Manufacturing and Material Specification of Natural Epoxy Composite

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***Abstract*: Lately, there has been a quick improvement in exploration in the normal fiber composite sector. the advantages of these materials stood out from others, for instance, produced fiber composites, including low regular impact and insignificant exertion and reinforce their potential over a broad assortment of usage. Much effort has gone into extending their mechanical execution to widen the limits and usages of this get-together of materials. This paper is planned to give the way toward extricating fiber through concoction process with shifting centralization of NaOH and alongside different test, for example, SEM and EDS, X-RD and FTIR of separated fiber was done to contemplate the morphological structure, constituents, warm properties and so on this paper additionally clarifies the creation of epoxy based composite by hand layup process. At that point the different mechanical testing (elasticity, compressive quality and flexural quality) were done to decide its conduct under various states of stacking. Further dampness retention test was done to consider its dampness. This work is completed to assess the improvement and properties of characteristic of fiber strengthened biodegradable polymer composites. They are the materials that have the ability to completely degrade and good with the earth.**

***Keywords*: Natural Polymer, Natural Fiber, Epoxy Fiber**

1. Introduction

Today's composite material existed from the beginning of civic establishments. Back to 1500 BC, where individuals used to make mud dividers with bamboo as support, mud blocks and so forth. It was just restricted to clay composite. With the advance of human in 1970s the engineered fiber based composite product made. Most usually fiber was glass fiber and carbon fiber. With increment sought after boron and different materials likewise utilized for making composites which fulfils the need, all things considered, however then again it offers another test of non-biodegradability all of a sudden the scientists and businesses moved the concentration to normal fiber strengthened composite in view of its profile degradable nature. In spite of the fact that it is some way or another legitimate with the natural concern however needs quality when contrasted with engineered fiber. This restricts its utilization to non-auxiliary to semi basic applications. Additionally look into is requiring influencing it to fit for auxiliary application.

To advance the utilization of normal fiber The United Nation proclaimed 2009 as the time of characteristic fiber. This has demonstrated an extensive interest in this area. Till date the gainful utilization of regular fiber for making composite is undermine facilitate consolation is important to convey the utilization of common fiber to its maximum capacity.

1.1 Natural Fiber

Natural fiber has been used as reinforcing materials for over 3000 years. Starting from ancient civilization, people used to make ceramic bricks, mud walls with bamboo sticks as reinforcing material though it was limited to ceramic composite but now its application move on to polymer matrix composite. A single fiber of all plant based natural fibers consists of several cells. These cells are formed out of crystalline micro fibrils based on cellulose, which are connected to a complete layer, by amorphous lignin and hemicellulose. Many of such cellulose-lignin / hemicellulose layers in one primary and three secondary cell walls stick together to a multilayer composite. These cell walls differ in their composition and in the orientation of the cellulose micro fibrils. These fibers are composed mainly of cellulose and some lignin and are sometimes called lingo-cellulosic fibers. Natural fibers are subdivided based on their origins, coming from plants, animals or minerals. All plant fibers contain cellulose as their major structural component, whereas animal fibers mainly consist of protein. Generally, plant or vegetable fibers are used to reinforce plastic. Plant fibers may include hairs (cotton, kapok), fiber sheaves of dicot plants or vessel sheaves of monocot plants, i.e. bast (flax, hemp, jute, and ramie) and hard fibers (sisal, henequen, and coir). The classification of natural fiber is shown in figure 1.1:

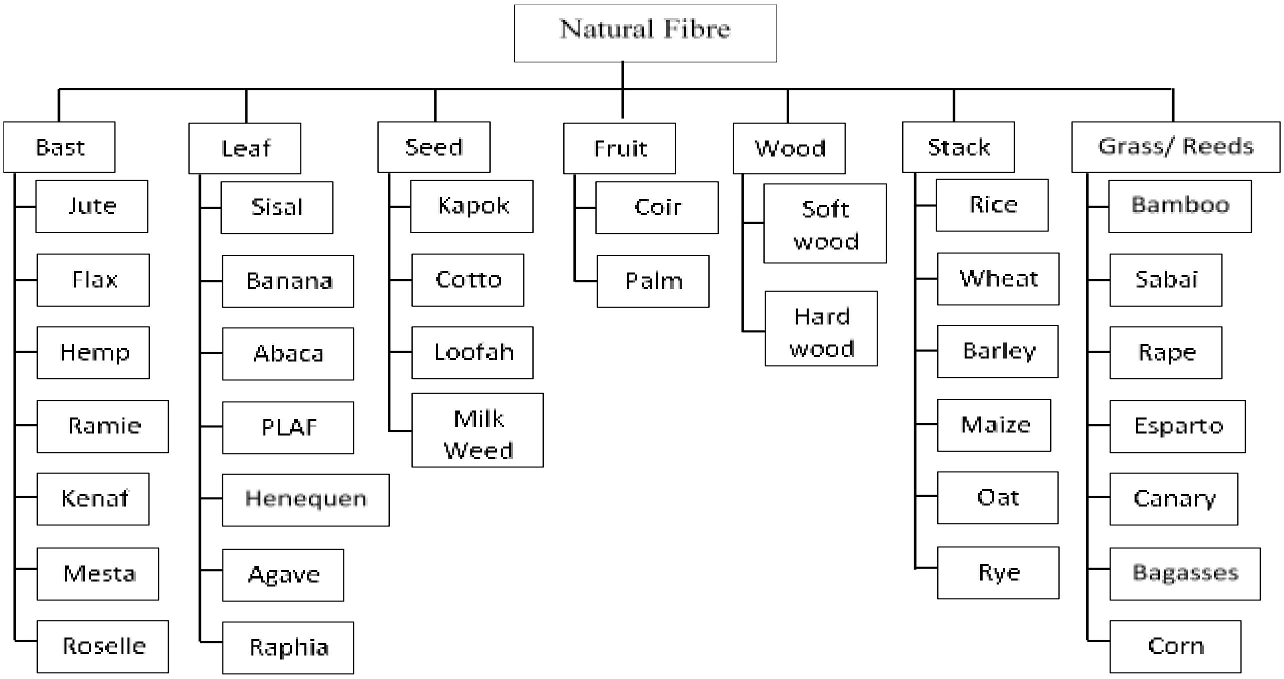

Figure 1.1 - Classification of Natural Fibers

1.2 Advantages of Natural Fibers

Natural fibers has following advantages:

1. Low specific weight which results in a higher specific strength and stiffness than glass.
2. It is a renewable resource wherein the production requires little energy and CO_2 is used while oxygen is given back to the environment
3. Production with low investment at low cost, which makes the material an interesting product for low wage countries
4. Friendly processing, no wear of tooling and no skin irritation
5. Thermal recycling is possible, where glass causes problems in combustion furnaces
6. Good thermal and acoustic insulating properties
7. Low emission of toxic fumes when subjected to heat and during incineration at the end of life

1.4 Drawbacks of Natural Fibers

Natural fibers has following disadvantages:

1. Lower strength properties, particularly its impact strength
2. Variable quality, depending on unpredictable influences such as weather
3. Moisture absorption, which causes swelling of the fibers
4. Restricted maximum processing temperature
5. Low durability but fiber treatment can improve this considerably
6. Poor fire resistance
7. Price can fluctuate by harvest results or agricultural politics

2. Natural Fiber Composites

Natural fiber composites, may in the future, become materials to replace synthetic fiber polymer composites. Natural fiber incorporated polymers have been very fashionable due to their flexibility, their lightness and the ease of fabrication of complicated shapes with economic saving. The quality and performance of plant fiber based composites can further be improved by adopting appropriate engineering techniques. In addition, these composites can easily substitute for conventional materials in several areas such as the automotive industry, building industry, consumer goods and sport goods. Many automotive and household components are produced using natural composites, mainly based on polyester and fiber like flax, hemp, pineapple, coir and sisal. The application of natural fiber composites in this industry is led by motives of price, weight reduction, and biodegradability.

2.1 Need for Natural Fiber Composites

The development of natural fiber composites has profited from the policy of a number of (Indian) governments to support the development of technical applications for renewable resources. Establishment of disposal methods for glass fiber reinforced plastics and their recycling laws are important contemporary subjects because many environmental problems have appeared. It is necessary to reduce environmental impacts such as global warming, which are generated by consumption of petroleum, a non-renewable resource. The driving forces of natural fiber composites are (i) cost reduction, (ii) weight reduction and (iii) marketing (application of renewable materials). The use of natural fiber reinforced polymer represents an attractive and suitable method for replacing. Natural fibers are low cost, renewable and high specific strength and its composites are used for fabricating some products such as furniture and architectural materials. Recently, they have gained widespread use in the automobile industry.

3. Materials and Experiments

The Fiber Extraction from Plant

Asian palm fibers (Palmyra fruit fiber) are extracted by mechanical and chemical process and the detailed step of the process is described below. The hemp fiber yarn was purchased from Forestry Hemp Bag Udhyog, Kathmandu, Nepal concerns related to civil infrastructure deterioration are not only limited to the economic cost of repair, maintenance and rehabilitation, but they also extend to social and environmental costs. It is generally meant that repeated repairs of civil infrastructure during their service life are absolutely unsustainable. Figure below explains it briefly.

Fig. 2 - Fruit Fiber

1. At first the ripe fruits are collected and then the blackish husk is removed. The seeds are separated from each other with fiber. The fibers from the seeds are collected with a sharp blade which contain yellow mesocarp. The mesocarp is washed off by water. Then the washed fiber is boiled with normal water at a temperature of 100^0C to remove gum like material from the fiber and finally dried in the sun. About 30g fiber can be collected from a fruit by hand.
2. Then alkalization of dried fiber was done at 4% NaOH solution at room temperature for 6 hours.
3. Bleaching operation is carried out to wash out pigments and other foreign particles from the cellulosic fiber Using 1.7 W/V% $NaClO_2$ at 50° C for 1 hour.
4. The hydrolyzed fiber is washed out with distilled water three times to neutralize it.

3.1 Alkali Treatment of Fiber

Alkalization: Alkalization is a chemical method for breaking the bond between various lignocellulose materials. Plant based natural fiber mainly contains cellulose, hemicellulose, lignin, wax and moisture. Each of them has different chemical resistance against NaOH. Since cellulose has less resistance against NaOH, it is able to break the bond between lignin and cellulose. When the hemicellulose is removed the interfibrillar region becomes less dense and less rigid leaving behind the high strength fiber. Treatment with NaOH leads to a decrease in spiral angle and increase in molecular orientation further the elastic modulus increases with increase in molecular orientation. The extent of alkalization depends upon the type of concentration of alkaline solution, Temperature, Time of treatment and tension of material as well as additives. Chemical tests were conducted with various NaOH concentrations of 4%, 6% and 8% Agave fibers. Alkali treatment did not affect the cellulose of the fiber but it resulted in the change of other chemical properties. Therefore, the alkali treated fiber has good adhesion property and improved strength.

3.2 Fabrication of Composite

5%, 7% & 10% of Palm fiber and Hemp fiber is added to epoxy matrix to fabricate composite with different content of fiber. Composite of different percentage of fiber was made by Hand Lay-up process. There are various methods of fabrication technologies are available these are

1. for continuous fibers
   - Hand lay-up methods
   - Compression moulding
   - Pultrusion process
   - Filament winding
2. for short fibers
   - Hand spray method
   - Transfer moulding
   - Injection moulding
   - Centrifugal casting
   - Continuous laminating

Out of above stated method considering the availability of fabrication technology we have chosen hand lay-up method for our fabrication.

3.3 Hand Lay-up Method

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats is cut as per the mold size and placed at the surface of mold after Perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperature is 24-48 hours. This method is mainly suitable for thermosetting polymer based composites. Hand lay-up method finds application in many areas like aircraft components, automotive parts, boat hulls, deck etc.

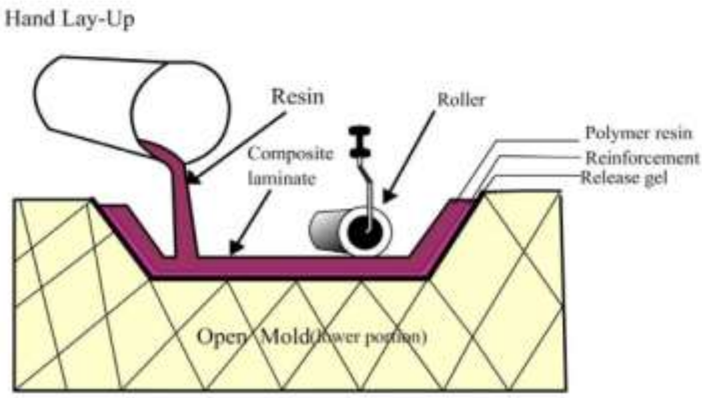

Figure 0.2 - Hand Lay-up Process

In this process first we prepared the mould with thermocol considering the finishing allowance. Then the mould was covered with Aluminum foil & the matrix and fiber mixture was poured in the mould, then for 24 hours it was kept for strengthening & curing. It was polished with grinder to get the smooth surface finish.

4. Results

Various tests like Tensile, Flexure, Hardness and Moisture absorption test has been performed on the collected and transformed specimens and the following results were obtainted:

4.1 Tensile test

It was observed that the specimen breaks at the middle without any necking formation. That is it has shown little deformation before undergoing fracture. This result is for 10%, 15% & 20% weight of agave fiber in the composite. Further with different percentage of fiber in the composite different result can be obtained. The data obtained from the test for various sample is given in table.

Weight % of Palm Fiber	Tensile Strength in N/mm2
5	12.9
7	12.7
10	15.8

Table 0.1 - Tensile Test Result for Samples

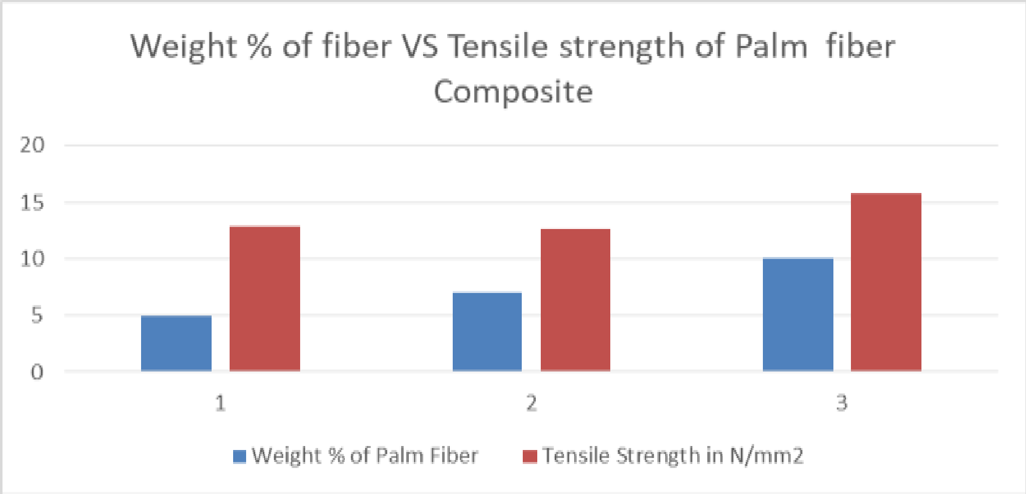

Figure 4.1 - Tensile Strength of Palm Fiber

Weight% of Hemp Fiber	**Tensile Strength in N/mm^2**
5	13.3
7	7.9
10	8.7

Table 0.2 - Tensile Test Result for Hamp Samples

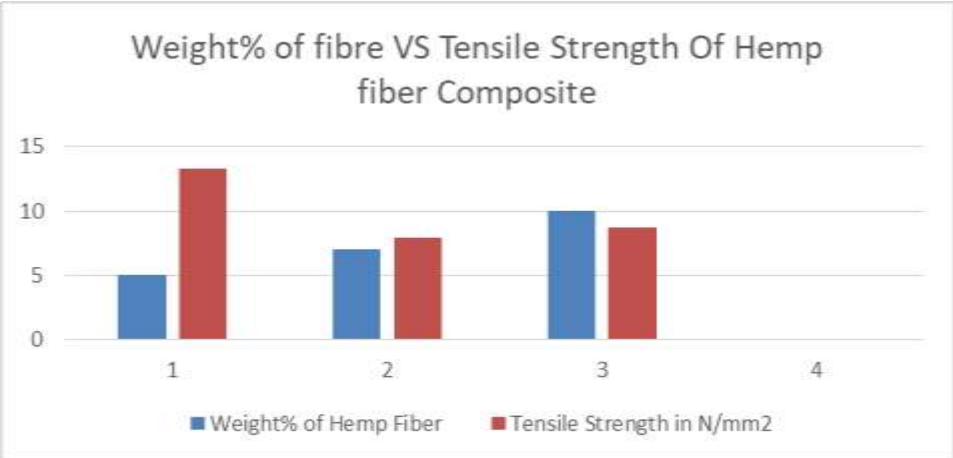

Figure 4.2 - Tensile Strength of Hemp Fiber

Weight% of Hybrid	**Tensile Strength in N/mm2**
5	12.8
7	9.9
10	14.7

Table 0.3 - Tensile Test Result for Hybrid Samples

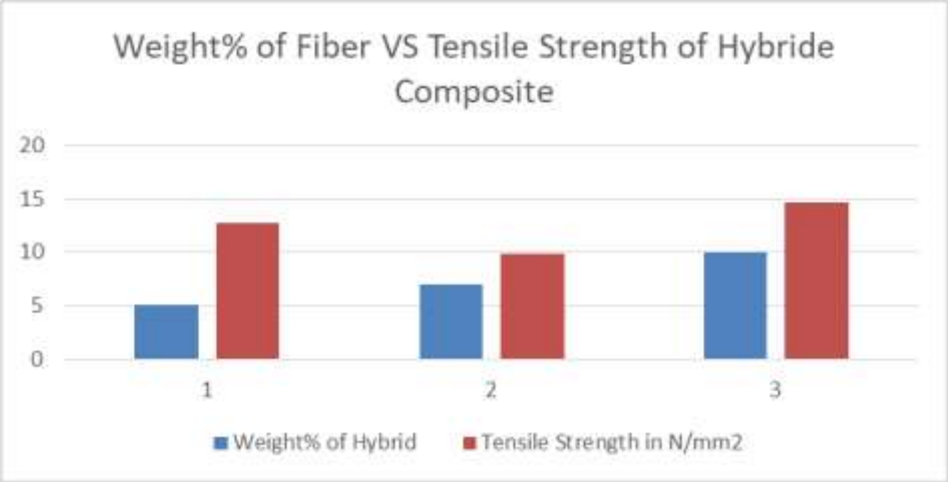

Figure 4.3 - Tensile Strength of Hybride

The graph between "Load and Deflection" & "Stress and Strain" for each sample is shown in figure Since there is no yielding reported the fracture seems to be brittle and show very less elongation.

Further, it is observed that the stress increases with increase in load and modulus of elasticity almost remains constant. at certain point where stress exceeds the modulus of elasticity the material undergoes failure. In the three samples it is observed that the material has flat breaking without any necking hence it seems to be brittle material and having very less tensile strength. Out of three samples it is observed that the sample having 5% fiber content has more strength then the sample having 7% and 10% fiber content.

4.2 Impact Test

The test specimen shows very little plastic deformation mostly flat surface was observed at the notch it absorbs very little amount of energy before fracture. The energy absorbed by the specimen found to be 6 J. This gives indication that this type of material only able to absorb small amount of energy. It shows the brittle behavior due to the strain aging effect.

Type of Composite	Impact Strength with 5% of Fiber in Joule	Impact Strength with 7% of Fiber in Joule	Impact Strength with 10% of Fiber in Joule
Palm	4	4	5
Hemp	4	4.5	5
Hybrid	4	4	6

Table 4.4 - Impact Strength of 5%,7% and 10% Fiber Composites

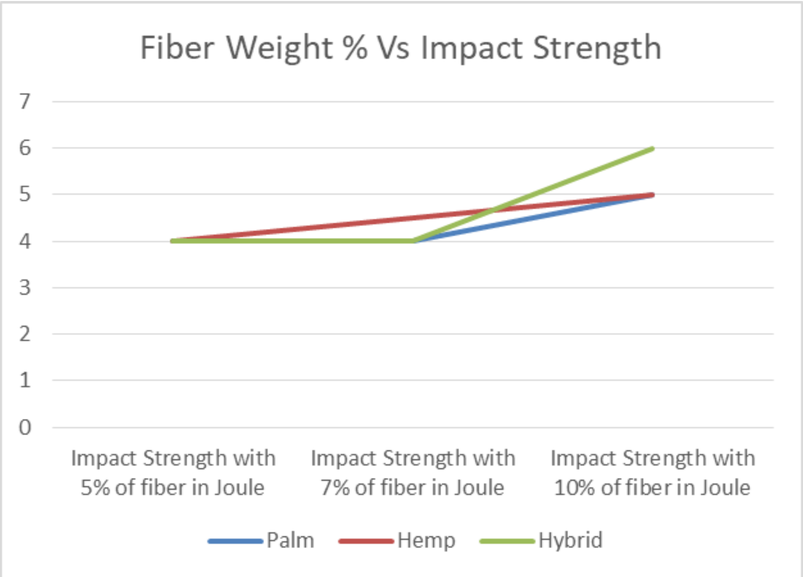

Figure 4.4 - Impact Strength of 5%, 7% and 10% Fiber Composites

4.3 Hardness of Specimen

The hardness result obtained from Brinell hardness tester of specification shown in below Table 4.4:

Weight % of Palm Fiber	Hardness No (BHN)
5	3.25
7	5.5
10	8

Table 4.4 - Brinell hardness Test for Palm Specimen

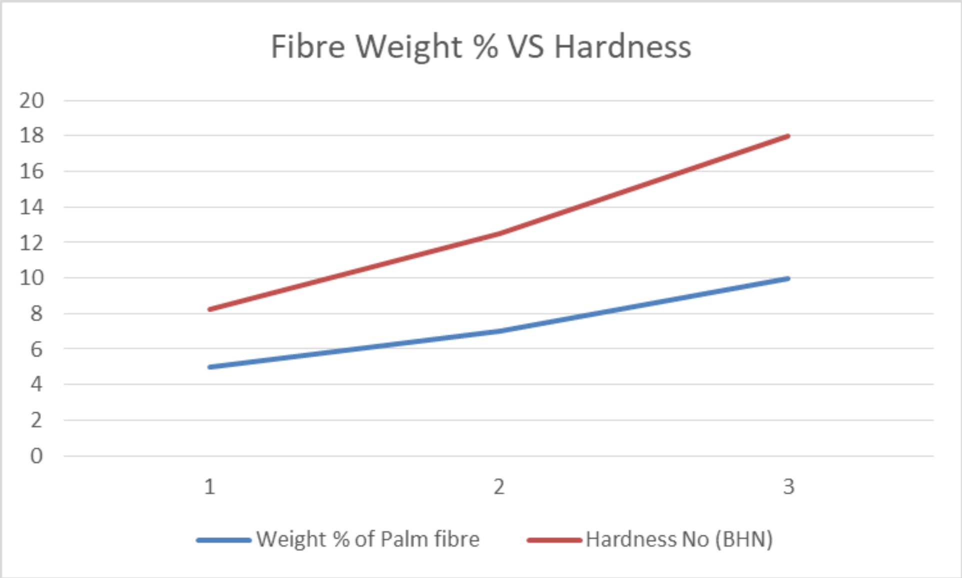

Figure 4.5 - Hardness of 5%,7% and 10% Palm Fiber Composites

Weight % of Hemp Fiber	Hardness No (BHN)
5	6.75
7	9
10	8

Table 4.6 - Brinell Hardness Test for Hemp Specimen

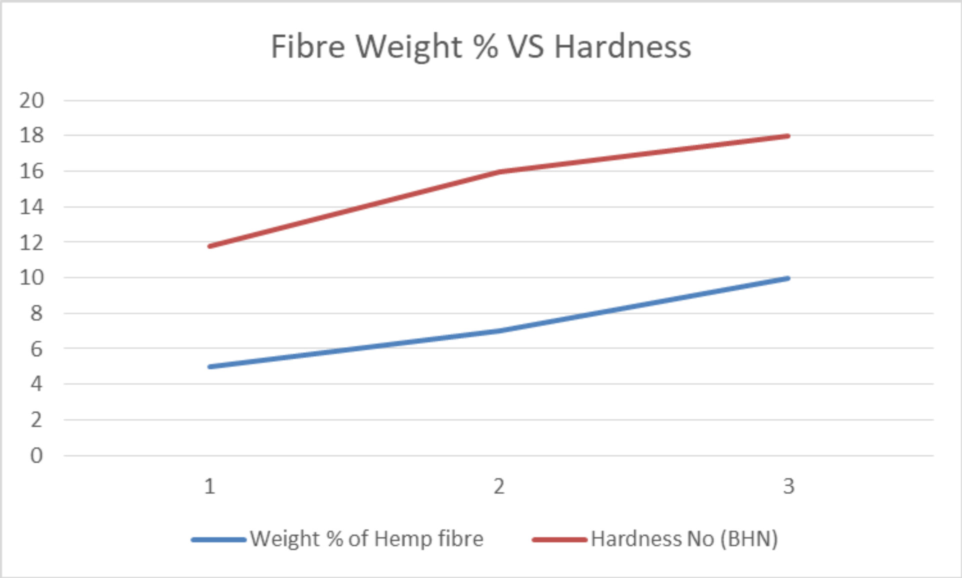

Figure 4.6 - Hardness of 5%,7% and 10% Hemp Fiber Composites

Weight % of Hybrid Fiber	Hardness No (BHN)
5	8.75
7	9
10	7

Table 0.7 - Brinell Hardness Test for Hybrid specimen

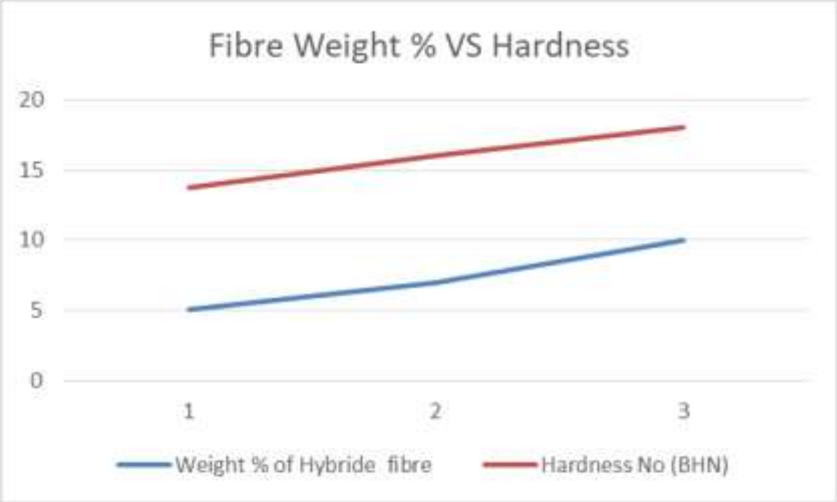

Figure 4.7 - Hardness of 5%,7% and 10% Hybrid Fiber Composites

From the above observation, it is concluded that the hardness of the sample specimen is dependent on the percentage content of fiber. It is observed that the composite having 5% fiber content has more hardness then 7 % and 10% fiber content. for different content of fiber the result will be different.

4.4 Moisture Absorption test of Specimen

The following table shows the percentage absorption of water for different sample at different time. The details are shown in Table 4.4:

S. No.	% of Fiber	W_i (gm)	Time (Hour)	W_f (gm)	% Absorption
01	5	2	24	2.2	10
02	7	2	24	2.3	15
03	10	2	24	2.5	25

Table 4.4 - Moisture Absorption of the specimen

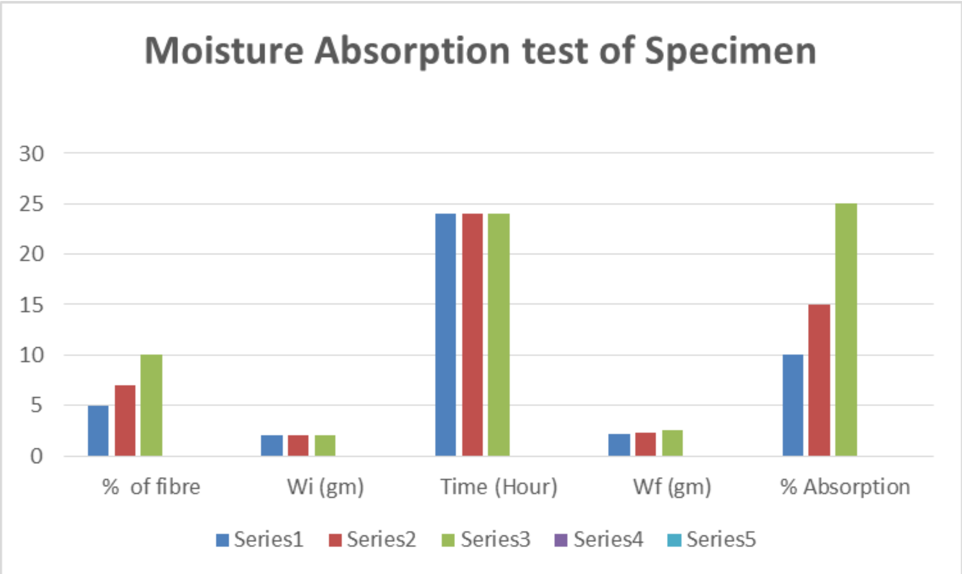

Figure 4.8 - Moisture Absorption Test of 5%, 7% and 10% Fiber Composites

The above observation show that the moisture absorption is function of time and fiber content of composite, it is observed that as the fiber content increases the moisture absorption of the composite increases.

5. Conclusion

In this undertaking work, distinctive weight level of Asian palm and hemp fiber have been oriented with epoxy in order to analyze their difference in mechanical and metallurgical properties. The study showed that the hardness and tensile strength increased invariably with increase the weight percentage of fiber from 5% to 10% in epoxy for both the fibers but with 7% weight percentage of fiber in the epoxy the hardness and tensile strength decreased a bit.

References:

[1] B. Zuccarello, R. Scaffaro Experimental analysis and micromechanical model of high performance renewable agave reinforced biocomposites
[2] Ashish Hulle, Pradyumkumar Kadole, and Pooja Katkar, Agave Americana leaf fibre
[3] A.A. Pérez-Fonseca, J.R. Robledo-Ortíz, D.E. Ramirez-Arreola, P. Ortega-Gudiño, D. Rodrigue, R. González-Núñez.Effect of hybridization on the physical and mechanical properties of high density polyethylene (pine/agave) composite
[4] Martin Hidalgo-Reyes, Magdaleno Caballero-Caballero, Luis Hector Hernandez-Gomez and Guillermo Urriolagoitia-Calderon. Chemical and merphologycal characterization of Agave agustifoliabegasses fibre
[5] Bledzki, A. K., Reihmane, S., & Gassan, J. (1996). Properties and modification methods for vegetable fibers for natural fiber composites. Journal of Applied Polymer Science, 59 (8), 1329–1336
[6] M. Jawaid, H.P.S. Abdul Khalil, Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review
[7] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres Progress in Polymer Science (Oxford), 24 (2), 221–274
[8] Reddy, N., & Yang, Y. (2005). Biofibers from agricultural byproducts for industrial applications. Trends in Biotechnology, 23(1), 22–27
[9] Han, J., & Rowell, R. (1997). Chemical composition of fibres. In R. Rowell, R. Young, & J. Rowell (Eds.), Paper and composites from agro-based resources (pp. 83–134). New York: CRC Lewis Publisher
[10] John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. Carbohydrate Polymers, 71 (3), 343–364
[11] Mohammed Khalifa, Altaf Hussain Bagawan, Experimental Investigation of Effect of Fibre Diameter on Tensile Properties of Jute: Banana Fibre (Hybrid) Reinforced Epoxy Composite
[12] P. Amuthakkannan, V. Manikandan, J.T. Winowlin Jappes, M. Uthayakumar.Effect of fibre length and fibre content on mechanical properties of short basalt fibre reinforced polymer matrix composite
[13] Law, K. N., & Jiang, X. (2001). Comparative papermaking properties of oil- empty fruit bunch. TAPPI Journal, 84 (1), 95
[14] Mohamad, H., Zin Zawawi, Z., & Abdul Halim, H. (1985). Potentials of oil byproducts as raw materials for agro-based industries. In National Symposium on Oil By-Products for Agro-Based Industries Kaulalumpur, Malaysia, pp. 7–15
[15] Khoo, K. C., & Lee, T. W. (1985). Sulphate pulping of the oil trunk. In National Symposium on Oil By-Products for Agro-Based Industries Kaulalumpur, Malaysia, pp. 57–66
[16] Reddy, N., & Yang, Y. (2005). Biofibers from agricultural byproducts for industrial applications. Trends in Biotechnology, 23 (1), 22–27
[17] Ibrahim, M. M., Dufresne, A., El-Zawawy, W. K., & Agblevor, F. A. (2010). Banana. fibers and microfibrils as lignocellulosic reinforcements in polymer composites. Carbohydrate Polymers, 81 (4), 811–819
[18] Rowell, R. M. (2008). Natural fibres: types and properties. In K. L. Pickering (Ed.), Properties and Performance of Natural-Fibre Composites. pp. 3–66. Cambridge England: Woodhead Publishing Limited
[19] Olesen, P. O., & Plackett, D. V. (1997). Perspective on the Performance of Natural Plant Fibres. pp. 1–7. Denmark: Royal Veterinary and Agricultural University
[20] Esfandiari, A. (2007). Mechanical properties of PP/Jute and glass fibers composites: The statistical investigation. Journal of Applied Sciences, 7 (24), 3943–3950
[21] Pickering K, Beckermann G, Alam S, Foreman N. Optimising industrial hemp fibre for composites. Composites Part A 2007; 38 (2), 461–8
[22] Bos HL, Van den Oever MJA, Peters O. Tensile and compressive properties of flax fibres for natural fibre reinforced composites. J Mater Sci 2002; 37 (8), 1683–92
[23] Charlet K, Baley C, Morvan C, Jernot JP, Gomina M, Breard J. Characteristics of Hermes flax fibres as a function of their location in the stem and properties of the derived unidirectional composites. Composites Part A 2007; 38 (8), 1912–21
[24] Shah DU, Porter D, Vollrath F. Can silk become an effective reinforcing fibre? A property comparison with flax and glass reinforced composites. Compos Sci Technol 2014; 101, 173–83
[25] Cheung HY, Ho MP, Lau KT, Cardona F, Hui D. Natural fibre-reinforced composites for bioengineering and environmental engineering applications. Composites Part B 2009; 40 (7), 655–63
[26] Efendy MGA, Pickering KL. Comparison of harakeke with hemp fibre as a potential reinforcement in composites. Composites Part A 2014; 67, 259–67
[27] Zhan M, Wool RP. Mechanical properties of chicken feather fibers. Polym Compos 2011;32 (6), 937–44
[28] Niu M, Liu X, Dai J, Hou W, Wei L, Xu B. Molecular structure and properties of wool fiber surface-grafted with nano-antibacterial materials. Spectrochim Acta Part A Mol Biomol Spectrosc 2012; 86, 289–93
[29] Rials, T. G., Wolcott, M. P., & Nassar, J. M. (2001). Interfacial contributions in lignocellulosic fiber-reinforced polyurethane composites. Journal of Applied Polymer Science, 80 (4), 546–555

[30] Gatenholm, P., Bertilsson, H., & Mathiasson, A. (1993). Effect of chemical composition of interphase on dispersion of cellulose fibers in polymers. I. PVC-coated cellulose in polystyrene. Journal of Applied Polymer Science, 49 (2), 197–208
[31] Ishak, Z. A. M., Aminullah, A., Ismail, H., & Rozman, H. D. (1998). Effect of silane-based coupling agents and acrylic acid based compatibilizers on mechanical properties of oil empty fruit bunch filled highdensity polyethylene composites. Journal of Applied Polymer Science, 68 (13), 2189–2203
[32] Sanadi AR, Caulfield DF, Jacobson RE. Agro-fiber thermoplastic composites. In: Paper and composites from agro-based resources. Boca Raton, FL: CRC; 1997. p. 377–401
[33] Dubois, P., Alexandre, M., Hindryckx, F., & Jerome, R. (1998). Polyolefinbased composites by polymerization-filling technique. Polymer Reviews, 38 (3), 511–565
[34] Jones, R. M. (1975). Mechanics of composite materials. New York: McGraw-Hill
[35] Nielsen, L. E., & Landel, R. F. (1994). Mechanical properties of polymers and composites. New York: Marcel Dekker
[36] Zhang, Y., Rodrigue, D., & AiÌˆt-Kadi, A. (2004a). Polyethylene–kevlar composite foams II: Mechanical properties. Cellular Polymers, 23 (2), 61–76
[37] Zhang, Y., Rodrigue, D., & AiÌˆt-Kadi, A. (2004b). Tensile properties of polymerization-filled kevlar pulp/polyethylene composites. Polymers and Polymer Composites, 12 (1), 1–15
[38] Amor IB, Rekik H, Kaddami H, Raihane M, Arous M, Kallel A. Effect of tree fiber orientation on electrical properties of tree fiber-reinforced polyester composites. J Compos Mater 2010; 44 (13), 1553–68
[39] Herrera-Franco PJ, Valadez-Gonzalez A. A study of the mechanical properties of short natural-fiber reinforced composites. Composites Part B 2005; 36 (8), 597–608
[40] Norman DA, Robertson RE. The effect of fiber orientation on the toughening of short fiber-reinforced polymers. J Appl Polym Sci 2003; 90 (10), 2740–51
[41] Joseph PV, Joseph K, Thomas S. Effect of processing variables on the mechanical properties of sisal-fiber-reinforced polypropylene composites. Compos Sci Technol 1999; 59 (11), 1625–40
[42] Brahim SB, Cheikh RB. Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite. Compos Sci Technol 2007; 67 (1), 140–7
[43] Baghaei B, Skrifvars M, Salehi M, Bashir T, Rissanen M, Nousiainen P. Novel aligned hemp fibre reinforcement for structural biocomposites: porosity, water absorption, mechanical performances and viscoelastic behaviour. Composites Part A 2014; 61, 1–12
[44] Business Communication Company, 2007
[45] Chen P, Lu C, Yu Q, Gao Y, Li J, Li X. Influence of fiber wettability on the interfacial adhesion of continuous fiber-reinforced PPESK composite. J Appl Polym Sci 2006; 102 (3), 2544–51
[46] Ragoubi M, Bienaimé D, Molina S, George B, Merlin A. Impact of corona treated hemp fibres onto mechanical properties of polypropylene composites made thereof. Ind Crops Prod 2010; 31 (2), 344–9
[47] Gassan J, Gutowski VS. Effects of corona discharge and UV treatment on the properties of jute-fibre epoxy composites. Compos Sci Technol 2000; 60 (15), 2857–63
[48] Wu XF, Dzenis YA. Droplet on a fiber: geometrical shape and contact angle. Acta Mech 2006; 185 (3–4), 215–25
[49] Bénard Q, Fois M, Grisel M. Roughness and fibre reinforcement effect onto wettability of composite surfaces. Appl Surf Sci 2007; 253 (10), 4753–8
[50] Sinha E, Panigrahi S. Effect of plasma treatment on structure, wettability of jute fiber and flexural strength of its composite. J Compos Mater 2009; 43 (17), 1791–802
[51] Liu ZT, Sun C, Liu ZW, Lu J. Adjustable wettability of methyl methacrylate modified ramie fiber. J Appl Polym Sci 2008; 109 (5), 2888–94
[52] Matthews FL, Rawlings RD. Composite materials: engineering and science. Cambridge, England: Woodhead Publishing; 1999
[53] Beckermann G. Performance of hemp-fibre reinforced polypropylene composite materials. PhD thesis. Hamilton, New Zealand: University of Waikato; 2007
[54] Sawpan MA, Pickering KL, Fernyhough A. Improvement of mechanical performance of industrial hemp fibre reinforced polylactide biocomposites. Composites Part A 2011; 42 (3), 310–9
[55] Hill CAS, Khalil HPS, Hale MD. A study of the potential of acetylation to improve the properties of plant fibres. Ind Crops Prod 1998; 8 (1), 53–63
[56] Joseph, S., & Thomas, S. (2008). Electrical properties of banana fiber-reinforced phenol formaldehyde composites. Journal of Applied Polymer Science, 109 (1), 256–263
[57] Rowell, R. M., Young, R. A., & Rowell, J. K. (1997). Processing of agro-based resources into pulp and paper. In R. M. Rowell (Ed.), Paper and composites from agro-based resources. Boca Raton, FL: Lewis Publishers/CRC Press
[58] Jacob, M., Francis, B., Thomas, S., & Varughese, K. T. (2006). Dynamical mechanical analysis of sisal/oil hybrid fiber-reinforced natural rubber composites. Polymer Composites, 27 (6), 671–680
[59] Jacob, M., Jose, S., Thomas, S., & Varughese, K. T. (2006). Stress relaxation and thermal analysis of hybrid biofiber reinforced rubber biocomposites. Journal of Reinforced Plastics and Composites, 25 (18), 1903–1917
[60] N. Saba, M. Jawaid, Othman Y. Alothman, M.T. Paridah. A review on dynamic mechanical properties of natural fibre reinforced polymer composites
[61] V. Pistor, F.G. Ornaghi, H.L. Ornaghi, A.J. Zattera, Dynamic mechanical characterization of epoxy/epoxycyclohexyl-POSS nanocomposites, Mater. Sci. Eng. A 532 (2012), 339–345

[62] H.L. Ornaghi, V. Pistor, A.J. Zattera, Effect of the epoxycyclohexyl polyhedral oligomeric silsesquioxane content on the dynamic fragility of an epoxy resin, J. Non-Cryst. Solids 358 (2012) 427–432
[63] N.T. Qazvini, N. Mohammadi, Dynamic mechanical analysis of segmental relaxation in unsaturated polyester resin networks: effect of styrene content, Polymer (Guildf) 46 (2005) 9088–9096
[64] Sreekala, M. S., George, J., Kumaran, M. G., & Thomas, S. (2002). The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil fibres. Composites Science and Technology, 62 (3), 339–353
[65] Sreekala, M. S., Thomas, S., & Groeninckx, G. (2005). Dynamic mechanical properties
[66] Madsen B, Thygesen A, Lilholt H. Plant fibre composites – porosity and stiffness. Compos Sci Technol 2009; 69 (7–8), 1057–69
[67] Madsen B, Lilholt H. Physical and mechanical properties of unidirectional plant fibre composites – an evaluation of the influence of porosity. Compos Sci Technol 2003; 63 (9), 1265–72
[68] Fu, S. Y., Xu, G., & Mai, Y. W. (2002). On the elastic modulus of hybrid particle/shortfiber/ polymer composites. Composites Part B: Engineering, 33 (4), 291–299
[69] Karger-Kocsis, J. (2000). Reinforced polymer blends. In D. R. Paul, & C. B. Bucknall (Eds.), Polymer blends (p. 395). New York: John Wiley & Sons
[70] Thwe, M. M., & Liao, K. (2003a). Durability of bamboo–glass fiber reinforced polymer matrix hybrid composites. Composites Science and Technology, 63 (3–4), 375–387
[71] John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. Carbohydrate Polymers, 71 (3), 343–364
[72] Idicula M, Joseph K, Thomas S. Mechanical performance of short banana/sisal hybrid fiber reinforced polyester composites. J Reinf Plast Compos 2010; 29 (1), 12–29
[73] Noor Afizah Rosli, Ishak Ahmad, and Ibrahim Abdullah. Isolation and characterization of cellulose nanocrystals from Agave Angustifolia fibre
[74] Dai, D. & Fan, M. (2011). Investigation of the dislocation of natural fibres by Fouriertransform infrared spectroscopy. Spectroscopy, Vol. 55, No. 2, pp. 300-306, ISSN 0924-2031
[75] V.Mastan, Prof.N.Jeevan Kumar, A.Harish Kumar. A Review Paper on Tensile Properties of Natural Fiber Polymer Matrix Composites. Research Inventy: International Journal Of Engineering And Science Vol. 04, Issue 12 (December 2014), pp. 60-63
[76] K.S.Chingl, M.Ealid, Y.C.Ching, M.Haniff, M.T.H.Beg. Preparation and characterisation of polyvinyl alcohol/oil palm empty fruit bunch fibre composite. Materials Research Innovatios. 2014, 18
[77] G. S. Divya1, B. Suresha. Recent Developments of Natural Fiber Reinforced Thermoset Polymer Composites and their Mechanical Properties. Indian Journal of Advances in Chemical Science. (2016) 267-274
[78] M. Jawaid, Othman Y. Alothman, M.T. Paridah and H.P.S Abdul Khalil, Effects of oil palm and jute fiber treatment on Mechanical Performance Of Epoxy Hybrid Composites. International Journal Of Polymers.19, 62-69, 2014
[79] K.Obi Reddy, C.Uma Maheswari, K.Ramakrishna Reddy, M.Shukla, E.Muzendra, A.Varada Rajula. Effects Of Chemicals Treatment and Fiber Loading on Mechanical Properties of Borassus (Toddy palm) Fiber/Epoxy Composites. New York University. 2015
[80] Artur Camposo Pereira, Sergio Neves Monteiro, Foluke Salgado de Assis, Frederico Muylaert Margemb, Fernanda Santos da Luz, Fábio de Oliveira Braga. Charpy Impact tenacity of epoxy matrix composites reinforced with aligned jute fibers. Journal Of Material Research and Technology, 2017, 312–316
[81] Layth Mohammed, M.N.M Ansari, Grace Pua, Mohammad Jawaid and M. Saiful Islam. A review on natural fiber reinforced polymer composite and its applications, International journal of polymer science, September 2015
[82] K. Mylsamy, I. Rajendran. The mechanical properties, deformation and thermomechanical properties. Journal of material science and design. 32, (2011), 3076–3084
[83] B.F.Yousif, A.Shalwan, C.W.Chin, K.C.Ming. Flexural Properties of treated and untreated kenaf/epoxy composites. Journal of Materials and Design. 40, (2012), 378-385
[84] L.Boopathi, P.S.Sampath, K.Myisamy. Investigation of Physical,and Chemical and mechanical properties of raw and alkali treated Borassus fruit fiber. Journal of Composites: Part B43 (2012), 3044-3052
[85] Ashwin Sailesh, Dr. S. Prakash. Review on recent developments in natural fibre composites and their mechanical performance. International journal of Engineering Research and Technology (IJERT), September 2013
[86] Gabriel Oliveira Glóriaa, Maria Carolina Andrade Teles, Anna Carolina Cerqueira Nevesa, Carlos Maurício Fontes Vieiraa, Felipe Perissé Duarte Lopesa, Maycon de Almeida Gomesb, Bending test in epoxy composites reinforced with continuous and aligned PALF fibers. Journal of Material Research and Technology, 2017; 6 (4), 411-416