Biodegradable composites from bamboo Fibers - Mechanical and Morphological Study

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Research Article

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Abstract

Realizing the need for conservation of environment due to contamination caused as a result of disposal of non-biodegradable waste. It has compelled researchers to search a new green material as a substitute to these toxic materials. The present research work focused on particularly the effective usage of Cellulose nanocrystalline (CNC) extracted from bamboo fibers as reinforcement in PLA/PBS polymeric blend. Polymer blend composites were fabricated using the hot-pressing technique with varying CNC contents. The morphological and mechanical properties of the composite samples with varying CNC contents were investigated. The results revealed that there was a positive effect of incorporation of CNC (extracted from bamboo fibers) on the properties of the polymer matrix.

Introduction

Due to growing concern for environmental degradation and renewable resource depletion, green and eco-friendly materials are preferred [1]. Natural polymers and cellulose are expected to be an appropriate way of solving such environmental issues. The possibility of using cellulosic reinforcements in composite materials has been studied extensively since long time. During the past two decades the growth of development of polymer composites based on renewable raw materials such as natural fibers has increased significantly [2, 3]. Natural fibers offer a suitable, low-cost, eco-friendly reinforcement for materials employed in various applications such as packaging, panels, and secondary and tertiary structures, that require high mechanical properties [4, 5]. This makes utilization of natural cellulose more interesting. Cellulosic fibers is now regarded as an efficient reinforcement material due to their ease of availability, low cost, renewability, high toughness, biodegradability, acceptable specific strength and low specific gravity [6, 7]. Various cellulosic fibers are preferred as reinforcements such as waste cotton, sisal, mulberry, roselle, jute, flax, and pine needles [8, 9]. These are mostly added to polymers that are produced from natural resource due to their biodegradability and acts as a possible solution for waste disposal [10]. One such polymer is poly-lactic acid (PLA). PLA is considered as a good polymer for several applications because it possesses good thermal, mechanical, and biodegradable properties [11]. However, it has some drawbacks, such as poor melt strength, brittleness, low thermal stability and low impact strength [12]. Also, higher price of PLA diminishes their possibility of commercialization. Their properties can be modified by blending them with other suitable polymer which is also biodegradable and possess comparably excellent impact strength, flexural properties, melt processibility and also reduces the overall material cost. PBS having good biocompatibility, is a highly flexible and eco-friendly polyester with better impact strength [13, 14]. Thus, to combine the desirable properties of blend polymers, PLA-PBS are blending thereby forming a potential matrix for development of biodegradable composites[15, 16].

In this study, the morphological analysis and mechanical testing of the PLA-20PBS blend composites developed by hot pressing techniques with varying wt.% of CNC (0, 0.5, 0.75, 1, 1.5wt.%) were investigated. The optimum mechanical properties were analyzed by tensile testing, and the morphological studies were carried out through atomic force microscopy (AFM) and scanning electron microscopy (SEM) analysis of fractured surfaces.

Experimental Procedure

Materials and Methods

PLA (154°C, 1.24 g/cm^3) and PBS (95 ˚C, 1.26g/cm$^{3)}$ were used as received. CNC's were isolated from bamboo fibre via acid hydrolysis technique. Bamboo fibres were pretreated with NaOH (17 wt.%) aqueous solution, followed by 40% of sodium hypochlorite and lastly with NaOH to eliminate the residual lignin, fatty acids, and other impurities, and also to remove the hemicellulose and lignin from bamboo pulp, respectively. Then finally treated with sulfuric acid ((64%,100 ml) at 45 °C for 45 min thus extracted CNC are acquired in the form of powder. The CNC of length of 200-500nm and 10nm average diameter [17] were mixed with PLA and PBS in a melt mixer at 175 ˚C with rotor speed of 60 rpm for 10 minutes and composites were prepared with fixed wt% of PBS (20%) and varying CNC content (0,0.5,0.75,1 and1.5). Followed by crushing the mixture via crusher and then finally compressed in a hot press at (Temperature:180 ˚C; Pressure:150 MPa: Reheat: time:5 min; and Pressing time: 4 min). All the samples were post-cured at 50 ˚C for 24 hrs.

Characterization and testing

Morphological analysis of composites

The morphologies of bio-composite films were analyzed by AFM. The analysis of fractured surface of tensile tested films was carried by Hitachi Model S-3400N SEM. Before examination, to prevent electrostatic charging, the fractured surfaces were sputter coated with gold.

Mechanical testing

The tensile testing was performed on a Lloyds LRX universal testing machine. Samples of dimension 10 mm× 100 mm were used for analysis. The tensile test was conducted s per ASTM D638-14 (2014) method at a constant cross head speed of 5 mm/min. The tensile strength, elongation at break, and tensile modulus were acquired from stress-strain curve.

Results And Discussions

Morphological analysis

AFM analysis was carried out to get more insights on the morphology of developed polymer composites, i.e., showing the miscibility/immiscibility of PBS with PLA, and the dispersion/distribution of CNC within PLA-PBS blend as shown in Fig.1(a-e). Moreover, the topography of the surface was determined by three dimensional (3D) topographies in Fig.1(f-j). Fig.1(a) displaying the PLA-PBS sample with the smoothest surface as compared to other composites. In addition, the AFM images of PLA-PBS composite obtained from either adhesion (Fig.1(a)) imaging do not exhibit a two-phase system, i.e., least dark regions are observed, implying that PBS is miscible with PLA. However, the surface topography becomes rougher

with the addition of CNC and roughness increases with increase in CNC content as evident from Fig.1(b-e) and 3D topography in Fig.1(g-j).

In case of CNC reinforced PBS-PLA blends, a phase separation is observed due to presence of the interface between the flat surfaces and peaks. When the CNC content is higher, more sharper peaks are observed, as indicated by darker areas on the surface Fig.2(g–j), thereby exhibiting the better dispersion of the CNC's [18]. The depth histogram presented by Fig.2, reveals the maximum depths of the of PLA-PBS-CNC (0, 0.5,0.75,1 and 1.5wt.%) composites in the range of 35-45, 38-47, 45-50 and 80-90 mV respectively. However, with increase in CNC loading the threshold depths of the dispersed phase increases significantly and reveals pronounced phase separated morphology as compared to PLA-PBS blend. Hence, the AFM analysis confirms a better dispersion of CNC's were attained throughout the blend composites.

The SEM micrography of the fractured surfaces of PLA-PBS-CNC with CNC (0, 0.5, 0.75, 1 and 1.5wt.%). The fracture surface of PLA-PBS is rougher, indicating a ductile behaviour, this may be due to presence of PBS reducing brittle nature of PLA[19]. Moreover, there was no debonding observed in the composites with CNC's upto 1wt.%, implying good matrix–CNC interactions. This interaction results into improved tensile strength of composites as evident from Fig.4. However, the fracture surface of composite with 1.5wt.% of CNC exhibited lot of cavities, showing the existence of agglomeration of the CNC's resulting into reduced mechanical properties as clearly evident from Fig.4 and Fig.5.

Mechanical Behavior

It is evident from Fig.4 that tensile strength of composites initially decreases on addition of 0.5wt.% of CNC followed by increased values on addition of CNC upto1 wt.%. The incorporation of CNC increases the strength due to presence of well dispersed CNC particles causing transfer of load uniformly when applied axially to the composite material. Above this percentage tensile strength decreases due to agglomeration of higher CNC content act as stress concentrators, facilitating propagation of defects at the interface growing larger on application of load resulting in reduction of strength [20]. In contrast, the tensile modulus of the composites decreased with addition of CNC upto 1wt.% resulting into decreased stiffness of composite material and beyond this it increases insignificantly.

From Fig.5, the elongation at break of composites increases on addition of CNC upto 1wt% thus improving their flexibility. The tenacity was also found to decline initially then increases upto 1wt% of CNC, beyond this it decreases. From Table 1, tensile stress and strains are found to be enhanced by the addition of CNC upto 1wt%. The improvement in the elongation at break and strain at break upto 1wt% of CNC reveals enhanced tensile toughness [21]. This can be due to uniform distribution of CNC that resist deformations in the composites thereby improving their mechanical properties however on further addition agglomeration and insufficient wetting of the higher content of CNC's by polymer matrix reduces their strength as well as their mechanical properties.

Table 1. Tensile properties of PLA-20PBS and PLA-20PBS-(0,0.5,0.75,1, and1.5wt.%) CNC bio-composites

CNC (wt.%)	Tensile strain at break (mm/mm)	Tensile stress at break (MPa)	Strain at break (mm/mm)	Tensile strain at max. load (mm/mm)
0	1.24×10^{-2}	0.193	0.8×10^{-4}	8.61×10^{-3}
0.5	1.38×10^{-2}	0.194	2×10^{-4}	10×10^{-3}
0.75	1.63×10^{-2}	0.346	1.6×10^{-4}	13×10^{-3}
1	1.75×10^{-2}	0.383	2.3×10^{-4}	13.8×10^{-3}
1.5	1.19×10^{-2}	0.341	1.1×10^{-4}	9.9×10^{-3}

Conclusions

This research work focused on enhancing the properties of PLA-PBS blend by inclusion of CNC extracted from bamboo fibre. These CNC's have an excellent ability to enhance the properties of polymers when used as reinforcements. The inclusion of CNC's in the polymer blend increased their roughness and their threshold depth. The fabrication process resulted into formation of well dispersed CNC in the polymer matrix. These uniformly distributed CNC's acted as load bearing elements in the polymer composites thereby improving their properties. The improved properties of the polymer composites imply the advantageous effect of addition of natural fiber derived reinforcements that are enable the development biodegradable materials. These biodegradable materials have potential to serve as an eco-friendly material for future applications.

Declarations

Acknowledgement

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Declaration

No conflict of interest

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Figures

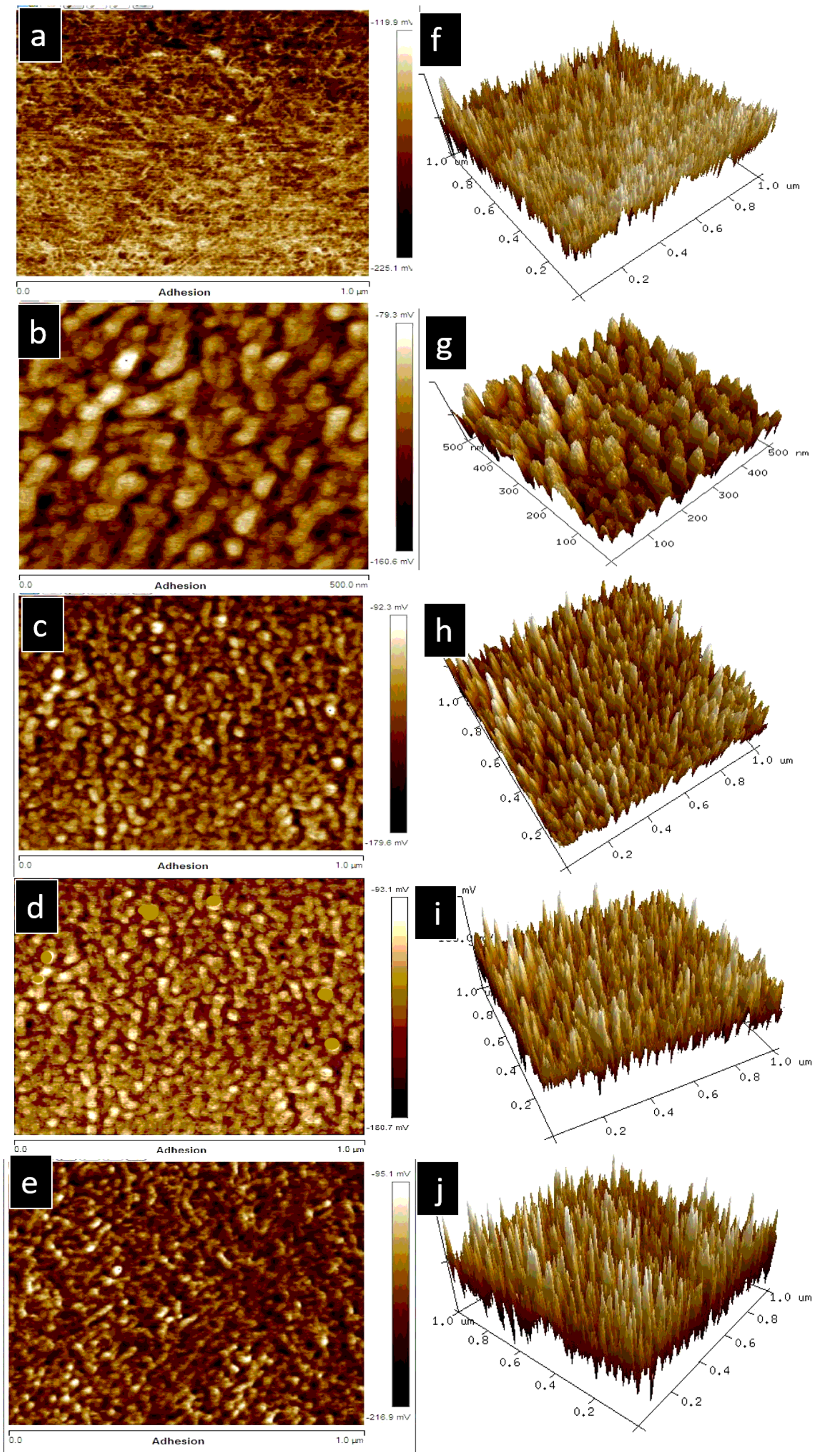

Figure 1

AFM at scanning square area of 1 μm × 1 μm for PLA-20PBS bio-composites, (a-e) Microtopographic 2-D orthographic image and, (f-j) microtopographic 3-D perspective image of PLA-PBS-CNC (0, 0.5, 0.75, 1, and 1.5wt.%) composites

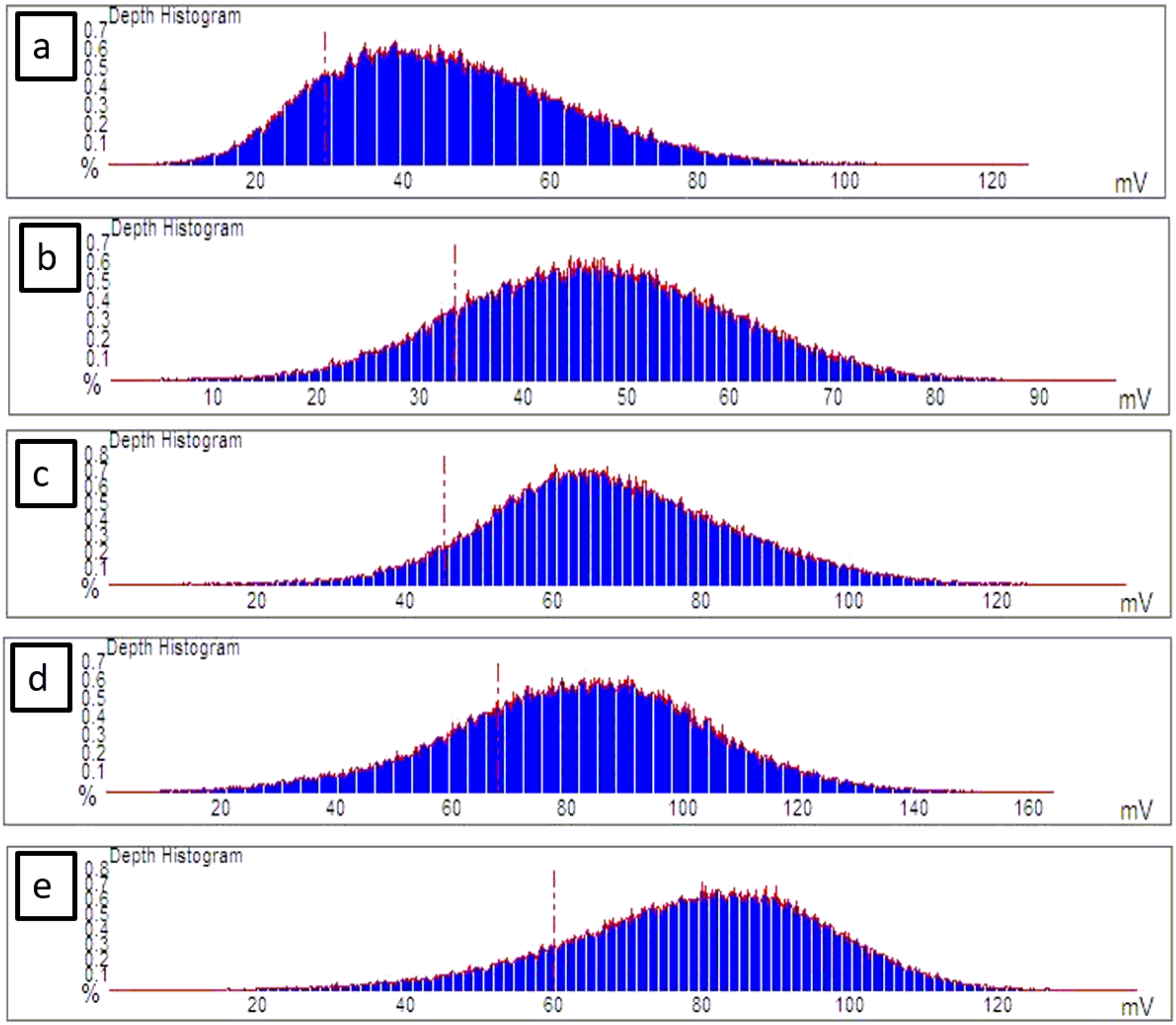

Figure 2

The depth histogram for the scanning square area of 1 μm × 1 μm of PLA-20PBS bio-composites with, (a) 0, (b) 0.5, (c) 0.75, (d) 1 and (e) 1.5wt.% CNC

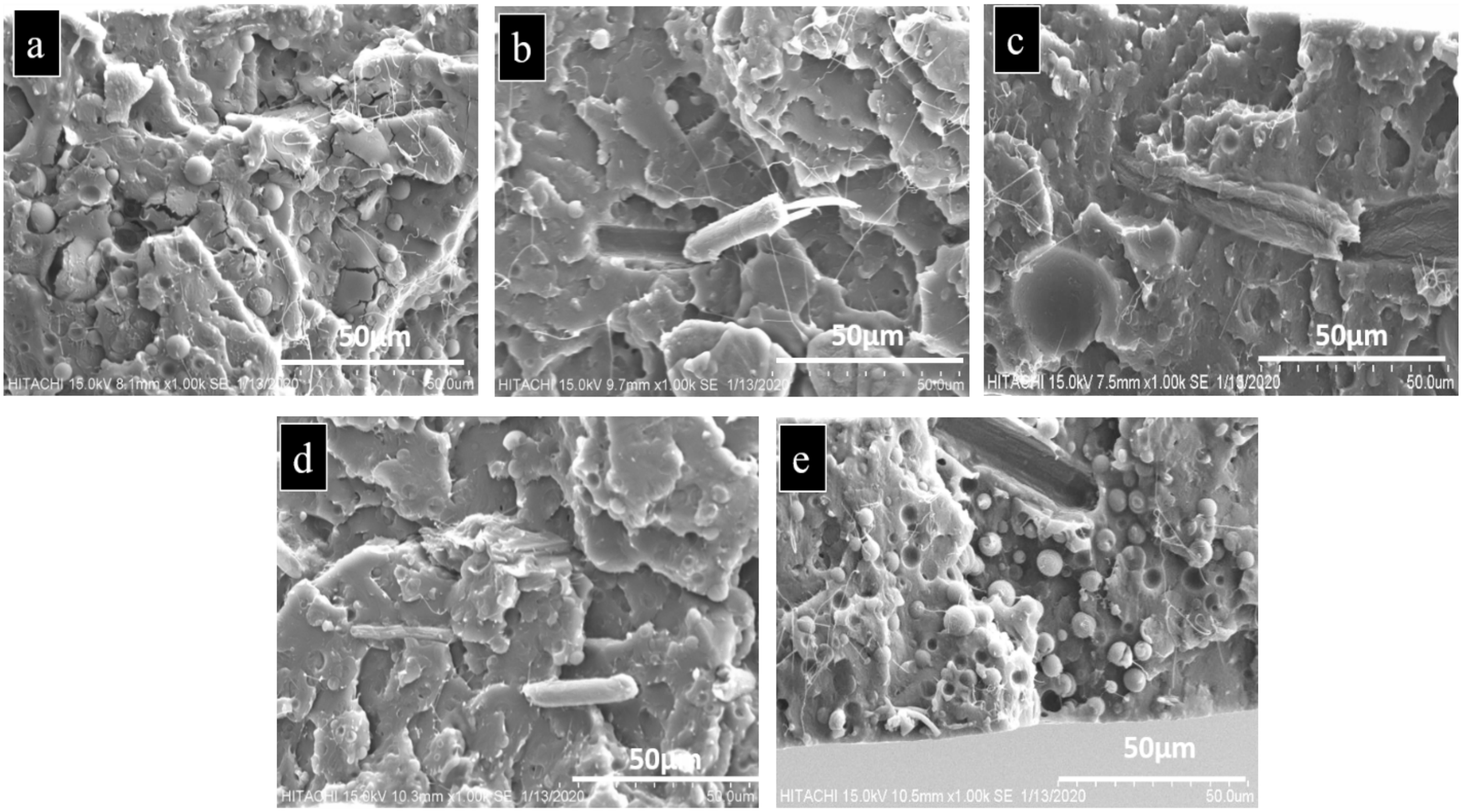

Figure 3

SEM of fractured surfaces of PLA-20PBS bio-composites with (a) 0 wt.%, (b)0.5 wt.%, (c) 0.75 wt.%, (d) 1 wt.%, and (e) 1.5wt.% of CNC

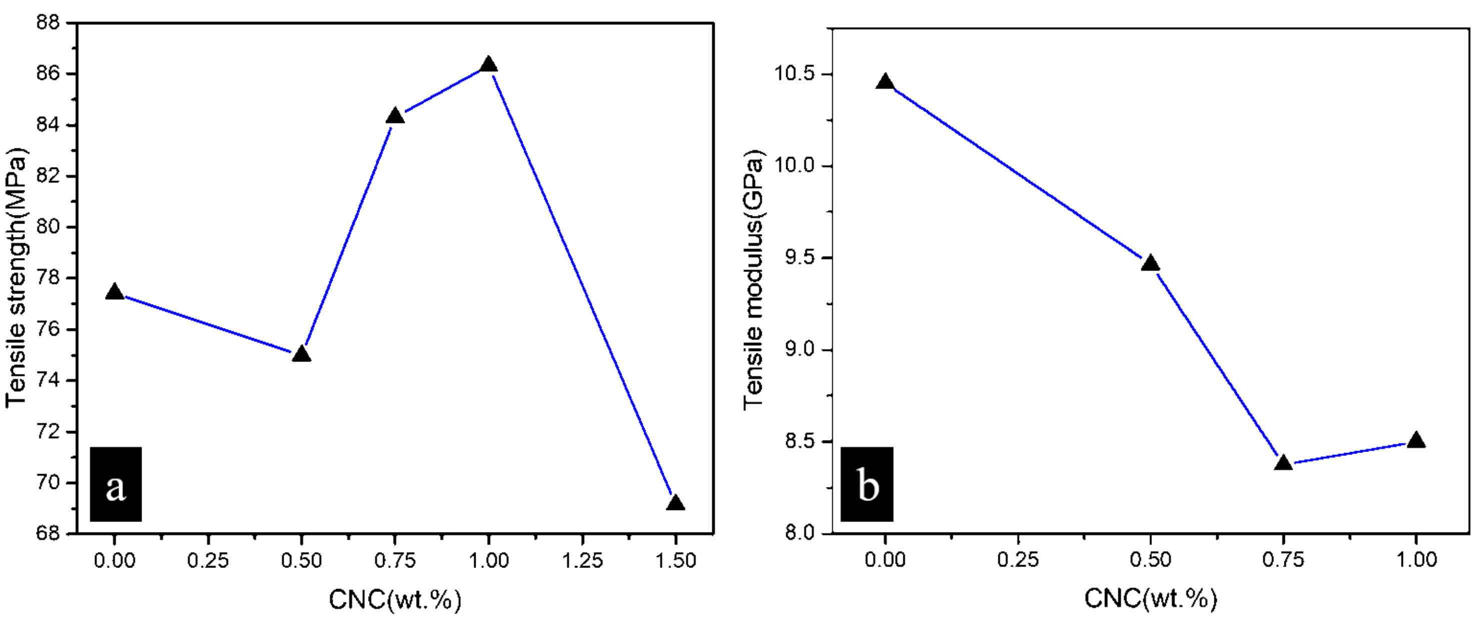

Figure 4

(a)Tensile strength (MPa), and (b)Tensile modulus (MPa) of PLA-20PBS bio-composites with varying wt.% of CNC

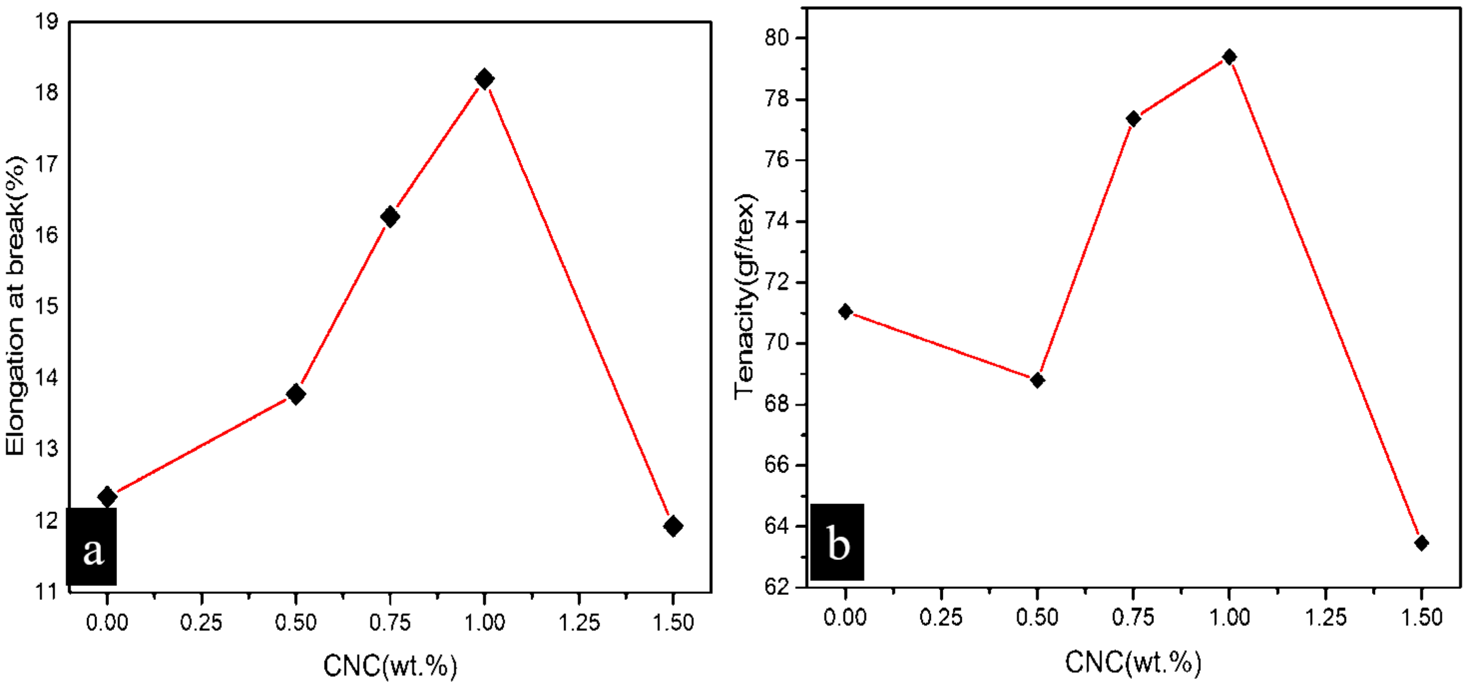

Figure 5

(a)Elongation at break (%), and (b)Tenacity (gf/tex) of PLA-20PBS bio-composites with varying wt.% of CNC