UPCYCLING OF WASTE BURLAP BIOMASS: ADVANCED BIOCARBON FILLED –POLYPROPYLENE BIOCOMPOSITES WITH IMPROVED PERFORMANCE AND REDUCED FLAMMABILITY FOR ELECTRIC VEHICLE PARTS USES

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EXTENDED ABSTRACT

Abstract brief: The electric vehicle parts need to be lightweight, strong with reduced to zero flammability. Bio-carbons from different waste biomass have been found to be effective sustainable fillers in enhancing the mechanical properties of composite materials. With this in mind, we have produced highly advanced biocarbon from waste burlap fiber at different operating conditions and studied the mechanical strengths and flammability of the biocarbon-filled polypropylene biocomposites. The catalyzed biomass-derived biocarbon (named as advanced biocarbon) has increased the tensile properties of the biocomposites. More importantly, the developed advanced biocarbon increased the flame retardant behavior of the developed biocomposites making those as better materials for use in electric vehicles with added advantages of lightweight and eco-friendliness as compared to mineral and short glass fiber-filled counterparts.

Introduction

Bio-based composites have numerous applications in diverse fields of our everyday life including the automotive industry such as auto body components, seatbacks, parcel shelves, boot and door linens. They are also widely applied in construction materials, aviation as well as in the area of electronics and electrical engineering. Hence, in addition to the required mechanical strengths, their flammability performance is also an important parameter to decide possible areas of application. Biobased composites are made up of two or more different components to produce a new material with better performance over the individual components.

The objective of this work was to produce different types of advanced biocarbons from waste burlap biomass and mix them with polypropylene matrix at various formulations to produce a biocomposite with better mechanical strengths and reduced flammability properties for possible applications in electric vehicles.

Materials and Methods

Waste burlap was pyrolyzed at 600˚C (called BC600 hereinafter), and this sample was further pyrolyzed to 1200˚C with and without catalyst (BC1200 and BC1200C hereinafter) to produce the other two biocarbon samples. The catalyst was prepared from iron nitrate (99.95% purity from Sigma-Aldrich). The iron nitrate was first dissolved in distilled water to produce 10% aqueous solution. Similarly, the biocarbon from BC600 was mixed with distilled water at 20:80 ratio (biocarbon to water ratio). Then the metal catalyst was poured into the biocarbon solution making a 2% catalyst concentration in the mixture. The mixture was then stirred for 2 hours at 80˚C, dried for a day in oven, resulting in moisture content below 1% and finally pyrolyzed at 1200˚C, 20˚C/min.

Composites Manufacturing and Mechanical Strength Measurements

To produce the impact, tensile and flexural specimens of biocomposites; 80% of PP was dry mixed with 20% of the biocarbon and then fed to a 15-cc micro compounder (DSM Xplore, Netherlands) with three independently controlled heating zones all set to 180ºC. Five specimens were produced with each type biocarbon-filled PP composite sample and tested for their tensile, flexural and impact, properties following the ASTM D638, ASTM D790 and ASTM D256 testing standards, respectively.

Flammability Tests

Flammability was measured following the ASTM D635-14. Briefly, the flexural bar specimen, which was used for flexural testing, was supported horizontally at one end. The free end was exposed to gas flame for 30 s. Time and extent of burning were measured, recorded and then used to determine the flammability of the materials.

Results and Discussion

The biocomposite processed with 80% PP and 20% of BC1200C has the highest flex modulus which was 25% greater than the neat PP. Similarly, the tensile modulus enhanced significantly (24%) from that of the neat PP. The lower particle size [1] and homogenous distribution [2] of the BC1200C, seen by the SEM images (Figure 1), have attributed to the improved flexural and tensile moduli of the BC1200C. Smaller particles are better encapsulated in the polymer matrix which can improve the dispersion and resist deformation for flex and tensile forces [3]. The stress transfer from the matrix to the biocarbon can also improve the tensile and flexural strengths of the materials [4]. However, the main reason behind these higher flexural and tensile moduli of the BC1200C is the high content of highly graphitized biocarbon in the sample; which has been demonstrated by the Raman spectra and high resolution transmission electron microscopy (HRTEM) results of the sample. It is worth mentioning that adding small amount of graphitic biocarbon to a polymer matrix improves the mechanical strength of the composite significantly [5]. The addition of BC600 in the polymer matrix reduced the flex modulus by 31%; which could be related to the poor biocarbon distribution in the matrix leading to its early failure. There was no significant change in impact strength however, adding the graphitized biocarbons reduced the flammability of the PP-based composite. The bar made from the neat PP has flammability of 21 ± 0.45 mm/min but slightly reduced to 20 ± 3 with BC1200 and further reduced to 18 ± 3 mm/min with the BC1200C. The graphitic nature of the bio-carbons at high temperatures has improved the thermal stability and fire resistance property of such biobased composites [6] (Sienkiewicz and Czub 2020).

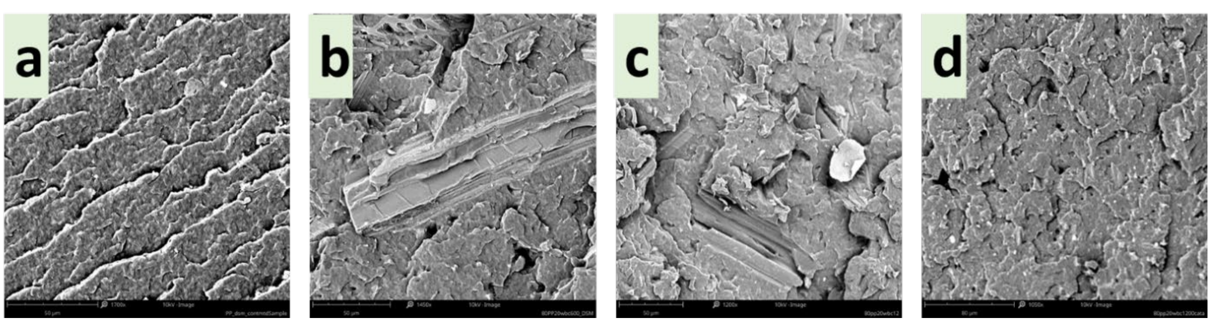

Figure 1. SEM images of the biocomposites, (a) neat PP, (b) 80% PP with 20% BC600, (c) 80% PP with 20% BC1200, and (d) 80%PP with 20% BC1200C

Table 1. Elemental analysis of the different burlap chars

Samples	H/C	O/C
BC600	$3.2x10^{-2}$	0.5
BC1200	$2.2x10^{-3}$	0.1
BC1200C	$4.3x10^{-4}$	0.07

Graphitized carbon is thermally stable. As can be noted from the CHNS analysis – Table 1, the hydrogen to carbon and oxygen to carbon ratio of the biocarbons significantly reduced with temperature. For example, the O/C for BC1200C is 86% and 30% lower than that of BC600 and BC1200, respectively. Which means the catalytically graphitized biocarbon (BC1200C) has high amount of carbon in the sample followed by the uncatalyzed sample (BC1200) and the lowest carbon content was found with BC600 which was only 63%.

Adding metallic catalyst during the graphitization process increased not only the carbon content but also structured the carbons to be more graphitic in nature.

In summary, addition of the char powders to the PP has improved the mechanical and flame retardant behaviours of the bio-based composite made out of it, hence can be applied for heat management in lightweight automobile and electrical vehicles.

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