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Dynamic and ballistic impact behavior of biocomposite armors made of HDPE reinforced with chonta palm wood (Bactris gasipaes) microparticles

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A B S T R A C T

The mechanical behavior of chonta palm wood (Bactris gasipaes) microparticles reinforced high density polyethylene (HDPE) under high strain-rate compressive and ballistic impact loading were investigated. The palm wood microparticles were introduced into the HDPE via an extrusion process using parallel twin screw extruder to produce biocomposite containing 10, 20, 25, and 30 wt % chonta wood microparticles. In addition to mechanical tests, fractographic analysis was done to understand the failure mechanism in the biocomposites under dynamic and ballistic impact loads. The results indicate that both quasi-static and dynamic mechanical properties of HDPE are enhanced by reinforcement with chonta palm wood particles. The biocomposites containing 25 wt % wood microparticles exhibited the highest strength, stiffness, ballistic impact resistance and impact energy absorption capability. Introduction of microparticles of chonta palm wood as reinforcement into a polymeric matrix such as HDPE is therefore a promising method to develop biocomposites with enhanced capacity to withstand dynamic impact loading and absorb impact energy.

1. Introduction

Development of polymer biocomposites using natural fibers or wood particles as the reinforcing components is gaining increasing attention since synthetic fibers are expensive, non-biodegradable and their production is energy consuming, with the attendant negative impact on the environment [1]. The use of wood fibers and wood flours as reinforcement in thermoplastics have been intensified due to their several advantages over the traditional synthetic fibers like glass, carbon and Kevlar fibers. Reinforcing polymer with wood fiber or particles enables the development of innovative, lightweight, strong, and low-cost materials that can find application in different areas of engineering. Most importantly, natural fibres are renewable, recyclable and biodegradable materials [2–4], which are very crucial for environmental sustainability.

Chonta palm (Bactris gasipaes), also called pupunha palm, peach palm, or heart palm has origin in the tropical Latin American regions (Amazonia). Peach palm fruits are used in great proportion as food and oil products. Chonta wood palm is believed to be one of the hardest woods in the Amazonia for its strong and durable fibers and they can be used to make crafts, building parts, and weapons for hunting and fishing [5]. Because of these properties, chonta palm fibers or wood particles offers innovative resource for reinforcement for polymer matrix composites. For example, heart palm residues have been used to build agglomerate and plywood panels, chopped fibers and polyurethane resins were mixed in a plywood mold, resulting in panels that can meet the ANSI 208.1 standard for flexural strength of particle boards [6]. Temer and Almeida [7] investigated the tensile properties of heart palm fibers and reported a low tensile strength, but a relatively high Young modulus that is superior to those of other palm fibers such as coir or piassava, and comparable to those of traditional lignocellulosic jute and sisal fibers.

Wood-plastic composites (WPCs), also called biocomposites, are polymer matrix composites containing wood fibers, whiskers or particles as organic reinforcing components. The polymer matrix could be thermoplastic such polypropylene, polyethylene among others, or even thermosetting resin such as epoxy. Chemical additives can be introduced during the manufacture process to improve the bonding between components of the WPCs. The reinforcing organic component improves mechanical and thermomechanical

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properties of the polymer matrices, those properties and mainly strength properties can be controlled depending of the type of natural reinforcement (particles, fibers, whiskers) and the volume fraction of the reinforcing components [8–12].

Biocomposites produced using different natural fiber reinforcements such as cotton, jute, flax, hemp, ramie and sisal fibers have been widely reported. For example, jowar fibers have been used to reinforce polyester, resulting in biocomposites with higher strength and rigidity for light weight applications compared to the polymer reinforced with the conventional sisal or bamboo fibers [8]. Reinforcement with oil palm empty fruit bunch fibers (OPF) has been reported to improve the tensile modulus and impact resistance of polypropylene and polyester resin, although the tensile modulus of epoxy resin decreased as a result of reinforcement with OPF [13]. Reinforcing polymer with Kenaf (KE) and palm empty fruit bunch fibres (EFB) resulted in increased tensile strength and flexural strength of polymer and the strength of the resulting composite increase as the weight fiber was increased to 40%. However, increasing fiber content in excess of 60% led to deterioration of properties, which was attributed to excessive clustering of fibre leading to debonding under mechanical load [14]. It was reported that the flexural strength of polypropylene increased while the Charpy impact strength dropped when the polymer was reinforced with the heart-of-peach waste residue [15]. On the other hand, Farias et al. [16] reported 157% increase in Izod impact strength of polyester when reinforced with leaf stalk fibers extracted from peach palm. Santos et al. [17] reported no significant improvement in tensile and impact properties of peach palm fiber reinforced polyester as a result so surface treatment of the fiber with NaOH or C_3H_3N. However, the composite's impact strength improved after surface treatment with H_2O_2, although surface treatment of the peach palm fiber did not improve the tensile strength of the composites.

Pupunha or heart palm in different varieties such as short and long fibers, leaf-stalk, and residues after harvest have been used to reinforce different polymeric matrices [6,7,14–17]. To the best of our knowledge, however, the dynamic impact response and the energy absorption behavior of the biocomposites produced with heart palm fiber or particles under ballistic impact loading have not yet been reported. In the current study, microparticles of chonta palm wood are used in reinforcing high density polyethylene (HDPE) to develop high performance biocomposites. The impact resistance and energy absorption capability under ballistic impact as a result of this particulate reinforcement are investigated and discussed in this paper.

2. Material and experimental procedure

2.1. Materials

High density polyethylene (SCLAIR 2909), used in this study, was supplied by NOVA Chemicals. The polymer characteristically has high stiffness, good impact strength and toughness. It has a density of 0.962 g/cm^3, melt mass-flow rate (MFR) of 13/10 g/min at 190 °C. High density polyethylene (HDPE) exhibits better energy absorption capability, stiffness, yield behavior and higher strength than low density polyethylene (LDPE) and low-linear density polyethylene (LLDPE) under dynamic compression loading [18]. The reinforcing material, chonta palm wood, was supplied by Indubalsa S.C. (Ecuador) in rectangular pieces that are 150 mm long, 30 mm wide. The thickness of the pieces range between 15 and 25 mm.

2.2. Biocomposite processing

The chonta palm wood pieces were cleaned and cut into small wood chips. Initial moisture content of the wood chips was measured using a Wagner moisture meter (MMC220), which was determined to be 40 wt % before drying. The dried wood chips were kept at 105 °C for 24 h in order to significantly reduce the moisture content. These were then milled using a Retsch knife (SM 2000) grinding mill with a sieve size of 0.75 mm. Chonta palm powder with particle sizes ranging between 500 and 750 μm was obtained. These chonta palm powder was further dried in Supermatec (Hotpack) industrial electric oven for 24 h at 105 °C in order to reduce the humidity of the wood microparticles to less than 1 wt %. This result is obtained by measuring the initial weight of wood chips (before milling) and the final weight of wood powder (after milling and drying process). A higher percentage of humidity will result in a porous composite. The HDPE was also milled in the Retsch knife grinding equipment, but with a screen of 1 mm and carbon dioxide gas flowing through to prevent a temperature increase that could affect its properties. Preliminary mixing of the polymer and chonta wood microparticles before extrusion was done using a rotatory type mixer (National hardware, Dresden, ON) at a speed of 90 RPM for 15 min. The operating parameters of the parallel twin screw extruder (SHJ-35) are: melting pressure (0.5 MPa), motor rotating speed (215 RPM), feeder speed (50 RPM), and a line temperature that was varied in the sequential order: 140-150-155-160-170-175-180-185-220 °C.

The extrusion process was first carried out by feeding the wood palm particles/HDPE mixture from the hopper into the barrel of an extruder through a feed throat. The mixture was gradually melted by heaters arranged along the barrel. Additional heat was generated by the intense pressure and frictional forces inside the barrel. At the end of the barrel, the molten mixture passed through a screen pack to remove contaminants from the melt. The molten mixture was then pushed into a die, which shaped it into long noodles that are cooled subsequently by water immersion and air flow. These long noodles were formed into cylindrical pellets with length ranging from 2 to 5 mm using a LQ-60 pelletizer. These pellets were dried at 75 °C for 48 h. They were subsequently cured in a fluid bed dryer at 55° C for 30 min in order to eliminate any moisture remaining. Pellets obtained were weighed before and after the drying process, and the moisture content of the pellets was estimated to be 0.7 wt %.

A Dake compression molding machine was used in forming the test specimens in a square mold (20 × 20 cm). During compression molding of the specimens, 200 g of the pellets (mixture of polymers and wood particles) were compressed at a constant pressure of 8.08 MPa at 160 °C for 10 min. Since lignin decomposes at temperatures ranging from 200 to 500 °C [19], thermal degradation of lignin wood materials will not occur at the selected compression temperature. Its original properties will therefore be retained during the elevated temperature thermoplastic forming. The resulting biocomposite plates were water-cooled for 30 min while the applied pressure was maintained to ensure better dimensional stability of the composites as the plates were cooled. The test specimens were cut from the obtained 200 × 200 × 5 mm plates. Similar manufacture procedure was used in previous studies, when hybrid composite armors were developed by addition of different types of micro- and nano-fillers to Kevlar short fibers to reinforce HDPE [20]. Unreinforced HDPE (HDPE neat) as reference sample and biocomposites samples containing 10, 20, 25 and 30 wt % of chonta wood particles were produced and characterized. The biocomposites are respectively codenamed Ch10, Ch20, Ch25 and Ch30 with two-digit figure standing for the weight percent of the chonta palm wood particles in the composites.

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