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Effect of process parameters on impact strength of short jute fibre reinforced polypropylene composite board

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The effect of temperature, pressure and treatment time on impact strength property of short jute fibre reinforced polypropylene composite board has been studied. Composite boards have been prepared from the web by using compression moulding technique. The best impact strength properties are observed if the composite board is manufactured by using low temperature (165°C), pressure (8.13 bar) and treatment time (3 min). The R^2 is found to be 0.89.

Keywords: Composite board, Impact strength, Jute fibre, Natural fibres, Polypropylene resin, Regression equation

1 Introduction

The use of economical agro-based renewable natural fibres such as jute, sisal, coir and bamboo in preparing composites by using various thermoplastic and thermosetting resins have successfully proven their high qualities in various fields of technical application in recent years[1-6]. Jute is a suitable natural fibre for use as reinforcement in composite because of its low cost, renewable nature and much lower energy requirement for processing. Jute is a strong, coarse and rigid fibre with very low extensibility which makes it suitable to act as reinforcing material in the composite. It is cheaper and process friendly[7].

The increased interest in using natural fibres as reinforcement in composite manufacturing to substitute conventional synthetic fibres in some structural applications has become one of the main concerns to study the potential of using natural fibres as reinforcement for polymers. In the light of this, researchers have focused on natural fibre composites (i.e. bio-composites) which are composed of natural or synthetic resins, reinforced with natural fibres. A composite containing at least one constituent (e.g. matrix or reinforcement) that is derived from readily renewable resources may be considered a bio-composite[8].

Advantages of a reinforcement by natural fibres result in their high absorptive behaviour, which creates excellent acoustics and an air cleaning effect. As far as industrial safety is concerned, natural fibres do not cause allergic reactions or skin irritations. Finally, a positive image and product marketing related to the utilization of a renewable material should be taken into consideration[9].

Polypropylene is vastly used in carpet, blankets and geotextile. Preference is given to polypropylene for its bulk, inert nature and low density. By blending jute with polypropylene the cost can be lowered and better material property can be maintained[10].

The present study highlights the effects of processing parameters on the impact strength of jute reinforced polypropylene composite board. Box-Behnken factorial design for three variables[11] is used to study the individual and interaction effect of choosen variables (temperature, pressure and time). A multiple regression analysis is also done to obtain the coefficients and the equation can be used to predict the response. The design is preferred because relatively few experimental combinations of the variables are adequate to estimate potentially complex response functions[12]. Extensive research has been carried out on the agro fibre plastic composites [13, 14].

2 Materials and Methods

2.1 Materials

The long staple jute fibre was bought from Jothi Jute Textiles Industry, Tamilnadu, India and then cut into the fibre length of 30mm. The jute fibre has the strength of 4 g/den, moisture regain of 13.5%, breaking extension of 1.6% and specific gravity of 1.48. The polypropylene staple fibre was

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bought from Zenith Fibres Ltd., Baroda, India. The polypropylene fibre has fibre length 51mm, denier 2.5, tenacity 6 g/den, melting temperature 160°C and specific gravity 0.91. In the composite board, the fibre reinforcement material is jute fibre and the resin is polypropylene.

2.2 Methods

2.2.1 Manufacturing of Composite Boards

Mixing of jute fibre with polypropylene (ratio 1:1) is done homogenously by manual blending. After the mixing of fibres (jute and polypropylene), these are fed into miniature carding machine for four times to ensure the homogenous blending and finally the web was produced. The webs were conditioned at 115°C for 24 h to remove any moisture present in it. Composite boards are produced from carded web by using compression moulding technique. Fibrous webs are cut into pieces and placed on the mould. Webs are stacked to get the required weight/unit area (1000 g/m^2). The platens are pressed to desired specific pressure and temperature for pre defined time to get moulded product. The widely used thermocouples temperature sensor was used to measure the temperature inside the stack and the temperature was regulated as per the requirement during composite manufacturing. After completion of compression cycle, the platens are cooled to optimum temperature and then the pressure is released to take out the board. Several of such fibre webs were compression molded by varying the process parameters such as temperature, pressure and time (Table 1).

2.2.2 Differential Scanning Calorimetry (DSC)

Differential scanning calorimetry (DSC) is a technique used to study the thermal transitions of a polymer. In most DSC design, two pans sit on a pair of identically positioned platforms connected to a heating source by a common heat flow path. One pan holds the sample of interest while the other pan is left empty as a reference. Turns on the heating source, will heat the two pans at a specific rate 10°C /min. The melting temperature (T_m) of a sample can be observed by a peak in the endothermic direction.

Table 1—Levels of variables chosen for the trials

Variables	Levels		
	-1	0	+1
Temperature, °C (X_1)	165	175	185
Pressure, bar (X_2)	5	10	15
Time, min (X_3)	3	6	9

2.2.3 Impact Strength Test

The test is performed based on the ASTM D256-93 (ASTM E290, 1990) in the charpy impact strength tester. Charpy impact tests were conducted on notched samples. Before the test sample was mounted on the machine, the pendulum was released to calibrate the machine. The test samples were then gripped horizontally in a vice and the force required to break the bar was released from the freely swinging pendulum.

The angle through which the pendulum has swung before the test sample was broken corresponded with the value of the energy absorbed in breaking the sample and this was noted from the calibrated scale on the machine. Seven specimens were tested and at least five imitate specimens were presented as an average of tested specimens. The unit of impact strength is observed in Joules.

2.2.4 SEM Analysis

The morphology and microscopy of composite samples were studied on gold coated tensile strength fracture surfaces by using JEOL JSM 5400 high resolution.

3 Results and Discussion

3.1 DSC and RSM Study

DSC curves of the polypropylene fibres using bulk sample and their melting temperatures obtained are studied. The latent heat of melting for the bulk sample is 100.142 J/g with a melting temperature peak at 160.43°C. By applying multiple regression analysis on the data, the experimental results of the full factorial central composite design are found to be fitted to the polynomial equation and the response surface equation of jute composite board on impact strength is shown in Eq. (1). The interactions are good enough to obtain a R^2 value of 0.89%. Equation (1) is shown below:

$$\text{Impact strength } (Y) = 1.016 - 0.395*(X_1) - 0.056*(X_2) - 0.271*(X_3) + 0.074*(X_1^2) - 0.293*(X_2^2) + 0.036*(X_3^2) - 0.087*(X_1X_2) + 0.057*(X_1X_3) + 0.250*(X_2X_3) \quad .... (1)$$

3.2 Impact Strength

The contour [Fig.1 (a)] shows the influence of pressure and temperature with respect to impact strength (Joule) by keeping the central value of time (6 min) as hold value. It is observed that the impact

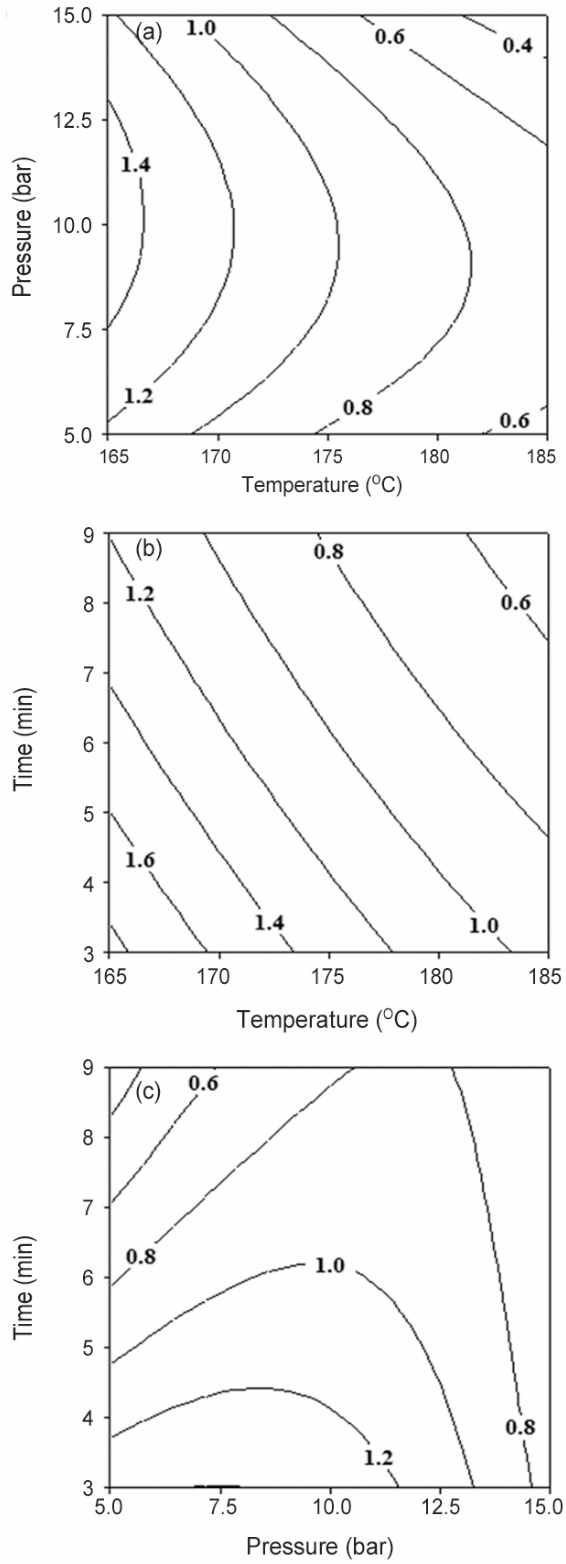

Fig. 1 —Contour diagrams of impact strength *vs.* (a) pressure and temperature (hold value: time 6 min), (b) time and temperature (hold value: pressure 10 bar), (c) time and pressure (hold value: temperature 165°C)

strength is increased with moderate pressure and minimum temperature. This is because an increasing processing temperature direct to lower viscosity of the binder component and thus to improved resin flow ability. These results in an improved fibre embedment during consolidation and therefore higher steadiness of the composite. In addition, an alteration of the fibre surface caused by thermal decomposition, leading to a weakening of adhesion between fibre and matrix, can also be implicit. The amount of pressure applied will determine the composite board stiffness and bulkiness respectively.

For the composite reinforced by natural fibres the measured impact strength depends strongly on the duration of the exposure to thermal condition. The relationship between time and temperature with respect to impact strength by keeping central value of pressure (10 bar) as hold value is shown in Fig. 1 (b). A continuous growth in impact strength can be observed with minimum time and temperature. This may be due to the fact that the decomposition of natural fibres will not occur during the lower temperature and short duration of thermal exposure.

The relationship between time and pressure with respect to impact strength by keeping central value of temperature (175°C) as hold value is shown in Fig. 1 (c). The impact strength is higher when the time is minimum and pressure is moderate. Increasing the time of exposure in thermal condition will make the resin to melt well and the interface between fibre and resin will also be high. Application of high pressure will make the composite board more stiff, which, in turn, reduces the impact strength.

3.3 SEM Analysis

Interfacial properties of short jute fibre reinforced polypropylene resin based composites are investigated by SEM. Fig. 2 shows the impact fracture surface of composite board. It clearly indicates that jute fibre pull-out is more if the temperature, time and pressure are high.

Impact strength of fibre reinforced materials is determined for the larger part by the energy dissipated during fibre pull-out. Fibre pull-out is presiding over by a competition between fibre breakage and interface failure and is thus determined both by the fibre tensile strength and by the interfacial shear strength. A higher fibre-matrix bond results in shorter average pull-out lengths and therefore causes lower impact strengths.

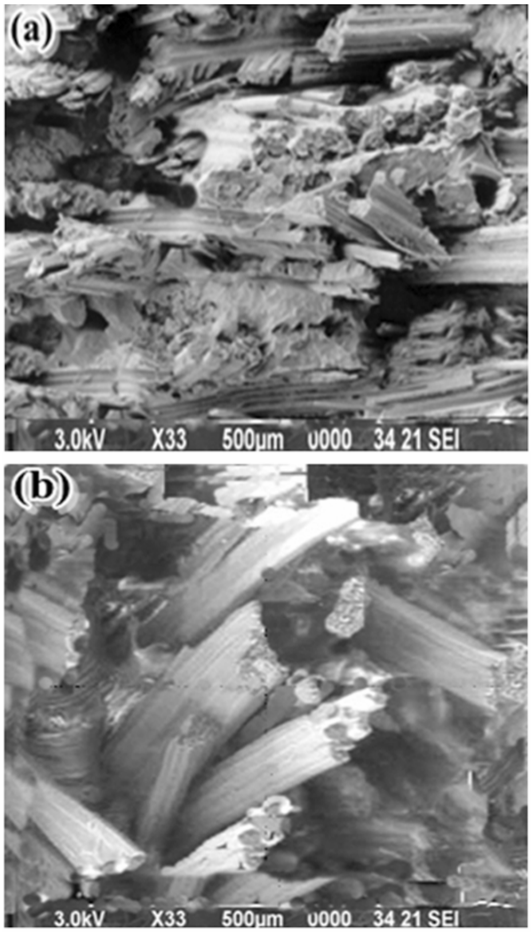

Fig. 2— SEM picture of impact fracture surface of composite board made with (a) high temperature, pressure and time, and (b) low temperature, time and moderate pressure

3.4 Response Optimization

With the help of Minitab 15 software the response optimization is obtained and from Fig. 3 it can be noted that the moderate increase in pressure increases the impact strength. There is no contribution made by temperature and time. To achieve the maximum impact strength from the available samples the optimum values would be temperature 165°C, pressure 8.13 bar and treatment time 3 min.

4 Conclusion

The results show that a useful short jute fibre-polypropylene bio-composite with good impact strength could be successfully manufactured with minimum temperature (165°C), treatment time (3 min) and moderate pressure (8.13 bar). The SEM image clearly reveals that processing variables have a significant contribution towards altering the fibre matrix interaction in the composites.

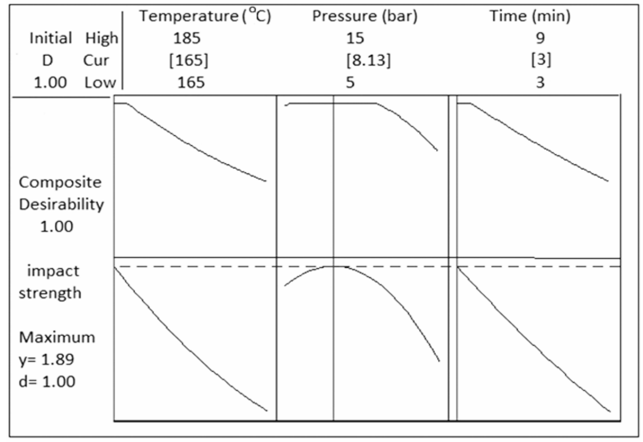

Fig. 3— Response optimization graph

The level of thermal contact, represented by the absolute processing temperature, as well as the preheating time, show a strong influence on the decomposition of natural fibres reinforced composites which is reflected in the impact strength properties. In conclusion, it can be assumed that this composite board can be used as a cost effective material in the field of technical textile.

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