Effect of bacterial cellulose reinforcement on morphology and tensile properties of starch-based biocomposite

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Abstract - This study aims to determine the effect of the addition of bacterial cellulose (BC) from nata de coco to the mechanical properties of the cassava starch-based biocomposite. This study was conducted by a tensile test using a standard specimen of ASTM D-638 type V and fracture morphology using SEM (Scanning Electron Microscopy), using variations in the addition of BC as much as 0% (without additional cellulose), 2.5%, 5%, 7.5%, and 10%. The results showed that the addition of BC to biocomposite could increase their tensile strength and stiffness. Biocomposite with the best mechanical properties was achieved by adding 10% BC to produce tensile strength 19.19 MPa, elongation percentage 10.97%, and modulus of elasticity 173.19 MPa. However, with the addition of higher BC, lower quality bioplastics can also be produced.

Keywords: bacterial cellulose, elastic modulus, tensile strength, starch-based biocomposite

1. Introduction
Plastic has become a basic necessity that brings many benefits to humans. Plastics are widely used in both the food and non-food industries because of their lightweight, waterproof, flexible, and transparent properties. It is known that plastics cannot be degraded once they are disposed of into the environment. As a result, the accumulation of plastic waste in nature will pollute the environment and will reduce the quality of the environment. One of the efforts to reduce the use of conventional plastics is to develop bioplastics that are friendly to the environment [1].

Many studies have been carried out in the manufacture of bioplastics from plant starch, such as starch from banana and potato peels [2], cassava [3], corn, and rice [4], even from agricultural waste [5]. However, starch-based bioplastics have the disadvantage of their low mechanical strength and hydrophilic nature. The hydrophilic nature of starch will cause the resulting bioplastic to be water-resistant and easily damaged [6]. In order to avoid the drawbacks of starch-
based bioplastics, it can be done by adding reinforcement of nanoclay [7], ZnO [8], graphene oxide [9] dan TiO2 [9] which aims to improve the performance of the bioplastic.

The use of cellulose as a filler of polymer composites in the form of cellulose nanocrystals has been widely reported [10-12]. Cellulose nanocrystal is extracted from the fibers by crushing the fibers, then continuing by process of acid hydrolysis to reduces the amorphous fraction, resulting in high crystalline nanoparticle [13]. Unfortunately, this process needs high energy so that a method of nanocellulose production from bacteria was developed, which can more easily replace plant cellulose nanofibrils [14]. One source of cellulose that can be used is cellulose fibers from bacteria in the form of nata de coco. Therefore, in this study, a bioplastic was made from cassava starch with the strengthening of BC fibers from nata de coco and evaluated its morphology and tensile strength.

2. Methods

2.1 Material
The cassava starch, BC, and glycerol (98%) in the technical grade were obtained from Malang, East Java, Indonesia.

2.2 Synthesis of biocomposite
Synthesis of biocomposite refers to previous studies [6] with modifications. Nata de coco was immersed in distilled water for a week, then was crushed using a blender. 98.5 ml distilled water in a beaker glass was added by glycerol 1.5% (v/v) while the stirred by 900 rpm, 5 min. on a magnetic stirrer. BC with the concentrations of 2.5%, 5.0%, 7.5%, 10.0% (b/b) were added into solution then conducted ultrasonication process (20 kHz, 30 min.) to obtain homogenized solution. The solution was heated 80°C for 45 min while stirred of 900 rpm on a hot magnetic stirrer. The cassava starch (5.0% (b/v)) was added into the solution and stirred for 45 min at 900 rpm. The solution was poured into a mold then dried in an oven at 60-70°C for 8 h. The film was peeled the saved in a dry box.

2.3 Mechanical properties analysis
The tensile test sample refers to the ASTM D-638 Type V standard. The tensile test was carried out using the "Techno" Fiber Tensile Tester Version 1.0. with a pull speed of 0.025 mm s⁻¹. until breaks [7].

2.4 Morphology analysis
Fracture surface morphology observations were carried out using SEM of the FEI brand with the type of Inspect-S50.

3. Result and discussion

3.1 Synthesis starch-based biocomposite
The results of biocomposite synthesis with variations in the addition of BC of 0% (without additional cellulose), 2.5%, 5%, 7.5%, and 10% are shown in Figure 1. The result of the synthesis produces a biocomposite with a physical form of a thin and transparent sheet with a shiny flat shape and a flexible and slippery texture. The more BC added, the less the transparency of the biocomposite.
3.2 Tensile properties

The tensile test diagram of the biocomposite is shown in Figure 2, which shows that the addition of BC to the biocomposite results in an increase in tensile strength and a decrease in strain. Based on Fig. 2, it is known that the tensile strength continues to increase with the addition of variations in BC from 2.5% to 10%. The highest tensile strength was achieved in the addition of 10% BC, namely 19.19 MPa (Fig. 3). With the continuous increase of variations in the addition of BC, it shows that there is an effect of the addition of BC on the mechanical properties of the bioplastic matrix of cassava starch. The increase in the tensile strength of bioplastics is due to the fact that BC has several advantages, including a high degree of crystallinity (83-85%) [15] with crystalline size 3.61 – 5.11 [16], elastic, and biodegradable [17]. In addition, BC has high water content, owing to the higher capability of water absorption [18], is non-toxic [19], and can be safely sterilized without causing a change in its characteristics [20]. BC film possessed a tensile strength and elongation at break of 112.4 MPa and 0.6%, respectively [21]. Increasing of tensile properties of biocomposite is caused by the high strength of BC.

Figure 2. Results of tensile testing of bioplastics with variations of BC reinforcement range from 0% to 10%
Figure 3. The effect of the addition of BC on the tensile strength of biocomposites

Figure 4. The effect of the addition of BC on the elastic modulus of biocomposites

Figure 4 shows that there is an increase in the elastic modulus of the bioplastic on the addition of BC. The biocomposite without the addition of BC produced a modulus of elasticity of 31.09 MPa. The addition of BC 2.5%, 5%, 7.5% and 10% resulted in a modulus of 70.92 MPa, 102.46 MPa, 108.30 MPa, and 173.19 MPa, respectively. The increased modulus of elasticity at each additional variation of BC is due to the fact that BC is evenly dispersed into the cassava matrix so that a bioplastic with optimum mechanical properties is obtained with unique BC properties. Besides, BC has high Young’s modulus as much as 9.14 GPa [21]. This reinforcement makes starch-based biocomposite has increased elastic modulus of biocomposite till 350% at BC reinforcement of 10%. 
3.3 Observation of fracture surface morphology

![SEM analysis of biocomposite with BC reinforcement: (a) 0% (b) 2.5%, (c) 5.0%, and (d) 10%](image)

**Figure 5.** SEM analysis of biocomposite with BC reinforcement: (a) 0% (b) 2.5%, (c) 5.0%, and (d) 10%

The fracture morphology of tensile test samples is shown in Fig. 5. Biocomposite without BC reinforcement shows the smooth surface fracture (Fig. 5a). Increasing of BC reinforcement, the
fracture morphology shows the rough surface (Fig. 5b-5e). Addition reinforcement of 7.5% BC has a smoother surface morphology (Fig. 5d) than reinforcement of 5% BC cellulose variation (Fig. 5e). But with the addition of higher BC, it can also produce lower quality biocomposite where BC makes biocomposite moreover rigid.

4. Conclusion
Based on the analysis, it can be concluded that the addition of BC can improve the physical and mechanical properties of the resulting biocomposites. Biocomposites with the best mechanical properties were achieved by adding 10% BC to produce tensile strength 19.19 MPa and modulus of elasticity 173.19 MPa. Bioplastics with the addition of 7.5% cellulose have a smoother surface morphology than 5% cellulose bioplastics. However, with the addition of higher BC, lower quality bioplastics can also be produced.

5. References
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