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Tensile & Flexural Characterisation and Finite Element Modelling of Bamboo Polypropylene Composite

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ABSTRACT: *In the past decade, due to environmental concerns, use of naturally available materials for engineering applications has increased. Natural fibres have attracted much attention of researchers, to use them as reinforcement in Fibre Reinforced Polymer (FRP) composites instead of inorganic fibres. Bamboo is one of the fastest growing and vastly available natural resource. Bamboo is being used in structural applications right from the dawn of civilization. In the present work, a novel Bamboo Polypropylene Composite (BPC) is developed and characterised for tensile and flexural properties. Finite Element (FE) Modelling of tensile and flexural behaviour of developed composite were performed using commercial FE analysis tools such as Hypermesh (Pre-processor) and LS DYNA (Explicit Solver). MAT_24 (Piecewise Linear Plasticity Model) an elasto-plastic material model was able to predict the behaviour of composite effectively.*

Keywords - *Bamboo Polypropylene Composite (BPC), Polypropylene (PP), Finite Element Modelling (FEM), m-isopropenyl α-α dimethylbenzyl-isocyanate(m-TMI), Maleic Anhydride Grafted Polypropylene(MAPP), Natural Fibre Reinforced Polymer Composites (NFPC), Computer Aided Engineering (CAE).*

I. INTRODUCTION

During the past decade lot of research is going on in the field of composites especially in Fibre Reinforced Polymer (FRP) composites. Inorganic composites such as glass, aramid and carbon FRP composites are well established in the aerospace and automotive industries. High cost of these composites is beneficial only in high end applications where strength to weight ratio should be as small as possible but for low load applications use of these composites is not beneficial. In inorganic composites, the fibres such as carbon and aramid are the one which increases the cost. Though glass fibres are cheap, there are many health hazardous to workers who are involved in its processing. So, researchers are in search of alternative fibres for reinforcement to polymer matrix for low load structural applications.

The use of natural fibres as reinforcement to polymers is one such innovation. Researchers in recent years are trying to develop Natural Fibre Reinforced Polymer Composites (NFPC) for engineering applications with different combinations of matrices (Polyester, Epoxy, Polypropylene, Polyethylene etc.,) and natural fibres (Jute, Hemp, Coir, Bamboo etc.,). The natural fibres can be used to reinforce both thermoset and thermoplastic matrices. Recently biopolymers such as soy plastic, cellulosic plastic, corn starch plastic, polylactic acid etc., have come to market which can also be used as matrices. Natural fibres offer several advantages like low cost, low density, high specific properties, nonabrasive to processing equipment and biodegradability.

Bamboo belongs to Graminae grass family. It is estimated that there are around 1250 species of Bamboo. Depending on the local soil and climatic conditions the growing rate of Bamboo varies from 20 to 100 cm per day [1]. Bamboo is fastest growing plant therefore it is classified as a grass not a tree [2]. In several engineering applications the cylindrical shaped culms of Bamboo can be directly used but, in some applications, it is one of the drawbacks. In those applications, extracted Bamboo fibres can be used as reinforcement to polymer matrices [3]. Khalil et al. [4] have reviewed the most recent developments in Bamboo Fibre Reinforced Bio-Composites. This review is focused on the most recent developments in processing methods of Bamboo Reinforced Polymer Composites. They have compared Bamboo Fibre Reinforced Composites and conventional composites and it was found that mechanical properties of Bamboo Fibre Reinforced Epoxy Composite can be compared with that of Glass Fibre Reinforced Epoxy Composites. They quote that Bamboo Bio- Composites are the promising future material for advanced engineering applications as the fibres used are sustainable and eco-friendly. Suhaily et al. [5] have discussed different processing methods and classification of

Bamboo Bio-Composites. Gozdecki et al. [6] prepared Wood/Low Density Polyethylene (PE-LD) Composites by injection moulding process. Industrial wood particles used for manufacturing particle boards were used as filler. Composites were prepared using different particle sizes and their effects on mechanical properties were studied. Increase in tensile, flexural and impact strengths were observed with increase in particle size.

Injection moulding and profile extrusion are the most suitable processes for mass and continuous production. Continuous natural fibre reinforced composites are difficult to manufacture by these methods. Therefore, most of the NFPC research is focused towards reinforcing short fibres on to the polymer matrix. Suitable coupling agents are added along with polymer during extrusion process. The main purpose of adding coupling agents is to bond fibres on to the polymer matrix. Maleic Anhydride Grafted Polypropylene (MAPP) is the most common coupling agent used in most of the researches. Chen et al. [7] developed Bamboo Fibre Reinforced Polypropylene Composite by using MAPP as compatibilizer. It was found that the mechanical properties of the composite increased significantly by using compatibilizer. They also claim that the new material developed was found to be lighter, water resistant, economical and has tensile strength three times more than Bamboo boards. In the last decade, several studies have been carried out on development and characterisation of Bamboo Fibre Filled Thermoplastic Composites [7-9]. In most of these studies, MAPP has been used as the coupling agent to improve the interfacial adhesion between fibre and polymer. m-isopropenly α-α dimethylbenzyl–isocyanate (m-TMI) grafted polypropylene has been reported to be an effective coupling agent for Wood-Fibre Reinforced Polypropylene Composites [10]. The mechanism of grafting of m-TMI onto polypropylene has been described thoroughly by Karmarkar et al. [11]. This coupling agent has been reported to be superior to commercial coupling agent like MAPP for Wood Polymer Composites in improving mechanical properties like tensile strength and flexural strength [12].

In the present work, a novel Bamboo Polypropylene Composite with 50% Bamboo fibre reinforcement to Polypropylene matrix using m-TMI coupling agent is prepared and characterized for tensile and flexural properties. Major application areas of this composite are in the construction and automotive industry.

CAE simulation is a method of virtually proving a product or design. The results from the simulation provide insight into the behaviour of the design and help engineers make design changes and improvements. Today most of the CAE simulation are devoted to non-metals like plastics than metals because of growing use of plastic components. However, the material models available are based on metal theory [13]. For the newly developed materials it is always necessary to calibrate available material models to find out which material model is best suited & also to assess the efficiency to simulate the behaviour of the newly developed material before carrying out further application design simulations. In the present work MAT 24 (Piecewise Linear Plasticity) an elasto-plastic isotropic material model in LS DYNA was used for Finite Element Modelling of tensile and flexural behaviour of BPC.

II. MATERIALS

The main materials which are required for composite preparation are Bamboo fibres, polymer and process additives.

2.1 Bamboo short fibres

Mature culms of Dendrocalmus strictus Bamboo were extracted from Bamboo plantation. The Bamboo culms were dried and fed into the chipper to get chips of Bamboo. Bamboo chips from the chipper were fed to the pulveriser to get Bamboo short fibres. Fig.1 shows the steps involved in preparation of Bamboo short fibres. These fibres were oven dried in a hot air oven at 105^0C for 24 hours before blending with Polymer.

Fig. 1 Preparation of Bamboo short fibres.

2.2 Polypropylene and process additives

Polypropylene (Repol H110MA), having a melt flow index of 11 g/10 min at 230^0C under 2.16 kg load, procured from Reliance Industries Limited, India, was used as the matrix material for composite preparation. In house synthesized m-TMI-grafted-PP was used as coupling agent. Dioctyl phthalate & zinc stearate procured from s.d. Fine-chem, India and Irganox B-215 procured from Hindustan Ciba-Geigy Ltd. were used as process additives.

III. PREPARATION OF COMPOSITE

Bamboo-PP Composites were prepared using a laboratory scale twin screw extruder equipped with a side feeder (Fig. 2). Polypropylene homopolymer (475g) (Fig. 3b), dioctyl pthalate (10 g), zinc stearate (10 g), Irganox B-215 (5 g), paraffin wax (10 g) and

coupling agent m-TMI-grafted-PP: 5 wt% of fibre (25g) for each one kg of composite batch were dry blended in a high-speed mixer. The PP granules mixed with additives were fed through the main inlet hopper of the extruder and Bamboo fibres 50 wt% of one kg batch (500g)(Fig. 3a) were fed through the side feeder. The extruded strands were passed through the cold-water strand bath and palletised into 3 mm long pallets (Fig. 4). The pallets were dried at 80^0C for minimum of 24 hours to remove moisture absorbed by the pallets in water bath. Standard specimens were injection moulded from the dried pallets using a 60 ton L&T make injection moulding machine. The moulded specimens were conditioned in an environmental chamber at 65% relative humidity and 30^0C temperature for a minimum 48 hours before testing.

Fig. 2 Twin Screw Extruder

(a) (b)

Fig. 3 a) Bamboo Short Fibres and b) Polypropylene

Fig. 4 Pellets of BPC

IV. MECHANICAL CHARACTERISATION

Test specimens were subjected to tensile & flexural tests as per the ASTM standards ASTM D638 & ASTM D790 using Shimadzu make 10 kN Universal Testing Machine. Fig. 5 shows tensile test setup and Fig. 6 shows schematic representation of Type I dog bone specimen used for tensile test. Cross head speed was 50 mm/min and extension of gauge length of the specimen was measured using an extensometer during tensile testing. Fig. 7 shows the flexural test setup and Fig. 8 shows the schematic representation of specimen used for flexural test. Cross head speed was 2.8 mm/min for flexural test.

Fig. 5 Tensile Test Setup

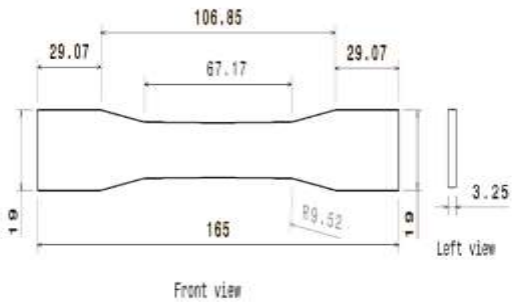

Fig. 6 Tensile Test Specimen (All dimensions are in mm)

Fig. 7 Flexural (3 Point bending) Test Setup

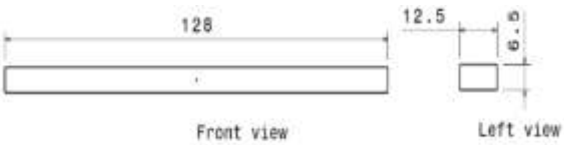

Fig. 8 Flexural Test Specimen (All dimensions are in mm)

V. FINITE ELEMENT MODELLING & SIMULATION

Since, Bamboo short fibres were blended with Polypropylene matrix using twin screw extrusion, the composite was assumed to behave as isotropic material (assuming uniform distribution of fibres inside PP matrix). Material model MAT 24 in LS-DYNA (MAT_PIECEWISE_LINEAR_PLASTICITY), an elasto-plastic isotropic material model was used to predict the stress-strain behaviour of the composite material. Strain rate dependency was not considered. The results from the solver will be in form of true stress and true strain. Therefore, for the comparison of experimental and simulated results true stress and true strain were calculated for the composite from the force and displacement (extension) values, which were recorded during the tensile test, using the following formula: -

$$\sigma_T=\sigma_E(1+\varepsilon_E) \quad (1)$$
$$\varepsilon_T=\ln(1+\varepsilon_E) \quad (2)$$
$$\sigma_E=F/A_0 \quad (3)$$
$$\varepsilon_E=E/L \quad (4)$$

Where σ_T, ε_T, σ_E and ε_E are true stress, true strain, engineering stress and engineering strain respectively. F, A_0, E and L are the force, initial area of cross section, extension and gauge length respectively.

Tensile specimen CAD model was developed using CATIA V5 (CAD Modeller). CAD model was imported to Hypermesh. Since tensile test specimen thickness is very small compared to length and width, the problem was simplified as 2D model. The mid surface of CAD model was extracted and meshed using 2D shell elements. Element formulation (Elform=2) Belytschko- Tsay was used. To control the hourglass associated with reduced integrated Belytschko-Tsay formulation, standard LS DYNA hourglass control was invoked through *Control_Hourglass card. Fig. 9 shows the FE model of tensile test with boundary conditions. Nodes in the left side of the specimen which is the griping region in the UTM is fully constrained and the right-side grip region nodes are applied with constant velocity. "Table I" shows the inputs that were provided for the material card 24.

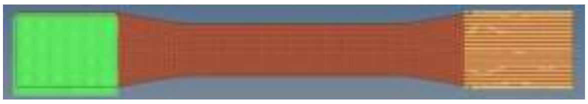

Fig. 9 FE Model of Tensile Test

Flexural test specimen along with the indenter and supports were CAD modelled in CATIA V5 and imported to Hypermesh for meshing & boundary condition application. Indenter & supports were modelled using 3D hexahedron &pentahedron elements and specimen was modelled using hexahedron elements. Fig. 10 shows the FE model of flexural test. Element formulation (Elform=1) constant stress solid element was used. Hourglass was controlled using *Control_Hourglass card with viscosity type Flanagan- Belytschko. Indenter and supports were defined as rigid material using *MAT_RIGID material card. Contact interface between indenter, supports & specimen were defined using*Contact_Automatic_Surface_to_Surface card.

Indenter & Supports were defined as master components and specimen as slave component. Indenter was moved with constant velocity. Since the indenter & supports are rigid, only specimen undergoes deformation. Reaction force of specimen on indenter was extracted from ASCII file. Displacement of the specimen was also recorded. Force vs displacement was plotted and compared with that of experiment.

Table I
Input Values for the Material Card 24

Sl. No	Property	Value
1.	Density (ρ)	1086 kg m^{-3}
2.	Poisson's ratio (υ)	0.39
3.	Young's modulus (E)	4.87 GPa
4.	Yield strength (σ_y)	35 MPa
5.	Failure Strain	0.0069
6.	Load curve defining effective stress v/s effective plastic strain	

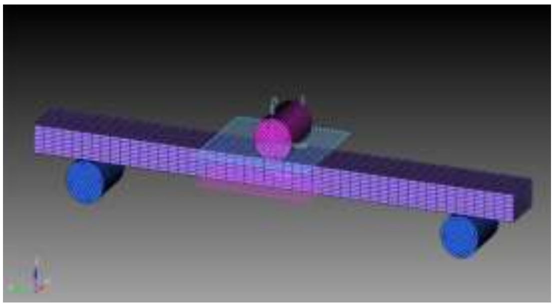

Fig.10 FE Model of Flexural Test

VI. RESULTS AND DISCUSSION

The test specimens were subjected to tensile and flexural test as per the ASTM standards. For each test five samples were tested and average values were calculated. Tensile & flexural strengths and modulus experienced significant increase with the reinforcement of Bamboo fibres. Further Finite Element Analysis of BPC under tensile & flexural loading was carried using MAT 24 material model in LS DYNA. MAT 24 was able to capture the behaviour of Bamboo Polypropylene Composite effectively.

5.1. Mechanical Characterisation

Tensile and flexural test results are tabulated and compared with base material PP (Tables II, III). "Table II" reveals that the tensile strength and modulus of the composite increased significantly by Bamboo fibre reinforcement, tensile strength of the composite was 43.87 MPa exhibiting 36.15% improvement over pure PP. The increase in strength with fibre reinforcement implies the effective load bearing by Bamboofibres. The tensile modulus of the composite was 5.99 GPa exhibiting 330% higher than PP (1.39 GPa).

Table II
Tensile Test Results of BPC and PP

Materials	Tensile Strength (MPa)	Increase in Tensile Strength over PP (%)	Tensile Modulus (GPa)	Increase in Tensile Modulus over PP (%)
PP	32.22	-	1.39	-
BPC	43.87	36.15	5.99	330

The flexural strength also increased with the Bamboo fibre reinforcement. However, the magnitude of increase in flexural strength was significantly higher than tensile strength. The flexural strength increased by 64.20% with respect to pure PP. The Flexural modulus also increased by 300% when compared with pure PP ("Table III").

Table III
Flexural Test Results of BPC and PP

Materials	Flexural Strength (MPa)	Increase in Flexural Strength over PP (%)	Flexural Modulus (GPa)	Increase in Flexural Modulus over PP (%)
PP	34.40	-	1.2	-
BPC	56.49	64.20	4.8	300

5.2. Finite Element Modelling & Simulation

The model generated behaviour was closely matching with the experimental results. Fig. 11 shows failure observed during experiment and as predicted by the simulation. The simulated failure behaviour was coinciding with the experimental failure. Fig. 12 shows the comparison of true stress-strain behaviour observed in experiment and simulation and it can be seen that MAT 24 was able to capture the tensile behaviour of BPC very effectively.

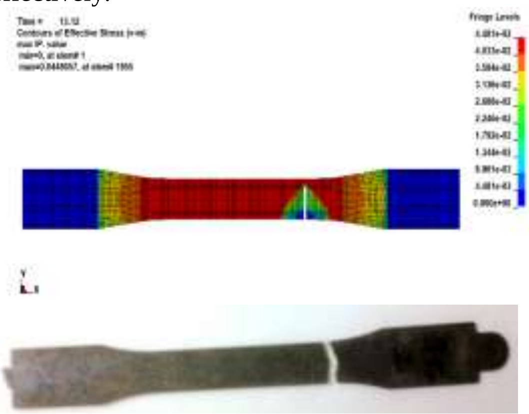

Fig. 11: Comparison of Failure of BPC in Experiment and Simulation

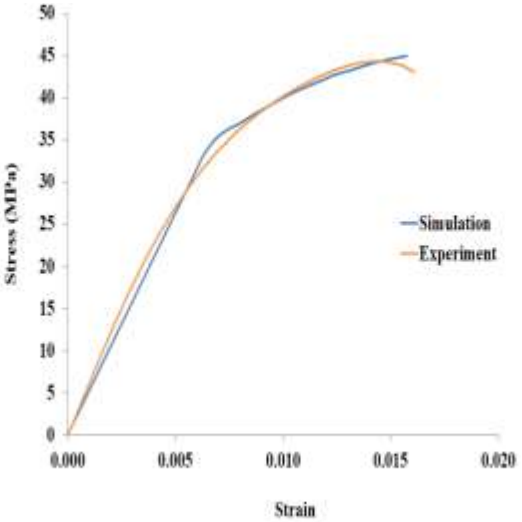

Fig. 12 Comparison of Tensile Behaviour of BPC in Experiment and Simulation

Flexural simulation (Fig. 13) was carried out to check whether MAT 24 model will be able to predict the flexural behaviour of BPC. Calibration of model through flexural test simulation is necessary if application of composite will be in bending load. Flexural simulation results matched very well in the elastic region but in plastic region the simulated behavior was slightly stiffer than the experiment (Fig. 14). Correlation of flexural simulation is good enough to carry out further product design simulations using MAT 24 material model.

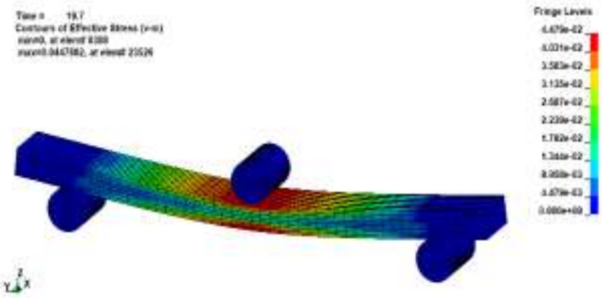

Fig. 13 3 Point Bending Simulation

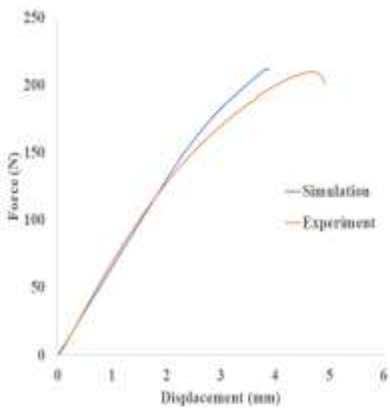

Fig. 14 Comparison of Behaviour of BPC in Experiment and Simulation

VII. CONCLUSION

Bamboo Polypropylene Composite was prepared with m-TMI-grafted-PP as coupling agent and 50% Bamboo fibre reinforcement to polypropylene matrix. BPC developed is showing improved tensile and flexural properties when compared to pure PP. The best possible application for the developed composite will be in applications where good flexural and tensile properties are required. Some of the suggestions are chairs, decking, window frames, door panels, furniture's etc. Uniaxial tensile test and 3-point bending test simulation results showed good agreement with experimental results using MAT 24 material model in LS-DYNA. MAT 24 material model in LS-DYNA can be used for further CAE product development simulations of BPC.

REFERENCES

[1] M Estrada, D L Linero, F Ramírez, Constitutive relationship of the fibre cluster of Bamboo Guadua angustifolia, determined by means of a Weibull probability function and a model of progressive failure, Mechanics of Materials 63 (2013); 12–20.

[2] W Liese,Research on Bamboo, Wood science and technology, 21 (1987); 189–209.

[3] L L Da Costa, R L Loiola, S N Monteiro, Diameter dependence of tensile strength by Weibull analysis: Part I Bamboo fibre, Revista Matéria 2010; 15(2):110–6.

[4] H P S Abdul Khalil, I U H Bhat, M Jawaid, A Zaidon, D Hermawan, Y S Hadi, Bamboo fibre reinforced Bio Composites: A review, Materials and Design, 42 (2012) 352-36.

[5] S S Suhaily, HPS Abdul Khalil, WO Wan Nadirahand M Jawaid, Bamboo Based Bio Composites Material, Design and Applications, Chapter 19, Material Science- Advanced Topics.

[6] C Gozdecki,S Zajchowski, M Kociszewski, A Wilczyñski, J Mirowski, Effect of wood particle size on mechanical properties of industrial wood particle-polyethylene Composites, Polimery 2011, 56 nr 5.

[7] X Chen, Q Guo, Mi Yongli, BambooFibre-Reinforced Polypropylene Composites: A Study of the Mechanical Properties, Journal of Applied Polymer Science, Vol. 69, 1891–1899 (1998).

[8] K Okubo, T Fujii, Y Yamamoto, Development of Bamboo-based polymer Composites and their mechanical properties, Compo: Part A 2004; 35: 377–383.

[9] Y C Zhang, H Y Wu, Y P Qiu, Morphology and properties of hybrid Composites based on polypropylene/polylactic acid blend and Bamboofibre, Biores Techno, 2010; 101: 7944-7950.

[10] A Karmarkar, SS Chauhan, J Modak, M Chanda, Mechanical properties of wood-fibre reinforced polypropylene Composites: effect of a novel compatibilizer with isocyanate functional group, Compo: Part A 2007; 38:227–33.

[11] A Karmarkar, P Aggarwal, J Modak, M Chanda, Grafting of m-isopropenyl- α-α - dimethylbenzyl isocyanate (m-TMI) onto isotactic polypropylene: synthesis and characterization, J Polym Mater 2003; 20:101–7.
[12] SS Chauhan, P Aggarwal, A Karmarkar, The effectiveness of m-TMI-grafted-PP as a coupling agent for wood polymer Composites, J Comp Mater 2015.
[13] H Lobo and J A Hutado, Characterization and Modelling of Non-Linear Behaviour of Plastics, 2006 ABAQUS Users Conference.
[14] Standard Test Method for Tensile Properties of Plastics, ASTM D638-14.
[15] Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM D790-15.