CHARACTERISTIC STUDY OF NATURAL FIBRE-REINFORCED COMPOSITE MATERIAL

N.Nandakumar [1], M.Arularasu [2],

[1]*Asst. Professor of Mech. Engg., Government College of Technology, Coimbatore, India*
[2]*Principal, Thanthai Periyar Government Institute of Technology, Vellore, India*

ABSTRACT

World-over there is a radical increasing demand for sustainable green material concepts and practices for raw materials which can work towards reducing the challenging environmental impact. This paper presents the research study and development of natural fibre reinforced composite board (NFCB) and its potentials over coconut coir cement boards. These boards were made from natural fibres including coconut coir, and sugarcane waste fibres mixed with binding mixture (lime+ pozzolans+ gypsum+ animal dung) water and chemicals such as borax and magnesium chloride. NFCB is made by forming the binder-fibre mixture into mats and pressing them to the desired thickness ranging from 8 mm to 25 mm at 160 degree and 190 bar pressure. The prototype was produced at three ratios 1:1:1, 1:2:1 and 2:1:2 (binding mixture: fibre: water+1.5% chemicals) then the optimum mixture ratio was found to be 2:1:2.the physical, chemical and thermal properties of the specimen were determined after 20 days of hydration. The initial testing was done for tensile strength, modulus of elasticity and ruptures which is more efficient than normal ply woods.

Keyword: - *Matrix, Dispersed phase, Natural fibres, Modulus of elasticity, Binding Mixture, Compression strength,*

1. INTRODUCTION

Our modern technologies now a day requires materials with unusual combinations of properties which cannot be met by conventional metal alloys, ceramics and polymeric materials. This formidable combination of characteristics can be satisfied by Natural fibres composite boards. Natural fibres are generally inexpensive, bio-degradable, renewable and non-toxic materials which can be used as reinforcement in manufacturing composite boards. They are complex and three-dimensional polymer composites, which are made up of cellulose like pectin, hemi-cellulose and lignin. Among the various natural fibres, coconut fibre has low cost, low density, non- abrasive, non-toxic, high filling levels resulting in high stiffness, good thermal and acoustic properties, good calorific value and enhanced energy recovery. The coconut fibres can be used instead of carbon and glass fibres which has comparable properties. Many composite materials are composed of just two phases; one is termed the matrix, which is continuous and surrounds the other phase, often called the dispersed phase. The properties of composites are a function of the properties of the constituent phases, their relative amounts, and the geometry of the dispersed phase. ‘‘Dispersed phase geometry’’ is defined as the shape of the particles and the particle size, distribution, and orientation. The three major types of composites are,

- Particle reinforced
- Fiber reinforced and
- Structural composites.

Natural fiber boards are usually fiber reinforced in which the dispersed phase has the geometry of a fiber (i.e., a large length-to diameter ratio).The major goals of fiber reinforced composites often include high strength and stiffness on a weight basis. These characteristics are expressed in terms of specific strength and specific modulus parameters, which correspond, respectively, to the ratios of tensile strength to specific gravity and modulus of elasticity to specific gravity. Fiber-reinforced composites with exceptionally high specific strengths and moduli have been produced that utilize low-density fiber and matrix materials. In this paper, the coconut coir along with sugarcane waste fiber is used for reinforcement and coconut shell powder is used as the main matrix agent.

NFCB resists contraction/ expansion due to temperature variations and does not absorb water or moisture. It is termite / insect & fire resistant due to presence of borax and magnesium chloride. The strength of Natural Fiber Boards (NFB) depends on the rate of adhesion between fiber and matrix which plays a major role in controlling processing temperature and water absorption properties of the fiber. For increasing the interfacial adhesion; a binding mixture containing Pozzolans, lime, gypsum, cow dung and certain chemicals is employed here. This mixture eliminates the usage of Portland cement which involves high emission of CO2 and other greenhouse gases.

2. PROBLEMS WITH PORTLAND CEMENT

The manufacturing of Portland cement is not only highly energy intensive but also a significant contributor of the greenhouse gases. The relative damage index of different GHG is given below, with CO_2 taken as one

a) CO_2 ---------------------1x
b) Methane ---------------- 20x
c) Nitrous oxides --------200 x
d) Fluorine---------------- 15000 x

The total CO_2 emissions per tons of cement can range from about 1.1 ton of CO_2 from the wet processing plants to about 0.8 tons from a plant with Pre-calcinators. About half of the CO_2 emissions are due to the Calcinations of limestone and the other half are due to the combustion of fossil fuels. According to world energy outlook 1995, issued by the International Energy Authority (IEA), the worldwide CO_2 emissions from all sources were 21.6 billion tons. Thus, the worldwide cement production accounts for almost 7 percent of the total world CO_2 emissions shown in table 2.1

Table 2.1 World-wide Cement Production and C02 Emissions

Year	Cement Production, billion tons	Total CO_2Emissions, billion tons	CO_2 Contribution by cement industry, %
1995	1.4	21.6	7
2010	1.9	28-30	7

Thus, for reducing the emission of GHG alternative for Portland cement should be suggested for employing in NFB production. Instead of cement POZZOLANS can be used for raising the strength of the board and to attain desirable properties. The production and utilization is shown in table 2.2.

Table 2.2 Pozzolan Production and Utilization in 2011

Country	Production (million tons)	Utilization instead of Concrete (%)
China	>600	>15
India	>110	15
U.S.A	>60	10
Russia	60	5
Germany	30	12
U.K	10	10

2.1 Pozzolan characteristics

Pozzolan is an amorphous or glassy alumino- silicate which reacts with hydroxides formed in the matrix agent in composites and converts into sulphates thereby increasing the strength of the board. Among different types of pozzolans VCAS micron HS type is widely used as it has low water demand, fine particle size (325 meshes), higher reactivity, raising strength, lowering permeability, lowering heat of hydration and increases durability. Pozzolan reaction has four major components involved,

a. Calcium tri-silicate (C3S)
b. Calcium di-silicate (C2S)
c. Calcium aluminate (C3A)and
d. Ferrite phase (C4AF).

Pozzolans have an important role to reduce the net greenhouse gas emissions (GHG) and energy consumption for a cubic yard of concrete. For every ton of cement replaced by VCAS pozzolans, there is a net reduction of about 1 ton of CO_2 emissions. In addition, the heat saved is 4.29 million BTU's/ton, which would heat the average home for more than a week every ton VCAS used saves 1.5 tons of virgin raw materials needed to make a ton of cement.

3. NFCB COMPOSITIONS

The three different ratios of compositions used for manufacturing NFCB are (binding mixture, fibre, water, +1.5% chemicals)

- 1:1:1
- 1:2:1 (Fiber specimen)
- 2:1:2. (Control Specimen)

Among the above, the optimum mixture is 2:1:2. Based on it, the weight of different constituents is given below. The chemicals employed in the paper for developing necessary properties are

- Borax,
- Boric acid,
- Titanium di-oxide,
- Magnesium chloride

Table 3.1 NFCB Composition

S.NO	TYPE OF MIXTURE	NAME	WEIGHT(gm)
1.	BINDING MIXTURE	Coconut shell powder	100
		Pozzolan	70
		Water	150
		Lime	30
		Gypsum	30
		Cow dung	20
2.	FIBER	Coconut fiber	200
3.	CHEMICALS	Water	250
		Borax	40
		Boric acid	40
		Magnesium chloride	35
		Titanium di oxide	35

3.1 Binding mixture

Borax is the refined form of natural sodium borate. Composed of boric oxide (B_2O_3), sodium oxide, and water, it is a mild, alkaline salt, white and crystalline, with excellent buffering and fluxing properties. Borax is incorporated in many aqueous systems requiring corrosion inhibition. It is part of the starch adhesive formulation for corrugated paper and paperboard, and is a peptizing agent in the manufacture of casein-based and dextrin-based adhesives. It greatly improves the tack and green strength of the adhesive by cross linking conjugated hydroxyl groups. Borax is used for making the board flame retardant by reacting with the cellulosic materials of coconut coir. Thus, it improves the corrosion resistance, flame retarding nature and increasing the adhesiveness between matrix and coir. Also on mixing boric acid with mixture the board is made resistant to insect as well as termites. This is because boric acid and borax preservative itself is highly toxic to decay fungi and termite attack.

4. EXPERIMENTAL WORK

The major processes involved in making NFCB are,

- Decortications
- Blending
- Pressing
- Trimming

Dry coconut shell powder was added to a mixing bowl containing water according to the mix design given in table3.1. The coir fibres were beaten for about 5 minutes; they were then dispersed in water for an extra minute before being added to the binding mixture and water. This was mixed thoroughly again with a double blade mixer at minimum speed for about 5 minutes. Sugarcane waste fibres were also dispersed in water. During mixing, a perforated stainless steel plate with filter paper on was placed inside the casting mould and the vacuum pump was switched on to vacuum the chamber for about 5 minutes and then switched off. Then, after careful mixing the slurry was poured into the mould and the pump was switched on again.

This time the perforated plate with filter paper on retains blending mixture with fibre particles while the excess water is drained off through suction by the pump. After 8-15 minutes when water is drained, a fibre cement sheet is formed. It is notable that the higher fibre content slurries tend to take longer to drain off the water. When the water is drained off the pump is switched off again and a weight of about 10kg is uniformly applied to compact the paste inside the mould while the pump is switched on again. This lasts for about 5 minutes to drain the remaining excess water so as to form a fibre blending mixture sheet paste that is not too wet. Then the specimen is remoulded and kept in an about 95 ± 5 percent RH and 20 ± 2 °C environment to cure.

5. CHARACTERISTIC ANALYSIS

5.1 Flexural Test

Flexural test was carried out at 7 and 21 days applying the load with a constant rate of deflection, driving at a speed of 20 m. The set up includes a specimen (Fiber sheet) measuring about 184mm x 82mm x 9mm thick.

For a rectangular specimen under a load in a three-point bending setup is,

$$\sigma = \frac{3FL}{2bd^2}$$

Where,'F' is force at the fracture point, 'L' is length of the support span, 'b' is width and 'd' is thickness of the specimen.

5.2 Moisture movement

Moisture movement is the linear variation in length and width of test specimen, with change in moisture content. This test is used to determine the serviceability of products in areas of high humidity and exposure to moisture. Each specimen was conditioned to practical equilibrium at a relative humidity of 30 ± 2 % and a temperature of 20 ± 2°C. Practical equilibrium is defined as the state of time change in weight where, for practical purposes, the specimen is neither gaining nor losing moisture content more than 0.1 wt. % in a 24-h period.

The length of each specimen was measured using a micrometre with the accuracy of 0.01 mm. Then the specimens were conditioned to practical equilibrium at a relative humidity of 95 ± 5 % and a temperature of 20 ± 2°C. The lengths of the specimens were measured again. The linear change in moisture content is the percentage change in length based on the length at relative humidity change of 30 to 90 that is,

$$\text{Linear change (\%)} = \frac{\text{length at 90\% - length at 30\%}}{\text{Length at 30\%}} \times 100$$

5.3 Water absorption

Water absorption test is done to determine the tendency of a product to absorb water and sometimes determine uniformity of the product. The increase in mass of the test specimen expressed as a percentage of its dry mass after immersion in water for a specified period of time is determined.. Each specimen was dried to constant weight in a ventilated oven at a temperature of 90 ± 2°C and cooled to room temperature in desiccators before being weighed. Then the specimens were submerged for 48 ± 8 h in clean water at 23 ± 3°C. Each specimen was then removed from the water, wiped with a damp cloth, and weighed. That is the water absorption percentage is

$$(Ws-Wd)/Wd \times 100$$

Where, Ws is weight of saturated specimen in grams and Wd is weight of dry specimen in grams.

5.4 Moisture content

The percentage of moisture content of the fiber-cement product when conditioned at 50 ± 5 % RH and a temperature of 23 ± 2°C were determined. The test specimen from the flexural test was used for this test. After equilibrium conditioning, each specimen is weighed (w). Each specimen is then dried to constant mass in a circulated oven at a temperature of 90 ± 2°C and cooled to room temperature in a desiccators and the final mass when oven-dried (F) is recorded. Moisture content percent is given by,

$$M= 100 \times (W- F) /F$$

6. TEST RESULTS AND DISCUSSION

6.1 Flexural results and analysis

The results of the tests are shown in the graphs of figure 2 for the coir and sugarcane fibres specimens. This results show that as expected the modulus of elasticity of specimens are less than the control specimen and with increasing fibre content, the maximum flexural strength is increased. Figure 2 shows that as expected, the fracture deflection of the specimens with fibres are increased profoundly (to over twice of that for the control specimen).

The fibres change the fracture mechanism from brittle in control specimen, to ductile behaviour in fibre specimen. This is due to the fibres bridging effect following the initial micro crack appearance. The figure shows that fibres contribute to sustaining of the flexural stresses right from the beginning of the loading. This is clear from the lower gradients of the curves at the beginning and the end of loading; unlike the control specimen (the dotted line in the graph) they do not have sudden brittle fracture

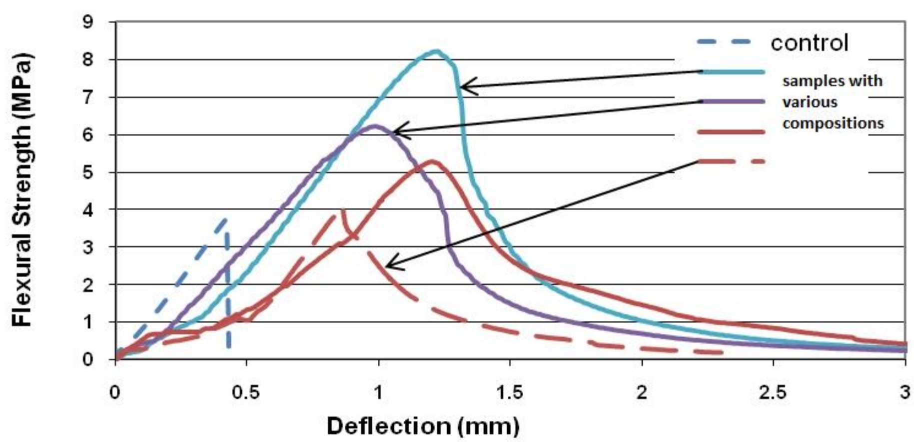

Figure 6.1 Flexural analysis

6.2 Moisture Movement results and analysis

The results of the moisture movement are shown in figure 6.2. It should be noted that due to limitation of precession of the measuring equipment of 0.01 mm, the results are presented in the range of 0, 0.14 and 0.24 percent. Although the results show minimal expansion due to moisture movement but in general increasing fibre content, leads to elongation of the length of specimens up to 0.25% which is however insignificant. This can be due to two main reasons; the first is due to the orientation of the fibres in the slurry mix. In pouring the slurry in the mould, some fibres may stand in vertical or incline position. Since the shapes of fibres are laminar, the vertical oriented fibred will cause the apparent minute elongation on the specimens. The second reason is due to moisture. As cellulose fibres have pores in their structures in case of moisture absorption the volumetric increase will be in the thickness direction and hence their length elongation cannot be significant.

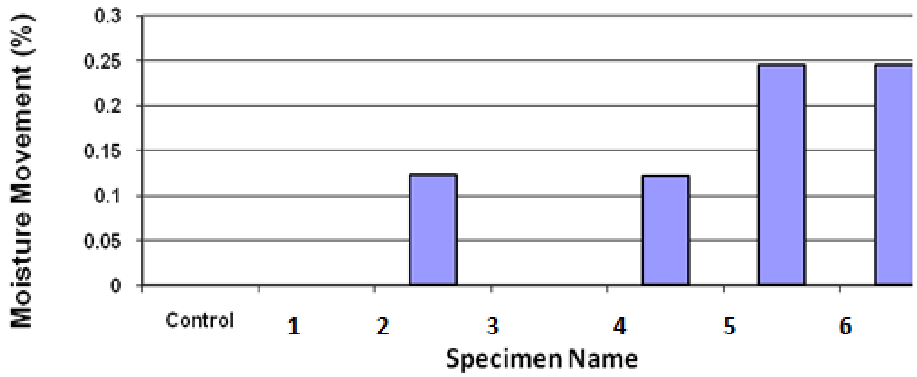

Figure 6.2 Moisture analysis

6.3 Water absorption results and analysis

The fig. 6.3 given below shows the results of water absorption. As it can be seen the water absorption of the NFBs do not follow a general trend but the increasing fiber content, increases the water absorption slightly when compared to the control specimen. This can be due to the orientation of the fibres in the cement matrix during the manufacturing of the fiber cement sheets which caused increased porosity of the specimen as the vacuum system might not have been efficiently removing the air between the fibres and the cement matrix. Increasing the time or suction power of the vacuum may reduce the porosity and the water absorption

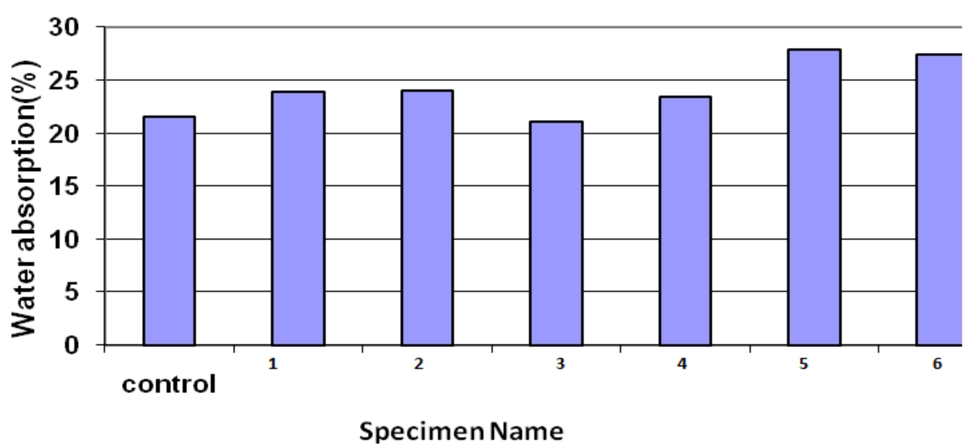

Figure 6.3 Water absorption analysis

6.4 Moisture content results and analysis

The moisture content values are shown in below figure. As expected the results show that fibres specimen have higher moisture content than the control specimen with less fibres. In general, coir and sugarcane fibres are hydrophilic and show typically about 10 percent weight increase in moisture content. However, the coconut shell powder and binding mixture paste matrix limits the moisture absorption of the fibres and reduces the moisture content increase to 2.5 to 3.2 percent only. (i.e. much closer to cement paste values). The manufactures of NFB usually spray a resin on the surfaces of the products to prevent the ambient moisture content to penetrate.

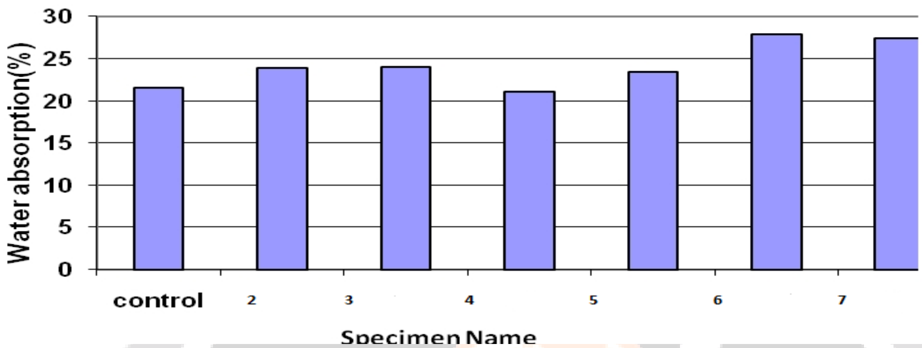

Figure 8.4 Moisture content analysis

7. CONCLUSION

Based on the research findings and discussion presented, the following conclusions are drawn. Natural fibres have beneficial effect on physical and mechanical characteristics of NFCBs. The flexural strength, energy absorption, moisture movement and water absorption of the board increases with increasing fibre content. The flexural strength enhancement varies depending on the type and the amount of fibres used. The fibre contents and types affect the flexural behavior and fracture mechanism of composite sheets significantly. The 2:1:2 (binding mixture: fibre: water+1.5% chemicals) specimen achieved the best results of flexural and toughness compared to other specimens. The coconut shell powder was more homogenously dispersed in the cement matrix and had better bonding and higher contact surfaces within the matrix and fibre.

NFCB manufacturing process gives it a natural, smooth; glossy finish on both sides and so can be used without surface treatment. It can also be painted, polished or laminated. The board has the lowest consumption rating per square foot, on paints and varnishes. It has both vertical and horizontal load bearing strengths and best compression strength ratios. It has high degrees of surface abrasion resistance and does not flake-off dust as in ordinary particle boards and asbestos. NFCB resists contraction/ expansion due to temperature variations and does not absorb water or moisture. It is termite / insect resistant due to presence of borax and magnesium chloride. Also have high fire retardant properties. NFCB Has both Vertical and Horizontal Load Bearing Strengths. The Best Compression / Strength Ratios among Phenol- Bonded Boards.

8. REFERENCES.

[1] Negro, C., Blanco, A., San Pio, I., and Tijero, J. (2006). "Methodology for Flocculent Selection in Fiber Cement manufacture", Cement and Concrete Composite, 28(1), 90-96.
[2] Pehanich, J. L., Blankenhorn, P. R., and Silsbee, M. R. (2004). "Wood Fiber Surface Treatment Level Effects on Selected Mechanical Properties of Wood fiber Cement Composites", Cement and Concrete Research, 34(1), 59-56.
[3] Savastano, H. P., Warden, P. G. and Coutts, R. S. P. (2003). "Potentials of Alternative Fiber Cements as Building Materials for Developing Areas", Cement and Concrete Composites, 25(6), 585-592.
[4] Soroushian, P., Marikunte, S., and Won, J. (1994). "Wood Fiber Reinforced cement composites Under Wetting Drying and Freezing Thaw Cycles", Civil Engineering Journal Material, 6(4), 595-611.
[5] Agarwal, B. D. and L. J. Broutman, Analysis and Performance of Fiber Composites, 2nd edition, John Wiley & Sons, New York, 1990.

[6] ASTM. 1981. Standard method of accelerated laboratory test of natural decay resistance of wood. ASTM D 2017-71 (Reapproved 1978). Pp. 639-645 in Annual Book of American sting and Materials Standards, Part 22. Philadelphia

[7] BAKSHI, B.K PURI, Y.N. & KHAN, S.N. 1967. Accelerated laboratory investigation on durability of wood. Final Technical Report. Forest Research Institute and Colleges, Dehra Dun.

[8] ASTM C1185-08. "Standard Test Methods for Sampling and Testing Non Asbestos Fiber- Cement Flat Sheet, Roofing and Siding Shingles, and Clapboards". ASTM International, West Conshohocken, PA.

[9] Banfill, G., Starrs, G., Derruau, G., McCarter, J., and Chrisp, M. (2006). "Rheology of low Carbon Fibers Cement mortar", Cement and Concrete Composites, 28(9), 773-780.

[10] BS EC 12467 (2007). "Fiber-cement flat sheets. Product specification and test methods"British-Adopted European Standard / 13-Dec-2004 / ISBN: 0580450481.

[11] Coutts, R. S. P. (2005). "A review of Australian research into natural fiber cement composites", Cement & Concrete Composites, 27,518-526.

[12] Ganjian, E., Khorami, M., and Sadeghi-pouya, H. (2008). "Application of Kraft and acrylic fibres to replace asbestos in composite cement sheets", 11th International Inorganic - Bonded Fiber Composites Conference, Madrid, Spain, Nov 2008, 52-61.

[13] Juarez, C., Alejandro, D., Pedro, V., and Gerardo, F. (2007). "Performance of Agave Lecheguilla Natural Fiber in Portland Cement Composites Exposed to Severe Environmental Conditions", Building and Environment, 42 (3), pp 1151-1157.

[14] Khorrami, M. Ganjian, E., and Khalili, M. (2008). "Improvement of characteristics in cement composite sheet with agriculture waste fiber", International Conference on Concrete Construction, Excellence in concrete construction through innovation, Kingston University, London, UK, 567-575, 9 -10th September 2008.

[15] Silva Flavio de Andrade, FilhoRomildo Dias Toledo, Filho Joao de Almeida Melo, Fairbairn Eduardo de Moraesrego. Physical and mechanical properties of durable sisal fiber–cement composites. Construct Build Mater 2010; 24: 777–85

[16] Perlman Hob, Ismail H, Bahrain A. 'A comparison of the mechanical properties of rice husk powder filed polypropylene composites with talc filled polypropylene composites.' Poly test 2002; 21 (7): 833 – 9.

[17] Mohanty AK, Rout J, Misra M, Tripalty SS, Nayak SK. Novel Eco-Friendly Biodegradable Coir-Polyester Amide Biocomposites:Fabrication and Properties Evaluation. Polymer Composites 2001;22(6):770–8.

[18] Sarkar BK, Ray D, Bose NR. Impact Fatigue Behaviour of Vinylester resin matrix composites reinforced with alkali treated jute fibres. Composites Part A2002;33:233–41.

[19] Canche´-Escamilla G, et al. Flexural, impact and compressive properties of a rigid-thermoplastic matrix/cellulose fibre reinforced composites. Composites Part A2002;33(4):539–49.