



Reinforcing potential of micro- and nano-sized fibers in the starch-based biocomposites

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ABSTRACT

Starch-based biocomposites reinforced with jute (micro-sized fiber) and bacterial cellulose (BC) (nano-sized fiber) were prepared by film casting. Reinforcement in the composites is essentially influenced by fiber nature, and amount of loading. The optimum amount of fiber loading for jute and bacterial cellulose in each composite system are 60 wt% and 50 wt% (of starch weight), respectively. Mechanical properties are largely improved due to the strong hydrogen interaction between the starch matrix and cellulose fiber together with good fiber dispersion and impregnation in these composites revealed by SEM. The composites reinforced with 40 wt% or higher bacterial cellulose contents have markedly superior mechanical properties than those reinforced with jute. Young's modulus and tensile strength of the optimum 50 wt% bacterial cellulose reinforced composite averaged 2.6 GPa and 58 MPa, respectively. These values are 106-fold and 20-fold more than the pure starch/glycerol film. DMTA revealed that the presence of bacterial cellulose (with optimum loading) significantly enhanced the storage modulus and glass transition temperature of the composite, with a 35 °C increment. Thermal degradation of the bacterial cellulose component occurred at higher temperatures implying improved thermal stability. The composites reinforced with bacterial cellulose also had much better water resistance than those associated with jute. In addition, even at high fiber loading, the composites reinforced by bacterial cellulose clearly retain an exceptional level of optical transparency owing to the effect of the nano-sized fibers and also good interfacial bonding between the matrix and bacterial cellulose.

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1. Introduction

Over the last two decades, there has been a renewed interest in natural and decomposable materials to replace non-degradable (oil-based synthetic) materials, due to a growing concern on the environmental impact and also the uncertainty of petroleum supply [1,2]. Starch is one of the most attractive environmentally friendly alternatives from renewable resources because of its biodegradability, low cost and wide availability [3]. Accordingly, the development of starch-based materials has been increasingly popular for applications in which synthetic polymers have traditionally been the materials of choice [3–5]. Starch by itself is, however, rather brittle and water sensitive [6,7]. Various approaches have been investigated to overcome these problems. Plasticizer (usually glycerol) is commonly added to the starch to improve the product flexibility. Addition of plasticizer also causes the plasticized starch to melt at a lower temperature (below the decomposition temperature of starch), leading to a significant

improvement in its processability [3,6]. In order to increase water resistance and strength, various biodegradable polymers have been blended with starch for example, poly(lactic acid) (PLA), poly(ε-caprolactone) (PCL), poly(vinyl alcohol) (PVA) and chitosan [8–10]. Addition of reinforcing agents to the starch matrix has proved an effective approach to obtaining high-performance starch-based composite materials. A number of natural cellulose fibers such as jute, flax and corn fibers have been used to reinforce starch-based biocomposites [9,11,12].

During the last decade, bionanocomposites, a new class of composite materials based on the incorporation of a nano-sized fiber or filler into a matrix phase have been extensively investigated. Each fractional component is usually derived from renewable resources such as starch, cellulose and protein [13–15]. Depending on the geometry and the nature of the nanofillers, nanocomposites may exhibit new and/or substantially improved properties (e.g. mechanical performance, barrier properties, thermal stability and higher transparency) [2,4,6,13–29]. Recently, starch-based nanocomposites have been prepared with various nano-sized fillers such as cellulose nanofibers, chitin and chitosan nanoparticles and nanoclays [3,6,7,13–15,21–24,28,29].

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Cellulose nanofibers have received a great deal of interest as a reinforcing agents in nanocomposites due to the high stiffness of the cellulose crystal, especially if its comparatively lower density is taken into account (i.e. possessing ~ 3.5 -fold of specific modulus compared to steel) [25]. These nanofibers have been variously named, such as cellulose nanowhiskers, nanocrystals, nanofibrils, microfibrils and microcrystals [2,4,21,22,28,29]. Cellulose nanofibers can be prepared by acid hydrolysis and mechanical and/or enzymatic treatments of plant sources; they can also be derived from non-plant sources, for example, they occur naturally in marine tunicates as animal cellulose whiskers and are produced when culturing bacteria (bacterial cellulose).

Bacterial cellulose possesses high purity, biocompatibility, high crystallinity (70–80%), a high degree of polymerization and strong mechanical properties. Young's modulus values for bacterial cellulose filament are estimated to be 78 GPa, while 114 GPa have been reported [30,31]. These indicates its high potential for utilization as an ideal reinforcement in nanocomposite materials [17,26,27]. Bacterial cellulose nanofibrils have already been incorporated in a number of polymer matrices such as starch, poly(lactic acid) (PLA), poly(vinyl alcohol) (PVA), polyurethane (PU), unsaturated polyesters, acrylic and phenol formaldehyde resins [17,26–29,32,33].

This study examines the different reinforcing potential between micro- vs. nano-sized cellulose fibers in starch-based biocomposites at various fiber loadings. Jute (micro-sized fiber) and bacterial cellulose (nano-sized fiber) were chosen as reinforcements of the biocomposites prepared by a film casting technique. The morphology, structure, mechanical, thermo-mechanical and thermal properties and water uptake behavior of the prepared composites were characterized using scanning electron microscopy (SEM), tensile testing, dynamic mechanical thermal analysis (DMTA), thermal gravimetric analysis (TGA) and water absorption measurement.

2. Experimental

2.1. Materials

Jute fiber mat was purchased from a local market in Chiang Mai, Thailand. For bacterial cellulose production, *Acetobacter xylinum* strain TISTR 975 was provided by S. Wongsakul, School of Agro-Industry, Mae Fah Luang University. Sucrose and NaOCl were purchased from Ajax Finechem; $(\text{NH}_4)_2\text{SO}_4$, KH_2PO_4 and NaOH from BDH Chemicals; $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ from Rankem; acetic acid from Merck Chemicals; agar and yeast extract from DIFCO, Voigt Global Distribution Inc. For composite's preparation, Super-find[®] corn starch (27% amylose content, from local market, Thailand) and glycerol supplied by BDH Chemicals were used.

2.2. Bacterial cellulose production

The culture medium was prepared by dissolving 50 g sucrose, 5 g yeast extract, 5 g $(\text{NH}_4)_2\text{SO}_4$, 3 g KH_2PO_4 , and 0.05 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ in a liter of distilled water (adapted from [26]). The pH was then adjusted to 5.0 by using acetic acid and sterilized at 121 °C for 15 min. The strain of *A. xylinum*, 5.0% (v/v), was inoculated into the culture medium under the growth condition at 35 °C for 7 days in an incubator under static conditions. Thereafter, the bacterial cellulose (BC) was harvested and purified by immersing in running water, 2% w/v NaOH, then 0.5% w/v NaOCl and finally again in running water. Each step took 24 h.

2.3. Preparation of starch/glycerol (standard) film

The ingredients, 3 g corn starch, 0.9 g glycerol and 100 g distilled water, were mixed to reach homogeneous conditions in a beaker. This mixture was then heated to 80 °C using a hot plate with continuous stirring for 30 min, until the starch was completely gelatinized.

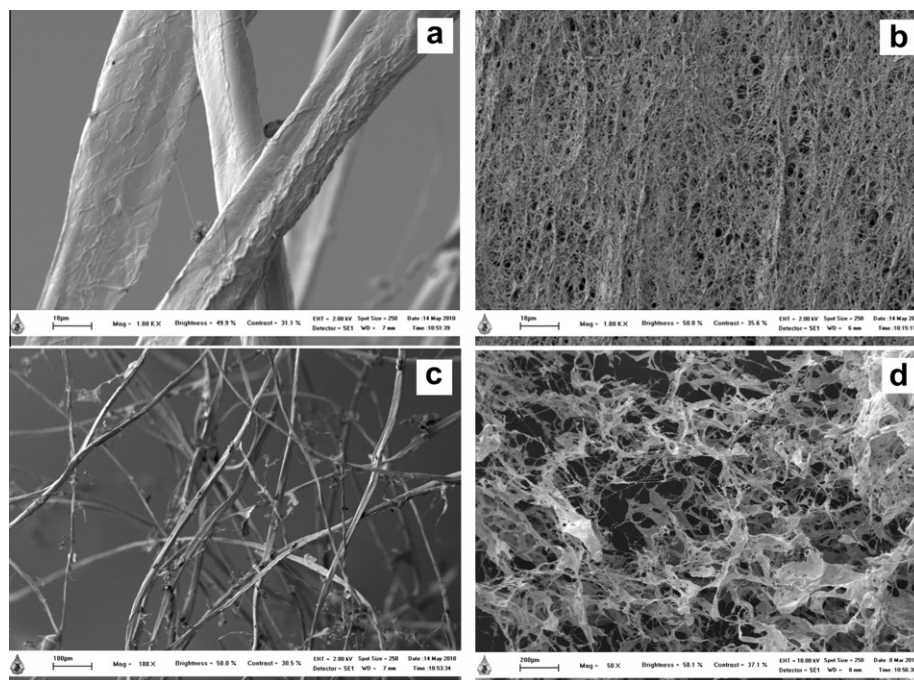


Fig. 1. Scanning electron micrographs of (a) jute, (b) freeze-dried bacterial cellulose (BC), (c) disintegrated jute (dis-Jute) and (d) disintegrated bacterial cellulose (dis-BC) after freeze-drying.

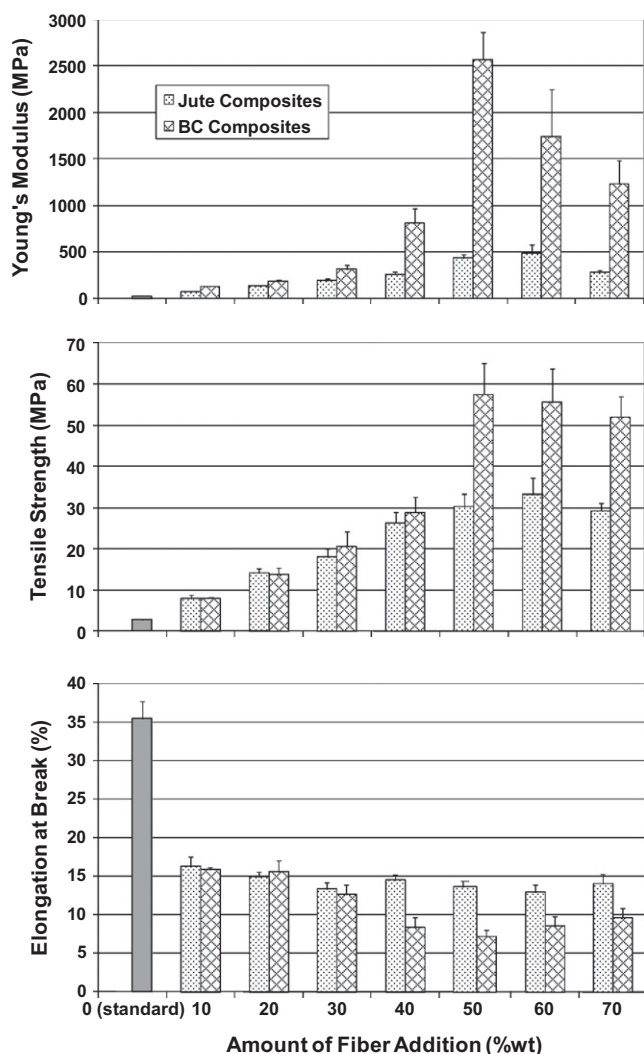


Fig. 2. The effect of fiber addition (wt%) on Young's modulus (MPa), tensile strength (MPa) and elongation at break (%) of the biocomposites reinforced with disintegrated jute (micro-size) and BC (nano-size) fibers.

Next, the viscous solution was degassed by sonification for 30 min. Then, 30 g of the solution was poured into a Petri dish and placed in the hot air oven at 40 °C until dried (~2–3 days).

2.4. Preparation of biocomposites reinforced with jute fiber (micro-size)

The jute fiber mat was immersed in distilled water for 1 h and then washed repeatedly to remove impurities. After that, it was disintegrated into fiber suspension by using a kitchen blender (PHILIPS HR 2094) at a medium speed until homogeneous suspension was obtained, usually after 3 min.

The dry weight of the disintegrated jute (dis-Jute) per unit of the jute suspension was determined in order to ascertain the amount of jute fiber added into the matrix. The fiber loading to reinforce the composites varied from 10% to 70% wt/wt to the dry weight of starch. The preparation of the dis-Jute reinforced composites was similar to those of the standard starch/glycerol film (see Section 2.3). However, varied amounts of jute suspension were added into the mixture to prepare the composites.

The measurement of dis-Jute's length (L) and diameter (D) was carried out by using a stereo microscope (Motic SMZ-168) equipped with a digital camera (Moticam 1000) and an image

analysis program (Motic Images Plus version 2.0 ML). The average values of 50 fibers are reported.

2.5. Preparation of biocomposites reinforced with bacterial cellulose (nano-size)

The purified bacterial cellulose (BC) was cut into small cubes (~1 cm³) and then made into a fiber suspension in a kitchen blender (PHILIPS HR 2094) at the maximum speed until a homogeneous suspension was obtained, approximately after 10 min.

The dry weight of the disintegrated BC (dis-BC) per unit of the BC suspension was determined in order to ascertain the amount of BC added into the matrix. The fiber addition to reinforce the composites varied from 10% to 70% wt/wt to the dry weight of starch. The preparation of the dis-BC reinforced composites was similar to those of the dis-Jute composites (see Section 2.4) except varied amounts of dis-BC suspension were added instead of dis-Jute suspension.

2.6. Scanning electron microscopy (SEM) observations

The morphology of jute, freeze-dried BC, dis-Jute and dis-BC and the fractured surface of the composites were observed using a scanning electron microscope (SEM), Leo 1450 VP, at an accelerating voltage of 10 kV. Prior to the examination, the surface of the specimen was sputter coated with a thin layer of gold.

2.7. Mechanical testing

Mechanical properties of the starch/glycerol film and composites were assessed using a universal tensile tester, Instron 5566, equipped with a 1 kN load cell. The gauge length of the specimens with a width of 7 mm was 30 mm and a cross-head speed of 3 mm/min was utilized for the tests conducted at 25 °C and a relative humidity of approximately 60%. The values of Young's modulus, tensile strength and elongation at break of the samples were evaluated and reported as the average values of five measurements of each material. Prior to all measurements, the specimens were conditioned at a controlled relative humidity (RH) of 75.3 ± 0.4% and 25–30 °C for 3 days (according to ASTM E104).

2.8. Dynamic mechanical thermal analysis (DMTA)

Dynamic mechanical thermal behavior of the samples were determined with a dynamic mechanical thermal analyzer (Mettler Toledo DMA/SDTA 861) at 1 Hz and a heating rate of 4 °C/min in the temperature range from –100 to 150 °C. Specimens of approximately 9 mm × 3.5 mm were used.

2.9. Thermal analysis

Thermal analysis was carried out using a Mettler Toledo (851e). Samples of approximately 3 mg were used. All the experiments were conducted using a constant heating rate of 10 °C/min, from 25 to 600 °C, in a nitrogen atmosphere. The obtained thermogravimetric curves were transformed into their first derivative ($\Delta\text{weight loss}/\Delta\text{time}$). The peak degradation temperatures of starch/glycerol and fiber components in the composites were determined.

2.10. Water uptake

Strips (10 mm × 40 mm) were dried at 105 °C for 2 h. After weighting, they were conditioned in a conditioning chamber which contains a saturated NaCl solution with controlled relative humidity (RH) of 75.3 ± 0.4% at 25–30 °C (according to ASTM E104). Thereafter, the samples were removed at specific intervals and

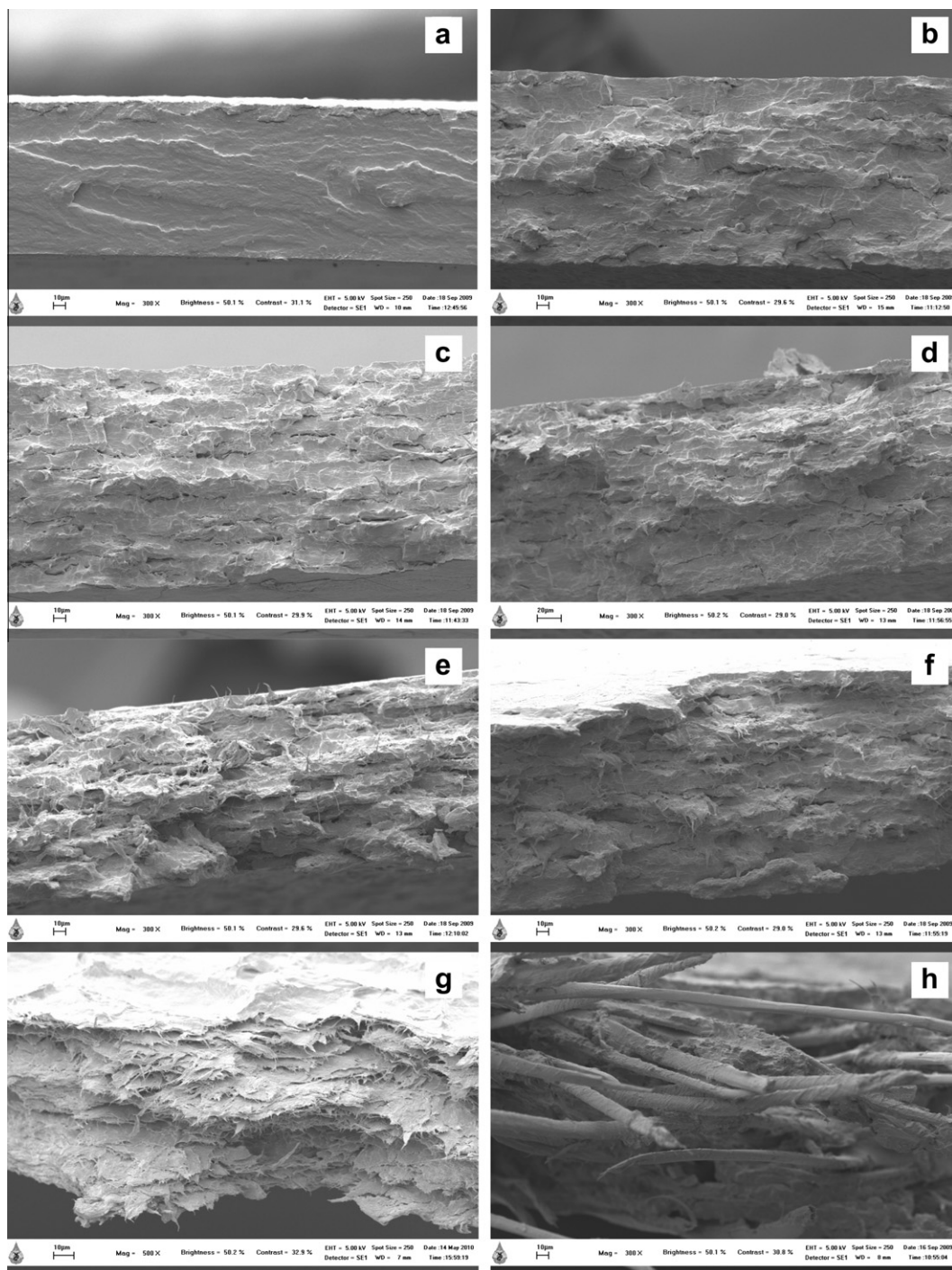


Fig. 3. Scanning electron micrographs of fractured surfaces of (a) the starch/glycerol matrix and (b) bionanocomposites reinforced with (b) 10 wt%, (c) 20 wt%, (d) 30 wt%, (e) 40 wt%, (f) 50 wt%, (g) 60 wt% of disintegrated bacterial cellulose (dis-BC) and (h) 60 wt% of disintegrated jute (dis-Jute).

weighed using a four-digit balance. The moisture content or water uptake of the samples was calculated as follows:

$$\text{Water uptake (\%)} = (M_t - M_0 / M_0) \times 100$$

where M_t and M_0 are the weights of the sample after t min exposure to 75.3% RH and before exposure to high moisture content, respectively. The average values of water uptake (%) of each material were calculated from three samples.

3. Results and discussion

3.1. Morphological investigation

Scanning electron micrographs of the jute and freeze-dried bacterial cellulose are shown in Fig. 1. Jute is the natural cellulosic fiber of micron size (Fig. 1a) which is considerably larger than the nano-size of bacterial cellulose fiber (Fig. 1b). After disintegration, the jute is broken into short fibers suspended in distilled water; so-called disintegrated jute (dis-Jute) with an average length (L) and

Table 1
Weight fraction of each composite component in relation to the fiber addition (wt%).

Amount of fiber addition (as a ratio of starch weight) (wt%)	Weight fraction in composites	
	Starch/glycerol ($W_S + G$)	Fiber (W_F)
10	0.929	0.071
20	0.867	0.133
30	0.813	0.188
40	0.765	0.235
50	0.722	0.278
60	0.684	0.316
70	0.650	0.350

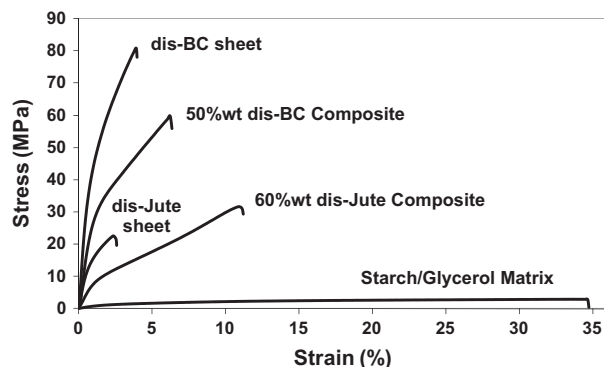


Fig. 4. The stress–strain curves of the starch matrix, disintegrated jute (dis-Jute), disintegrated BC (dis-BC) and biocomposites reinforced with 50 wt% of dis-BC and 60 wt% of dis-Jute.

diameter (D) of 3039.27 and 14.80 μm , respectively, and averaged L/D ratio of ~ 206 . The continuous network of bacterial cellulose disintegrates into small fiber mats (so-called disintegrated bacterial cellulose, dis-BC). SEM micrographs of dis-Jute and dis-BC after freeze-drying are shown in Fig. 1c and d, respectively.

3.2. Mechanical analysis

With the addition of randomly oriented dis-Jute and dis-BC to reinforce the starch/glycerol (standard) matrix, the mechanical properties of the composite materials are shown to be greatly improved (Fig. 2). By increasing the amount of fiber loading or addition (wt%), the Young's modulus and tensile strength of the composites continuously increase at the expense of the elongation at break. This indicates an efficient stress-transfer in both composites reinforced by dis-Jute and dis-BC. This is essentially attributed to a great reinforcing potential of cellulose fibers and indeed, a good interfacial interaction or strong hydrogen bonding between the added fibers and starch matrix phase owing to their chemical similarity [2,12]. The SEM images of fractured surfaces of both composites (Fig. 3) provide good evidence for the strong interfacial adhesion as shown by the remaining starch on the surface of the pulled-out fibers [12,18,23]. In addition, good fiber dispersion and impregnation within the starch/glycerol matrix are also indicated.

The starch/glycerol matrix was reinforced with the addition of fibers to an optimum amount of 60 wt% dis-Jute and 50 wt% dis-BC (Fig. 2). The weight fractions of fiber and other components (starch and glycerol) in the composites corresponding to the amount of fiber addition (wt%) are shown in Table 1. Stress–strain curves of the starch/glycerol matrix, dis-Jute and dis-BC sheets and the optimum composites reinforced with dis-Jute and dis-BC are illustrated in Fig. 4. The pure networks of dis-Jute and dis-BC

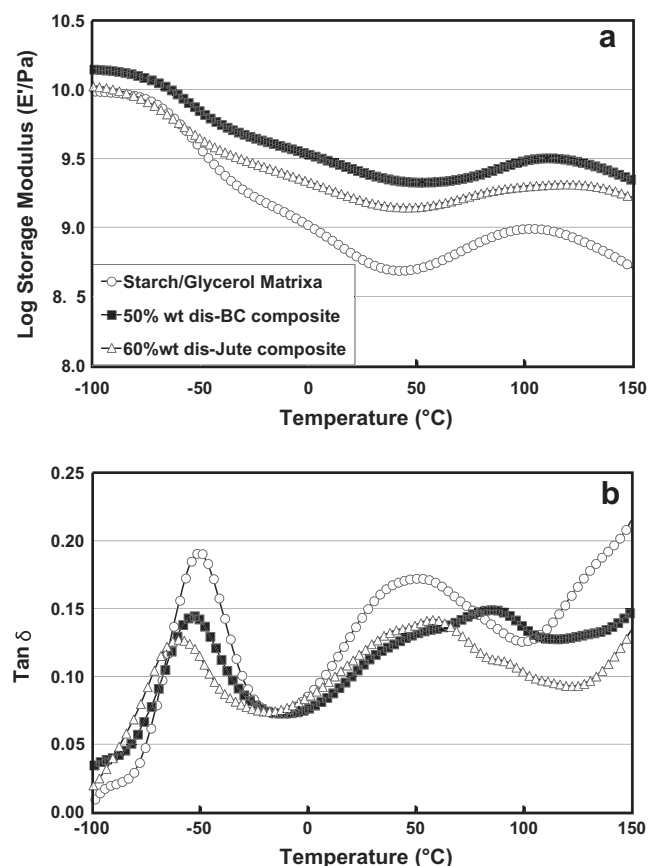


Fig. 5. Temperature dependence of (a) logarithm of the storage tensile modulus (E') and (b) $\tan \delta$ of the starch matrix and biocomposites reinforced with 50 wt% of disintegrated BC (dis-BC) and 60 wt% of disintegrated jute (dis-Jute).

prepared in this work have the average Young's modulus of 2.2 GPa and 5.2 GPa, tensile strength of 21.3 MPa and 80.9 MPa, and elongation at break of 3.0% and 4.8%, respectively. Certainly, for each composite system, the optimum amount of fiber addition varies with various factors, for instance, the nature of fiber and matrix, fiber/matrix interfacial adhesion and fiber aspect ratio. After the optimum amount, with further addition of fiber into these composite systems, the mechanical properties of the materials then gradually decrease. The diminished performance of the composites at higher amounts of fiber loading is possibly due to the lack of resin infusion and/or the presence of so many fiber ends in the materials, which could cause crack initiation and hence potential composite failure beforehand (Fig. 3) [34].

Noticeably, the composites reinforced with dis-BC of 40 wt% or higher amounts exhibit markedly superior mechanical properties when compared to those reinforced with dis-Jute, especially the dramatic jump in the Young's modulus (stiffness) of the materials. One main reason is likely to be because BC naturally possesses higher mechanical property than jute. Young's modulus of BC filament as high as 78 GPa and 114 GPa have been reported [30,31] while that of jute has only 26.5 GPa [35]. Another reason is based upon a possible formation of a weak network of the dis-BC (at high content) in these composites [4]. Hence, these reasons presumably contribute to the notable increases in the stiffness and strength of these composite materials at the further expense of the elongation at break, approaching to that of the pure network of the dis-BC sheet (see Fig. 2). Young's modulus and tensile strength of the optimum composites reinforced with 50 wt% BC ($W_F \sim 0.278$) averaged 2.6 GPa and 58 MPa, respectively. These values are 106-fold and 20-fold more than the neat starch/glycerol film. Furthermore, mechanical

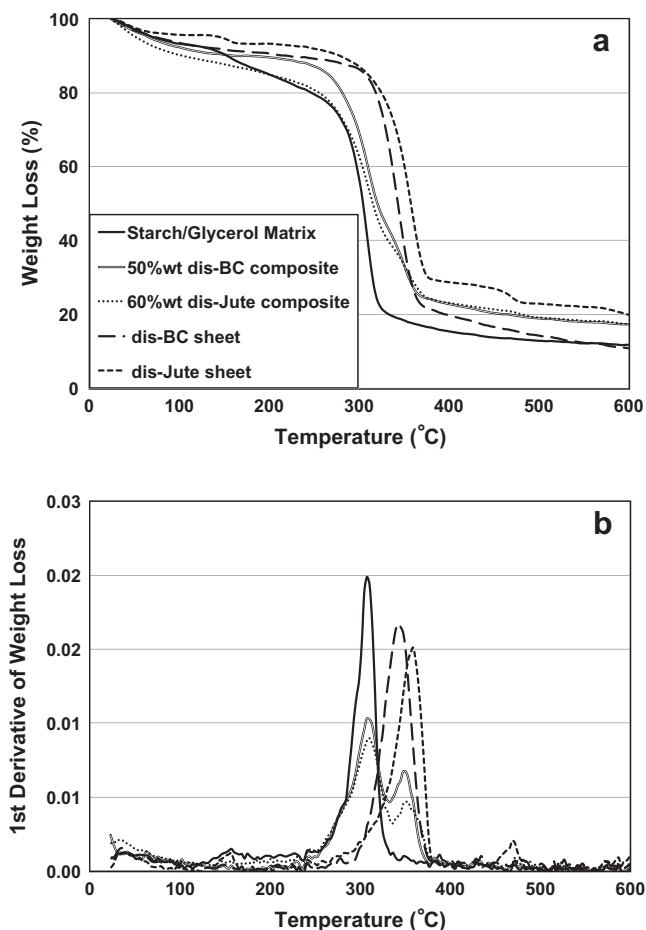


Fig. 6. (a) TG and (b) DTG curves of the starch matrix, disintegrated jute (dis-Jute), disintegrated BC (dis-BC) and biocomposites reinforced with 50 wt% of dis-BC and 60 wt% of dis-Jute.

Table 2

DTG analysis of the starch/glycerol matrix, dis-BC, dis-Jute and composites reinforced with 50 wt% dis-BC and 60 wt% dis-Jute.

Materials	Peak degradation temperature (°C)		%Residue at 600 °C
	Starch/glycerol component	Fiber component	
Starch/glycerol	308.14	–	11.78
dis-BC	–	342.68	10.96
dis-Jute	–	359.92	19.92
		469.73	
50 wt% dis-BC composite	308.07	348.46	17.38
60 wt% dis-Jute composite	308.01	348.42	17.30

properties of the optimum composite achieved in this present study have shown to be the highest values reported in literature so far for systems of nanocellulose (i.e. cellulose ramie nanocrystallites, cellulose cassava bagasse nanofibrils, bacterial cellulose, microfibrillated cellulose and tunicin whiskers) reinforced starch-based composite materials at the similar levels of fiber content [2,4,6,22,28]. Thus, this is also another indication for a high reinforcing potential of bacterial cellulose in nanocomposite materials.

3.3. Dynamic mechanical thermal analysis

The logarithm of the storage tensile modulus (E') and evolution of the loss factor ($\tan \delta$) as a function of temperature for the starch/glycerol matrix, and 60 wt% dis-Jute and 50 wt% dis-BC composites are shown in Fig. 5a and b, respectively. In general, the storage modulus decreased as the temperature increased; however, the modulus drop with temperature was obviously less in both composites when compared to the starch/glycerol matrix, representing a significant improvement in a thermo-mechanical property of the composites with addition of these fibers. Over the entire range of temperatures studied, the presence of dis-BC in the composite provided higher storage modulus values than those associated with the dis-Jute counterpart. These results were in good agreement with the mechanical tests performed at room temperature (previously shown in Figs. 2 and 4). For the evolution of the loss factor ($\tan \delta$) with temperature, two relaxation transitions were displayed for the starch/glycerol matrix, corresponding to two separate phases in this system (Fig. 5b) [6,15,22]. The upper transition (50.3 °C) is ascribed to the main α relaxation associated with the glass transition of the starch-rich phase whereas the lower transition (−51.5 °C) is assigned to the second relaxation (β) of the glycerol-rich phase [4,18]. The introduction of dis-Jute and dis-BC into the starch/glycerol matrix resulted in a shift towards higher temperatures, and a broadening and a magnitude decrease of the main α relaxation process of the starch-rich phase. In the dis-Jute and dis-BC composites, the main α relaxation was shifted to 57.7 °C and 84.9 °C, respectively, compared to 50.3 °C of that of the pure matrix. The temperature shift in the dis-BC composite was quite remarkable, approximately 35 °C, which pointed to the improved thermal stability of this composite and further confirmed the strong interfacial interactions between the matrix phase and dis-BC [6,15,18].

3.4. Thermal analysis

The thermal degradation (TG) and 1st derivative thermogravimetric (DTG) curves of the prepared materials are shown in Fig. 6. These data evidently show that dis-Jute and dis-BC (having cellulose as a main component) are more thermally stable than the starch/glycerol matrix. Thermal stability of the composites appears to be in between the two components (their fibers and starch/glycerol matrix). For DTG curves, the initial peaks below 100 °C and 200 °C correspond to the vaporization of water and glycerol in the materials, respectively [18]. The main peak temperatures of degradation of starch/glycerol matrix, dis-BC, dis-Jute and

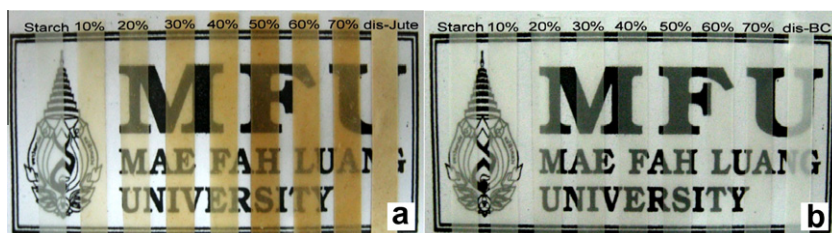


Fig. 7. Casted films of the starch matrix, biocomposites reinforced with (a) disintegrated jute (dis-Jute) and (b) disintegrated BC (dis-BC) and dis-Jute and dis-BC sheets.

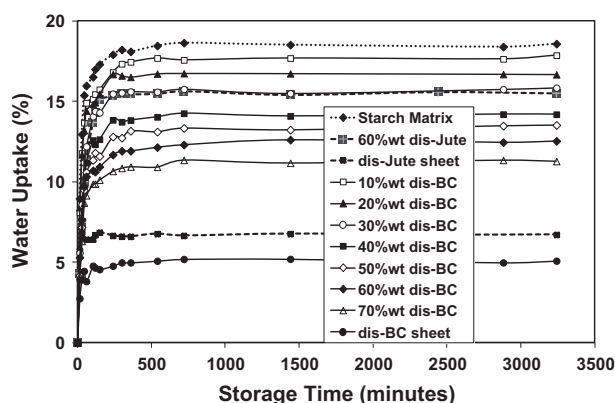


Fig. 8. Water uptake as a function of storage time of the starch matrix, biocomposites reinforced with disintegrated jute (dis-Jute) and disintegrated BC (dis-BC) and dis-Jute and dis-BC sheets.

composites reinforced with 50 wt% dis-BC and 60 wt% dis-Jute are shown in Table 2. For dis-Jute, after cellulose degradation at 359.9 °C, there is apparently another higher temperature degradation range with the peak of 469.7 °C. This is supposed to be a degradation of remaining dye substance in the jute mat, even after several cycles of washing before the disintegration step. Moreover, due to the nature of ligno-cellulosic fibers, jute has also an existing lignin–cellulose complex which is more stable than highly pure cellulose in BC [36]. Accordingly, this is reflected in the higher amount of residual char left at 600 °C for dis-Jute (Table 2).

In the two composites reinforced with 50 wt% dis-BC and 60 wt% dis-Jute, two main peaks of degradation regarding to both the starch/glycerol and fiber components were observed. The peak degradation temperatures of starch/glycerol components in both composites occur at similar temperatures of those of the pure starch/glycerol matrix. Nevertheless, the peak degradation temperatures of fiber components in both composites shifted compared to those of the dis-Jute and dis-BC (see Table 2). Interestingly, in the 50 wt% dis-BC composite, a thermal degradation of the dis-BC component is delayed to a higher temperature. In this case, it is possible that the prior degradation of starch/glycerol component, and the formation of its char influences the later decomposition of dis-BC phase, resulting in better thermal stability in this composite [37,38]. This phenomenon is not observed in the system reinforced with dis-Jute. Perhaps, other compositions in addition to cellulose (i.e. hemicelluloses, lignin, wax and pectin) and impurities in dis-Jute influenced the thermal degradation process of these composites in a different manner [36].

3.5. Optical transparency

The composites reinforced with dis-BC (nano-sized fiber) exhibit significant improvements in mechanical and thermal properties when compared to those reinforced with dis-Jute (micro-sized fiber). Furthermore, these composites reinforced with dis-BC are shown to retain a high level of optical transparency, especially at the high fiber loadings (see Fig. 7). This phenomenon is attributed to the effect of the nano-size of BC fiber which has a diameter less than the light's wavelength and also good interfacial bonding between the matrix and dis-BC. As a result, scattering of visible light at the interface of BC nanofibers decreased, leading to a high transparency allowed in these composites [26].

3.6. Water uptake

One of the major drawbacks of starch-based materials is their sensitivity to moisture and water. In this study, an improvement

in water uptake behavior of the composites with addition of dis-Jute and dis-BC was investigated. The values of water uptake as a function of storage time upon conditioning at 75.3% RH are plotted in Fig. 8. The water uptake in all materials was observed to be constant after 720 min of conditioning. The pure starch matrix film had much greater water absorption ability than the dis-Jute and dis-BC sheets. Undoubtedly, the water resistance of the starch matrix increases steadily with addition of the fiber phase into the composites. Therefore, it can be concluded that the swelling of the materials is suppressed in the presence of fibers within the starch matrix. This can be attributed firstly to the low water uptake of fibers themselves; and secondly to the presence of strong hydrogen bonding interactions between fiber/fiber and fiber/starch matrix [39]. At the same fiber content (60 wt%), the composite reinforced with dis-BC absorbs water much less than those associated with dis-Jute. Initially, the dis-BC absorbs less moisture than the dis-Jute (see Fig. 8). Moreover, with the nano-size, dis-BC has higher total surface area than dis-Jute. This probably lead to more intensive interactions between fiber/fiber and fiber/matrix in the dis-BC reinforced composites and consequently, results in a greater suppression in the swelling of the starch and therefore its water uptake.

4. Conclusions

To establish the different reinforcing potentials between micro- and nano-sized fibers, composites reinforced by dis-Jute and dis-BC were prepared. With increasing fiber loading, mechanical properties are largely improved due to the strong hydrogen interaction between starch matrix/cellulose fiber and also good fiber dispersion and impregnation in these composites revealed by SEM. The optimum amounts of fiber addition in each composite system are found to be 60 wt% for dis-Jute and 50 wt% for dis-BC. Nevertheless, the composites reinforced with dis-BC of 40 wt% or higher amounts exhibit markedly superior mechanical properties when compared to those reinforced with dis-Jute. DMTA results indicate that the introduction of dis-BC significantly improved the storage modulus and glass transition of the composite. Furthermore, only in the composite reinforced with dis-BC, is the thermal degradation of the fiber component delayed to a higher temperature, implying better thermal stability gained in this composite system. In addition, at high fiber loadings, the composites reinforced with dis-BC clearly retain an exceptional level of optical transparency which is an important factor for application such as packaging. The dis-BC reinforced composites also show a much better water resistance than those reinforced with dis-Jute.

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