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Flexural behavior of commingled jute/polypropylene nonwoven fabric reinforced sandwich composites

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In this study, flexural behavior of nonwoven fabric reinforced sandwich composites from jute and polypropylene (PP) fibers was investigated. Jute/PP composite plates reinforced with jute/PP commingled nonwoven fabrics of different jute/PP fractions were used as facing materials in sandwich production. Balsa wood, polyester (PET) foam and PP honeycomb were used as core materials. Jute/PP nonwoven fabrics were treated with NaOH solution prior to sandwich production in an attempt to improve the fiber–matrix adhesion and the quality of facing-core bonding. The flexural behavior of the sandwiches was investigated experimentally as well as using Euler–Bernoulli and Timoshenko beam theories. The flexural properties of the sandwiches improved as the jute fiber content increases. Euler–Bernoulli model yielded smaller deflection values when compared to experimental results whereas Timoshenko model provided a good estimation of sandwich flexural properties. The effectiveness of fiber/matrix adhesion and facing/core bonding was determined by conducting scanning electron microscopy (SEM) analysis.

1. Introduction

Natural fibers have a growing popularity as reinforcement materials for lightweight and environmentally friendly polymer composites which can replace glass fiber reinforced composites in certain industrial areas [1–3]. Natural fibers are eco-friendly, low-cost, renewable, biodegradable and sustainable as well as being sufficiently stiff and strong to be used as reinforcement materials [4–8]. The most common fiber types used for composite reinforcement are flax, jute, hemp and kenaf, as recent studies continually introduce new fiber types such as *Ferula communis* (chakshir) [9], *Arundo donax* L. [10], *Althaea officinalis* L. (Marshmallow) [11], *Sansevieria ehrenbergii* [12], Artichoke (*Cynara cardunculus* L.) [13] and piassava (*Attalea funifera*) [14]. Several studies have shown that the strength and stiffness of natural fiber reinforced composites are comparable with those of glass fiber composites on a per-weight basis [2,3]. Hence, natural fibers have emerged as a green alternative to glass fiber for the production of certain semi-structural parts in various industries such as automotive, packaging and construction [15–20]. Nevertheless, natural fiber composites have some limitations that compromise their performance as a product and impede their wide-scale usage. These include the poor bonding between natural fibers and polymer matrices due to different surface energies and affinity of natural fibers to moisture [21,22]. Studies generally addressed these issues for the purpose of improving the performance of natural fiber composites and expand their industrial usage. One of the most effective methods used for improving the properties of natural fiber composites is hybridization which combines at least two different fiber types in a matrix to achieve optimum properties. Several studies have shown that combining natural and synthetic fibers improves the resulting composite properties and compensates for the weak properties of natural fibers [23–25].

Jute is especially important as a reinforcement since it is abundantly available at a much lower cost when compared to other bast fibers, even though its strength and stiffness are somewhat lower than stronger fibers like flax and hemp [26]. Studies on jute fiber composites generally focused on improving the fiber/matrix interface by means of various fiber pretreatments. These include alkali (NaOH) treatment [27–29], use of coupling agents [30–32], dewaxing, bleaching, cyanoethylation and grafting [33,34]. Alkali treatment is a simple, low-cost and well-established fiber modification method whose effectiveness has been demonstrated by several studies. It has been shown that alkali treatment removes

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Table 1
The characteristics of untreated and alkali treated jute fibers, PP fiber and PP polymer [43].

Material	Linear density (tex)	Diameter (μm)	Tensile strength (MPa)	Young's modulus (GPa)	Breaking elongation (%)
Jute fiber (untreated)	2.81 ± 0.24	53.38 ± 5.93	369 ± 97	38.92 ± 10.52	1.18 ± 0.30
Alkali treated jute fiber (%4)	2.74 ± 0.20	49.00 ± 4.36	533 ± 17	42.40 ± 7.92	1.30 ± 0.25
PP fiber	0.66 ± 0.01	25.24 ± 0.04	548 ± 66	1.30 ± 0.30	30 ± 4.43
PP polymer (granules)	–	–	21.91 ± 0.96	1.21 ± 0.016	4.47 ± 0.21

Table 2
Specifications of the core materials used in the study.

Core type	Product code	Thickness (mm)	Density (kg/m^3)	Compressive strength (MPa)	Compressive modulus (MPa)	Shear strength (MPa)	Shear modulus (MPa)
Balsa wood	SB.100	12.7–19.1	153	12.9	4005	3	160
PET foam	T.90.150	15–20	150	2.0	90	1	30
PP honeycomb	PP8.80.T30.F75	15–20	80	1.6	70	0.5	13

pectin, hemicelluloses, wax and impurities from jute fiber and causes fiber fibrillation resulting in an easier penetration of polymer matrix into the fiber structure. This results in an improved fiber/matrix adhesion and hence, better composite properties [27–29].

Sandwich materials offer high mechanical properties and low weight. The use of sandwich structures was limited to aviation industry until 1960s. Today these materials are used in various industries including packaging, construction, marine and automotive. A sandwich structure is made up of a lightweight, thick core material and two thin and stiff facings bonded to the core with the aid of an adhesive. Metals and composites are commonly used as facing materials whereas balsa wood, various foams and honeycomb structures are used as core materials [35]. Utilization of natural fibers in sandwich panels is a new research topic and to date, a limited number of studies have been reported on the subject. Mallaiah et al. [36] investigated the flexural and compressive properties of sandwich composites reinforced with different natural fibers and glass fiber. Polyurethane (PUR) foam was used as core material. The compressive strength of jute fiber reinforced sandwich panel was reported to be similar to that of glass fiber reinforced sandwich. On the other hand, bamboo fiber reinforced

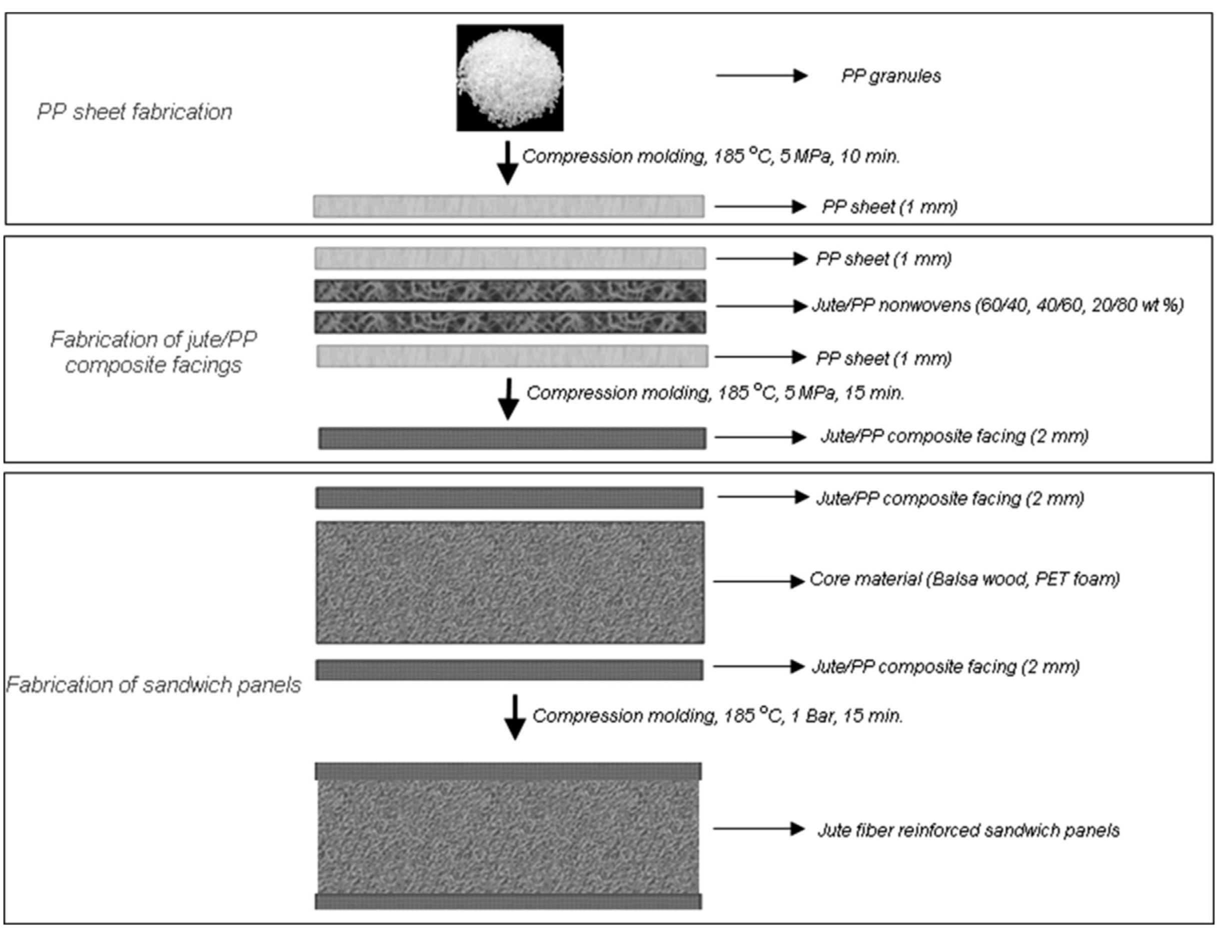

Fig. 1. Fabrication route for balsa wood and PET foam-cored sandwich panels.