Application of Sisal, Bamboo, Coir and Jute Natural Composites in Structural Upgradation

Tara Sen, H. N. Jagannatha Reddy

Abstract—**The materials chosen for structural upgradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, should fulfil some criterion, for the cause of sustainability and a better quality. For example, these materials should not pollute the environment and endanger bioreserves, should be such that they are self sustaining and promote self-reliance, should help in recycling of polluting waste into usable materials, should make use of locally available materials, utilise local skills, manpower and management systems, should benefit local economy by being income generating, should be accessible to the ordinary people and be low in monetary cost. Besides improving the strength of the structure using FRPs as the raw material, it is also necessary to make use of local materials in construction. So far the work on construction. So far the work on retrofitting of structures is confined to using of carbon, glass or aramid fibres etc, very little work is being imparted in improving structures using naturally available materials, or natural fibres. The application of composites in structural facilities is mostly concentrated on increasing the strength of the structure with the help of artificial fibres and does not address the issue of sustainability of these raw materials used for strengthening purposes. In an expanding world population and with the increase of the purchasing potentials, the need for raw materials required for structural strengthening, that would satisfy the demand on world market is rapidly growing. In times when we cannot expect the fibre reinforced polymer prices to come down, with the consumption growing day by day. Also waste disposal has become one of the major problems in modern cities. At present there are two major methods in practice to dispose wastes. One is land filling and the other is burning. First one requires more valuable land and second one pollutes the environment. So, alternate methods to dispose solid waste should be found. New materials that would be cheaper and at the same time offer equal or better properties have to be developed. We have enough natural resources and we must keep on researching on these natural resources. Development of plant fibre composites has only begun. Among the various natural fibres such as, sisal fibres, bamboo fibres, coir fibres and jute fibres are of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres. Among the various natural fibres, sisal fibre reinforced composite, bamboo fibre reinforced composite, coir reinforced composite and jute fibre reinforced composite are of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres. Hence encouragement should be given for the use of natural fibres such as sisal fibres, bamboo fibres, coir fibres and jute fibres which are locally available materials, in the field of civil engineering. Also by considering the case of waste disposal, here an attempt is made to study the possibilities of reusing the sisal fibres, bamboo fibres, coir fibres and jute fibres which not only has various applications but also helps to solve the problem of waste disposal atleast to a small extent. Economic and other related factors in many developing countries where natural fibres are abundant, demand that scientists and engineers apply appropriate technology to utilize these natural fibres as effectively and economically as possible for structural upgradation and also other purposes for housing and other needs and also for various other applications etc.**

Index Terms—**Natural Fibres, Sustainable Development, Sisal fibres, Bamboo fibres, Coir fibres and Jute fibres**

Manuscript received April 1, 2011; revised June 3, 2011.

Tara Sen, is Assistant Professor in the department of Civil Engineering, at National Institute of Technology(NIT), Agartala, Barjala, District-West Tripura, State-Tripura, India(e-mail: tara.sen@rediffmail.com). Mobile No :+919436541206 (Corresponding Author)

H. N. Jagannatha, Reddy is Professor in the department of Civil Engineering, at Bangalore Institute of Technology, K.R.Road, Bangalore,India(e-mail: girija.bitcse@gmail.com)

I. Introduction

A judicious combination of two or more materials that produces a synergistic effect. A material system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents. Composites are hybrid materials made of a polymer resin reinforced by fibres, combining the high mechanical and physical performance of the fibres and the appearance, bonding and physical properties of polymers, the short and discontinuous fibre composites are responsible for the biggest share of successful applications, whether measured by number of parts or quantity of material used. A composite in this respect is a compound between a polymer (such as polyester or PP) and a fibrous material (such as glass, carbon or natural fibres). Composite products have good mechanical properties per unit weight, are durable and their technologies allow the manufacture of complex and large shapes. For these applications the substitution of industrial fibres with natural fibres could be considered. Many natural fibres traditionally employed in weaving, sacking and ropes; present various potentials to be used as reinforcement elements in composites. Retrofitting of flexural concrete elements are traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and difficult to install. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fibre reinforced polymer (FRP) plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. Also recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength good fatigue and corrosion resistance and ease of use, make them an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements. FRP can be convenient compared to steel for a number of reasons. These materials have higher ultimate strength and lower density than steel. The installation is easier and temporary support until the adhesive gains its strength is not required due to the low weight. NF composites products are constructions made of "glued together" First at any costs, with development of improved materials with increasing costs, nowadays cost reduction during manufacturing and operation are the main technology drivers. Latest development is the use of composites to protect man against fire and impact and a tendency to a more environmental friendly design, leading to the reintroduction of natural fibres in the composite technology, natural fibres. They can be formed on site into complicated shapes and can also be easily cut to length on site. These include wood fibres, jute, sisal, coconut, bamboo and banana leaves. Such fibres could be added alone or in hybrid composites, in partial substitution for industrial fibres.

Natural fibres such as sisal, bamboo, coir and jute can be used successfully in composite components in order to realise reduction of weight and cost. These fibres are renewable, non-abrasive to Process equipment, and can be incinerated at the end of their life cycle for energy recovery as they possess a good deal of calorific value. They are also very safe during handling, processing and use. The distinctive properties of natural fibre reinforced polymers are improved tensile and bending strength, greater ductility and greater resistance to cracking and hence improved impact strength and toughness. By changing the direction of the fibres in the resin, the material properties can be tailored to the external loads. To optimize the construction multiple adjusted layers (laminae) can be used to form a laminate. By this joining, the poor capabilities and drawbacks of the individual components disappear. By this joining, the poor capabilities and drawbacks of the individual components disappear. For instance, composites combine a high stiffness and strength with a low weight and their corrosion resistance is often excellent. Composites have worked their way up amongst wood and metal due to their outstanding price performance ratio during a lifetime. A powerful approach in improving this ratio is to minimise the steps required from raw material to end product.

II. Different Types of Natural Fibres

A. Sisal

The plants look like giant pineapples, and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibres by hand or machine. The fibres are dried and brushes remove the remaining dirt, resulting in a clean fibre. Sisal produces sturdy and strong fibres. Sisal fibre is one of the prospective reinforcing materials that its use has been more experiential than technical until now. The use of 0.2% volume fraction of 25mm sisal fibres leads to free plastic shrinkage reduction. Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength after 420 days. As for the immersion of the fibres in a calcium hydroxide solution, it was noticed that original strength was completely lost after

300 days. According to those authors the explanation for the higher attack by Ca (OH) 2 can be related to a crystallization of lime in the fibres pores. Agave Sisalana Perrini is a native species to the Yucatan peninsula, and known worldwide, the plant and also the fibres, as Sisal, belonging to the class of natural hard fibres. Presently, Sisal represents the first natural fibre in commercial application, in which it is estimated in more than half of the total of all natural fibres used. The Sisal plant is a monocotyledonous, whose roots are fibrous, emerging from the base of pseudo stem. The fibres of Sisal are made of elementary fibres of 4 to 12 μm diameter that are aggregated by natural bound forming small cells of 1 to 2 μm. Such arrays are placed along the length of the plant on a regular shape, with lengths of 45 to 160 cm. The leaves of Sisal are an example of natural composite with lignocellulosic material presenting in 75 to 80 % of the total weight of the leaves, reinforced by helical micro fibres of cellulose, which represent about 9 to 12 % the total weight. The composition of Sisal fibre is basically of cellulose, lignin and hemicelluloses. The failure strength and the modulus of elasticity, besides the lengthening of rupture, depend on the amount of cellulose and the orientation of the micro-fibres. As a natural product these characteristics have a wide variation from one plant to another. The Sisal fibres are found commercially in several formats: fabric, cords, strips, wire, rolls, etc.

Properties of this fibre are as follows :

Specific gravity [Kg/m3]	1370
Water absorption [%]	110
Tensile strength [M Pa]	347-378
Modulus of elasticity [G Pa]	15

Available countries:-
East Africa, Bahamas, Antiqua, Kenya, Tanzania, India

1) *Advantages*
   a) They are very well resistant against moist.
   b) These fibres have a good tension resistance or tensile strength.
   c) They are very well resistant against heat.
   d) Sisal short fibres delay restrained plastic shrinkage controlling crack development at early ages.
   e) Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength.
2) *Disadvantages*
   a) decomposition in alkaline environments or in biological attack
3) *Applications*
   a) It is mainly used for ropes, mats, carpets. and cement reinforcement.

b) It is also used cement reinforcement.
c) In developing countries, sisal fibres are used as reinforcement in houses.

B. Bamboo

Bamboo has been one of the common materials in pre-industrial architecture in Asia and South American countries, employed as structural elements. The utilization of bamboo as construction component is motivated by its widespread availability in the tropical and subtropical climatic regions, its rapid growth and the combination o f elevated mechanical strength and low specific weight. However, at the present time, even the most modern construction where bamboo is used rely on a craft approach, with the know-how of construction techniques restricted to a small group of researchers, engineers and architects. Although bamboo has an immense potential, standardization and a definition of a correct construction practice still present some difficulties. Actually, there is an on-going research on bamboo with regards to special treatments leading to higher durability ,improved connectors and mathematical modeling for the structural analysis of bamboo structures, along with the micro, macro- and nano-structural properties shutter bamboo concrete slabs, application of bamboo segments as reinforcement of concrete beams, circular columns and pillars in quadratic form of concrete, double–layer spatial and plane truss bamboo structure and special joints between the bamboo elements, which can be easily used for plane and double-layer spatial structures. It is now well established that bamboo is a composite material of cellulose fibres, with an average tensile resistance of about 700 MPa. These cellulose fibres are immersed in a lignin matrix. Studies showed that bamboo is a material with the variation of its physical and mechanical properties in an optimized form, according to the stresses generated due to wind load and its own weight. It has been observed on a macroscopic scale that the distances between the nodes (stiffeners), the diameter and the thickness vary along the total length of the bamboo Culm. The thickness, size and volumetric fraction of fibres vary, becoming more concentrated as they approach the external shell. This is due to the higher forces applied to the external surface when the bamboo is subjected to bending by wind load. The determination of how the variation of volumetric fracture occurs in the thickness is necessary for applying the theory of composite materials to bamboo, which allows the optimized use of bamboo on engineering sites. This variation of the properties as well as the macro, meso and microscopic characterize the graduate functionality of bamboo. There is on-going research concerned with the structural analysis of bamboo frame structures commonly used by local people, improvement of the concrete permanent bamboo shutter slabs and reinforced concrete beams and columns, having in mind its improvement according to available knowledge. Fabrication of corrugated composite slabs based on cement paste reinforced with cellulose pulp of bamboo. The cement composites reinforced by bamboo pulps are produced by the vacuum pressure process, seeking to establish the characteristics of a material which can be easily fabricated, utilising the machinery of asbestos cement industry. The bamboo pulp is used in the paper industry on a large scale. There are studies underway to produce durable furniture and new geometrical structural forms, as well as bicycles, tricycles and car bodies using bamboo. The first aero plane which succeeded to fly was made with bamboo by the Brazilian Santos Dumont.

Properties of this fibre are as follows:

Specific gravity [Kg/m3]	1158
Water absorption [%]	145
Tensile strength [MPa]	73-505
Modulus of elasticity [GPa]	10-40

Available countries:-

India, Sri Lanka, Egypt, Guyana, Jamaica, Philippines, Malaysia

1) *Advantages*
   a) It has elevated mechanical strength.
   b) It has low specific weight too.
   c) It has high tensile strength.
   d) It has better modulus of elasticity than any other natural material.
   e) Easily and locally available material.
2) *Disadvantages*
   a) It is very much bad in torsion when it become mature.
   b) Probability of decomposition in biological attack.
3) *Applications*
   a) Bamboo segments are used as reinforcement of concrete beams, circular columns and pillars in quadratic form of concrete, double–layer spatial and plane truss bamboo structure and special joints between the bamboo elements, which can be easily used for plane and double-layer spatial structures.
   b) Bamboo frame structures commonly used by local people for improvement of the concrete permanent bamboo shutter slabs and reinforced concrete beams and columns.

C. Coir (Coconut Fibre)

Coconut fibre is obtained from the husk of the fruit of the coconut palm; the trees can grow up to 20 m, making harvesting a difficult job. People climb the tree to pick the nuts, or a pole with an attached knife is used. The fruits are dehusked with on a spike and after retting, the fibres are subtracted from the husk with beating and washing. The fibres are strong, light and easily withstand heat and salt water. After nine months of growth, the nuts are still green and contain white fibre, which can be used for the production of yarn, rope and fishing nets. After twelve months of growth, the fibres are brown and can be used for brushes and mattresses. The combined use of coconut and sisal short fibres seem to delayed restrained plastic shrinkage controlling crack development at early ages. Many aspects of the use of coir fibres as reinforcement in polymer–matrix composites are described in the literature. Coir is an abundant, versatile, renewable, cheap, and biodegradable lignocellulosic fibre used for making a wide variety of products. Coir has also been tested as a filler or a reinforcement in different composite materials. Furthermore, it represents an additional agro-industrial non food feedstock (agro industrial and food industry waste) that should be considered as feedstock for the formulation of ecocompatible composite materials. Coconut coir is the most interesting products as it has the lowest thermal conductivity and bulk density. The addition of coconut coir reduced the thermal conductivity of the composite specimens and yielded a lightweight product. Development of composite materials for buildings using natural fibre as coconut coir with low thermal conductivity is an interesting alternative which would solve environment and energy concern. Geethamma et al. have studied the dynamic mechanical behavior of natural rubber and its composites reinforced with short coir fibres. Coir fibre–polyester composites were tested as helmets, as roofing and postboxes. These composites, with coir loading ranging from 9 to 15 wt%, have a flexural strength of about 38 MPa. Coir–polyester composites with untreated and treated coir fibres, and with fibre loading of 17 wt%, were tested in tension, flexure and notched Izod impact. The results obtained with the untreated fibres show clear signs of the presence of a weak interface long pulled-out fibres without any resin adhered to the fibres—and low mechanical properties were obtained. Although showing better mechanical performance, the composites with treated fibres present, however, only a moderate increase on the values of the mechanical properties analyzed. Alkali treatment is also reported for coir fibres. Treated fibre–polyester composites, with volume fraction ranging from 10% to 30%, show better properties than composites with untreated fibres, but the flexural strength of these composites was consistently lower than that of the bare matrix. A maximum value of 42.3MPa is reported against a value of 48.5MPa for the neat polyester. Acetylation of coir fibres increases the hydrophobic behaviour, increases the resistance to fungi attack and also increases the tensile strength of coir– polyester composites. However, the fibre loading has to be fairly high, 45 wt% or even higher, to attain a significant reinforcing effect when the composite is tested in tension. Moreover, even with high coir fibre loading fractions, there is no improvement in the flexural strength. From these results, it is apparent that the usual fibre treatments reported so far did not significantly change the mechanical performance of coir–polyester composites. Although there are several reports in the literature which discuss the mechanical behaviour of natural fibres reinforced polymer composites. However, very limited work has been done on effect of fibre length on mechanical behaviour of coir fibre reinforced epoxy composites. Against this background, the present research work has been undertaken, with an objective to explore the potential of coir fibre as a reinforcing material in polymer composites and to investigate its effect on the mechanical behaviour of the resulting composites. The present work thus aims to develop this new class of natural fibre based polymer composites with different fibre lengths and to analyse their mechanical behaviour by experimentation.

Properties of this fibre are as follows:

Specific gravity [Kg/m3]	1177
Water absorption [%]	93
Tensile strength [MPa]	95-118
Modulus of elasticity [GPa]	8

Available countries:-
India, Sri Lanka, Philippines, Malaysia

1) *Advantages*
   - *a)* The fibres are strong, light.
   - *b)* The fibres can easily withstand heat.
   - *c)* The fibres can withstand salt water.
   - *d)* The use of coconut fibres seem to delayed restrained plastic shrinkage controlling crack development at early ages.
   - *e)* Coir is an abundant, versatile, renewable, cheap, and lignocellulosic fibre.
   - *f)* The addition of coconut coir reduced the thermal conductivity of the composite specimens
2) *Disadvantages*
   - *a)* The fibres are biodegradable.
3) *Applications*
   - *a)* It is used for the production of yarn.
   - *b)* It is used for manufacture of rope and fishing nets.
   - *c)* It can be used for the production of brushes and mattresses.
   - *d)* Coir has also been tested as a filler or a reinforcement in different composite materials.

D. Jute

The fibres are extracted from the ribbon of the stem. When harvested the plants are cut near the ground with a sickle shaped knife. The small fibres, 5 mm, are obtained by successively retting in water, beating, stripping the fibre from the core and drying. A single jute fibre is a three dimensional composite composed mainly of cellulose, hemicelluloses, and lignin with minor amounts of protein, extractives and inorganics. These fibres were designed, after millions of years of evolution, to perform, in nature, in a wet environment. Nature is programmed to recycle jute, in a timely way, back to basic building blocks of carbon dioxide, and water through biological, thermal, aqueous, photochemica1, chemical, and mechanical degradations. In order to expand the use of jute fibre-based composites in adverse environments, it is necessary to interfere with natures recycling chemistry. One of the most studied chemistries to interfere with natures recycling chemistry and improve performance properties of jute fibre based composites involves reactions with acetic anhydride (acetylation). Chemical modifications of this type react with accessible hydroxyl groups on the cell wall polymers. These are the same hydroxyl groups involved in the natural degradation chemistries. The addition of a simple acetate group on the natural fibre changes both rate and equilibrium properties. Lignocellulosic fibres are favorably bonded with phenolic resin to have better water resistance rather than urea or melamine resin. Hence, water soluble phenol formaldehyde resin was selected for the development of rigid jute board for good serviceable mechanical properties. To achieve better wet ability of jute with resin and to improve strength properties, fibre pre-treatment is necessary. Simple pre-treatment is done with low-condensed resins like melamine resin, phenolic resin and CNSL modified phenol formaldehyde resin. Jute as other lignocellulosic fibres consists of –OH group which causes it susceptible to moisture and directly impairs the properties of jute composite specially dimensional stability. Due to this polar group, jute also is not efficiently adhered to non polar matrices. To overcome this difficulties this fibre should be modified chemically or hydrothermally. To improve the interface adhesion between the non polar matrices and hydrophilic fibre, coupling agent or compatibiliser should be used. Some investigations were done by cyanoethylation and acetylation of jute fibre to reduce the –OH content. The both processes are effective for dimensional stability. Cyanoethylation also improves the bonding between jute and non polar matrix like unsaturated polyester resin.

Properties of the fibre are as follows:

Specific gravity [kg/m^3]	1460
Water absorption [%]	13
Tensile strength [MPa]	400-800
Stiffness [KN/mm^2]	10-30

Available countries:-

India, Egypt, Guyana, Jamaica, Ghana, Malawi, Sudan, Tanzania

1) *Advantages*
   a) It can withstand rotting very easily.
   b) Lignocellulosic fibres are favorably bonded with phenolic resin to have better water resistance.
   c) The fibres can easily withstand heat.
   d) It has high tensile strength.
2) *Disadvantages*
   a) Due to its short fibre length, Jute is the weakest stem fibre than other fibres.
   b) Jute fibre based composites involve reactions with acetic anhydride (acetylation).
   c) The fibres are biodegradable.
3) *Applications*
   a) It is used as packaging material (bags).
   b) It is used as carpet backing, ropes, yarns.
   c) It is used for wall decoration.

III. Comparison of These Natural Fibres

A. *Differences between the properties*

Fibres	Density [g/cm3]	Tensile strength [N/mm2]	Modulus of elasticity (GPa)	Moist absorption [%]
Sisal	1370	347-378	15	110
Bamboo	1158	73-505	10-40	145
Coir	1177	95-118	8	93
Jute	1460	400-800	10-30	13
Hemp	1480	550-900	15-45	8

B. *Applicational differences*

Names of the fibres	Applications
Sisal	1. It is mainly used for ropes, mats, carpets. and cement reinforcement. 2. It is also used cement reinforcement. 3. In developing countries, sisal fibres are used as reinforcement in houses.
Bamboo	1. Bamboo segments are used as reinforcement of concrete beams, circular columns and pillars in quadratic form of concrete, double–layer spatial and plane truss bamboo structure and special joints between the bamboo elements, which can be easily used for plane and double-layer spatial structures. 2. Bamboo frame structures commonly used by local people for improvement of the concrete permanent bamboo shutter slabs and reinforced concrete beams and columns. 3. It has many uses which include erosion control, watershed protection, soil remediation, environmental greening and medicinal application. 4. Bamboo is a high-yield renewable natural resource: ply bamboo is now being used for wall paneling, floor tiles; bamboo pulp for paper making, briquettes for fuel.
Coir	1. It is used for the production of yarn. 2. It is used for manufacture of rope and fishing nets. 3. It can be used for the production of brushes and mattresses. 4. Coir has also been tested as a filler or a reinforcement in different composite materials.
Jute	1. It is used as packaging material (bags). 2. It is used as carpet backing, ropes, yarns. 3. It is used for wall decoration.

References

[1] ACI Committee 544, *Fibre Reinforced Concrete*, SP-81, American Concrete Institute, Detroit, 1984.

[2] Mansur, M. A., "Jute Fibre Reinforced Composite Building Materials," *Proc. 2nd Australian Conf. Eng. Materials,* University of New South Wales, 1981, pp. 585-596.

[3] Paramasivan, P.; Nathan, G. K.; and Das Gupta, N. C., "Coconut Fibre Reinforced Corrugated Slabs," *Int. J. Cement Composites and Lightweight Concrete*, Vol. 6, No. 1, 1984, pp. 19-27.

[4] Racines, P. G., and Pama, R. P., "A Study of Bagasse Fibre-Cement Composite as Low-Cost Construction Materials," *Proc. Int. Conf. Materials for Developing Countries,* Bangkok, 1978, pp. 191-206.

[5] Pakotiprapha, B.; Pama, R. P.; and Lee, S. L., "Behaviour of Bamboo Fibre-Cement Paste Composites," *J. Ferrocement*, Vol. 13, No. 3,1983, pp. 235-248.

[6] Weerasinghe, A. L. S. D., "Fundamental Study on the Use of Coir-Fibre Board as a Roofing Material," M. Eng. Thesis, The Asian Institute of Technology, Bangkok, 1977.

[7] Lewis, G., and Mirihagalia, P., "A Low-Cost Roofing Material for Developing Countries," *Building and Environment*, Vol. 14, No. 2, 1979, pp. 131-134.

[8] Swift, P. G., and Smith, R. B. L., "Sisal-Cement Composites as Low-Cost Construction Materials," *Appropriate Technology*, London, Vol. 6, No. 3, 1979, pp. 6-8.

[9] Subrahmanyam, B. V., "Bamboo Reinforcement for Cement Matrices," *New Reinforced Concretes*, edited by R. N. Swamy, Surrey UniversityPress, U.K., 1984, pp. 141-194.

[10] Narayana, S. K., and Rehman, P. M. A., "Bamboo-Concrete Composite Construction," *J. Inst. of Engineers,* India, Vol. 42, 1962, pp. 426-440.

[11] Youssef, M. A. R., "Bamboo as a Substitute for Steel Reinforcement in Structural Concrete," *New Horizons in Construction Materials,* 1, edited by H. Y. Fang, Envo Publishing Co., Lehigh Valley, 1976, pp. 522-554.

[12] "The Use of Bamboo and Reeds in Building Construction," *Publication* No. St/So/113, Department of Economic and Social Affairs, United Nations, New York, 1972.

[13] Purushotham, A., "Utilization of Bamboo," *J. Timber and Dry Preservatives Association of India,* Vol. 9, 1963, pp. 2-19.

[14] Coutts, R. S. P., "Sticks and Stones," *Forest Products News Letter*, CSIRO Division of Chemical and Wood Technology (Australia), Vol. 2, No. 1, Jan. 1988, pp. 1-4.

[15] Suschland, O., and Woodson, G. E., "Fibre Board Manufacturing Practices in the United States," *United States Dept. of Agriculture, Forest Service, Agriculture Handbook*, No. 640, 1986, 263 pp.

[16] Pederson, N., "Commercial Development of Alternatives to Asbestos Sheet Products Based on Short Fibres," *Fibrous Concrete*, Proceedings of the Symposium on Fibrous Concrete in London, Apr. 1980, The Concrete Society, Concrete International 1980, The Construction Press, Lancaster, London and New York, 1980, pp. 189-193.

[17] CSIRO, "New—A Wood Fibre Cement Building Board," *CSIRO Industrial Research News* 146, Australia, May 1981.

[18] Coutts, R. S. P., "Fibre-Matrix Interface in Air Cured Wood-Pulp Fibre-Cement Composites," *Journal of Materials Science Letters*, Vol. 6, pp. 140-142.

[19] Akers, S. A. S., and Studinka, J. B., "Ageing Behaviour of Cellulose Fibre Cement Composites in Natural Weathering and Accelerated Tests," *International Journal of Cement Composites and Lightweight Concrete*, Vol. 11, No. 2, 1989, pp.93-97.

[20] Bentur, A., and Akers, S. A. S., "The Microstructure and Ageing of Cellulose Fibre Reinforced Cement Composites Cured in a Normal Environment," *International Journal of Cement Composites and Lightweight Concrete,* Vol. 11, No. 2, 1989, pp. 99-109.

[21] Tait, R. B., and Akers, S. A. S., "Micromechanical Studies of Fresh and Weathered Fibre Cement Composites, Part 2: Wet Testing," *International Journal of Cement Composites and Lightweight Concrete*, Vol. 11, No. 2, 1989, pp. 125-131.

[22] Afa Austin Waifielate Bolarinma Oluseun Abiola (2008). "Mechanical Property Evaluation of Coconut Fibre". *Thesis Master's Degree (ISRN: BTH-AMT-EX—2008/D05—SE),* Department of Mechanical Engineering, Blekinge Institute of Technology, Kariskrone, Sweden.

[23] Asasutjarit, C., Hirunlabh, J., Khedari, J., Charoenvai, S., Zeghmati, B., and Shin, U. C. (2007). "Development of coconut coir-based lightweight cement board." *Construction and Building Materials*, 21(2), 277-288.

[24] Baruah, P., and Talukdar, S. (2007). "A comparative study of compressive, flexural, tensile and shear strength of concrete with fibres of different origins." *Indian Concrete Journal*, 81(7), 17-24. Baylor University.

[25] Flower, P. A., Hughes, J.M. and Melias, R. (2006). "Review Bio Composites: Technology, Environmental Credentials and Market Forces." *Journal f the Science of Food and Agriculure,* 86: 1781-1789.

[26] Ramakrishna, G., and Sundararajan, T. (2005a). "Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar." *Cement and Concrete Composites*, 27(5), 575-582.

[27] Ramakrishna, G., and Sundararajan, T. (2005b). "Impact strength of a few natural fibre reinforced cement mortar slabs: A comparative study." *Cement and Concrete Composites*, 27(5), 547-553.

[28] Rao, K. M. M., and Rao, K. M. (2007). "Extraction and tensile properties of natural fibres: Vakka, date and bamboo." *Composite Structures*, 77(3), 288-295.

[29] Li, Z., Wang, L., and Wang, X. (2007). "Cement composites reinforced with surface modified coir fibres." Journal of Composite Materials, 41(12), 1445-1457.

[30] Sivaraja, M., and Kandasamy, S. (2008). "Characterization of concrete composites for energy absorption." Journal of Reinforced Plastics and Composites, 27(2), 135-144.

Tara Sen, Assistant Professor in the department of Civil Engineering, at National Institute of Technology(NIT), Agartala, Barjala, District-West Tripura, State-Tripura, India

H. N. Jagannatha Reddy is Professor in the department of Civil Engineering, at Bangalore Institute of Technology, K.R.Road, Bangalore,India