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Study of Impact Behavior of Coconut fibre Reinforced Concrete Slabs

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Abstract— Coconut fibres have the highest toughness amongst natural fibres. In tropical earthquake regions, the coconut fibre are used as reinforcement for low cost buildings. This paper presents the experimental investigations of the resistance to impact loading of concrete mortar slabs (size: 1000mm × 1000mm × 25mm) reinforced with natural fibre coir subjected to impact loading using a simple projectile test. The influence of 1%, 2%, and 3% 4% and 5% fibre contents by mass of cement and fibre lengths of 5 cm is investigated. The properties of plain concrete are used as a reference to evaluate the effect of coconut fibres in improving the properties of concrete. It is found that CFRC with a fibre length of 5 cm and a fibre content of 2% have got the best hardened properties and further with the combination of welded mesh and hexagonal mesh in slab has the best properties such as the impact resistance (R_u), residual impact strength ratio (I_{rs}), impact crack-resistance ratio (C_r) and the condition of fibre at ultimate failure.

Index Terms— Natural fibres; Hardened properties; Impact strength; Projectile test; Residual impact strength ratio; Impact crack-resistance ratio

1 INTRODUCTION

Plain concrete possesses a very low tensile strength, less ductility and very little resistance to cracking. In the concrete internal micro cracks are inherently present and due to the propagation of such micro cracks which leads to poor tensile strength and finally leading to brittle fracture of the concrete structures. It has been noted that the addition of small, uniformly dispersed and closely spaced fibres to concrete would act as crack arrester and would substantially improve its overall properties such as static and dynamic properties, which is known to be as fibre reinforced concrete. A composite material consisting of mixtures of cement mortar or concrete and discrete, discontinuous, uniformly dispersed suitable fibres can be defined as fibre reinforced concrete. Woven fabrics continuous meshes and long wires or rods are not considered as discrete fibres.

Researchers have used plant fibres as an alternative of steel or synthetic fibres in composites such as cement paste, mortar and concrete. These natural fibres include coconut, sisal, jute, hibiscus cannabinus, palm, banana, hemp, flax, cotton eucalyptus, pineapple leaf, kenaf bast, sansevieria leaf, abaca leaf, vakka, date, grandis pulp, malva, ramie bast bamboo and sugarcane fibres[3-8]. Artificial fibres include steel fibres, polypropylene, nylons, asbestos, glass, carbon, acrylic, polyester. In many countries, natural fibres are cheap and locally available. It can be used as a construction material, for improvement in the properties of the composites as the cost is very little when compared to the total cost of the composites. Especially when high percentages of fibres are involved, because of their flexibility natural fibres are also easy to use or handle compared to steel fibres. Therefore a methodology for casting needs to be developed in that case. For expressing the quantities of fibres, fibre content and volume fraction are often used. Volume fraction can either be part of volume of any ingredient or part of total volume of composite has been replaced. Fibre content can be any ingredient or part of total weight/mass of composite to be replaced. To achieve maximum strength of the composite, the optimum quantity and length of fibres often investigated by the researchers; any further increase or decrease in volume fraction and/or fibre length may reduce the composite strength.

From the outer most shell of a coconut coconut fibre is extracted. The common name, scientific name and plant family of coconut fibre are coir, cocos nucifera and arecaceae (Palm), respectively. Two types of coconut fibres are available, brown fibre which is extracted from matured coconuts and white fibres from immature coconuts. Brown fibres are strong, thick and have high abrasion resistance, while white fibres are finer and smoother, but also weaker. Three forms of coconut fibres are commercially available, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). The different types of these fibres have been used for different purposes depending upon the requirement. Brown fibres are mostly used in engineering. The general advantages of coconut fibres include resistant to fungi and rot, moth-proof, provide excellent insulation against temperature and sound, unaffected by moisture and dampness, tough and durable, resilient, flame-retardant, spring back to shape even after constant use. Coconut fibre is the toughest fibre amongst natural fibres. They are also capable of taking strain 4–6 times more than that of other fibre [10]. According to official website of International Year for Natural Fibres 2009 [9], approximately, 500000 tones of coconut fibres are produced annually worldwide, mainly in Sri Lanka and India. $100 million is the total estimated value. Sri Lanka and India are also the main exporters, followed by Vietnam, Thailand Indonesia and the Philippines. In the form of raw fibre, around half of the coconut fibres produced is exported.

Toughness is often called the capability to absorb energy, is of importance in actual service conditions of fibre reinforced composites, when they may be subjected to dynamic, static and fatigue loads. Toughness evaluated under impact loads, is called the impact strength. It is necessary to study the impact strength characteristics of natural fibre reinforced cement composites to understand their behavior and assess their performance for various potential uses apart from ensuring durability of natural fibres in the cement matrix. A number of different test methods are available to determine the impact resistance of fibre reinforced composite, which can be broadly grouped into the following categories: (i) drop weight single or repeated impact test, (ii) projectile impact test, (iii) weighted pendulum charpy type impact test (iv) explosion – impact test, (v) constant strain rate test, (vi) instrumented pendulum impact test and (vii) split Hopkinson bar test. The resistance of the material is measured using one of the criteria, such as, (i) energy needed to cause fracture in the specimen; (ii) number of blows to achieve a specified distress level (in a repeated impact test) and (iii) the size of the damage (i.e. perforation, crater size) or the size and velocity of spall after the specimen is subjected to a surface blast loading [11].

The main objective of this paper, is therefore, to study the behavior of CFR concrete having five different fibre contents (1.0%, 2.0%, 3.0%, 4.0% and 5.0% — by wt. of cement) and fibre length of 5cm and the impact behavior under a repeated drop hammer test (manually operated). With the reference of a concrete slab specimen, the results obtained have been compared and their relative performance have been evaluated based on the set of chosen indicators, namely, the ultimate impact resistance (R_u), residual impact strength ratio (I_{rs}), crack-resistance ratio (C_r) and the condition of fibre at ultimate failure [12].

2 Experimental Investigation

2.1 Preparation of coconut fibres and CFRC

Ordinary Portland cement, sand, aggregates, water and brown coconut fibres were used for preparation of CFRC. The maximum size of aggregates was 6 mm. The mean diameter of coconut fibres is of 0.2 – 0.25 mm.

Preparation of fibres into the required length was a laborious task and time consuming, since fibres were in hydraulic compressed form. To get the fibres into the required length quickly different approaches were tried. Then finally coconut fibres were loosed and soaked in tap water for 30 min to soften the fibres and to remove coir dust and fibres were washed and soaked again for 30 min. Three times washing and soaking were repeated. Then it was straightened manually and combed with a steel comb. The drying process, were accelerated by putting the wet long fibres in an oven at 30°C for 10–12 h where for the most part moisture were removed. Finally the fibres were then completely dried in the open air, combed and cut into the required length by means of guillotine. The precut fibres are also commercially available at relatively high cost, for special purposes like brushes, mat etc, may be noted. If fibres are mechanically prepared at large scales, the cost can be reduced [2].

2.2 Mix design

For plain concrete, the mix design for m30 is obtained as 1:1.6:2.74:0.5. The mix design for CFRC was the same as that of plain concrete, except that (1) adding more water to mix (stepwise to avoid bleeding) because the addition of fibre make CFRC workable and (2) the amount of fibre content and the aggregates of same amount was deducted from the total mass of aggregates. All materials were taken by the ratio of weight of cement. It is well known that the W/C ratio is an important factor which has an influence on properties of concrete, but compaction is also inevitable. The W/C ratios for CFRC were increased to ensure its proper compaction with workable mix so that the good strength in concrete could be achieved. The addition of water on CFRC will cause bleeding ultimately reduce its strength in hardened state hence the obtained properties of CFRC with respective W/C ratio can be taken as optimum one. Improper compactions, resulting in less strength were caused when the W/C ratio is reduced.

2.3 Casting procedure

A rotary type concrete mixer was used in preparing plain concrete. All materials were put in the mixer machine along with the water, and the mixer was rotated for five minutes. For the preparation of CFRC, a layer of coconut fibres was spread in the pan, followed by spreading of sand, cement and aggregates. With the help of a spade, the first layer of fibres was hidden under the dry concrete materials. After that, another layer of coconut fibres followed by layers of sand, cement and aggregates was spread. The process is repeated until the rest materials were put into the concrete mixer pan. Approximately, half quarters of the water was added, and the mixer was rotated for 3 min. Finally the remaining water was added and the mixer was again rotated for 3 min. All CFRCs were not workable at this stage; water was added in small increments until the CFRC workable.

2.4 Specimens

Cubes (150mm × 150mm × 150mm) in size, cylinders 150 mm in diameter and 300 mm in height and prism 100 mm wide, 100 mm deep and 500 mm long were prepared for PC and CFRC. Slabs of size (1000mm × 1000mm × 25mm) with welded mesh and having the combination of welded mesh and orthogonal mesh with and without fibres were made. Cubes, cylinders and prism were made for testing the hardened properties of concrete such as compressive strength, split tensile strength and flexural strength. Slabs are made for testing the impact behavior and the properties such as the ultimate impact resistance (R_u), residual impact strength ratio (I_{rs}), crack-resistance ratio (C_r) and the condition of fibre at ultimate failure .All the specimen are made with and without fibres. A total of 24 cubes, 18 cylinders, 12 prisms and 4 slabs were prepared and tested.

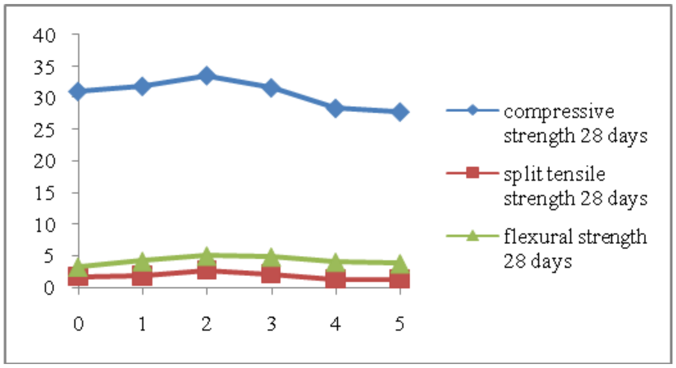

Fig 1 Influence of fibre content on compressive strength, split tensile strength and flexural strength

2.5 Testing procedure

2.5.1 Cube, cylinder and beam tests

All cubes and cylinders were tested in a compression testing machine to determine the compressive strength and split tensile strength. Compressive strength of cubes f_{cu} was tested at 7th day and 28th day, whereas split tensile strength f_t was tested at 28th day. All prisms were tested in a universal testing machine of capacity 100 kN using 2-point loads to obtain modulus of rupture f_b. Cracking load is the load taken by fibres and part of concrete after the first visible crack is produced.

2.5.2 Slab test by means of impact load

The slab specimens were tested in a projectile impact test set-up specially fabricated for the present study with the specimen mounted on a M.S. frame. For each slab specimen, the numbers of blows required for the appearance of the first crack, the crack width and crack length at failure, were noted. The experiment is continued till the metallic ball pierces through the slab. The height of fall (i.e.3000mm) and the weight of the metallic ball (weighing 11.5kg) were maintained constant for testing all the specimens. The test set-up was so adjusted, such that the metallic hammer will fall exactly at the center of the specimen and it was also ensured that the four edges of the specimens were simply supported.

3 Theoritical Background

3.1 Compressive strength

Compressive strength of concrete is the most important property and this value is used for the design of structures. The specimen is loaded in a compression testing machine at a standard rate 315kN/minute. Note the load at which the specimen ceases to break.

Compressive strength $f_{cu} = P/A$ (1)

Where, P = breaking load; A = area of cross section of specimen.

3.2 Split tensile strength

The tensile strength of concrete can be obtained indirectly, by means of a concrete cylinder to the action of a compressive force along the two opposite ends of a generator. Due to the compressive force acting through the top and bottom plate, the cylinder is subjected to a large magnitude of compressive

Fig 2 Impact testing machine

stress near the loading region. So along the length of the cylinder it is subjected to uniform tensile stress. The load at which the specimen split into two pieces was noted.

Split tensile strength $f_t = 2W/\Pi DL$ (2)

Where, W = Load at which specimen break; D = Diameter of the specimen; L = Length of the specimen

3.3 Flexural strength

The modulus of rupture depends on the dimension of the beam and the type of loading. The systems of loading used in finding out the flexural tension are central point loading and third point loading. In the central point loading, the maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two point loading will yield a lower value of the modulus of rupture than the centre point loading. The flexural strength of the specimen is expressed as the modulus of rupture f_b which if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05Mpa as;

Flexural strength $f_b = Pl/bd^2$ (3)

When 'a' is greater than 13.3 cm or,

Flexural strength $fb = 3Pa/bd^2$ (4)

when 'a' is less than 13.3 cm and greater than 11cm,

Where, l = Span of the beam; a = Distance between line of fracture and nearer support; b = Width of specimen; d = Depth of specimen; P = Maximum load in kg applied to the specimen.

TABLE 1
HARDENED PROPERTIES

Sl.no	*Fibre percentage*	*Compressive strength*	*Split tensile strength*	*Flexural strength*
1.	0	31.05	1.76	3.26
2	1	31.85	1.82	4.18
3	2	33.85	2.716	5.02
4	3	31.60	2.065	4.85
5	4	28.35	1.36	4.03
6	5	27.78	1.3	3.8

3.4. Impact properties

When a concrete slab is subjected to a load released from a defined height thereby constituting an impact loading, in general, there is a loss of potential energy which is absorbed and dissipated as strain energy, causing cracks due to stresses developed in the element. The width of crack thus developed is related to the intensity of the energy, the amount of energy absorbed and the properties of the concrete. The energy absorbed is dissipated in the form of crack patterns produced from the impact loading and that the crack pattern is also dependent on the properties of the concrete. A relationship for the potential energy (PE) of an impact loading due to a falling body and the strain energy dissipated in cracks that develop in a target may be expressed based on fundamentals of strength of materials approach as

$$Ne = R_u\, l_c\, w_c\, d_c \qquad (5)$$

where, N = no. of blows; e = energy (in Joules)/blow; l_c = total length of all cracks; d_c = maximum crack dept; w_c = maximum crack width. The above relationship was based on the equation proposed by Kankan. Using Eq. (5), the ultimate crack resistances (R_u) of the mortar slab specimens were calculated. A dimensionless factor impact crack resistance ratio (C_r) was also defined (Eq. (6)) and evaluated [13].

$$C_r = R_u/f_{cu} \qquad (6)$$

where, C_r = impact crack resistance ratio; f_{cu} = cube compressive strength of the reference mortar in MPa.
Eq. (5) can be used with confidence to study the behavior of specimens subjected to impact loading. These are used for the analysis of impact behavior of slab with and without fibres under different mesh conditions.

4 Results and Discussion

4.1 Hardened properties

The hardened properties of concrete mixtures such as compressive strength, split tensile strength and flexural strength was measured at the 28 days and shown in Table 1and the graphs representing them are shown in figure. There was an increase up to 8% in compressive strength, 54% in split tensile strength and flexural strength with coconut fibre. Coconut fibre of length 5cm and fibre content of 2% has got the best properties. Further increase in fibre content will decrease the hardened properties. These are shown in figure 1.

TABLE 2
IMPACT PROPERTIES

Sl. no	*Type of mesh*	*Maximum crack width w_c (mm)*	*Maximum crack length l_c (mm)*	*Ultimate crack resistance R_u (N/mm^2)*	*Crack resistance ratio C_r*
1	Welded mesh without fibre	0.2	630	39.82	1.19
2	Welded mesh with fibre	0.15	590	57.98	1.73
3	Welded mesh with hexagonal mesh w/o fibre	0.15	600	63.56	1.89
4	Welded mesh with hexagonal mesh with fibre	0.1	620	90.65	2.7
5	Ferrocement slab w/o fibre	0.2	570	32.898	0.98
6	Ferrocement slab with fibre	0.15	590	42.27	1.26

4.2 Impact energy

From the projectile impact test, the number of blows required for the initiation of first crack was based on visual observation and the ultimate failure was determined based on the number of blows required to open the crack in the specimen sufficiently and for the propagation of the crack through the entire depth of the specimen. It was observed during testing that the crack propagates and also widens simultaneously. As only the relative performance of impact resistance can be evaluated by any type of drop-weight method, it is essential to determine the maximum energy absorbed under impact load. Hence, the test was conducted till the crack propagated to the entire depth of slab. It was also observed that there is not much variation in the maximum crack width of slab specimens with and without fibre content. Hence, the maximum crack width and the crack depth (i.e. entire depth of the specimen) were used to compute the energy absorbed by the specimen. The impact energy per blow was computed for the (chosen) weight of the ball and its velocity at the instant it strikes the slab specimen.

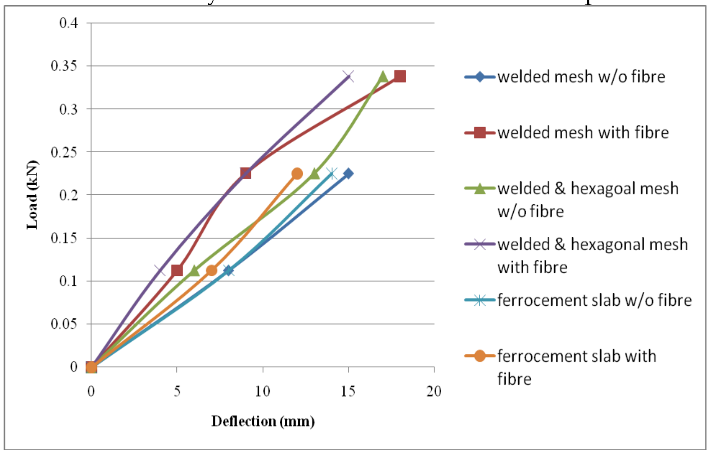

Fig 3 Load vs Deflection graph for different cases

The impact energy absorbed by the reinforced slab specimens were computed based on the number of blows required to cause ultimate failure and the impact energy per blow (i.e. 338.445 J). The impact energy absorbed by the fibre reinforced mortar specimens were compared with that of the reference mortar specimens. It was observed that the fibre reinforced mortar slab specimens do not break into distinct pieces, whereas, plain mortar slab specimens were broken into separate (distinct) pieces.

From the above results, it is seen that due to incorporation of fibres in mortar the impact resistance of the slabs has increased 2–20 fold (in terms of impact energy absorbed), depending on the fibre content and type of natural fibre. Moreover, the ultimate crack resistance generally increases with increase in fibre content, but, irrespective of the fibre length. Coir fibre reinforced slab specimens with combination of welded and octagonal mesh have absorbed higher energy was 2030.67 J (fibre content = 2% and fibre length = 50mm). This may be due to the higher ductility and lesser susceptibility to embrittlement of coir fibres. Due to the interlocking of the fibres in the cement matrix, the impact resistance of natural fibre reinforced slab specimens also increases with increase in the fibre length. Slab specimens which appear to possess relatively a low impact resistance at the appearance of first crack were found to improve and obtain higher impact resistance at failure. For example, slabs reinforced with coir fibres (fibre content = 2% and fibre length = 50mm) needs only 676.89 J for the initiation of first crack, whereas, 2030.67 J is required to cause ultimate failure. Hence, the residual impact strength ratio (I_{rs}), defined as in Eq. 7 for the above fibre reinforced slab specimen is about 2-5.

Residual impact strength ratio (I_{rs})

$$= \frac{[\text{Energy absorbed at ultimate failure}]}{[\text{Energy absorbed at initiation of first crack}]} \qquad (7)$$

The same phenomenon i.e. substantial improvement in the impact resistance characteristic in the form of large amount of absorption of energy after the initiation of first crack and up to the ultimate failure was observed for all the other three types of fibre reinforced slab specimens at higher fibre contents. However, only the residual impact strength ratio (Irs) was found to be different, which varied from 5 to 3 in case of coconut fibre.

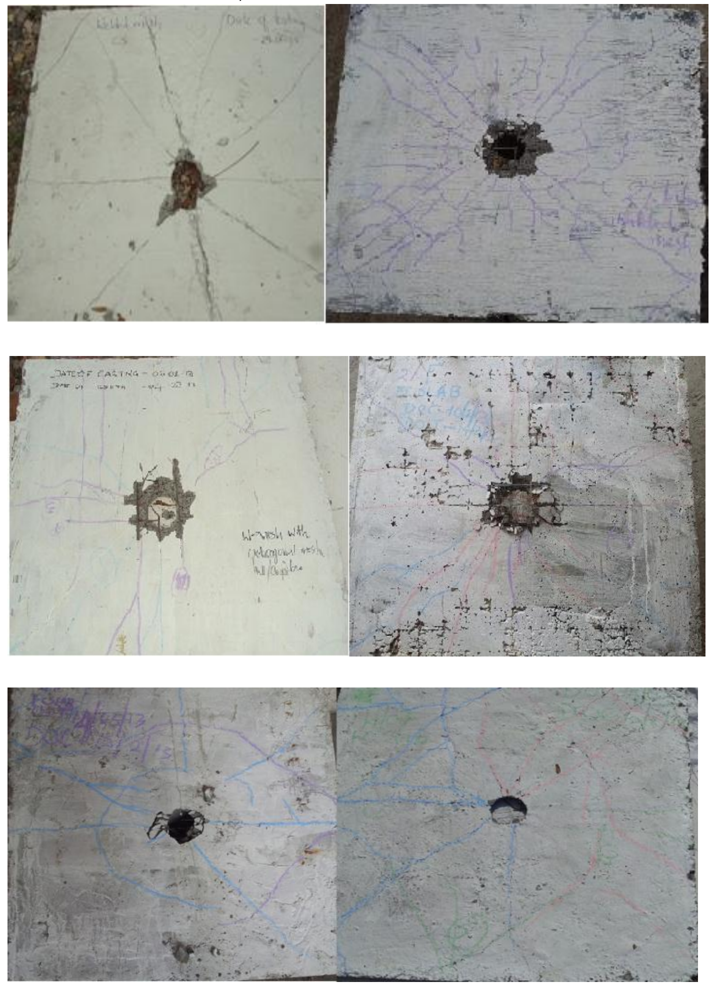

Fig 4 Typical crack pattern for different conditions

4.3 Crack resistance and crack resistance ratio

Based on the energy absorbed, the maximum crack width (w_c), crack length (l_c) at failure, the ultimate crack resistance (R_u) and the crack resistance ratio (C_{rs}) were evaluated and presented in Table 2. From the results, it is seen that the maximum crack width and the maximum crack length do not exhibit appreciable variation with respect to the fibre content, fibre length and the type of fibre. On the other hand, the ultimate crack resistance follows the same trend as that of the ultimate impact resistance. Maximum ultimate crack resistance has been offered by coir fibre reinforced slab specimens with welded mesh and octagonal mesh at 2.0% fibre content and reinforced with 50 mm length of fibres. On the other hand, the ultimate crack resistance follows the same trend as that of the ultimate impact resistance. Maximum ultimate crack resistance has been offered by coir fibre reinforced slab specimens with welded mesh and octagonal mesh at 2.0% fibre content and reinforced with 50 mm length of fibres. The crack resistance ratio generally shows an increasing trend with increase in the fibre content and length of fibre [14]. But after certain increase in fibre content and fibre length will decrease the properties of the concrete. The load- deflections under different conditions were shown in figure 3.

4.4 Failure pattern

Considering the nature of failure, it is observed that the reinforced slab with welded mesh and the combination of welded mesh and octagonal mesh with and without fibre is different The impact testing is continued till the hammer completely pierces the slabs. The crack is first formed in the edges, since the slabs are simply supported. The crack will then formed at the centre portion then originating towards outside. More number of cracks are formed in the case of coconut fibre reinforced concrete slabs but the width of the crack is less where as in the case of reinforced slab the crack pattern obtain is less and width of crack is more. The crack pattern occurs only around the central portion and at the edges. It was observed that the coconut fibre reinforced with welded and octagonal mesh gives the best results. That is the coconut fibre of fibre content 2% and length 50 mm with the combination of welded mesh and octagonal mesh gives the best results such best crack pattern along all sides of the slabs, at the edges also. The failure patterns of different slabs are shown in figure 4.

5 Conclusions

Following are the salient conclusions based on the experimental investigations reported in this study:

- The hardened properties of coconut fibre reinforced slabs is evaluated that the fibre content of 2% and fibre length 50mm has got the best properties.
- The impact resistances of the coconut fibre reinforced cement mortar slabs considered in this study are found to be 45 times higher than that of reinforced concrete slabs.
- Coir fibre reinforced mortar slab with combination of welded mesh and octagonal mesh have absorbed the highest impact energy 2030.67 J, at 2% fibre content and fibre length = 50mm.
- Residual impact strength ratio (I_{rs}) of coconut fibre reinforced slab specimens ranges from 3 to 6
- The maximum crack width and length are not sensitive to the type and content of fibre, whereas, the ultimate crack resistance exhibits the same trend as that of the ultimate impact resistance.
- The average increase in the crack resistance ratio ranges from 0.98 – 2.7.
- Coconut fibre reinforced slab specimens exhibit fibre pull out failure with more crack pattern whereas, other slab without fibre show simple failure with less crack pattern.
- The width of the crack in the fibre reinforced slab is less whereas the slab without fibre the crack width is more.
- The projectile test set-up (manually operated) has proved to an economical, simple, portable and reliable one, to evaluate the impact resistance of coconut fibre reinforced concrete slab specimens.

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7 References

[1] Ramakrishna G, Sundararajan T. *Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar.* Cem Concr Compos. 27 (2005) 547–553

[2] Majid Ali, Anthony Liu, Hou Sou, Nawawi Chouw. *Mechanical and dynamic properties of coconut fibre reinforced concrete.* Construction and Building Materials 30 (2012) 814–825

[3] Slate FO. *Coconut fibers in concrete*. Eng J Singapore 1976;3(1):51–4.

[4] Cook DJ, Pama RP, Weerasingle HLSD. *Coir fibre reinforced cement as a low cost roofing material.* Build Environ 1978;13(3):193–8

[5] Aziz MA, Paramasivam P, Lee SL. *Prospects for natural fibre reinforced concretes in construction*. Int J Cem Compos Lightweight Concr 1981;3(2): 123–32.

[6] Das Gupta N C, Paramsivam P, Lee S L. *Mechanical properties of coir reinforced cement pastes composites*. Housing Sci 1978;2(5):391–406.

[7] Das Gupta NC, Paramsivam P, Lee SL. *Coir reinforced cement pastes composites.* In: Conference proceedings of our world in concrete and structures; 1979. p. 111–6.

[8] Paramasivam P, Nathan GK, Das Gupta NC. *Coconut fibre reinforced corrugated slabs*. Int J Cem Compos Lightweight Concr 1984;6(1):19–27.

[9] Munawar SS, Umemura K, Kawai S. *Characterization of the morphological, physical, and mechanical properties of seven non-wood plant fibre bundles.* J Wood Sci 2007;53(2):108–13.

[10] Satyanarayana KG, Sukumaran K, Mukherjee PS, Pavithran C, Pillai SGK. *Natural fibre–polymer composites*. Cem Concr Compos 1990;12(2):117–36.

[11] Balaguru PN, Shah SP. *Fibre-reinforced cement composites*.UK: McGraw Hill Inc; 1992. 530 pp.

[12] Gopalartnam VS, Shah SP. *Properties of fibre reinforced concrete subjected to impact loading*. ACI J 1986;83(1):117–26.

[13] Kankam CK. *Impact resistance of palm kernel fibre-reinforced concrete pavement slab.* J Ferrocement 1999;29(4):279–86. Oct.

[14] Gopalartnam VS, Shah SP. *Properties of fibre reinforced concrete subjected to impact loading.* ACI J 1986;83(1):117–26.