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Wettability Properties of Biochar Added Wood/ Polypropylene Composites

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Abstract

In an attempt to comprehend the outdoor application potential of biochar reinforced wood and polypropylene composites, their wettability properties were investigated. The localised water affinity was measured through drop shape analysis in a Goniometer whereas the comprehensive susceptibility towards water was done through a thickness swell test. The results indicate that the addition of 12wt% of wood waste (*Pinus radiata*) biochar to a wood and polypropylene composite had the highest resistance towards water among the three component composites. In general, the predilection towards water increased with an increase in the amount of biochar in the composites. It is recommended to produce the biochar with low pyrolysis temperature (yielding a more hydrophobic biochar) to develop composites with acceptable water opposing properties.

Keywords: Wood; Polypropylene; Biocomposites; Biochar; Wettability; Goniometer

Introduction

Increased environmental awareness and diminishing natural resources have together provided the impetus to explore and use materials that are waste based. These motivations coupled with regulation-based impetus enforced by government and regional councils have led to the research and development of innovative waste-derived products [1,2]. Biochar is a renewable material which can be produced by valorising any organic biomass (e.g. forestry, crop residue, poultry waste, dairy manure) in an oxygen free environment by a pyrolysis process [3]. Until now, the application of biochar was limited to soil amendment, filtration and contaminant/heavy metal removal [4]. In order to make its application diverse, the biochar derived from organic wastes was incorporated with conventional wood and polymer composites to yield wood polymer biochar composites (WPBC) [5-7]. Through these works, the authors have demonstrated that biochar could be applied as reinforcement in wood polymer composites to improve their mechanical, thermal and fire properties as well as to reduce the use of costly coupling agents. The development of wood polymer and biochar composites requires the knowledge of its physico-mechanical properties. The mechanical, chemical and thermal properties of the WPBC were evaluated by Das et al. [5] However, prior to the application of this composite, it is critical to comprehend the endurance of WPBC towards external environment. Similarly, to other wood polymer composites (WPCs), WPBC can be applied in making decking material, windows and door panels and automotive parts [8]. These types of applications may expose the WPBC to rainfall and humid conditions, hence, the wettability properties of WPBC should be investigated.

WPBC consists of three distinct constituents (biochar, wood and polymer) that differ in their interactions with water. The physical and chemical properties of the different constituents of WPBC may stay distinct macroscopically in the final product while exhibiting synergistic material properties [9]. As a result, individual components would have an additive effect on the final physico-chemical nature of the composites. This would consequently affect the overall wettability properties of WPBC.

The main objective of the study was to investigate the resistance of WPBC towards water in general and specifically how different loading amounts of biochar in the composite affected the resulting wettability.

Materials and Methods

The detail description of the process and methods used to develop biochar added wood and polymer composites can be found in Das et al. [5]. Briefly, the constituents were dry blended, then melt blended in an extruder and finally compression moulded to manufacture the samples. Six different samples were manufactured containing 0, 6, 12, 18, 24, and 30 wt% biochar, which was produced by pyrolysis of waste pine wood. The samples were named WPC (control, 0 wt%

biochar reinforcement), WPBC 6; WPBC 12; WPBC 18; WPBC 24 and WPBC 30, based on the weight percentage of biochar in them. After manufacturing of the WPC and WPBCs, wettability properties were investigated.

Localised wettability was measured in a Goniometer (KSV instruments, Finland, Model: CAM101, software: Attension Theta) through drop shape analysis. The contact angles of deionised (D.I.) water (volume= 4µl) was measured (mean of right and left contact angles) on a flat sample surface at an interval of 60 s for a period of 20min. Swelling tests were carried out according to ASTM D-7031-04 protocol. Three specimens of each formulation were selected at random and bone dried in a convection oven for 24h at 105 °C. This was followed by cooling the samples to room temperature in a desiccator. The specimens were then immersed in D.I. water for 24h at room temperature. The excess water on the surface was wiped off by tissue paper. The values of the thickness swelling in percentages were calculated using the following equation:

$$TS = \frac{T(f) - T(i)}{T(i)} \times 100$$

where,

TS= Thickness swell in percentage

T(f)= Final thickness

T(i)= Initial thickness

Results and Discussion

Figure 1 shows the localised water absorption of the WPC and WPBCs measured with a Goniometer. Figure 1a shows the changes in contact angles of water on the composite's surface with respect to time, whereas, Figure 1b shows the difference in initial and final contact angles for each sample. The initial contact angle at 1min was not indicative of the samples' affinity (i.e. degree of absorption) towards water. The noteworthy observation is how the contact angle changed i.e. became smaller with respect to time. It can be observed from Figure 1a that all the composites follow a similar pattern when wettability towards water is concerned: with time, the contact angle decreased representing the movement of water into the surface of the composite and evaporation.

The composites' affinity towards water can be understood by the change in the initial and the final contact angle of water droplet. The higher the difference is between the final and the initial value of contact angle, the higher is the affinity towards water. It is clear from the Figure 1b that the composites having higher amount of biochar (WPBC 18, 24 and 30) had a higher affinity towards water. This is attributed to the lower amount of the hydrophobic polymer (i.e. polypropylene) in the blends. WPBC 30 had the highest affinity towards water, as the polypropylene content was the lowest among all blends. Though biochar can be hydrophobic provided they are made at lower pyrolysis temperature (<400 °C) [10], the one used in this study was made at 450 °C. As the pyrolysis temperature is raised, the volatiles escape creating pores on biochar surface. Water can be absorbed into these pores through capillary action. Hence, the higher temperature biochar's inherent affinity towards water and the lower content of the hydrophobic polypropylene made the composites with higher amount of biochar more susceptible to water. Additionally, the increase in the amount of biochar also increased the proportion of wood in each blend [5,11]. The prominence of the wood component further made the composite samples containing higher amounts of biochar more susceptible to wetting. This is because the wood is naturally hygroscopic due to formation of hydrogen bonds between wood biopolymers and the water molecules [12].

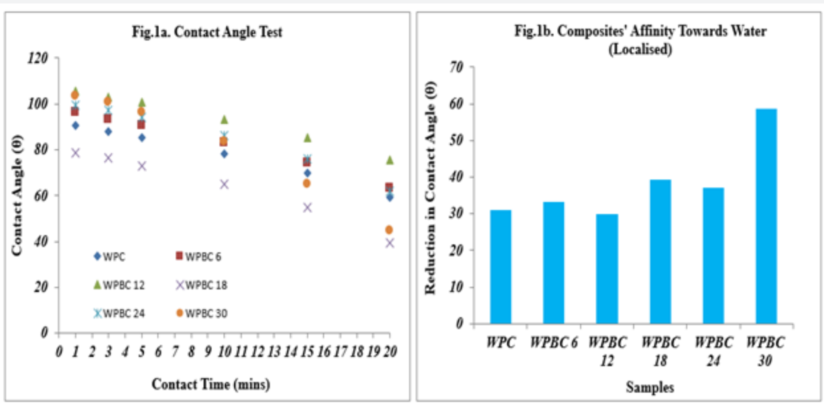

Figure 1: Goniometer measurement of contact angles of WPC and WPBCs.

Figure 2 shows the shape of the water droplet, as seen through the goniometer telescope, on the flat surfaces of each samples at intervals of 1, 3, 5, 10, 15, and 20min. WPC (control) was most resistant to water compared to all the composites containing biochar. Similar to the observation made from Figure 1a and 1b, the contact angles drastically decreased in the WPBC samples containing more biochar (WPBC 6, 18, 24, and 30). An exception was WPBC 12, where the amounts of wood, biochar and polymer were optimal to provide it with maximum resistance towards water. WPBC 12 and WPC had an almost similar resistance towards localised water absorption. This observation corroborates the results of Figure 1b.

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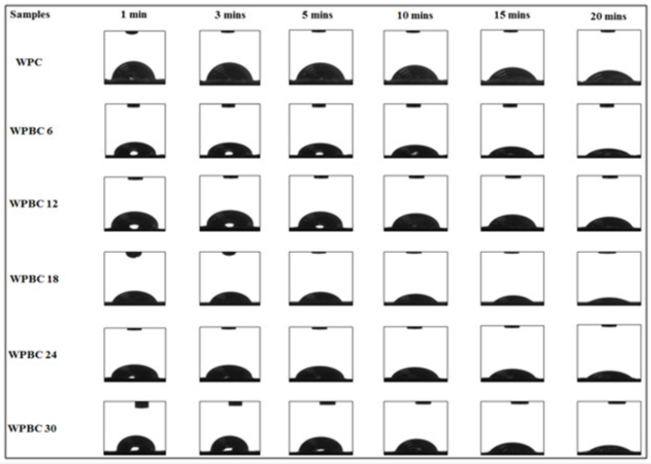

Figure 2: Water droplet as seen through Goniometer telescope.

Figure 3 shows the percentage thickness swell of the samples after immersion in water for 24h. It can be seen that, in general, there was a gradual increase in the thickness swell as the amount of biochar increased in the samples of WPBC (not considering WPBC 6). This trend is attributed to the increased amount of less hydrophobic biochar, decreased amount of hydrophobic polypropylene and increased contribution of hydrophilic wood [5]. The thickness swell value for WPBC 6 was the highest among all WPBCs and this was probably due to the presence of voids formed during its manufacturing [5]. The voids acted as pockets for the increased collection of water and consequently increased in size leading to WPBC 6's overall high thickness swell. Theoretically, WPBC 30 should have had the highest swelling value but from Figure 3 it can be observed that both WPBC 6 and 30 have identical swelling values (13.8 and 13.8%, respectively). Hence, it becomes clear that the presence voids from manufacturing are detrimental for the wettability properties of composites having biochar additive. On the other hand, the composite WPBC 12 had the lowest swelling value (12.7%) among all WPBCs, which is in agreement with the observation made in Figure 1 & 2.

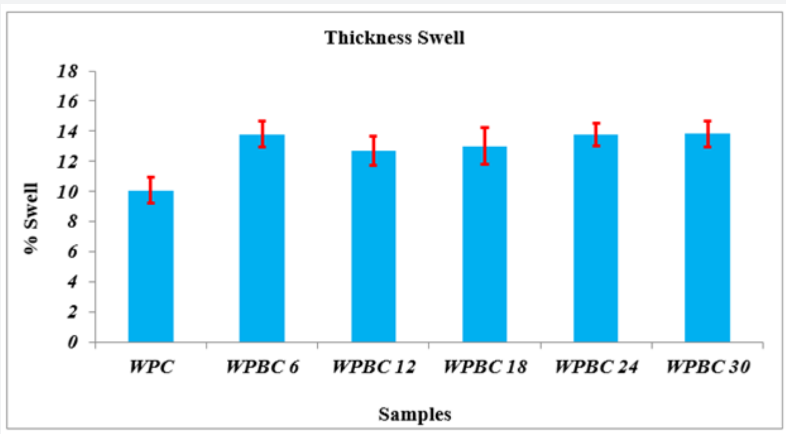

Figure 3: Thickness swelling values of WPC and WPBCs.

The swelling of any WPBCs was higher than the control (WPC). This is not favourable when application of WPBC in field conditions is considered. However, to make a composite resistant to the swelling, it is recommended to use biochars that are made at lower pyrolysis temperatures (<400 °C). Biochars made at lower temperatures have pores that are clogged by the tar, which is unable to escape during pyrolysis. Due to the presence of tar, these biochars exhibit hydrophobic aliphatic groups on their surface [13]. This clogging also makes the number of pores and the surface area smaller. Hence, the collective effect of hydrophobic tar on the surface and pore clogging lowers the affinity of the biochar towards water [14]. On the other hand, biochar made at lower pyrolysis temperatures tend to have a lower content of elemental carbon and lower hardness [4,15], which consequently reduces the quality and reinforcement ability of this biochar. In order to make a high-quality biocomposite, an optimal production temperature of biochar should be chosen to obtain a hydrophobic biochar containing a high amount of elemental carbon and having an increased hardness.

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Conclusion

From the investigation conducted on the wettability properties of wood and polypropylene composites having a biochar additive, the following conclusions can be drawn:

i. The addition of 12wt% of biochar in a wood and polymer composite bestows it the highest resistance towards water.

ii. The increase of biochar content in the composite makes it more susceptible to water.

iii. High production temperature of biochar increases its affinity towards water (absorption through capillary action of pores); hence such biochar type is not recommended for reinforcing composites aimed for the robust hydrophobicity.

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