World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:12, No:9, 2018

Effect of Curing Temperature on Mechanical Properties of Jute Fiber Reinforced Polylactic Acid Based Green Composite

Sehijpal Singh Khangura, Jai Inder Preet Singh, Vikas Dhawan

***Abstract*—**Global warming, growing awareness of the environment, waste management issues, dwindling fossil resources, and rising oil prices resulted to increase the research in the materials that are friendly to our health and environment. Due to these reasons, green products are increasingly being promoted for sustainable development. In this work, fully biodegradable green composites have been developed using jute fibers as reinforcement and poly lactic acid as matrix material by film stacking technique. The effect of curing temperature during development of composites ranging from 160 °C, 170 °C, 180 °C and 190 °C was investigated for various mechanical properties. Results obtained from various tests indicate that impact strength decreases with an increase in curing temperature, but tensile and flexural strength increases till 180 °C, thereafter both the properties decrease. This study gives an optimum curing temperature for the development of jute/PLA composites.

***Keywords*—**Natural fibers, polymer matrix composites, jute, compression molding, biodegradation.

I. Introduction

FIBER reinforced polymers (FRPs) have been used in many automobile and structural applications, but traditional FRP composites often pose considerable problems related to their recycle or reuse at the end of their usable lifetime. These issues lead to the development of green composites that are eco-friendly in nature and do not have any negative impact on the environment. Green composites are the material which generally consists of matrix, reinforcement, and an interface between the matrix and reinforcement [1]. These materials are further classified into two categories, i.e. fully biodegradable and partially biodegradable green composites. Fully biodegradable green composites are the materials in which both matrix and reinforcement are derived from natural resource, whereas partially biodegradable green composites are the materials in which either matrix or reinforcement used is derived from the natural resource. As per the report, European automotive industry has used around 43,000 tonnes of natural fibers as composite reinforcement materials in year 2003 [2]. The amount climbed to about 315,000 tonnes, in the year 2010. The exponential growth in the biocomposites is indicative of their wider application in future. Flax, hemp, jute, sisal, bamboo, and kenaf are the popular reinforcement materials because of their low density with high specific strength and stiffness [3], cost effective, and readily available.

Sehijpal Singh Khangura is with the Guru Nanak Dev Engineering College, Ludhiana, India (e-mail: sehijpalsingh@yahoo.in).

A number of innovative works have been reported on the use of natural fibers to improve the mechanical properties of polymer composites. Dhawan et al. [4] investigated the effect of natural fillers on the mechanical characteristics of GFRPs and found coconut coir shows better mechanical properties as compared to the other fillers in glass/epoxy composites. Dhawan et al. [5] discussed novel approach for the prediction of forces during the drilling of composite laminates using artificial neural network. Jai Inder et al. [6] studied the effect of curing temperature on mechanical properties of jute fibers/epoxy based green composites and found that tensile and flexural strength are maximum when curing is done at 100 °C. Gomes et al. [7] studied the effect of high concentration alkali treatment on mechanical properties of curaua fibers/corn starch based green composites and the results proved that the appropriate alkali treatment is the key technology for improving the mechanical properties of green composites. Later on, many researchers have proposed various surface treatment techniques to improve the mechanical properties of polymer composites. Goriparthi et al. [8] studied the effect of fiber surface treatments on mechanical and abrasive wear performance of polylactic acid/jute composites and results of thermo-gravimetric analysis showed a higher thermal stability for silane treated composites. Lee et al. [9] investigated the interfacial adhesion of ramie/acetylated epoxidized soybean oil based green composites and found that silane treated fibers improve the interfacial property. Saenghirunwattana et al. [10] investigated the effect of surface treated corn husk fiber/soy protein based green composite on mechanical properties and found that significant improvement of all the mechanical properties were observed at 5 wt.% fiber loading with the use of silane treated corn husk fiber composite. During alkali treatment, fibers structure changes because of alkali's bleaching action which removes the lignin, waxy material and other impurities [11]. A lot of researchers have also contributed their research in the field of surface treatment of fibers for the thermal stability of polymer composites. Oza et al. [12] investigated the thermal behaviour of untreated and treated hemp/PLA based composites, and the results revealed that composites prepared with acetic anhydride modified hemp had 10-13% higher activation energy as compared to other composites. The present research initiative has been taken up to study the variation of curing temperature ranging from 160 °C to 190 °C on mechanical properties of Jute/PLA based green composite.

II. Experimental Procedure

A. Materials

The matrix used in this study is Polylactic Acid (PLA) with a density of 1.24 g/cc and purchased from the NatureWorks, India, and woven jute fiber is used as reinforcement. The biodegradable polymer is the thermoplastic polymer which is extracted from the cornstarch. Properties of PLA and jute fibers are mentioned in Tables I and II.

TABLE I
PROPERTIES OF POLY LACTIC ACID (PLA)

Properties	Values
Density	1.24 g/cc
Glass Transition Temperature	135 °C
Melting Point	150 °C
Spencer Impact	2.5 Joules

TABLE II
PROPERTIES OF JUTE FIBER

Properties	Values
Density	1.3 g/cm^3
Tensile Strength	393-773 MPa
E- Modulus	26.5 GPa
Elongation	1.5-1.8%

The tensile strength of the neat PLA was calculated by tensile tenting using a universal testing machine with the cross speed of 1 mm/min and the gauge length of 150 mm. Fig. 1 shows the polymerization process of PLA.

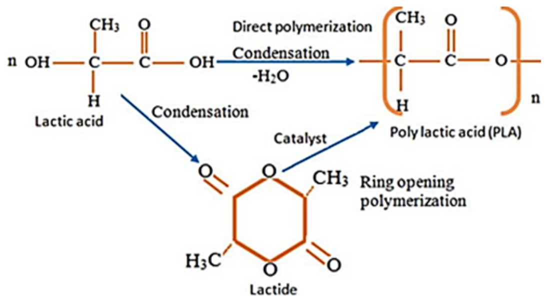

Fig. 1 Polymerization of PLA [1]

B. Development of Jute/PLA Based Green Composites

Jute fiber/PLA based green composites are developed with the help of hand lay-up followed by the compression moulding film stacking technique. In this process, bi-directional woven jute mat is used as the reinforcement and polylactic acid as the matrix material. The complete setup was equipped with the metallic die, heater rods, thermocouples, control panels, and compression moulding machine. Initially, woven jute fiber mat was washed with tap water to remove the dust particles and then dried under the sunlight for two days until its get completely dry. Metallic die consists of the upper and lower part with the drilled holes to add the heater rods into it. Metallic die was designed to develop 320 mm x 120 mm x 4 mm thick laminate sheets which were further cut as per the ASTM standards for mechanical testing.

After the pilot runs, it was decided to use four layers of jute fiber mat to develop 4 mm thick laminate. All the composites were developed with 25% fiber volume fraction at different temperatures. Fiber volume fraction of jute fibers was calculated using (1) [7].

$$V_f = 1 - \frac{W - W_f}{\rho_m V} \quad (1)$$

where Vf = Fiber volume fraction, W is the weight of the developed composite, Wf is the weight of the fibers in composite, V is the volume of the developed composite, and ρ_m is the density of matrix material. Fig. 2 shows the schematic of representation of film stacking technique.

Initially the jute fiber mat and PLA granuals were dried in the oven for 4 hours at 80 °C temperature to remove the moisture content. PLA pellets were converted into the PLA films of 1 mm thickness by compression molding machine at different temperature ranges. Initially 0.5 MPa of pressure was applied on the die for 5 minutes. Thereafter, pressure was increased to 3 MPa at the same temperature for another 3 minutes. The films are them allowed to cool under pressure, and finally films were removed at 80 °C. For jute fiber reinforced composites, woven jute fiber layer and PLA film were stacked alternatively in the metallic mold. 2 mm thick teflon sheet was used as releasing agent to avoid sticking of films with the metallic mold. The complete assembly was then hot pressed at defined temperature at the load of 60 kN for 6 min and then subsequently increases to 210 kN for 9 min and switch off the heaters to allow the complete die to cool and finally removed the composite at 80 °C. The thickness of the developed composites was 4 mm. All laminated were further stored in a desiccator till further use. The same procedure was adopted to develop the composites at different curing temperature. Fig. 3 shows the developed jute fiber reinforced PLA based green composites at three different temperatures 160 °C, 170 °C, and 180 °C.

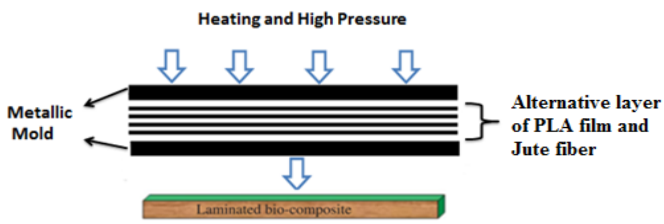

Fig. 2 Film stacking technique for the development of Jute/PLA based green composites

Fig. 3 Developed Jute/PLA composites at different curing temperature

C. Mechanical Properties

Tensile, flexural, impact and hardness test were performed as per the ASTM Standards D3039, D790-02, ISO 180:1993 and D2583 respectively. Specimens were cut for tensile, flexural and impact test as per the dimensions 250 mm x 25 mm x 4 mm, 120 mm x 15 mm x 4 mm, 63.5 mm x 12.7 mm x 4 mm, respectively. Tensile and flexural tests were performed on universal testing machine with the strain rate kept constant at the rate of 2 mm/min for all the specimens.

Izod impact tests were performed on the specimens as the ISO 180:1993, on an impact testing machine. V- Notched specimens were prepared by considering the equal distance from both the sides. The specimens were clamped in the die with providing the notch face of the specimen towards the face of the striker. Energy absorbed during the test was further calculated using (2):

$$\text{Izod Impact strength (kJ/m}^2\text{)} = \frac{Energy\ Absorbed\ in\ Joules}{width\ of\ the\ notched\ face\ X\ Length\ below\ the\ notch} \quad (2)$$

Hardness/degree of curing of the specimen is calculated using barcolhardner tester. It consists of the steel needle or cone which is pushed into the surface of the specimen, and the depth of penetration is indicated on a dial gauge. Fig. 4 shows the optical view of tensile and flexural testing on the universal testing machine.

D. Water Absorption Test

The water absorption test is performed as per IS: 1998-1962 [4]. A square test specimen of 38+0.5 mm was prepared. The specimen was first weighed in air (W_1), and it was submerged in water for one full day.

On the removal of specimen, it was wiped out properly by the clean cloth and then weight was measured and recorded as (W_2). Total waster absorption was calculated using (3).

$$\text{Water absorption} = \frac{W2-W1}{W1}\ X\ 100 \quad (3)$$

Fig. 4 Tensile and flexural testing of developed composites on UTM machine

III. Results and Discussions

A. Tensile Strength

Experimental results of tensile strength and Young's modulus for jute/PLA based composites are shown in Figs. 5 and 6. Results of tensile strength show that maximum of 9.76 MPa was recorded at 180 °C. It has also observed that, with increase in the temperature, tensile strength increases and then decreases after attaining the maximum value at 180 °C. The increase in the tensile strength from 160 °C is because of good adhesion between the matrix and fibers and which leads to good wettability of the fibers, and hence, strength increases. The decrease in the tensile strength at 190 °C is because of fiber burn out at higher temperatures.

Maximum Young's modulus of 1695 MPa was recorded at 180 °C. The increase in the tensile strength and Young's modulus was also mentioned by various researchers [6].

B. Flexural Strength

Fig. 7 shows the variation of flexural strength of developed composites at different curing temperatures. From the results, it has been observed that the flexural strength increases with increase in curing temperature and then decreases after attaining the maximum value of 18.8 MPa at 180 °C. Fiber burn out and fiber pull out are the main parameters effecting the flexural strength of jute/PLA composites.

C. Impact Strength

Impact strength of the composites was calculated using Izod impact testing machine. Results show that, with the increase in curing temperature, impact strength decreases. Maximum impact strength was recorded as 2 J at 160 °C. The decrease in the impact strength is due to the high cellulose content in the jute fibers and stress concentration near the interface between the matrix and the fibers, due to which less energy is required for the crack initiation. The figure shows the effect of curing temperature on the impact strength of jute/PLA composites.

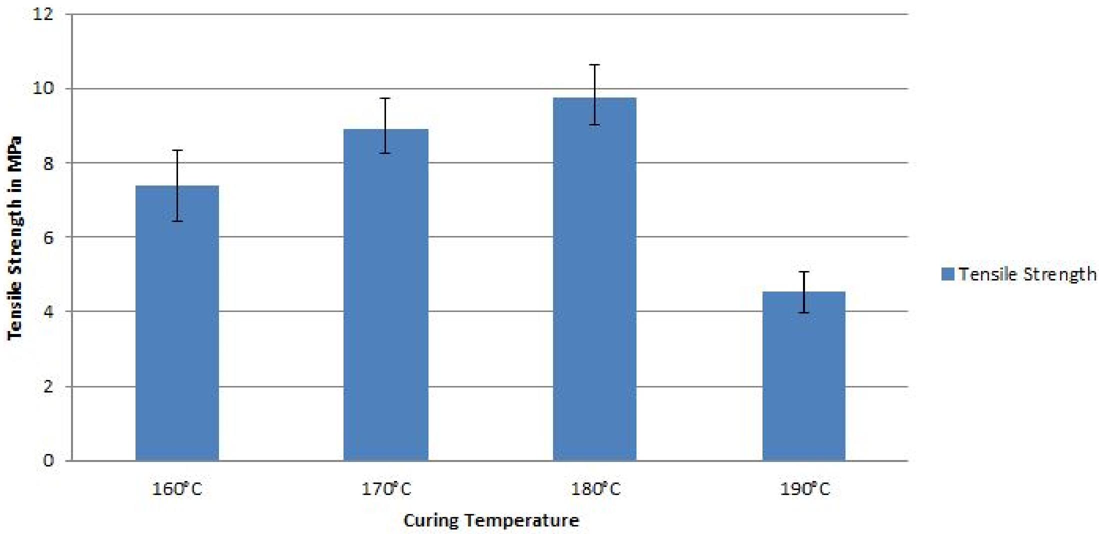

Fig. 5 Effect of curing temperature on tensile strength

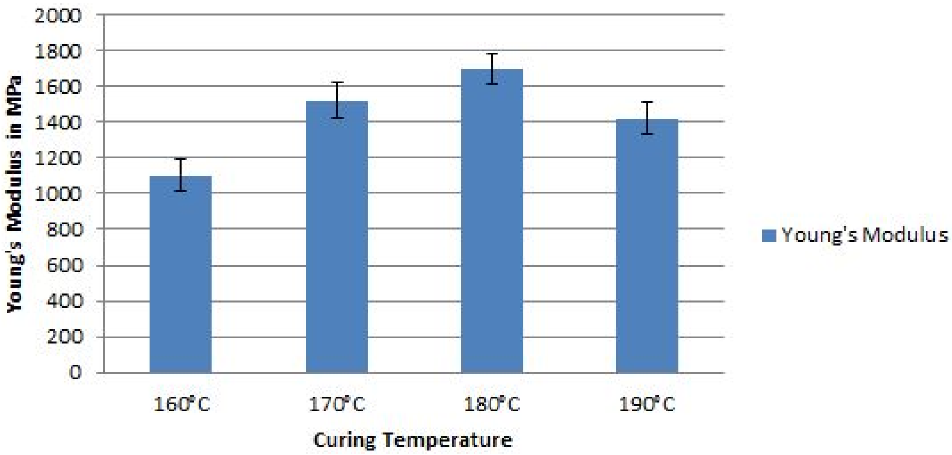

Fig. 6 Effect of curing temperature on Young's modulus

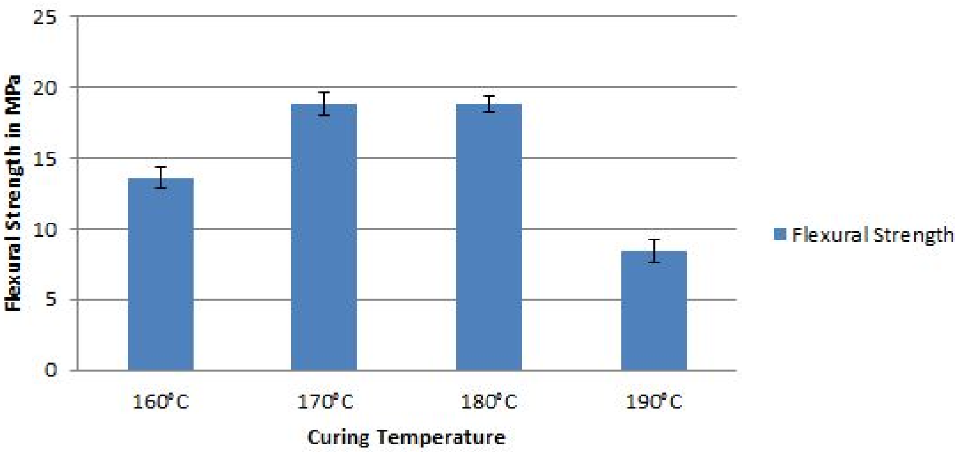

Fig. 7 Effect of curing temperature on flexural strength

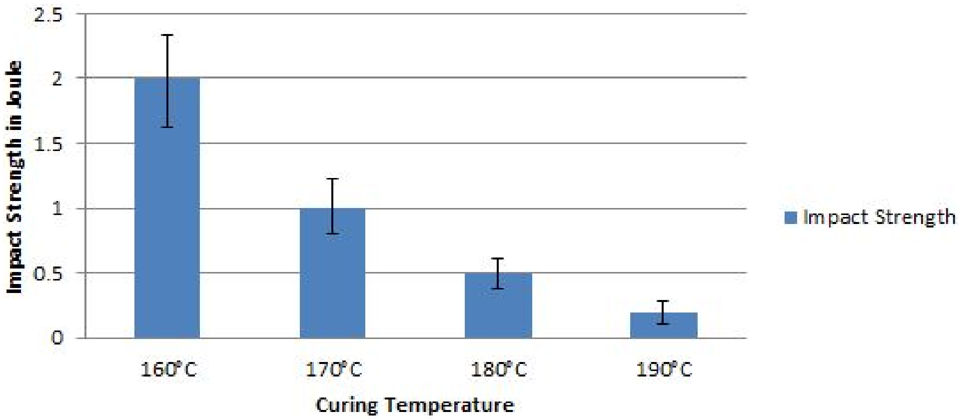

Fig. 8 Effect of curing temperature on impact strength

D. Water Absorption Test

The water absorption test is done according to the Indian standard IS: 1998-1962. The test specimen is 38 mm square with a 0.5-mm clearance. Firstly, the weight of the specimens was measured in air (W1), and then specimens were dipped in distilled water for a time period of 24+-1 hours. After completion of time, the specimens get out of water and measured the weight (W2) within 2 minutes. Figs. 9 (a) and (b) show the optical view of before and after water absorption.

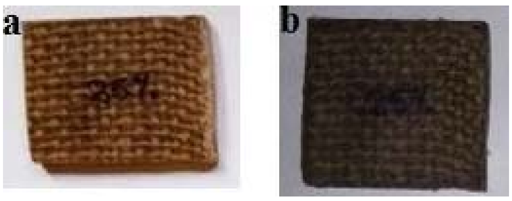

Fig. 9 (a) Composite before; (b) After water absorption

7% of water uptake has been observed in the results. During the observation, it clearly shows that the water uptake may result in the mechanical behavior of developed composites.

IV. Conclusion

In this study, Jute fiber reinforced Poly lactic acid based green composites were developed at different curing temperature 160 °C, 170 °C, 180 °C, and 190 °C. Mechanical properties of the developed composites were recorded and analyzed.

The following are the conclusions drawn from the study as.

1. Jute fiber reinforced poly lactic acid based green composites have developed successfully at different curing temperature 160 °C, 170 °C, 180 °C, and 190 °C using film stacking technique.
2. The tensile strength of the composite increases with increases in curing temperature till 180 °C and then decreases with further increase in temperature till 190 °C. Maximum tensile strength of 9.76 MPa was observed at 180 °C.
3. Flexural test results show the maximum strength of 18.83 MPa at 180 °C. It is observed that flexural strength increases with increase in curing temperature and then decreases after attaining the maximum value at 180 °C.
4. Maximum impact strength of 2 J was recorded at 160 °C and decreases with further increase in curing temperature from 160 °C to 190 °C.

Acknowledgment

The authors would like to thank School of Mechanical and Civil Engineering, Lovely Professional University, Phagwara, India for his support to perform tensile and flexural testing and other technical and infrastructural support is gratefully acknowledged.

References

[1] P. K. Bajpai, I. Singh, and J. Madaan, “Development and characterization of PLA-based green composites: A review,” *J. Thermoplast. Compos. Mater.*, vol. 27, no. 1, pp. 52–81, Mar. 2012.
[2] L. Yan, N. Chouw, and X. Yuan, “Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment,” *J. Reinf. Plast. Compos.*, vol. 31, no. 6, pp. 425–437, Feb. 2012.
[3] P. K. Bajpai, I. Singh, and J. Madaan, “Comparative studies of mechanical and morphological properties of polylactic acid and polypropylene based natural fiber composites,” *J. Reinf. Plast. Compos.*, vol. 31, no. 24, pp. 1712–1724, Oct. 2012.
[4] V. Dhawan, S. Singh, and I. Singh, “Effect of Natural Fillers on Mechanical Properties of GFRP Composites,” *J. Compos.*, vol. 2013, pp. 1–8, 2013.
[5] V. Dhawan, K. Debnath, I. Singh, and S. Singh, “Prediction of Forces during Drilling of Composite Laminates Using Artificial Neural Network: A New Approach,” no. January, 2015.
[6] J. Inder, P. Singh, S. Singh, and V. Dhawan, “Effect of Curing Temperature on Mechanical Properties of Natural Fiber Reinforced Polymer Composites Effect of Curing Temperature on Mechanical Properties of Natural Fiber Reinforced Polymer Composites,” *J. Nat. Fibers*, vol. 00, no. 00, pp. 1–10, 2017.
[7] A. Gomes, “Development and effect of alkali treatment on tensile properties of curaua fiber green composites,” vol. 38, pp. 1811–1820, 2007.
[8] B. K. Goriparthi, K. N. S. Suman, and N. Mohan Rao, “Effect of fiber surface treatments on mechanical and abrasive wear performance of polylactide/jute composites,” *Compos. Part A Appl. Sci. Manuf.*, vol. 43, no. 10, pp. 1800–1808, Oct. 2012.
[9] T. S. Lee, H. Y. Choi, H. N. Choi, K.-Y. Lee, S.-H. Kim, S. G. Lee, and D. K. Yong, “Effect of surface treatment of ramie fiber on the interfacial adhesion of ramie/acetylated epoxidized soybean oil (AESO) green composite,” *J. Adhes. Sci. Technol.*, vol. 27, no. 12, pp. 1335–1347, 2013.
[10] P. Saenghirunwattana, A. Noomhorm, and V. Rungsardthong, “Mechanical properties of soy protein based ‘green’ composites

reinforced with surface modified cornhusk fiber," *Ind. Crops Prod.*, vol. 60, pp. 144–150, Sep. 2014.

[11] J. Inder, P. Singh, V. Dhawan, S. Singh, and K. Jangid, "ScienceDirect Study of Effect of Surface Treatment on Mechanical Properties of Natural Fiber Reinforced Composites," *Mater. Today Proc.*, vol. 4, no. 2, pp. 2793–2799, 2017.

[12] S. Oza, H. Ning, I. Ferguson, and N. Lu, "Effect of surface treatment on thermal stability of the hemp-PLA composites: Correlation of activation energy with thermal degradation," *Compos. Part B Eng.*, vol. 67, pp. 227–232, 2014.