ISSN (e): 2250 – 3005 || Volume, 06 || Issue, 2|| February – 2016 ||
International Journal of Computational Engineering Research (IJCER)

Coconut fibre: A versatile material in construction

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Abstract
This paper presents the versatility of coconut fibres and its applications in different branches of engineering, particularly in civil engineering as a construction material. Coconut fibre is one of the natural fibres abundantly available in tropical regions, and is extracted from the husk of coconut fruit. Not only the physical, chemical and mechanical properties of coconut fibres are shown; but also properties of composites (cement pastes, mortar and/or concrete etc), in which coconut fibres are used as reinforcement, are discussed. The research carried out and the conclusions drawn by different researchers in last few decades are also briefly presented. Graphs showing the relationship between different properties are shown in this paper. Coconut fibres reinforced composites have been used as cheap and durable non-structural elements. The aim of this review is to spread awareness of coconut fibres as a construction material in civil engineering.
Key words: *Coconut fibres, construction material, composites, cement and concrete.*

I. INTRODUCTION

Coconut fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocos nucifera and Arecaceae (Palm), respectively. Coconut cultivation is concentrated in the tropical belts of Asia and East Africa (Aziz et al., 1984).

There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Coconut fibres are stiff and tough and have low thermal conductivity (Asasutjarit et al., 2005). Coconut fibres are commercial available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement. In engineering, brown fibres are mostly used (Aggarwal, 1992; Agopyan et al., 2005; Asasutjarit et al., 2007; Aziz et al., 1981; 1984; Corradini et al., 2006; Fernandez, 2002; Li et al., 2007; Munawar et al., 2007; Paramasivam et al., 1984; Ramakrishna and Sundararajan, 2005a, b; Rao et al., 2007; Reis, 2006; Satyanarayana et al., 1990; Toledo et al., 2005).

According to official website of International Year for Natural Fibres 2009, approximately, 500 000 tonnes of coconut fibres are produced annually worldwide, mainly in India and Sri Lanka. Its total value is estimated at $100 million. India and Sri Lanka are also the main exporters, followed by Thailand, Vietnam, the Philippines and Indonesia. Around half of the coconut fibres produced is exported in the form of raw fibre.

Figure 1 show a coconut tree, coconut and coconut fibres. Figure 2 shows the structure (longitudinal and cross section) of an individual fibre cell (Abiola, 2008).

There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, pro-vide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean.

PROPERTIES OF COCONUT FIBRES

Physical and mechanical properties

The physical and mechanical properties of coconut fibres are presented in Table 1. The conditions specifically mentioned by the researchers are given at the end of Table 1. Coconut fibres were investigated by many

Figure 1. Coconut tree, coconut and coconut fibres.

researchers for different purposes.

There is a huge difference in some properties, for example, diameter of coconut fibres is approximately same and magnitudes of tensile strength are quite different, e.g. compare tensile strength of coconut fibres mentioned by Ramakrishna and Sundararajan (2005a) and Toledo et al. (2005) in Table 1.

Also, the range shown for a particular property is quite wide; Toledo et al. (2005) mentioned the density of coconut fibre as 0.67-10.0 g/cm^3. These values seem to be unrealistic, real values may be 0.67-1.00 g/cm^3.

There are variations in properties of coconut fibres, and this makes it difficult for their frequent use as construction material. The purpose of compilation of data for the properties of fibres is to get a guideline, but after compilation, a huge variation is seen. There should be some standards for such variations, just like we have standards for sand and aggregates.

Figure 3 shows stress-strain relationship for coconut fibres as reported by some researchers (Paramasivam et al., 1984; Munawar et al., 2007; Satyanarayana et al., 1990). Coconut fibre is the most ductile fibre amongst all natural fibres. Coconut fibres are capable of taking strain 4-6 times more than that of other fibres as shown in Figures 3b and 3c (Munawar et al., 2007; Satyanarayana et al., 1990).

Fibre dimensions of the various individual cells are said to be dependent on the type of species, location and maturity of the plant. The flexibility and rupture of the fibre is affected by the length to diameter ratio of the fibre and this also determines the product that can be made from it. The shape and size of central hollow cavity, lumen, depends on (i) the thickness of the cell wall and (ii) the source of the fibre. The hollow cavity serves as an acoustic and thermal insulator because its presence decreases the bulk density of the fibre (Flower et al., 2006 as cited by Abiola, 2008).

Abiola (2008) evaluated the mechanical properties (load-extension curves, stress-strain curves, Young's modulus, yield stress, stress and strain at break) of inner and outer coconut fibres experimentally, and the results were verified by finite element method using a commercial software ABAQUS. The author found that the inner coconut fibre had a higher mechanical strength as compared to that of outer fibre, but the outer coconut fibre had a higher elongation property which could makes it to absorb or with stand higher stretching energy as compared to the inner coconut fibre.

Chemical properties

Coconut fibres contain cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut fibres. The pre-treat-ment of fibres changes the composition and ultimately changes not only its properties but also the properties of composites. Sometimes it improves the behaviour of fibres but sometimes its effect is not favourable. The chemical composition of coconut fibres is presented in Table 2.

Ramakrishna and Sandararajan (2005a) investigated the variation in chemical composition and tensile strength of four natural fibres (coconut, sisal, jute and hibiscus cannabinus fibres), when subjected to alternate wetting and drying and continuous immersion for 60 days in three mediums (water, saturated lime and sodium hydroxide). Chemical composition of all fibres changed for tested conditions (continuous immersion was found to be critical), and fibres lost their strength. But coconut fibres were reported best for retaining a good percentage of its original tensile strength for all tested conditions. The effect of pre-treatment of coconut fibres is also investigated by Asasutjarit et al. (2007) for light weight cement boards.

II. PROPERTIES OF COCONUT FIBRE REINFORCED COMPOSITES

Cement paste

Aziz et al. (1981) cited the work of Das Gupta et al. (1978, 1979) who studied the mechanical properties of cement paste composites for different lengths and volume fractions of coconut fibres. The authors con-cluded that the tensile strength and modulus of rupture of cement paste increased up to a certain length and volume fraction; and further increase in length or volume fraction decreased the strength of composite. Table 3 shows the tensile strength and modulus of rupture of cement paste composite reinforced with different volume fractions of 38 mm long coconut fibres ranging from 2 to 6 %. It can be easily observed that 4 % volume fraction of coconut fibres had given the highest mechanical properties amongst all tested volume fractions.

With 4% volume fraction, the authors also studied the tensile strength of cement paste reinforced with different lengths of coconut fibres. The reported tensile strengths were 2.3, 2.8 and 2.7 MPa with lengths of 25, 38 and 50 mm, respectively. Thus coconut fibres with a length of 38

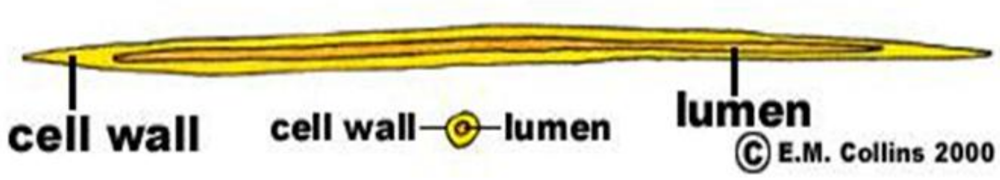

Figure 2. Longitudinal and cross-section of a fibre cell (Abiola, 2008).
Fig. 2. Longitudnal and Cross-section of a Fibre Cell [3]

mm and a volume fraction of 4% gave maximum strength of cement paste composite

Cement sand mortar

Effect of fibre content

Slate (1976) investigated mechanical properties of coir fibre reinforced cement sand mortar. The researcher tested two different design mixes (cement sand ratio by weight), first was 1:2.75 with water cement ratio of 0.54 and second was 1:4 with water cement ratio of 0.82. Fibres content was 0.08, 0.16 and 0.32 % by total weight of cement, sand and water. The mortars for both design mixes without any fibres were also tested as reference.

Cylinders having size of 50 mm diameter and 100 mm height and beams having size of 50 mm width, 50 mm depth and 200 mm length were tested for compressive and flexural strength. The curing was done for 8 days only. ASTM standards were used (C196-72, C78-64, C39-71 and C109-73).

It was found that all strengths were increased in case of fibre reinforced mortar as compared to that of plain mortar for both mix design with all fibre contents. However, a decrease in strength of mortar was also observed with an increase in fibre content.

Effect of fibre pre-treatment

Li et al. (2006) studied untreated and alkalized coconut fibres with two lengths of 20 and 40 mm in cementitious composites as reinforcement materials. Mortar was mixed in a laboratory mixer at a constant speed of 30 rpm, with cement: sand: water: super plasticizer ratio of

1: 3: 0.43: 0.01 by weight and fibres were slowly put into the running mixer. Australian standards AS 1012.8.1-2000 and 1012.8.2-2000 were used.

The resulting mortar had better flexural strength, higher energy absorbing ability and ductility, and lighter than the conventional mortar. Good results were achieved with the addition of a low percentage of coconut fibres and chemical agents in cementitious matrix.

Concrete

Epoxy polymer concrete

Reis (2006) investigated the mechanical characterization (flexural strength, fracture toughness and fracture energy) of epoxy polymer concrete reinforced with natural fibres (coconut, sugarcane bagasse and banana fibres). RILEM standards TC-113/PC2, TC 89-FMT, TC50-FMC and TC-113/PCM-8 were followed.

Fracture toughness and fracture energy of coconut fibre reinforced polymer concrete were higher than that of other fibres reinforced polymer concrete. And flexural strength was increased up to 25 % with coconut fibre only.

Effect of fibre volume fraction

Baruah and Talukdar (2007) investigated the static properties of plain concrete (PC) and fibre reinforced concrete (FRC) with different fibre volume fractions ranging from 0.5 to 2 %. Fibres used were steel, artificial and natural fibres (jute and coir fibres only). Here, discussion is limited only to PC and the coir fibres reinforced concrete (CFRC).

The mix design (cement: sand: aggregates) for plain concrete was 1: 1.67: 3.64 with water cement ratio of 0.535. Per cubic meter of concrete mix was cement = 350 kg, fine aggregates = 568.40 kg, coarse aggregate = 1239.40 kg and water = 182 kg. The maximum size of aggregates was 20 mm. Coir fibres having length of 4 cm and diameter of 0.4 mm with volume fraction of 0.5, 1, 1.5 and 2% were added to prepare CFRC. The sizes of specimens were (1) 150 mm diameter and 300 mm height for cylinders (2) 150 mm width, 150 mm depth and 700 mm length for beams, and (3) 150 mm cubes having a cut of 90 × 60 mm in cross-section and 150 mm high for L-shaped shear test specimens. All specimens were cured for 28 days. The investigated properties, compressive strength (□), splitting tensile strength (STS), modulus of rupture (MOR) using four point load test and shear strength (□), are shown in Table 4 for PC and CFRC. It can be noted that CFRC with 2 % fibres showed better results amongst all volume fractions.

The compressive strength, splitting tensile strength, modulus of rupture and shear strength of coir fibre reinforced concrete with 2% fibres by volume fraction were increased up to 13.7, 22.9, 28.0 and 32.7%, respectively as compared to those of plain concrete. It is also noted from their research that all these properties were also improved for CFRC with all other tested volume fractions of fibres (0.5, 1 and 1.5%). These properties were increased up to only 1.3, 4.9, 4.0 and

Table 1. Physical and mechanical properties of coconut fibres.

Diameter (mm)	Length (mm)	Tensile strength (MPa)	Specific Tensile strength (MPa)	Average Tensile Modulus (GPa)	Specific Tensile Modulus (GPa)	Tensile Strain (%)	Elongation (%)	Young's Modulus (GPa)	Specific Young's Modulus (GPa)	Toughness (MPa)	Permeable Void (%) *	Moisture Content (%)	Water Absorption Saturation (%) *	Elastic Modulus (GPa)	Density (Kg/m^3)	Reference
0.40- 0.10	60- 250	15- 327	-	-	-	-	75	-	-	-	-	-	-	-	-	Ramakrishna and Sundararajan, 2005a
0.21 [a,b]	-	107[e]	-	-	-	-	37.7[d,e]	-	-	-	56.6- 73.1	-	93.8- 161.0	2.8[e]	1104- 1370	Agopyan et al., 2005[c]
0.3	-	69.3[f]	-	-	-	-	-	-	-	-	-	-	-	2.0	1140	Paramasivam et al., 1984
-	-	50.9 [g]	-	-	-	-	17.6[g]	-	-	-	-	-	180 [h]	-	1000	Ramakrishna and Sundararajan, 2005b[i]
0.27± 0.073	50± 10	142± 36	-	-	-	-	24 ±10[k]	-	-	-	-	10 [m]	24	2.0 ± 0.3	-	Li et al., 2007
0.11– 0.53	-	108- 252	-	-	-	-	13.7– 41[n]	-	-	-	-	-	85.0- 135.0	2.50- 4.50	670- 1000	Toledo et al., 2005
0.12± 0.005	-	137± 11	158	-	-	-	-	3.7± 0.6	4.2	21.5± 2.4	-	-	-	-	870	Munawar et al., 2007 [o]
-	-	500	0.43[q]	2.50	2.17[q]	20	-	-	-	-	-	11.4[p]	-	-	1150	Rao and Rao, 2007
-	-	175	-	-	-	-	30	4-6	-	-	-	-	-	-	1200	Fernandez, 2002
0.1- 0.4	-	174	-	-	-	-	10-25	-	-	-	-	-	-	16-26	-	Reis, 2006
0.1-0.4	50- 250	100 - 130	-	-	-	-	10-26	-	-	-	-	-	130 - 180	19-26	145- 280	Aggarwal, 1992
0.10- 0.45	-	106 - 175	-	-	-	-	17-47	4-6	-	-	-	-	-	-	1150	Satyanarayana et al., 1990

[a] Coefficients of variation frequently over 50 % - [b] Determinations of thickness by scanning electron microscopy - [c] Brazilian Standard NBR-9778 - [d] Elongation on rupture – [e] Authors took other researchers data - [f] Ultimate value - [g] (Unit: mm) Maximum Value and it do not agree with the general accepted value which may be due to the test conditions adopted by [4] – [h] In 24hrs – [i] used natural dry condition of fibres - [j] width - [k] At break - [l] Water absorption ratio (100 % humidity) - [m] At 20 °C - [n] Strain at failure – [o] Data for mechanical properties are given as averages and 95 % confidence interval - [p] Percentage moisture present on weight basis at normal atmospheric condition – [q] MPa / (Kg m^{-3}) **By Vol. *By mass

4.7%, respectively for CFRC with 0.5 % fibres by volume fraction.

APPLICATIONS IN CIVIL ENGINEERING TECHNOLOGY

Plaster

low alkaline cement taken from the internal and external walls of a 12 year old house. The panel of the house were produced using 1:1.5:0.504 (binder: sand: water, by mass) mortar reinforced with 2% of coconut fibres by volume.

Fibres removed from the old samples were reported to be undamaged. No significant difference was found in the lignin content of fibres removed from external and internal walls.

Roofing material

Effect of fibre length and volume fraction

Cook et al. (1978) reported the use of randomly distributed coir fibre reinforced cement composites as low cost materials for roofing. The studied parameters were fibre lengths (2.5, 3.75 and 6.35 cm), fibre volumes (2.5, 5, 7.5, 10 and

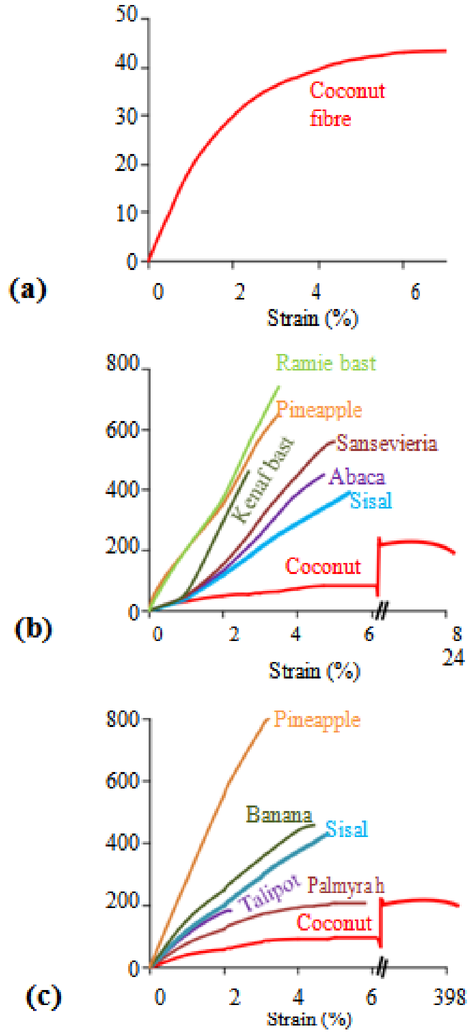

Figure 3. Correlation of mechanical properties for natural fibres (a) Paramasivan et al. (1984) (b) Munawar et al. (2007) (c) Satyanarayana et al. (1990). (Graphs are reproduced here for better quality).

composite with a fibre length of 3.75 cm, a fibre volume fraction of 7.5% and cast at pressure of 1.67 MPa. Cost comparison revealed that this composite was substan- tially cheaper than the locally available roofing materials.

Effect of weather conditions

Agopyan et al. (2005) studied coconut and sisal fibres as replacement for asbestos in roofing tiles. 2 % total fibre volume fraction was used. The dimensions of the tiles were 487 x 263 x 6 mm (frame measures) with consumption of 12.5 pieces / m2 and format very similar to ceramic Roman tiles. Three-point bend test specimen (span = 350 mm, deflection rate = 5 mm/min) was employed for determination of maximum load. The tiles were exposed in a rack facing North with 30° of inclina- tion and submitted to natural ageing under environmental condition in a rural area at Pirassununga, State of Sa˜o Paulo, Brazil (21° 59 ′ S of latitude), for up to 16 and 60 months. The main long-term climate conditions for the region were: average maximum temperature for January= 30.1°C, average minimum temperature for July= 9.5°C, average maximum relative humidity for January/February = 77%, average minimum relative humidity for August = 63% and average rainfall = 1363 mm/year. After the ageing period of 16 and 60 months, the maximum load taken by coir tile were 235 and 248 N, respectively while that by sisal tiles were 237 and 159 N, respectively. The major benefit of reinforced tiles was the at least 22% higher energy absorption than that of the unreinforced tiles which could help to avoid fragile rupture of tiles in the short-term under transportation or installation.

Slabs

Effect of fibre length and volume fraction

Paramasivam et al. (1984) conducted a feasible study of making coir fibre reinforced corrugated slabs for use in low cost housing particularly for developing countries. They gave recommendations for the production of coconut fibre reinforced corrugated slabs along casting technique. Tests for flexural strength, thermal and acoustic properties were performed. For producing required slabs g. 3. Correlations of mechanical properties for natural fibres*. (a) Paramasivamhavingflexuralet strength of 22 MPa, a volume fraction of 3%, a fibre length of 2.5 cm and a casting pressure of al. (1984) (b) Munawar et al. (2007) (c) Satyanarayana et al. (1990). 0.15 MPa (1.5 atmosphere) were recommended. The thermal conductivity and sound absorption coefficient for low frequency were comparable with those of locally available asbestos boards.

Effect of impact loading

Ramakrishna and Sandararajan (2005b) investigated the

Table 2. Chemical composition of coconut fibres.

Fibre	Hemi-cellulose (%)	Cellulose (%)	Lignin (%)	Reference
Coir	31.1 [a]	33.2 [a]	20.5 [a]	Ramakrishna and Sundararajan, 2005a
	15 - 28 [b]	35 - 60 [b]	20 - 48 [b]	Agopyan et al., 2005
	-	43	45	Satyanarayana et al., 1990
	16.8	68.9	32.1	Asasutjarit et al., 2007
	0.15 – 0.25	36-43	41-45	Corradini et al., 2008

[a] The compositions are % by weight of dry and powdered fibre sample.
[b] Chemical compositions are % by mass and author took other researchers data.

Table 3. Mechanical properties of coconut fibre reinforced cement paste composites (Das Gupta et al., 1978 as cited by Aziz et al., 1981).

Fibre volume fraction (%)	Tensile strength (MPa)	Modulus of rupture (MPa)
2	1.9	3.6
3	2.5	4.9
4	2.8	5.45
5	2.2	5.4
6	1.5	4.6

resistance to impact loading for cement sand mortar (1:3) slabs. The slab specimens (300 x 300 x 20 mm) were reinforced with natural fibres (coconut, sisal, jute and hibiscus cannabinus fibres) having four different fibre contents (0.5, 1.0, 1.5 and 2.5% by cement weight) and three fibre lengths (20, 30 and 40 mm).

A fibre content of 2% and a fibre length of 40 mm of coconut fibres showed best performance by absorbing 253.5 J impact energy among all tested fibres. All fibres, except coconut fibres, showed fibre fracture, at ultimate failure where as coconut fibre showed fibre pull out failure.

Coir mesh reinforcement in slab

Li et al. (2007) studied fibre volume fraction and fibre surface treatment with a wetting agent for coir mesh reinforced mortar using nonwoven coir mesh matting. They performed a four-point bending test on a slab specimen and concluded that cementitious composites, reinforced by three layers of coir mesh (with a low fibre content of 1.8%) resulted in a 40% improvement in the maximum flexural stress, were 25 times stronger in flexural toughness, and about 20 times higher in flexural ductility.

Boards

Asasutjarit et al. (2007) determined the physical, mechanical and thermal properties of coconut-based light weight cement board after 28 days of hydration. The parameters studied were fibre length, coir pre-treatment and mixture ratio. Boiled and washed fibres with 6 cm fibre length gave better results. On the other hand, optimum mixture ratio by weight for cement: fibre: water was 2:1:2. Also, tested board had lower thermal conductivity than commercial flake board composite.

Wall paneling system

Mohammad (2005) tested wall panels made of gypsum and cement as binder and coconut fiber as the reinforce-ment. Bending strength, compressive strength, moisture content, density, and absorption were investigated. Coconut fibres did not contribute to bending strength of the tested wall panels. Compressive strength increased with the addition of coconut fibres, but the compressive strength decreased with an increase in water content and density was increased. There was no significant change of moisture content with coconut fibres. However, moisture content increased with time. There was also no significant effect to water absorption on increasing coconut fibre content.

House construction

Some researchers (Luisito et al., 2005) of PCA-Zamboanga Research Center, San Ramon, Zamboanga city invented coconut fibre boards (CFB) for different applications as shown in Figure 4. According to them, CFB can replace construction materials such as tiles, bricks, plywood, and asbestos and cement hollow blocks.

Table 4. Properties of coconut fibre reinforced concrete (CFRC) (Baruah and Talukdar, 2007).

Fibre volume fraction (%)	Compressive strength (MPa)	Split tensile strength (MPa)	Modulus of rupture (MPa)	Shear strength (MPa)	Toughness index, I5	Toughness index , I10
-	21.42	2.88	3.25	6.18	1.934	1.934
0.5	21.70	3.02	3.38	6.47	2.165	2.270
1.0	22.74	3.18	3.68	6.81	2.109	2.773
1.5	25.10	3.37	4.07	8.18	2.706	4.274
2.0	24.35	3.54	4.16	8.21	2.345	3.452

Figure 4. Applications of coconut fibre boards in house construction and other utilities (Luisito et al., 2005).

It is used for internal and exterior walls, partitions and ceiling. It can also be used as a component in the fabrication of furniture, cabinets, boxes and vases, among others.

Slope stabilization

Coir erosion fabrics provide firm support on slopes and unlike other natural fibre alternatives like cotton or jute, do not degrade until 5 years. They have the necessary strength and come in a number of forms such as matting, rolls and logs and are used for soil stabilization.

Coconut fiber finds applications in slope stabilization in railway cutting and embankments, protection of water courses, reinforcement of temporary walls and rural unpaved roads, providing a sub base layer in road pavements, land reclamation and filtration in road drains, containment of soil and concrete as temporary seeding etc, highway cut and fill slopes, control of gully erosion and shallow mass waste.

APPLICATIONS IN OTHER ENGINEERING TECHNOLOGIES

Bullet proof vest

Yuhazri and Dan (2008) developed a unique bullet proof vest made of coconut fibre, which provides all the protection that can be found in a regular vest. It is not only economical but also lighter. A normal bullet-proof vest costs about RM 16, 000/- and weighs 9 kg, but this vest is only 3 kg and cost RM 2, 000/-. The test proved that the vest was capable of stopping 9 mm calibre bullets at a 5 m range. They also tested high impact hybrid composite material with coconut fibres as reinforcement for ballistic armor, and satisfactory results were reported.

Motorcycle helmet

Yuhazri and Dan (2007) utilized coconut fibres in the manufacturing of motor cycle helmet. They used epoxy resins from thermo set polymer as the matrix materials and coconut fibres as the reinforcement. After the deve-lopment of helmet shells fabrication method, mechanical testing (dynamic penetration) was performed on this composite material to determine its performance. The result in the mechanical performance showed that coconut fibres performed well as a suitable reinforcement to the epoxy resin matrix.

Car parts

A team of Baylor University researchers is trying develop a technology to use coconut fiber as a replacement for synthetic polyester fibers in compression molded composites. Their aim is to use the coconut fibers to make trunk liners, floorboards and interior door covers on car.

General use

Apart from applications in engineering, coconut fibres are also used in yarn, ropes, mats, mattresses, brushes, sacking, caulking boats, rugs, geo-textiles, insulation panels and packaging.

III. CONCLUSIONS

The versatility and applications of coconut fibres in different fields is discussed in detail. Coconut fibres are reported as most ductile and energy absorbent material. It is concluded that coconut fibres have the potential to be used in composites for different purposes. Various aspects of many coconut fibres reinforced composites have already been investigated; and the economical and better results are achieved as reported by many researchers.

Since the use of coconut fibres has given some marvellous products, there is still possibility of the invention of new products containing coconut fibres with improved results. In civil engineering, coconut fibres have been used as reinforcement in composites for non-structural components. There is a need of investigating the behaviour of coconut fibre reinforced concrete to be used in main structural components like beams, columns and walls.

REFERENCES

[1]. Abiola AAWBO (2008). Mechanical Property Evaluation of Coconut Fibre. Thesis Master's Degree (ISRN: BTH-AMT-EX-2008/D05-SE), Dept of Mechanical Engineering, Blekinge Institute of Technology, Kariskrone, Sweden.

[2]. Aggarwal L (1992). Studies on cement bonded coir fibre boards. Cement Conc. Comp., 14(1): 63-69.

[3]. Agopyan V, Savastano JH, John VM, Cincotto MA (2005). Developments on vegetable fibre-cement based materials in Paulo, Brazil: An overview. Cement Conc. Comp., 27(5): 527-536.

[4]. Asasutjarit C, Hirrunlabh J, Khedari J, Paguenet M, Quenard D (2005). Coconut Coir Cement Board. 10^{th} International Conference on the Durability of Building Materials and Components. Lyon, France. TT3-103.

[5]. Asasutjarit C, Hirunlabh J, Khedari J, Charoenvai S, Zeghmati B, Shin UC (2007). Development of coir-based light weight cement board. Constr. Build. Mater. 21(2): 277-288.

[6]. Aziz MA, Paramasivam P, Lee SL (1981). Prospects for natural fibre reinforced concretes in construction. Int. J. Cement Comp. Lightweight Conc., 3(2): 123-132.

[7]. Aziz MA, Paramasivam P, Lee SL (1984). Concrete reinforced with natural fibres. New Reinforced Concrete; pp. 106-140.
[8]. Baruah P, Talukdar SA (2007). Comparative study of compressive, flexural, tensile and shear strength of concrete with fibres of different origins. Indian Conc. J., 81(7): 17-24.
[9]. Cook DJ, Pama RP, Weerasingle HLSD (1978). Coir fibre reinforced cement as a low cost roofing material. Building Environ., 13(3): 193-198.
[10]. Corradini E, De Morais LC, De Rosa MF, Mazzetto SE, Mattoso LH, Agnelli JA (2008). A preliminary study for the use of natural fibers as reinforcement in starch-gluten-glycerol matrix. Macromolecular Symposia; pp. 245-246: 558-564.
[11]. Das Gupta NC, Paramsivam P, Lee SL (1978). Coir reinforced cement pastes composites. Conference Proceedings of Our World in Concrete and Structures, pp. 111-116.
[12]. Das Gupta NC, Paramsivam P, Lee SL (1979). Mechanical properties of coir reinforced cement pastes composites. Housing Science, Pergamon Press Inc. London, 2(5): 391-406.
[13]. Fernandez JE (2002). Flax fiber reinforced concrete - A natural fiber biocomposite for sustainable building materials. High Performance Structures and Materials, CA. Brebbia and WP. Wilde, eds., Seville; pp. 193-207.
[14]. Flower PA, Hughes JM, Melias R (2006). Review bio composites: technology, environmental credentials and market forces. J. Sci. Food Agric., 86: 1781-1789. John VM, Cincotto MA, Sjostrom C, Agopyan V, Oliveira C (2005).
[15]. Durability of slag mortar reinforced with coconut fibre. Cement Conc. Comp., 27(5): 565-574.
[16]. Li Z, Wang L, Wang X (2006). Flexural characteristics of coir fiber reinforced cementitious composites. Fibers Polym., 7(3): 286-294.
[17]. Li Z, Wang L, Wang X (2007). Cement composites reinforced with surface modified coir fibers. J. Comp. Mat., 41(12): 1445-1457.
[18]. Luisito JP, Neil JM, Rolendio N (2005). Coconut fibre boards. http://www.ecocoboard.net/dwnloads/Presentations%20workshop/Penamora_Coconut%20fibre%20cement%20boards.pdf
[19]. Mohammad HBMH (2005). Coconut fiber reinforced wall panelling system. Thesis Master of Engineering (Civil-Structure), Faculty of Civil Engineering, Universiti Teknologi, Malaysia.
[20]. Munawar SS, Umemura K, Kawai S (2007). Characterization of the morphological, physical, and mechanical properties of seven non-wood plant fibre bundles. J. Wood Sci., 53(2): 108-113.
[21]. Paramasivam P, Nathan GK, Das Gupta NC (1984). Coconut fibre reinforced corrugated slabs. Int. J. Cement Comp. Lightweight Conc., 6(1): 19-27.
[22]. Ramakrishna G, Sundararajan T (2005a). Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar. Cement Conc. Comp., 27(5): 575-582.