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Developing high-performance hybrid green composites

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ABSTRACT

Particleboards made of a mixture of wood particles and short glass fibers as the core and two layers of woven jute fabric as skin layers were fabricated using a vacuum-assisted resin transfer mold. The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding (IB) were evaluated as indicators of mechanical performance. The vertical density profile, water absorption, and thickness swelling were analyzed to evaluate the physical performance. The results revealed that the proposed panels have excellent mechanical properties as compared to commercial wood composites. The MOR, MOE, and IB values for commercial particleboard composites are 14.69 MPa, 2.54 GPa, and 0.53 MPa, respectively, whereas the MOR, MOE, and IB for the proposed hybrid structure with zero glass fibers and no skin were 18.04 MPa, 2.99 GPa, and 2.18 MPa. Higher values were obtained by adding short glass fibers or using woven jute fibers as skin or both. The results indicated that the proposed sandwich composites exhibited excellent water resistance and dimensional stability as compared to commercial wood composites. The results also showed that these hybrid green composites with enhanced performance could be used in the construction and automotive industries.

1. Introduction

With increasing consumption of fiber-reinforced polymers, environmental concerns relating to the energy-intensive fabrication, sustainability, recyclability, and biodegradability of such fiber-reinforced polymers have been highlighted [1,2]. Utilization of lignocellulosic materials are a rapidly growing sector not only for commodities production, such as textiles, paper, and home furniture, but also for high-added-value products such as functionalized fibers and reinforcing elements in natural fiber-based composite materials. Lignocellulosic fibers are characterized by their low density, sustainability, availability at low cost and, in many forms, their easy recyclability and biodegradability [3–5].

Particleboard is known as a panel product manufactured from lignocellulosic materials in the form of particles combined with a binder and bonded together under heat and pressure. The primary difference between particleboard and other wood products, such as wafer board, oriented-strand board (OSB), medium-density fiberboard (MDF), and hardboard is the type of materials, particle size, and/or geometry used. The main types of wood particles used to manufacture particleboard are wood shavings, flakes, sawdust, wafers, chips, and wood strands. Particleboard is less expensive, denser, and more uniform than most other conventional wood products. It can be substituted for other types of wood when appearance and strength are less important than cost [6–8]. Table 1 shows modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding (IB) values defined by EN 312 (2010) concerning boards for use in dry conditions in different applications [9].

Many researches have been carried out to improve the mechanical and physical properties of wood particleboard using different materials and treatments. De Melo et al. [10] developed particleboard from wood (*Eucalyptus grandis*), bamboo (*Bambusa vulgaris*), and/or rice husk (*Oryza sativa*) particles. Five samples were produced as follows: 100% wood, 100% bamboo, 100% rice husk, 50% wood–50% rice husk, and 50% bamboo–50% rice husk. The 100% wood board showed the highest flexure and elastic modulus values of 16.15 MPa and 1.9 GPa, respectively. In another study [11], the potential of using wood biomass from fruit tree branches and evergreen hardwood shrubs as raw materials for particleboard when mixed with Greek fire wood particles was investigated. Particleboards with several combinations of the

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Table 1
Mechanical properties of P1, P2, P4, and P6 board types according to EN 312:2010 [9].

Board type	P1	P2	P4	P6
Utilization	General purpose for use in dry conditions	Interior fitments (including furniture) for use in dry conditions	Load-bearing board for use in dry conditions	Heavy-duty load-bearing boards for use in dry conditions
MOR (MPa)	10.5	11.0	16.0	20
MOE (MPa)	–	1800	2300	3150
IB (MPa)	0.28	0.45	0.40	0.60

abovementioned particles have been manufactured using traditional production methods. The highest MOR and MOE values were 27.78 MPa and 4.4 GPa, respectively. In the work of Holt et al. [12], composite boards were produced using cotton carpel, cotton stalks, kenaf, flax, southern yellow pine, and its blend. The highest values recorded for the MOR and MOE were 27.6 MPa and 4.5 GPa, respectively. Hemp-based composite materials were developed by Sassoni et al. [13], where panels were manufactured by bonding hemp hurds using a hybrid organic–inorganic binder under heat and pressure. Different samples with different bulk densities of 0.3 g/cm^3, 0.6 g/cm^3, and 1.3 g/cm^3 were manufactured. The flexural strength of the high-density panels were 17.4 MPa and the tensile strength was 1.8 MPa. These results are close to those reported by Holt et al. [12]. Khanjanzadeh et al. [14] investigated the MOE, MOR, IB, thickness swelling, and water absorption of wood particleboard made of different cotton stalks and underutilized paulownia wood particles with different blend ratios and using urea formaldehyde as the binder. 26.7 Ma and 2.9 GPa were the highest values recorded for the MOR and MOE, respectively. Various studies have been carried out to improve the mechanical and physical properties of wood particleboard using different lignocellulosic materials [15–18].

The goal of our study was to develop and evaluate high-performance particleboard in the form of a sandwich structure using lightweight and relatively thick core materials from lignocellulosic resources and thin, stiff woven fabric as skins. The vacuum-assisted resin transform molding technique (VARTM) was used to fabricate the final composite material.

2. Experimental

Sandwich biocomposite of wood particles mixed with different ratios of short glass fibers and sandwiched between two layers of jute woven fabrics will be fabricated in two steps. First, hot pressing will be used to fabricate the particleboard with low density (approx. 0.3 g/cm^3) in order to have a void between the wood particles to facilities the resin infusion between the wood particles during the VARTM process in the second fabrication steps. Jute woven fabric will be used as a skin layers in some samples to produce sandwich composite structure.

MOE, MOR and IB were analyzed to evaluate mechanical performance of the hybrid biocomposites. Density, moisture content (MC), thickness swelling (TS), and water absorption (WA) tests were carried out to obtain physical properties of the composites.

2.1. Materials

2.1.1. Wood particles

A wood particle mixture of 45% maritime pine (*Pinus pinaster*), 35% mixed pine wood growing in Turkey, and 20% mixed oak and poplar wood growing in Turkey were supplied by Kastamonu Integrated Wood Industry and Trade Inc., Turkey (Fig. 1). Wood particles were mixed with a 60% concentration of urea formaldehyde resin, with ammonium chloride as a hardener. The mixing procedure was repeated several times to ensure good distribution of the urea formaldehyde resin within the wood particles.

2.1.2. Glass fibers

Short glass fibers (12 mm long) were used as reinforcement. Ten samples were prepared by mixing the wood particles with different ratios of short glass fibers: 0, 5, 10, 15, and 20 wt%. The wood particles and short glass fibers were mixed manually inside a wood frame. The mixing procedure was repeated several times to ensure the homogenous distribution of the short glass fibers among the wood particles.

2.1.3. Woven jute fabric

Woven jute fabric acquired from the market was used as skin layers for the sandwich hybrid biocomposite. The jute fabric had a balanced plain weave 1/1 structure with an areal density of 280 g/m^2. Due to its balanced woven structure, jute fabric has almost

Fig. 1. Wood particles.

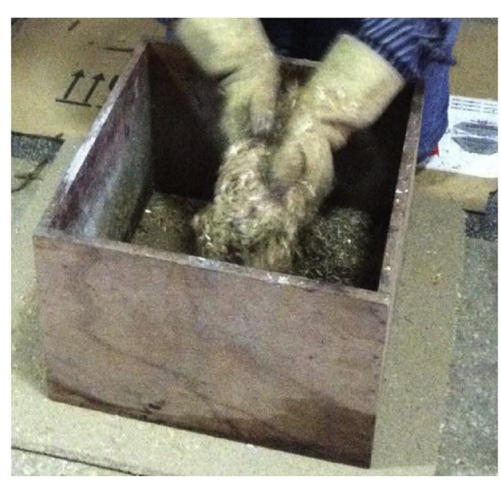

Fig. 2. Mixing procedure of short glass fibers and wood particles.