	Value/description
1	Specific gravity	2.48
2	Water absorption	1.4%
3	Rodded bulk density	1.737 gm/cc
4	Fineness modulus	2.5

Note: Procedure is based on IS: 383 - 1997 [44].

Table-6. Physical properties of sisal fibres.

S. No.	Fibre-type	Fibre length (mm)	Fibre diameter (mm)	Tensile strength (N/mm^2)	Elongation (%)	Specific gravity	Elastic-modulus GPa
1	Sisal	180 - 600	0.10 - 0.50	31 - 221	14.8	1.4	7.83

2.2 Preparation and testing of specimens

Corrugated AC sheets of size 1.0m x 1.2m x 6mm (commercially available) was used as a mould to cast sisal fibre cementitious composite corrugated sheets of size 250 x 500 x 6 mm. 1:3 mix (Cement: Sand) was selected and adopted to cast the sheets using flyash by partially replacing OPC. However, replacement of OPC by flyash was restricted to a maximum of 30%. Therefore, only three replacement levels of flyash (i.e., 10%, 20% and 30%) were adopted for the above investigation. Six fibre (sisal) contents in the range of 0.25% to 2.0% were considered, for the splitting studies on the corrugations of roofing sheets. Altogether 25 mix combinations were considered (one without fibre and flyash; 6 combinations without flyash but with sisal fibres and 18 combinations with flyash and sisal fibres). For each mix combination, three sheets were cast. Water content required for each combination of the mix was obtained from the flow table test for 1:3 mix, with and without flyash and with and without sisal fibres, at a constant flow value of 50, the details of which are reported elsewhere [49-51].

2.2.1 Casting procedure

A brief description of the casting procedure is given below:

(i) A molding frame made of MS flat (size 320 x 500 x 6 mm) is kept over a GI sheet and both of them are kept on the table vibrator. A plastic sheet is placed in between the frame and the GI sheet, to provide a smooth surface for casting and for easy demolding.
(ii) Freshly mixed mortar was carefully placed within the mould frame and spread to cover the entire area, and properly leveled.
(iii) The mortar mix was spread into a uniform thickness and then vibrated for 10 seconds, and after vibration the plastic sheet was removed and the surface was once again leveled and smoothened.
(iv) The MS molding frame was removed carefully and the flat molded mortar specimen was gently placed over a corrugated ACC sheet. Care was taken to ensure that the flat molded mortar specimen comes over the valley of the 'corrugated ACC sheet' so that the wet or green mortar will not slide down.
(v) After shifting the molded mortar over the 'corrugated ACC sheet' a PVC pipe having its diameter equal to dimensions of the valley was rolled over the wet mortar in the valleys and in the ridges so as to form corrugations on the wet cementitious mortar specimen. Finally the surface was finished smooth using a trowel.
(vi) The above sheets were then 'moist cured' initially for 3 days and then subjected to 'immersion curing' for the remaining 25 days to complete 28 days of normal curing.

The salient stages in the casting of corrugated sheets are shown in Figure-1.

(a) Spreading the Mortar (b) Dragging the Spread Mortar Over Corrugated Mould
(c) Creating and Finishing the Corrugations (d) Cast Corrugated Sheet in Wet State
(e) Finished Product with Base Frame

Fig.1 : Stages of Casting Corrugated Sheets

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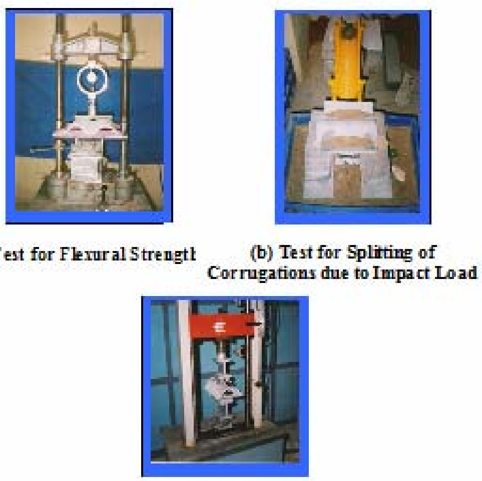
2.2.2 Tests and test procedure

Generally roofing sheets are expected to fulfill certain properties such as : (i) light in weight so as not to impose a heavy load on the building; (ii) good flexural strength - so as to offer a good load - (super imposed/total) carrying capacity; (iii) ductility - so as to sustain impact loading; (iv) water tightness - so as to prevent penetration/seepage of rain water into the building ; (v) fire resistant - so as to prevent/retard ignition and spreading of fire; (vi) good thermal properties - so as to provide a 'pleasant indoor climate' for a comfortable living.

In the present study, tests were conducted to determine the following characteristics of the corrugated sisal fibre reinforced sheets: (i) direct load (gradually applied) required for splitting the corrugations (ii) impact strength to split the corrugations; and (iii) flexural strength of the corrugated sheets. The experimental test set-ups used for direct and impact loads on corrugations for splitting and flexural strengths are shown in Figure-2.



(a) Test for Flexural Strength (b) Test for Splitting of Corrugations due to Impact Load

(c) Test for Splitting of Corrugations due to DirectLoad (gradually applied)

Fig. 2: Experimental Test Set-up for Various Strength Tests on Corrugations of Sisal Fibre Corrugated Sheets

(a) Splitting test on corrugations due to direct load (gradually applied)

Splitting test (i.e., the load required to split corrugations) was conducted on a 5kN capacity universal (tension) testing machine which is interfaced to a computerized data-logging system. Corrugated specimen of size 120x150mm was selected and kept in such a way that the 90mm side is supported over the two roller supports. A point load is applied along the centre of the span and the load increased steadily till splitting occurred along the span of the corrugation. The (maximum) load at the above point is noted, which gives the 'splitting load' for the corrugated specimen.

(b) Splitting test on corrugations due to impact load

Corrugated portion of a size 220mm x 150mm was cut from the corrugated roofing sheet and used for the impact test. A simple projectile impact test was adopted (the details of which are available elsewhere [49, 51]). The projectile was so arranged such that the impact will take place exactly on the crown of the specimen. For each corrugated sheet, the number of blows required for the appearance/ initiation of first crack at the Crown point, and the number of blows required for complete propagation of the crack along the crown line of the specimen, were noted. There is provision in the experimental set-up to adjust the height of fall from 20 to 200 mm, according to the material being tested. For the above test, the height of fall was fixed as 60mm which was based on a few initial trials conducted on the corrugated fibre sheets. The weight of the metallic ball was 0.475kg and the height of fall and weight of ball used were maintained constant through out the above test for all specimens. The impact energy per blow was computed based on the above arrangement, which works out 0.27 Joules. Based on the number of blows for the initiation of crack and at failure, the corresponding impact energy was calculated for the various specimens of corrugated sheets. In order to evaluate qualitatively the relative performance of the composites under an impact load, a simple parameter called 'residual impact strength' (I_{rs}) as defined in Eqn. (1) was used. 'I_{rs}' as defined above helps to evaluate the post - cracking behaviour of the composites very easily and can also be taken as a measure of 'ductility' of the composites due to the fibres, incorporated into the cement/cementitious matrix. As the usefulness of the above approach has been established based on earlier investigations [49,51], the same was adopted for evaluating the (relative) strength of corrugations of roofing sheet of cement / cementitious in this study.

Residual impact strength ratio (I_{rs}) =

$$\left\{ \frac{\text{Energy absorbed upto ultimate failure}}{\text{Energy absorbed at initiation of first crack}} \right\} \quad \ldots (1)$$

(c) Flexural strength test on the corrugated sheet

The testing arrangement for the flexural (bending) tests are similar to that of testing of tiles and as specified in IS: 654-1972 [50]. Corrugated sheets are subjected to a central line load over a simply supported span of 307.5mm. The corrugated sheets were all tested in natural dry condition and the load was measured using a 50kN proving ring. Load was gradually applied till failure of the specimen.

3. RESULTS AND DISCUSSIONS

3.1 Flexural load

The above characteristics of sisal fibre corrugated roofing sheets in CM 1:3 and in fly ash-cement mortar (1:3, fly ash content 10 - 30%) are given in Table-7.

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Table-7. Flexural and splitting loads of corrugations of sisal fibre flyash - cement mortar corrugated roofing sheets (1:3; specimen size: 250 x 500 x 6 mm)

S. No.	Fibre content (%)	Characteristic loads at fly ash contents of							
		0%		10 %		20 %		30 %	
		A	B	A	B	A	B	A	B
1	0	142	430	147	473	150	565	144	525
2	0.25	151	476	159	498	165	620	155	570
3	0.50	163	520	174	574	179	716	167	630
4	0.75	172	583	180	656	186	815	175	725
5	1.00	175	697	182	815	189	922	178	810
6	1.50	152	576	166	621	178	797	161	688
7	2.00	110	397	122	450	137	555	115	492

Note: (1) (A) - Flexural load (kg); (B) Splitting load (N).
(2) Strength of reference sheet (ACC brand), corrugated sheet, commercial type = 209kg and 1057N respectively, for (A) and (B).

It is seen from the above results that the sisal fibre corrugated roofing sheets (mortar / composite) couldn't match the strength of a commercial type of corrugated sheet, popularly available in the Indian market. Incorporation of fly ash upto 30% in the fly ash - cement mortar (1:3), has yielded comparable load carrying - capacity with that of cement mortar roofing sheets. Incorporation of sisal fibres into the cement mortar matrix has gently increased the above load carrying - capacity upto 1.0% of fibre content, beyond which, the load carrying - capacity have decreased and found to be minimum when the fibre content is maximum i.e., 2.0%, in the cement mortar composite. Similar trends in the above strengths have been observed for the fly ash-cement mortar roofing sheet also, for the range of flyash contents, considered.

Incorporation of sisal fibres into cement mortar and flyash - cement mortar has improved the above load carrying - capacity of the above in the composite (corrugated) sheets, upto a fibre content of 1% over cement mortar composite sheets. The maximum flexural load attained by the cement / flyash - cement mortar composite corrugated sheets are generally found to be about 25% higher than the cement / flyash- cement mortar roofing sheets (reference, without sisal fibres), at 1.0% fibre content and within the range of flyash contents / fibre contents, considered. However, the maximum flexural load (i.e., about 180kg) carried by the composite roofing sheets are found to about 85% of the corresponding strength of the 'commercial type roofing sheet' tested under identical conditions.

3.2 Splitting load of corrugations

The results of the corrugations of composite roofing sheets under the 'splitting load' are given in Table-7 and it is found to be significantly different, when compared to the flexural load carrying - capacity, especially, for fly ash content at 20% and fibre content = 1%, at which the splitting load carried by the above composite is maximum and that there is 63% increase in the splitting load over the corrugations of fly ash mortar sheet (with fly ash content = 20%) and 100% increase over that of the corrugations of cement mortar sheet. The above improvement in the splitting load of the corrugations is tremendous, which is attributed to the positive influence of fly ash and fibres in the composite. However, the maximum splitting load of the corrugations of above composite is about 87% of the corresponding load of the corrugations of the commercial roofing sheet considered. Moreover, the increase in splitting load of the corrugations of composite is found to be generally double the increase in flexural loads of sheets and it is found to be independent of the type of mortar used in the composite. When the fly ash content in the composite is 30%, the maximum splitting load of the composite has increased to nearly 88% over the splitting load of cement mortar sheet and 54% increase over that of fly ash mortar sheet with fly ash content = 30%. Hence, it can be safely considered that at fly ash content = 20% and fibre content = 1.0%, the flexural and splitting loads of the composite, yield nearly comparable results with that of the commercial roofing sheet considered. However, further improvement may be possible by adopting better casting procedures, which incidentally may lead to incorporation of higher sisal fibre content in the composite, and hence its improvement in overall performance.

3.3 Impact strength of corrugations

The results of the above test on corrugations of sisal fibre corrugated sheets in CM 1:3 are given in Table-8. It is seen that the corrugations of sisal fibre corrugated roofing sheets perform very poorly when compared to the corrugations of 'commercial type', in terms of the actual energy absorbed under the impact load. But, the 'ductility' measured in terms of 'I_{rs}', of the corrugations of commercial type of corrugated sheet is lower than almost all mix combinations considered for the impact studies.

Table-8. Energy absorbed by the corrugations of sisal fibre flyash-cement mortar corrugated sheets (1:3; with and without fibres).

#	Fibre content (%)	Energy absorbed (Joules) for fly ash contents of											
		0%			10%			20%			30%		
		A	B	C	A	B	C	A	B	C	A	B	C
1	0	1.45	1.61	1.11	2.61	4.04	1.55	3.77	6.55	1.74	0.87	0.92	1.06
2	0.25	1.74	2.87	1.65	3.48	6.33	1.82	4.06	7.79	1.92	2.32	3.29	1.42
3	0.50	2.61	4.35	1.67	4.35	8.13	1.87	5.22	10.44	2.00	4.35	6.61	1.52
4	0.75	3.19	5.58	1.75	6.09	11.57	1.90	6.67	14.40	2.16	5.51	8.81	1.60
5	1.00	4.35	7.83	1.80	7.25	14.79	2.04	10.73	14.4	2.27	6.38	10.33	1.62
6	1.50	5.22	7.36	1.41	8.41	12.19	1.45	12.47	24.37	2.00	9.28	12.43	1.34
7	2.00	9.57	13.49	1.41	11.20	16.91	1.51	13.63	22.62	1.66	8.70	9.83	1.13

Note: (i) Height of fall = 200mm (for A.C. sheet); (ii) Height of fall = 60mm (for fibre reinforced sheets) (iii) (A) and (B) indicate the energy absorbed for initiation of crack at the point of contact of load and propagation of crack to the supports till failure, respectively; (iv) (C) - indicates ratio of (B/A) for all types of mortar/composites; (v) Energy absorbed by reference mortar sheet (ACC brand, corrugated, Commercial type) = 41 J and 47J for (A) and (B), respectively and hence C = 1.15.

Incorporation of sisal fibres in the cement mortar had generally contributed to comparable/marginal improvement in the impact strength and 'post-cracking behavior', i.e., 'ductility' measured in terms of 'I_{rs}', to that of plain cement mortar sheets, upto 2% of fibre content in the composite. Impact strength characteristics of corrugations of fly ash cement mortar composite corrugated sheets are not significantly improved due to the incorporation of fly ash, especially, the 'ductility' of the composite, as evident from the I_{rs} values. However, in terms of actual energy absorbed there is substantial improvement up to at least 1% fibre content and with 10-30% fly ash content, in the composite. From the point of actual energy absorbed (i.e., at initiation of crack and at failure) and ductility in terms of I_{rs}, corrugations of sheets with 20% fly ash and 1% fibre content in the composite, are better/ comparable to that of corrugations of cement mortar corrugated sheets (i.e., control). Fractured specimens of corrugations of sheet after the splitting test (V_f = 1.0%; flyash content = 0 - 30%) are shown in Figures 3 and 4. It is seen that the specimens exhibit a typical failure pattern i.e., along the corrugation, under the two types of loading.

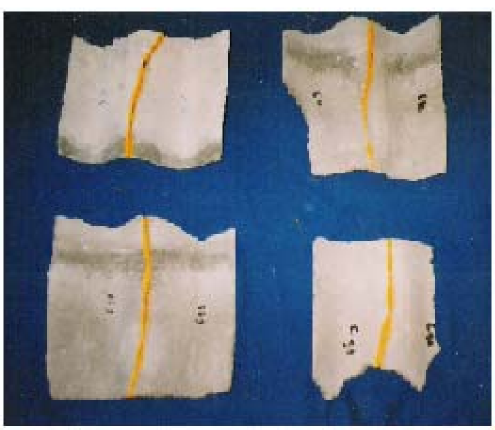

Fig. 3: Fractured Specimens of Corrugations after the Splitting Test due to Direct Load (V_f = 1.0%; Fly ash = 0 -30%)

Fig. 4: Fractured Specimens of Corrugations After the Splitting Test due to Impact Loads (V_f = 1.0%; Fly ash= 0 -30%)

4. CONCLUSIONS

Salient conclusions, based on the comprehensive experimental investigations carried out and on the range of various parameters considered in the present study, are summarized below:

Sisal fibre corrugated roofing sheets of (mortar / composites) couldn't match the high strength exhibited by the commercial type corrugated roofing sheet considered in this study, with respect to the flexural and splitting loads and with in the range of sisal fibre contents (0 - 2%) and flyash contents (0 - 30%) considered.

(i) Flexural and splitting loads of cement mortar (1:3) and flyash - cement mortar corrugated sheets are comparable, within the range of flyash contents (10 - 30%), considered.
(ii) Incorporation of sisal fibres into cement mortar and flyash - cement mortar matrix has contributed for enhancing the flexural and splitting loads and that the above loads are maximum at sisal fibre content of 1.0% in the above composite roof sheets.
(iii) Maximum flexural load of about 180kg carried by the cement / cementitious mortar composite corrugated sheets, is about 25% higher than the load carried by the reference mortar roofing sheet, at sisal fibre content of 1.0%. The above maximum flexural load is about 85% of the 'commercial type roofing sheet', tested under identical conditions.
(iv) There is tremendous improvement in the splitting load carried by of the corrugations of flyash - cement mortar composite roofing sheet and that the above load is maximum (i.e., 922N or 92.2kg) at flyash content = 20% and sisal fibre content = 1%. The above maximum load is about 87% of the splitting load carried by the corrugations of'commercial type roofing sheet', evaluated under identical conditions.
(v) Even though, the actual energy absorbed by the corrugations of 'commercial type' roofing sheet is higher under the impact load, the ductility of the above roofing sheet, measured in terms of I_{rs} values are lower, than all mix combinations considered for the impact studies of the corrugations of sisal fibre composite.
(vi) From the point of actual energy absorbed (i.e., at initiation of crack and at failure and ductility in terms of I_{rs}), corrugations of sheets with flyash content = 20% and sisal fibre content = 1% in the composite, are better than the corrugations of cement mortar corrugated sheets.
(vii) From an overall assessment, the performance of sisal fibre flyash - cement mortar composite roofing sheet (V_f = 1%; flyash content = 20%) and its corrugations developed and investigated, is comparable to that of a commercial type roofing sheet and its corrugations. Hence the above product can be considered as an effective alternative to the commercial / conventional roofing sheets, so far widely used. However, further improvement in the performance of sisal fibre flyash - cement mortar composite roofing sheet is possible by studying the geometry of the corrugations and placing the sisal fibres perpendicular to the span of the corrugations.

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