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Poly Propylene Chrysanthemum Bio-Composite: Mechanical And Thermal Studies

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Abstract: ***During the recent years, polymeric composite materials are being used in variety of applications due to their high strength and stiffness, light weight and high corrosion resistance. Most of the products are made from non-biodegradable fibers, where the problem of disposal arises after the end use; this raised the attention of people for the use of natural, sustainable, biodegradable and renewable resources. The use of various natural reinforcing fibers in thermoplastics with the fibers such as hemp, jute, flax, sisal, and kapok had gained acceptance in commodity plastics and applications of these materials during the past decade has been reported in literature. However, still various fibers and particulate fillers need to be explored. Amongst the thermoplastic materials used; polypropylene is an outstanding commercially available thermoplastic material with wide range of applications.***

The aim of the present work is to develop polypropylene (PP) composites, using renewable bio resources. Chrysanthemum flower petals powder was used as natural reinforcing fillers in this research work. They are relatively inexpensive and abundantly available in nature. The mechanical and thermal studies are carried out to evaluate the effect of filler content on polypropylene. The tensile properties decrease with increase in the filler content. The tensile property of treated composites shows a higher value than neat polypropylene matrix. Impact strength also decreases with filler content but improved strength is obtained for maximum filler composite.

This project has shown that the composites with maleic anhydride as a coupling agent will be desirable for making house hold products due to their considerable stability and strength properties. The prepared composite samples were characterized with different techniques to ascertain their utility house hold and industrial applications.

Keywords: Polypropylene, agro waste, coupling agent, bio composite, thermoplastic composites.

I. INTRODUCTION

Lignocellulosic materials have become important as fillers or reinforcements in polymer or ceramic matrices due to their advantages in relation to other inorganic or synthetic materials [1] because of their easily recyclable, minimum requirements, non-abrasive to machinery, stronger performance even with lower weight, impact and shatter resistant. Further they have lower processing energy requirements and a low thermal expansion coefficient; they have a natural appearance, are easily coloured and are low cost, costing less than the base resin [2].

Several lignocellulosic materials are used as fillers or reinforcement in thermoplastic composites, including fibres of sugarcane, banana, jute, ramie, flax, pineapple, curaua, sisal, cotton, coir, luffa cylindrica [1], guayule biomass [2], heart-of-peach palm sheath [3], bagasse [4], sunflower stalk flour [5], and palm leaf waste [6], as well as fibres and wood particles of different tree species [7–10].

Chrysanthemums are some of the most popular flowers in the world, next to rose. The name “chrysanthemum” comes from the Greek words for gold (chrysos) and flower (anthos) and is often affectionately shortened to “mum.” Chrysanthemums were first cultivated in China as a flowering herb during 15th century BC. Japan celebrates the flower as “Festival of Happiness”. Van der ploeg and E. Heuvelink studied the influence of temperature on as biomass (specifically on chrysanthemum) production and partitioning

to different plant organs. The other developmental traits, there are clear differences between cultivars in their response to temperature [11].

Various parts of chrysanthemum plant have many applications, amongst which post fiber application in reinforcing thermo and thermosetting plastics had gained importance in the current decade. Fibers obtained from chrysanthemum flower are a bast fiber which has a structure and relatively good mechanical properties. They consist of helically wound cellulose microfibrils in amorphous matrix of lignin and hemicellulose.

Lignin are composed of nine carbon units derived from substituted cinnamyl alcohol which is in turn associated with the hemicelluloses and play an important role in the natural decay resistance of the lingo cellulosic material. It can be noted that cellulose is the main constituent of plant fibers followed by hemi-celluloses and lignin interchangeably and pectin respectively.

Cellulose present in the plant fiber in turn acts as the reinforcement for lignin, hemi cellulose and pectin. This makes plant fibers exhibit characteristics of a composite material. From the available literature, it was observed that the chrysanthemum fiber possesses good specific strength properties comparable to those of conventional materials like glass fibers. Therefore utilization and application of the cheaper goods in high performance appliance is possible with the help of this composite technology.

Alkali treatments have been proven effective in removing impurities from the fiber, decreasing water sorption and enabling mechanical bonding and thereby improving matrix interface interaction. Therefore an effort had been taken to treat the chrysanthemum fibers with sodium hydroxide (6wt %) for the reinforcement in polypropylene matrix and to study their mechanical and thermal properties.

II. OBJECTIVES OF THE RESEARCH WORK

- ✓ Utilization of biodegradable agricultural waste such as flower waste for the development of composites.
- ✓ Choice of polypropylene as the matrix material for preparation of the composites because of its huge commercial availability.
- ✓ To evaluate and report the efficient processing methods and their relationship with varying percentages of filler as reinforcement.
- ✓ To study the characteristics of polypropylene composites in terms of various physical parameters essential for their acceptance as marketable products.

III. MATEIALS AND METHODS

The commercially available and industrially important polypropylene was used in the present study as a matrix material is homo-polymer grade (Repol HIIO)–P2, which were supplied by Reliance Industries.

Renewable reinforcing filler used is chrysanthemum flower. The compatibilizers used were maleic anhydride grafted polypropylene-MAPP (Amplify GR 216) with density of 0.875g/cm^{3}was obtained from Dow chemicals (Bhimrajka Implex Ltd.).

A. PREPARATION OF FILLER WITHOUT CHEMICAL TREATMENT

Chrysanthemum flower were used as such without any modification and with modification by chemical treatment to compare the properties of the prepared composite with respect the virgin matrix.

Figure 1: Chrysanthemum flower

B. DRYING OF FILLERS

Flowers with yellow petals were picked by hands. Spread under sun light for 3 days, then moved to shadow until they are completely dry. The dried flowers are ground into powder using a food processor to get filler powder.

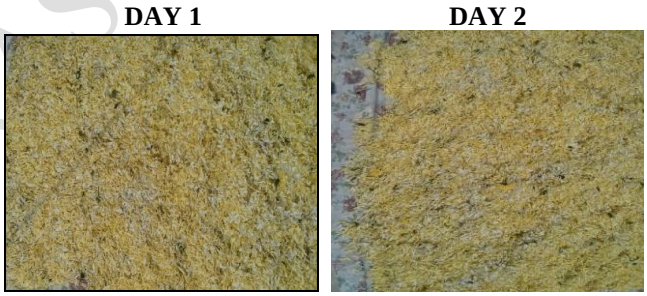

Figure 2: Drying of fillers in sunlight

C. GRINDING AND SIEVING OF FILLERS

The dried flowers are ground into powder using a wood grinding machine to get filler powder. The powdered filler are passed into the sieve shaker to get uniform particle size of <75 μm.

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Figure 3: Grinding of dried flowers powder

Figure 4: Segregating the filler using sieve shaker

Figure 5: Chrysanthemum filler

D. PREPARATION OF FILLER WIIH CHEMICAL TREATMENT

10g of chrysanthemum filler in the form of powder was treated with alkaline solution under mild condition by soaking them in17.5wt% sodium hydroxide solution for 1hr in a glass beaker at room temperature. The effect of alkali on cellulose fiber is a swelling reaction, during which the natural crystalline structure of the cellulose relaxes. The resulting mixture was filtered off and the extract obtained is dried and ground again and taken as chemically treated sample.

Figure 6: Chemical treatment of Chrysanthemum filler

IV. COMPOUNDING

Polypropylene granules, bio fillers and compatiblizer were pre dried in an air oven at 80°C for 4h and mixed well before blending. The compounding materials were melt blended by directly adding into the feeding zone of twin screw extruder as shown in the figure (HAAKE Rheomex OS, PTW16 Thermo Scientific, Germany). Blending was carried out at a temperature range of 210°C, 200°C, 190°C, 180°C and 150°C at a screw speed of 75rpm. The process of mixing with fillers after transfer of polymer materials into mould was completed within 80 seconds to avoid heat loss and to ensure thorough mixing. Compression force of 100kN was applied to the molten polymer mix for about 20 minutes. Mould was cooled by circulating cold water through the columns around the mould.

Figure 7: PP granules

Figure 8: MAPP

SAMPLE	CF (Wt%)	CF(Gms)	PP(Gms)	MAPP(Gms)
Neat PP	0	0	1000	0
UCFPP 5	5	100	1800	100
UCFPP 7.5	7.5	150	1750	100
UCFPP 10	10	200	1700	100

TCFPP 5	5	100	1800	100

**PP- PolyPropylene; CF – Chrysanthemum Filler; MAPP – Maleic Anhydride Grafted Poly Propylene U-Untreated, T-treated*

Table 1: Composition of Samples

Composite samples which were extruded form the mould were in the form of strands, which were further chopped into smaller pellets further characterization and for making test samples according to ASTM standard. Composites of following composition were prepared as given in Table 1. After compounding the samples are taken for the injection moulding.

Figure 9: Extruded CF biocomposites

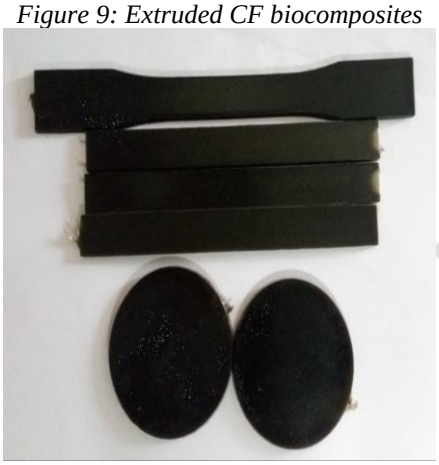

Figure 10: The moulded ASTM products

V. MECHANICAL TESTING

Mechanical Testing were carried out as per American Standard Testing Methods (ASTM). Four tests were performed on bio composites namely tensile strength, impact strength, hardness and flexural test. All the composite samples used for testing mechanical properties were machined into shape by grinding machine according to the ASTM standards and the cut edges were made smooth using sand paper to have a control on the specimen dimension.

A. CONDITIONING

The test specimens were conditioned at 23±2°C and 50±5% relative humidity for 40h prior to the testing.

B. TENSILE TESTING

Tensile strength is a measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before breaking. Tensile modulus, an indication of the relative stiffness of a material, can be determined from a stress-strain diagram.

Tensile properties were studied as per ASTM-D 3039 using Instron testing machine (Model 6025 UK), at 10 mm/minute cross-head speed, using specimen with a width of 25 mm, length of 200mm and thickness of 3mm. A distance of 115mm is kept in between the grips. Five specimens were tested for each sample.

C. TENSILE STRENGTH

Tensile strength or tenacity is the stress at the breaking point of the test specimen. Tensile strength is obtained from the experimental data using equation

Tensile strength = Load at break / Original cross-sectional area

$= L / b \times D$

Where L = the load applied in N,

b = the width in mm and D = the thickness in mm

Tensile Modulus = Tensile stress/Tensile strain

= Difference in load (N)/Difference in extension (mm)

D. IMPACT STRENGTH

The unnotched Izod impact strength of each sample was tested as per ASTM D 256-88. All the samples were tested as unnotched so that they would be more sensitive to the transition between ductility and brittleness.

Specimens having thickness 3.2 mm with 10mm cross-section and 64 mm long were clamped in the base of the pendulum testing machine so that they were cantilevered upward. The pendulum was released and the force consumed in breaking the sample was calculated.

E. FLEXURAL PROPERTIES

The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Flexural properties were studied as per ASTM-D 290 using Instron testing machine (Model 6025 UK), at 10 mm/minute cross-head speed, using specimen with a width of 25 mm, length of 200mm and thickness of 3mm.Adistance of 115mm is kept in between the grips. Five specimens were tested for each sample.

F. HARDNESS

Hardness of the composite material was measured using durometer as per ASTM D2240 specimen with 3mm thickness. The specimen was placed on a hard horizontal surface. The durometer was held in a position in the point of indenter at least 12 mm from any edge of the specimen. The durometer had a pointed indenter projecting below the base of the pressure foot. The indenter was pressed into the plastic

specimen, so that the base rests on the plastic materials surface and the amount of Indentation was registered directly on the dial indicator. Hardness was determined at five different positions on the specimen at least 6mm.

VI. RESULTS AND DISCUSSION

A. TENSILE STRENGTH

The tensile test results depict that ultimate tensile strength of neat polypropylene is 24.5 MPa. The tensile strength of chrysanthemum filler reinforced polypropylene composites is in the range of 23.8-26.3 MPa, and that of treated chrysanthemum powder reinforced polypropylene composite is 23.5 MPa.

Sample (Wt %)	Tensile Strength(MPa)
Neat PP	24.5
UCFPP 5	26.3
UCFPP 7.5	25.0
UCFPP 10	23.8
TCFPP 10	23.5

Table 2: Tensile Strength of PP and CFPP composites

Figure 11 shows the ultimate tensile strength (UTS) of neat polypropylene and chrysanthemum powder reinforced polypropylene composites. The tensile strength of chrysanthemum powder reinforced polypropylene composites shows tremendous increase for 5wt% loading and decreases gradually for 7.5wt% and 10wt% loading compared to that of neat homo polypropylene. The polypropylene matrix transmits and distributes the applied stress through the coupling agent (MAPP) to the chrysanthemum reinforcing filler resulting in higher strength. Therefore, the composite can sustain higher load before failure compared to the neat polypropylene. But at higher loading decrease in tensile strength may be due to insufficient coupling; however the strength of 7.5 wt% shows almost equivalent strength as that of neat matrix material.

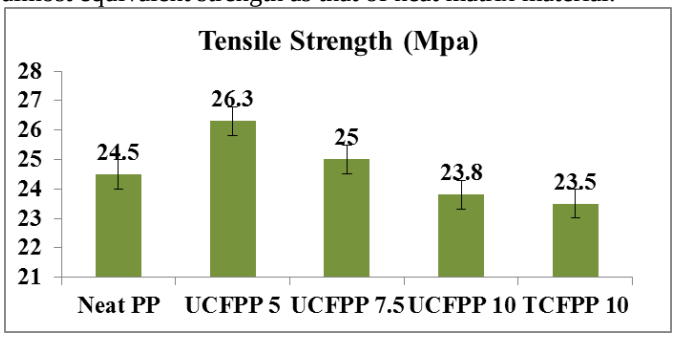

Figure 11: Tensile strength of Neat PP, UCFPP and TCFPP Composites

B. IMPACT STRENGTH

The impact test results show that impact strength of neat polypropylene is 4.12 KJ/m^2. The impact strength of chrysanthemum filler reinforced polypropylene composites is in the range of 2.9-3.66 KJ/m^2, and that of treated chrysanthemum powder reinforced polypropylene composite is 2.35 KJ/m^2.

Sample (Wt %)	Impact Strength(KJ/m^2)
Neat PP	4.12
UCFPP 5	2.90
UCFPP 7.5	2.92
UCFPP 10	3.66
TCFPP 10	2.35

Table 3: Impact Strength of PP and CFPP composites

Table 3 shows the impact strength values for neat, coupled and treated chrysanthemum powder reinforced polypropylene composite from which the following conclusions could be drawn.

The result of impact test shows an improved the impact strength of 3.66KJ/m^2 properties for maximum filler content of 10wt% compared to other lower weight percentage composites, thereby increasing the toughness properties of the composite material. This may be probably due to the addition of filler material might have filled the small voids and the regions of particle corners thereby improving the impact strength.

In case of treated chrysanthemum reinforced composites, the impact strength was found to decrease comparatively from polypropylene; this may be due to the reason that chemical treatment had decreased the surface polarity thereby increasing the surface roughness. Therefore, response of treated chrysanthemum reinforcement towards impact strength of composites reflects a failure process involving crack initiation and growth in the resin matrix due to fiber breakage, pull out delaminating and disbanding due to chemical treatment.

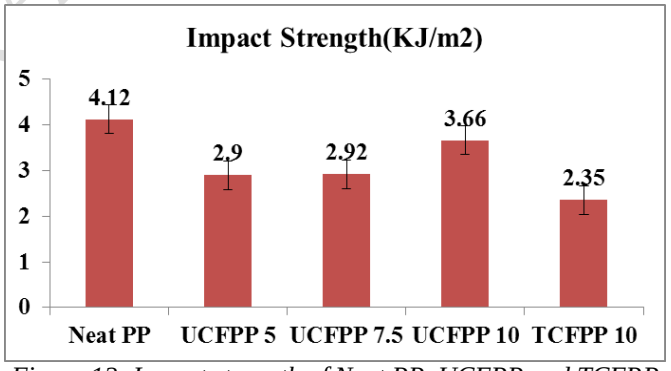

Figure 12: Impact strength of Neat PP, UCFPP and TCFPP Composites

C. FLEXURAL STRENGTH

The izod impact test results show the impact strength of neat polypropylene is 36.4 MPa. The flexural strength of untreated chrysanthemum filler reinforced polypropylene composites is in the range of 34.6-37.5 MPa, and that of treated chrysanthemum powder reinforced polypropylene composite is 41.6 MPa.

Sample (Wt %)	Flexural Strength(MPa)
Neat PP	36.4
UCFPP 5	37.5
UCFPP 7.5	36.7
UCFPP 10	34.6
TCFPP 10	41.6

Table 4: Flexural Strength of PP and CFPP composites

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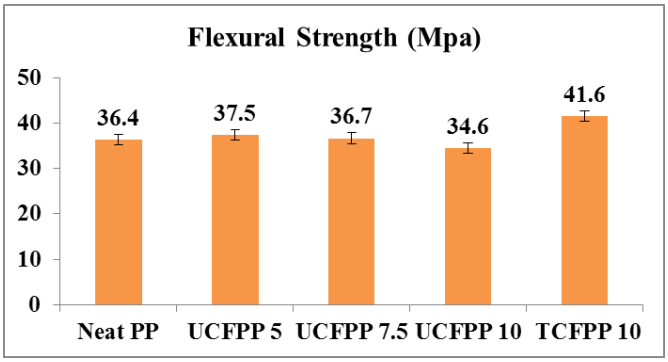

Figure 12: Flexural strength of Neat PP, UCFPP and TCFPP Composites

The effect of maleic anhydride on the flexural strength of chrysanthemum composite is shown in Figure 12. As can be seen, flexural strength of composites increases with filler percentage of 5wt% but decreases for 10wt%compared to the controlled matrix material. Whereas treated composite material shows enhanced flexural property. This may be because of the effect of coupling agent enhances the interface adhesion between matrix and that of chrysanthemum filler resulting in higher flexural modulus. But at higher loading shows decrease in flexural strength may be due to insufficient coupling, however the flexural strength of treated composite material show very good improvement when compared to that of neat PP matrix, due to the induced polar group within the matrix through chemical treatment.

D. HARDNESS

It is well known that hardness implies a resistance to indentation, permanent or temporary deformation of the material. Table 5 shows the hardness of neat polypropylene is 68.8. The hardness of untreated chrysanthemum filler reinforced polypropylene composites is in the range of 78.6-79.8, and that of treated chrysanthemum powder reinforced polypropylene composite is 79.6.

Sample (Wt %)	Hardness
Neat PP	68.8
UCFPP 5	78.6
UCFPP 7.5	79.0
UCFPP 10	79.8
TCFPP 10	79.6

Table 5: Hardness of PP and CFPP composites

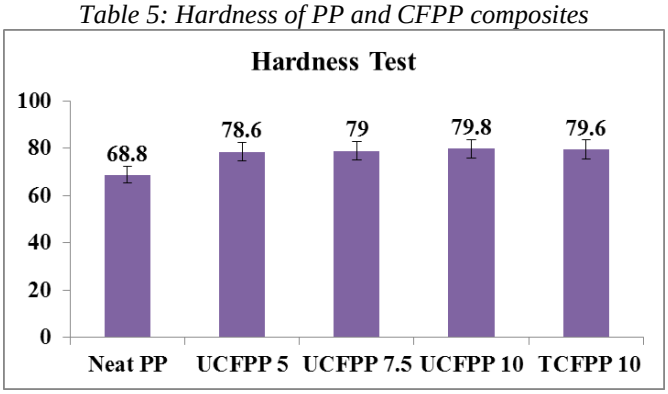

Figure 13: Hardness of Neat PP, UCFPP and TCFPP Composites

Figure 13 shows that hardness increases with increase in filler content in case of coupled chrysanthemum powder composites compared to that of controlled matrix material. Maximum hardness is obtained for 10% filler content and that of treated composite material as shown in the figure 13. This reflects the resistance of the chrysanthemum filler (10%) and that of treated filler to deformation in the polypropylene matrix.

VII. THERMAL PROPERTIES

A. THERMO GRAVIMETRIC ANALYSIS

Sample (Wt %)	Decomposition temperature (°C)
Neat PP	170°C
UCFPP 5	163°C
UCFPP 7.5	164°C
UCFPP 10	167°C
TCFPP 10	165°C

Table 6: Degradation temperatures of PP and CFPP composites

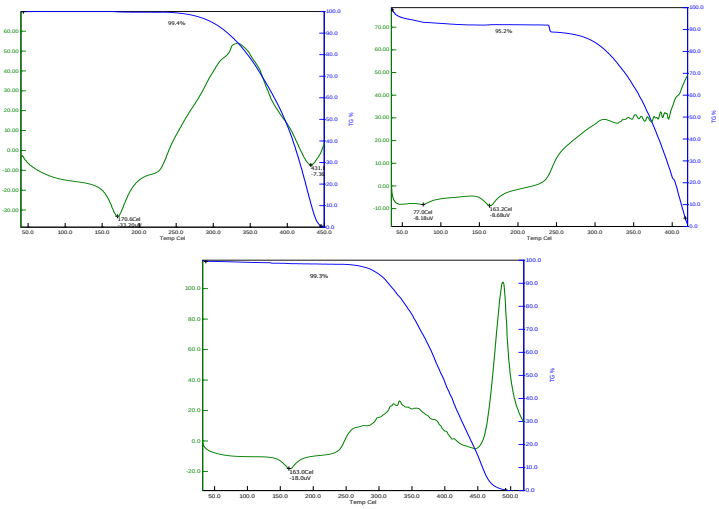

Figure 14: TGA of PP, UCFPP and TCFPP composites

Figure 14 shows the TGA scans of neat PP, UCFPP and TCFPP. All the TG curves exhibit a single degradation step. The decomposition temperatures at 50% degradation for all samples are given in Table 6 and it is evident from Table 6 that thermal stability of 10% UCFPP composites less than neat PP but comparatively high than the lower filler composites. This shows that capability temperature resistance of chrysanthemum filler at higher loading level. Temperature withstanding 10% TCFPP is less than 10% UCFPP which may be due to delaminating and disbanding due to chemical treatment.

VIII. CONCLUSION

- ✓ The tensile strength decreases with increase in the filler content.
- ✓ The tensile strength of treated composites shows a higher value than neat polypropylene.

- ✓ Impact strength also decreases with filler content, but improved strength is obtained for maximum filler composite material.
- ✓ Treated impact material shows a drastic decrease in strength.
- ✓ Increase in impact strength of composites with maleic anhydride as a coupling agent will be desirable for making house hold products due to their considerable stability and strength properties.
- ✓ The flexural strength of 5wt% is higher than the neat material but gradually decreases with increase in the filler content.
- ✓ The flexural strength of treated composites shows a higher value than neat polypropylene matrix.
- ✓ Hardness increases with filler content for coupled composite and as well for treated one.
- ✓ Thermal stability increases with increase in chrysanthemum filler content.
- ✓ Increase in hardness and thermal stability of maleic anhydride coupled untreated composites will be desirable for furniture parts and making building materials due to their improved hardness and thermal stability.

Figure 15: Moulded product of chrysanthemum Composite

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REFERENCES

[1] A. R. Kakroodi, S. Cheng, M. Sain, and A. Asiri, "Mechanical, thermal, and morphological properties of nanocomposites based on polyvinyl alcohol and cellulose nanofiber from Aloe vera rind," Journal of Nanomaterials, vol. 2014, Article ID 903498, 7 pages, 2014.

[2] M. S. Sreekala, M. G. Kumaran, and S. Thomas, "Stress relaxation behaviour in oil palm fibres" Materials Letters, vol. 50, no. 4, pp. 263–273, 2001.

[3] B. Ren, T. Mizue, K. Goda, and J. Noda, "Effects of fluctuation of fibre orientation on tensile properties of flax sliver-reinforced green composites," Composite Structures, vol. 94, no. 12, pp. 3457–3464, 2012.

[4] Y. Pan and Z. Zhong, "A micromechanical model for the mechanical degradation of natural fiber reinforced composites induced by moisture absorption," Mechanics of Materials, vol. 85, pp. 7–15, 2015.

[5] E. Jayamani, S. Hamdan, M. R. Rahman, and M. K. B. Bakri, "Investigation of fiber surface treatment on mechanical, acoustical and thermal properties of betelnut fiber polyester composites," Procedia Engineering, vol. 97, pp. 545–554, 2014

[6] L. Boopathi, P. S. Sampath, and K. Mylsamy, "Investigation of physical, chemical and mechanical properties of raw and alkali treated Borassus fruit fiber," Composites Part B: Engineering, vol. 43, no. 8, pp. 3044–3052, 2012

[7] M. Ramesh, T. S. A. Atreya, U. S. Aswin, H. Eashwar, and C. Deepa, "Processing and mechanical property evaluation of banana fiber reinforced polymer composites," Procedia Engineering, vol. 97, pp. 563–572, 2014.

[8] N. Venkateshwaran, A. ElayaPerumal, and D. Arunsundaranayagam, "Fiber surface treatment and its effect on mechanical and visco-elastic behaviour of banana/epoxy composite," Materials & Design, vol. 47, pp. 151–159, 2013

[9] A. Van der ploeg and E. Heuvelink The influence of temperature on growth and development of chrysanthemum cultivars, Horticultural Production Chains Group, Wageningen University, Marijkeweg 22, 6709 PG Wageningen, The Netherlands (e-mail: ep.heuvelink@wur.nl) (Accepted 20 October 2005)

[10] S. N. Monteiro, K. G. Satyanarayana, A. S. Ferreira et al., "Selection of high strength natural fibers,"Matéria, vol. 15, no. 4, pp. 488–505, 2010.

[11] H. Ismail, H. D. Rozman, R. M. Jaffri, and Z. A. MohdIshak, "Oil palm wood flour reinforced epoxidized natural rubber composites: the effect of filler content and size," European Polymer Journal, vol. 33, no. 10–12, pp. 1627–1632, 1997.

[12] M. Jawaid and H. P. S. Abdul Khalil, "Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review," Carbohydrate Polymers, vol. 86, no. 1, pp. 1–18, 2011.

[13] M. George, P. G. Mussone, Z. Abboud, and D. C. Bressler, "Characterization of chemically and enzymatically treated hemp fibres using atomic force microscopy and spectroscopy," Applied Surface Science, vol. 314, pp. 1019–1025, 2014.

[14] P. Wongsriraksa, K. Togashi, A. Nakai, and H. Hamada, "Continuous natural fiber reinforced thermoplastic composites by fiber surface modification," Advances in Mechanical Engineering, vol. 5, Article ID 685104, 2013.

[15] J. Gassan and A. K. Bledzki, "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres," Composites Science and Technology, vol. 59, no. 9, pp. 1303–1309, 1999.

[16] M. Z. Rong, M. Q. Zhang, Y. Liu, G. C. Yang, and H. M. Zeng, "The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy

composites," Composites Science and Technology, vol. 61, no. 10, pp. 1437–1447, 2001.
[17] T. P. T. Tran, J.-C. Bénézet, and A. Bergeret, "Rice and Einkorn wheat husks reinforced poly (lactic acid) (PLA) biocomposites: effects of alkaline and silane surface treatments of husks," Industrial Crops and Products, vol. 58, pp. 111–124, 2014.
[18] S. I. Hossain, M. Hasan, M. N. Hasan, and A. Hassan, "Effect of chemical treatment on physical, mechanical and thermal properties of ladies finger natural fiber," Advances in Materials Science and Engineering, vol. 2013, Article ID 824274, 6 pages, 2013
[19] A. O'Donnell, M. A. Dweib, and R. P. Wool, "Natural fiber composites with plant oil-based resin," Composites Science and Technology, vol. 64, no. 9, pp. 1135–1145, 2004.
[20] H. Luo, G. Xiong, C. Ma et al., "Mechanical and thermo-mechanical behaviors of sizing-treated corn fiber/polylactide composites," Polymer Testing, vol. 39, pp. 45–52, 2014.
[21] H. Ismail, A. Rusli, and A. A. Rashid, "Maleated natural rubber as a coupling agent for paper sludge filled natural rubber composites," Polymer Testing, vol. 24, no. 7, pp. 856–862, 2005.
[22] A. Paul, K. Joseph, and S. Thomas, "Effect of surface treatments on the electrical properties of low-density polyethylene composites reinforced with short sisal fibers," Composites Science and Technology, vol. 57, no. 1, pp. 67–79, 1997
[23] F. Corrales, F. Vilaseca, M. Llop, J. Gironès, J. A. Méndez, and P. Mutjè, "Chemical modification of jute fibers for the production of green-composites," Journal of Hazardous Materials, vol. 144, no. 3, pp. 730–735, 2007.
[24] F. G. Torres and M. L. Cubillas, "Study of the interfacial properties of natural fibre reinforced polyethylene," Polymer Testing, vol. 24, no. 6, pp. 694–698, 2005.
[25] He, X. Li, W. Li, J. Yuan, and H. Zhou, "A method for determining reactive hydroxyl groups in natural fibers: application to ramie fiber and its modification," Carbohydrate Research, vol. 348, pp. 95–98, 2012
[26] K. Xie, H. Liu, and X. Wang, "Surface modification of cellulose with triazine derivative to improve printability with reactive dyes," Carbohydrate Polymers, vol. 78, no. 3, pp. 538–542, 2009.
[27] N. Cordeiroa, M. Ornelasa, A. Ashorib, S. Sheshmanic, and H. Norouzic, "Investigation on the surface properties of chemically modified natural fibers using inverse gas chromatography," Carbohydrate Polymers, vol. 87, no. 4, pp. 2367–2375, 2012
[28] M. Le Troedec, D. Sedan, C. Peyratout et al., "Influence of various chemical treatments on the composition and structure of hemp fibres," Composites Part A: Applied Science and Manufacturing, vol. 39, no. 3, pp. 514–522, 2008.