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Characterisation of waste derived biochar added biocomposites: chemical and thermal modifications

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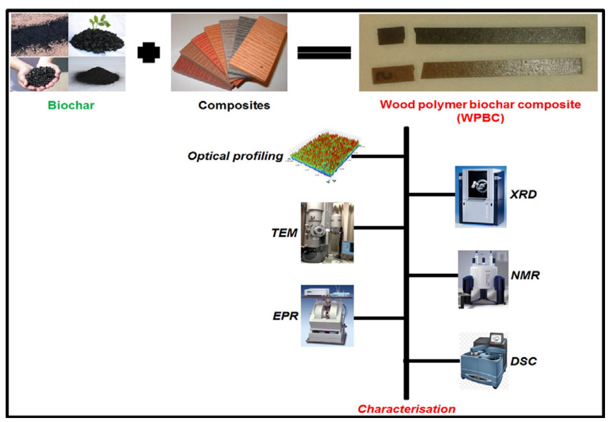
HIGHLIGHTS

- Waste derived biochars were used to make polymer based biocomposites.
- Composites were characterised by NMR, ESR, DSC, XRD, TEM etc.
- Biochar increased the thermal conductivity of composites.
- Biochar did not disrupt the crystal structure of polypropylene.
- NMR revealed aromatic nature of biochar in composites.

GRAPHICAL ABSTRACT



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ABSTRACT

A step towards sustainability was taken by incorporating waste based pyrolysed biochar in wood and polypropylene biocomposites. The effect of biochar particles on the chemistry and thermal makeup of the composites was determined by characterising them through an array of characterisation techniques such as 3D optical profiling, X-ray diffraction, transmission electron microscopy, electron spin/nuclear magnetic resonance spectroscopy, and differential scanning calorimetry. It was observed that addition of biochar increased the presence of free radicals in the composite while also improving its thermal conductivity. Biochar particles did not interfere with the melting behaviour of polymer in the thermal regime. However, wood and biochar acted as nucleation agents consequently increasing the crystallisation temperature. The crystal structure of polypropylene was not disrupted by biochar inclusion in composite. Transmission electron microscopy images illustrated the aggregated nature of the biochar particles at higher loading levels. Nuclear magnetic resonance studies revealed the aromatic nature of biochar and the broadening of peak intensities of composites with increasing biochar levels due to its amorphous nature and presence of free radicals. Thus, this insight into the chemical and thermal modification of biochar added composites would allow effective engineering to optimise their properties while simultaneously utilising wastes.

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1. Introduction

Owing to the problems related with the application of petroleum based products, it becomes critical to resort to methods and processes that encourage and facilitate the development of bio-based renewable materials (Das and Sarmah, 2015a). These materials would potentially be able to curtail the ubiquitous dependency on synthetics and simultaneously utilize organic wastes. Furthermore, the bio-based materials would stimulate the concept of sustainability while being capable of being resilient, diverse, efficient, and adaptable (Fiksel, 2003). The renewed interest in natural products spurred by ecological concerns led to the keywords of 'recyclability' and 'environmental safety' when introducing and developing new products and materials (Das et al., 2015a). Additionally, most developing nations are facing problems arising from the landfill disposal of organic wastes (Das et al., 2015b). The regional councils and local governments are, thus, focussing their attention on a long term and alternative solution for organic waste utilisation.

In the light of the popularity, necessity, and importance of polymer based materials, the sustainability of their feedstocks becomes an important consideration. The philosophy of 'eco-design' and 'green' products is being applied in manufacture of polymeric materials which avoid the application of petroleum based products while maximising bio-based feedstocks and minimising the production of recalcitrant wastes (George et al., 2001). Extensive investigations have been conducted where polymeric materials have been reinforced with numerous natural fibres (hemp, jute, kenaf, coir, etc.) and waste derived organics (Ashori, 2010; Ashori and Nourbakhsh, 2010; Netravali and Pastore, 2014). However, the natural and waste based reinforcements have the disadvantages of being uncertain in their quality and possess inconsistencies in their physical properties (Das et al., 2015a). Therefore, innovative waste based materials with coherent structure and chemistry; need to be explored to comprehend their ability to be used as additives in polymer composites.

The organic wastes can be converted to a carbonaceous material called biochar through the process of pyrolysis (Das and Sarmah, 2015b). Biochar is comparatively cheaper and renewable material which, at present, lacks value added applications other than the conventional carbon sequestration, soil amendment, and contaminant removal (Das et al., 2015b). In order to bestow biochar with versatility in its application potential, previously unexplored avenues should be considered. Recently Nan et al. (2015) added biochar (loading rate of 2 wt.% and 10 wt.%) with polyvinyl alcohol to create composites having comparable electrical conductivity to graphene and carbon nanotube based composites. The authors also reported an improved moduli of the biochar added composites along with an elevation of thermal stability. Elsewhere, biochar has been used as reinforcements in styrene–butadiene rubber and epoxy resin with promising results (Ahmetli et al., 2013; Peterson, 2012). Additionally, building walls made with biochar are being investigated at the Ithaka Institute, which could be potential controller of humidity, heat, electromagnetic radiation, etc. (Schmidt, 2013). In the areas of polymer composites Das et al. (2015a, 2015b, 2016) proposed and conducted biochar addition in wood and polypropylene (PP) composites. The authors found that the addition of biochar to wood and PP composites (WPBCs) enhanced the tensile/flexural strength and modulus compared to conventional wood plastic composites (WPCs). More recently, DeVallance et al. (2015) used hardwood biochar to fabricate wood and polymer composites and Ho et al. (2015) manufactured polylactic acid (PLA) composites with bamboo biochar. Biochar was thus realised to be an effective addition in polymer composites having advantages, which is two-fold in nature: firstly, improving the mechanical and physico-chemical properties of composites and secondly, utilizing organic wastes.

Given the potential of waste derived biochar for fabrication applications, there is a need to comprehend and quantify the chemical, thermal, mechanical, etc. effects that biochar particles have on polymer composites. Structurally, biochar has porous honeycomb structure with a carbon backbone, whereas, chemically, biochar may exhibit several functional groups (hydroxyl, aliphatic, etc.) on its surface (Das and Sarmah, 2015b). Due to the physical and chemical difference between biochar and polymer, their unique interaction would determine the interfacial adhesion and eventually would control the stress transfer and bond distribution. A clear comprehension of the complex nature of biochar integrated within a polymer is essential to enable effective engineering of the composites, and to enhance the usefulness of biochar as a constituent of composites.

Almost all the cognizance towards characterisation of bio-based polymer composites is mostly limited to infrared spectroscopy, thermogravimetry, scanning electron microscopy, and the conventional mechanical tests (tension, bending, impact, etc.). As the application of biochar in wood and polymer composites is at its infancy, a more in-depth investigation becomes necessary to fully understand its effect on the chemistry and thermic properties of the resulting composites. Only a few studies have conducted characterisation of polymer based composites using unconventional (for polymer composites) techniques of nuclear magnetic resonance (NMR), electron spin resonance (ESR), and transmission electron microscopy (TEM). Luetkmeyer et al. (2007) characterised the molecular dynamics of composites made from wood and high impact polystyrene using a low field solid state

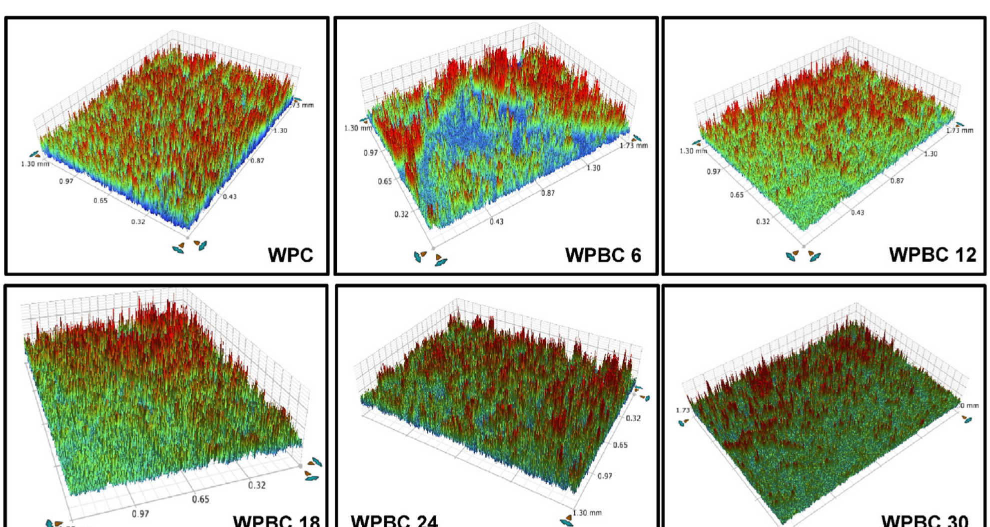

Fig. 1. 3D Optical profiling of composites.