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Date palm biochar-polymer composites: An investigation of electrical, mechanical, thermal and rheological characteristics

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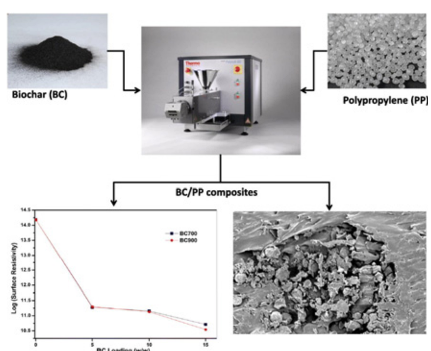
HIGHLIGHTS

- Date palm waste derived biochar was used as filler for polymer composites' applications.
- Biochar/polypropylene (BC/PP) composites' properties such as electrical, mechanical, thermal and rheological were investigated.
- The BC/PP composites' surface resistivity was decreased by four orders of magnitude.

GRAPHICAL ABSTRACT



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ABSTRACT

The application of biochar (BC) as a filler in polymers can be viewed as a sustainable approach that incorporates pyrolysed waste based value-added material and simultaneously mitigate bio-waste in a smart way. The overarching aim of this work was to investigate the electrical, mechanical, thermal and rheological properties of biocomposite developed by utilizing date palm waste-derived BC for the reinforcing of polypropylene (PP) matrix. Date palm waste derived BC prepared at (700 and 900 °C) were blended at different proportions with polypropylene and the resultant composites (BC/PP) were characterized using an array of techniques (scanning electron microscope, energy-dispersive X-ray spectroscopy and Fourier transform infra-red spectroscopy). Additionally the thermal, mechanical, electrical and rheological properties of the BC/PP composites were evaluated at different loading of BC content (from 0 to15% w/w). The mechanical properties of BC/PP composites showed an improvement in the tensile modulus while that of electrical characterization revealed an enhanced electrical conductivity with increased BC loading. Although the BC incorporation into the PP matrix has significantly reduced the total crystallinity of the resulted composites, however; a positive effect on the crystallization temperature (T_c) was observed. The rheological characterization of BC/PP composites revealed that the addition of BC had minimal effect on the storage modulus (G′) compared to the neat (PP).

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1. Introduction

Environmental pollution due to unabated disposal of organic wastes, coupled with the global climatic changes have disturbed the balance of nature to a great extent. One of the major causes of environmental pollution is due to the reckless disposal of organic waste which generates significant quantities of greenhouse gases (GHG), adversely affecting the climatic conditions. Judicious disposal of organic waste is of great prominence in today's world (Rushton, 2003). There is an urgent need to convert organic wastes into value-added products which would help not only in waste mitigation, but also enable to save and conserve energy (Xiu et al., 2017; Giusti, 2009). The organic wastes can be effectively converted into a useful renewable material called biochar through the pyrolysis of bio-wastes in a limited or oxygen free atmosphere (Balwant et al., 2010; Kookana et al., 2011). In addition to biochar, other valuable byproducts of bio-waste pyrolysis are bio-oil, hydrogen, chemicals etc. can be utilized as an alternative energy resources (Alonso et al., 2012; Huber et al., 2006; Lehmann, 2007; Zhou et al., 2011). The benefits of biochar and its applications for agricultural purposes as a soil amendment agent are well established to some extent, these applications include high crop yield, soil water retention, enriching of soil quality and storage of atmospheric carbon (Balwant et al., 2010; Creamer et al., 2014; Van Zwieten et al., 2009). Designer engineered biochar can be produced with high quantities of fixed carbon and with specific surface functional groups as well as high surface area according to the targeted niche application. In other words, the surface functionality and porosity of the biochar can be tuned for the synthesis of engineered functional materials suitable for different applications such as: catalysis (González et al., 2017; Lee et al., 2017), energy storage (Cheng et al., 2017; Xiu et al., 2017), pollutant removal (Tan et al., 2015) and CO_2 capture applications (Mohd et al., 2013; Sethupathi et al., 2017). Furthermore; biochar has porous honeycomb structure with high thermal stability favorable for contaminant remediation agent applications (Balwant et al., 2010; Kilic et al., 2013; Srinivasan et al., 2015; Usman et al., 2015).

The demand for reinforced plastics has grown rapidly and accordingly the carbon based filler composites as well. The carbonaceous materials such as carbon black (Manjaly Poulose et al., 2015; Zhao et al., 2014), carbon nanotubes (CNT) (Krause et al., 2009; Ma et al., 2014), carbon fiber (Kasgoz et al., 2014; Tekinalp et al., 2014) and graphene (Du and Cheng, 2012; Wang et al., 2016) have been widely used as reinforcing and conductive fillers in polymer composites. Production of petro-based carbon materials needs tedious synthetic methods and is not environmentally and economically viable. Efforts have been made to explore various renewable carbon resources as the feedstock that are environmental friendly, cost effective and are abundant in nature.

In recent years; there is a scope for the successful application of biochar in thermoplastic composites due to its porous structure, large surface area, high carbon content which could facilitate the physical bonding with the polymer matrix (Das et al., 2015c). Biochar has been successfully incorporated with different types of polymer matrices for improving their mechanical, electrical and thermal properties such as polyamides (Huber et al., 2015), polyesters (Richard et al., 2016), poly (vinyl alcohol) (PVA) (Nan et al., 2015), styrene-butadiene rubber (SBR) (Peterson, 2012; Peterson et al., 2015), poly (trimethylene terephthalate) (PTT) (Myllytie et al., 2016), epoxy (Ahmetli et al., 2013), poly (trimethylene terephthalate/poly (lactic acid) (PTT/PLA) blend (Nagarajan et al., 2016) and polypropylene (Das et al., 2016a, 2016b). For instance, the impact strength of the polyester having particle loading of 2.5% w/w of biochar (45 nm particle size) increased by 77.50% and its dielectric constant increased by 7% when compared with the neat polyester resin (Richard et al., 2016). The PVA/biochar composites filled with 2 and 10%, w/w of biochar exhibited electrical conductivity values similar to carbon nanotube and graphene reinforced PVA composites. The thermal stability, tensile modulus and storage modulus of PVA/biochar composites were improved with BC addition (Nan et al., 2015). Partially replacing the carbon black (CB) with biochar in SBR matrix improved the tensile strength, toughness and elongation of the composites (Peterson, 2012). PTT/biochar composites exhibited good dimensional stability, 89% increase in heat deflection temperature, 60% increase in flexural modulus and 14% increase in flexural strength in comparison to neat PTT (Myllytie et al., 2016).

Biochar is more advantageous than the natural fibers as a filler in polymer composites since the properties of biochar can be altered by modifying the pyrolysis conditions for achieving the hydrophobic nature in biochar (Das et al., 2015) and to obtain greater compatibility with the polymer matrix than the hydrophilic natural fibers (Monteiro et al., 2012). The thermal stability of the resulting biochar composites has been reported to be higher than the composites with natural fibers such as jute, sisal, flax, hemp, coir and cotton (Monteiro et al., 2012). In general, carbon fillers are incorporated into polymers to improve the mechanical, thermal, electrical and chemical corrosion resistance properties compared to metal filled composites (Das et al., 2016a; Das et al., 2016c; Das et al., 2015a; Das et al., 2015b). Improving one or more of these properties is desirable for the many applications such as for electrostatic dissipation material, electromagnetic interference shielding, semiconducting layer to prevent electrical discharge (Khushnood et al., 2015). The end properties of the resultant composites are determined by many factors such as the matrix and the filler characteristics, matrix-filler interactions and dispersion of the filler particles in polymer matrix (Manjaly Poulose et al., 2015; Alig et al., 2012). For example, the electrical conductivity of the composites is determined by the dispersion of fillers and network formation in polymer matrix above a threshold value of filler concentration (percolation threshold) (Danqi Ren et al., 2014).

Date palm (*Phoenix dactylifera*) is highly cultivated crop in Saudi Arabia, it is estimated that >23 million date palm tree is cultivated annually which produce around 780 thousand tons of agriculture residues per year as a seasonal pruning and refinement of palms (Usman et al., 2015; Miandad et al., 2017). This huge amount of agricultural wastes produced are either burned in farms or disposed in landfills which cause a serious environmental pollution. The major constituents of date palm biomass are cellulose, hemicellulose, lignin and volatile contents which could converted into biochar. In this study, the biochar was prepared by the pyrolysis of date palm waste (Usman et al., 2015). The pyrolysis conditions such as temperature, pressure, heating rate and duration of heating are the most important factor for controlling the physical and chemical properties of the biochar prepared (Das et al., 2015b; Usman et al., 2015). Generally it has been found that biochar prepared at higher pyrolysis temperatures (>500 °C) yields larger surface area (Usman et al., 2015; Joseph et al., 2010) due to the removal of volatile impurities clogged in its pores. Though there have been a few studies utilizing biochar in polymer composites (Das et al., 2015a, 2015b, 2015c, 2016a, 2016b, 2016c, 2016d; Ogunsona et al., 2017), to date, the application of biochar derived from date palm waste has not been investigated. Furthermore, the effect of biochar addition on the electrical conductivity of BC/PP composites has not been reported in the literature. Generally, biochar characteristics and its stability are mainly dependent upon feedstock and pyrolysis conditions. It has been reported that biochars produced at high pyrolysis temperature have high content of fixed carbon, predominately recalcitrant aromatic C structure and high thermal stability (Zhao et al., 2017; Usman et al., 2015;

Table 1
Elemental composition, moisture, ash content and BET surface area of biochar samples in percentages.

Sample	Moisture	Ash	C	H	N	O[a]	SSA[b] (m^2/g)
BC700	3.48	20.57	66.70	1.01	0.19	8.05	283.62
BC900	3.06	21.35	69.38	0.65	0.21	5.35	291.11

[a] Obtained by deduction.
[b] BET specific surface area.