Mechanical Properties of Starch-Based Biocomposite Foam with Bacterial Cellulose Reinforcement

J Maulana¹, H Suryanto¹,２*, Sukarni¹

¹Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Malang, Indonesia
²Center Excellent for Cellulose Composite, Faculty of Engineering, Universitas Negeri Malang, Indonesia

*Corresponding author’s email: heru.suryanto.ft@um.ac.id

Abstract. Biofoam is foam derived from starch so that it can be degraded and does not interfere with the environment. Cassava has the largest starch content among tubers, but the level of consumption of household people tends to make cassava a potential source of starch that is used in other forms such as biofoam. This study aims to determine the effect of the vary content of bacterial cellulose on cassava starch-based biocomposite foam. This research varied the content of bacterial cellulose to cassava starch, ie 0.0%, 0.5%, 1.0%, 1.5%, and 2.0% weight, then produce and tested its mechanical properties and surface morphology with the Scanning Electron Microscope. The results of this study are the highest tensile strength produced by biocomposite foam with the addition of 1% bacterial cellulose with an increase of 690.8 kPa and the most homogeneous cavity area produced by biocomposite foam with the addition of 1% bacterial cellulose.

Keywords: Bacterial cellulose, biocomposite foam, SEM, tensile strength

1. Introduction

Indonesia ranks second in the world as a producer of plastic waste to the sea after China [1] and the use of plastic in Indonesia reached 4.7 tons in 2015 [2]. One type of plastic that is often used by the public is styrofoam.

Styrofoam is a trading name of a type of polystyrene plastic (PS). This plastic is produced from a mixture of 90-95% polystyrene and 5-10% n-butane or n-pentane gas which is blown using Cloro Fluoro Carbon (CFC) or commonly called Freon to form a foam structure. However, if the human body gets exposure to styrene too often then negative effects will occur in the form of neurological disorders such as fatigue, difficulty sleeping, and excessive anxiety. In addition, there will also be a decrease in hemoglobin blood which will cause anemia and cytogenetic disorders and carcinogenic effects [3].

Biofoam products are developed which are expected to replace Styrofoam today. In this study, biocomposite foam used is biocomposite foam derived from cassava starch because cassava production in Indonesia tends to increase to 21,801,415 tons in 2015 [4] and the level of household consumption tends to decrease 6.39% from 2010 - 2019 [5]. It makes cassava as source of starch that can be used without disturbing people's consumption of cassava.
One study that uses cassava starch as a raw material for making biocomposite foam is a study conducted by Silva (2013). In his research with the percentage of cassava starch 92%, 1% magnesium stearate, and 1% guar gum and 5% glycerol increased the tensile strength by 18%, and the length increase ranged from 1.69% [6]. This research objective is to find out the influence the bacterial cellulose content on the mechanical strength and morphology of starch-based biocomposite foam.

2. Methods

2.1. Materials
The research material used the commercial cassava starch and bacterial cellulose in the form of nata purchased from CV. Sari Kimia Malang, Indonesia. Magnesium stearate and guar gum in technical grade was obtained from CV. Makmur Sejati, Malang, Indonesia.

2.2. Research Design
Research was conducted using experimental design research with independent variables were the content of bacterial cellulose in the biocomposite with variation of 0%, 0.5%, 1%, 1.5%, and 2%wt. Independent variable were tensile strength and elastic modulus of starch-based biocomposite. Controlled variable were baking and drying process in biocomposite synthesis.

2.3. Synthesis of biocomposite foam
The ingredients mixed in each specimen were 35 g starch and 50 mL distilled water. After tapioca starch has been wet evenly then mix 4% magnesium stearate, and 0.5 gr guar gum, then stir until evenly distributed. The addition of bacterial cellulose was done separately at each percentage (0%, 0.5%, 1%, 1.5%, 2%wt). Before added in solution, bacterial cellulose was blended using high-speed blender for 15 min. After adding bacterial cellulose into solution, stir the ingredients using a blender for 10 minutes or until the ingredients are evenly distributed. After that add the 5 mL glycerol and stir again until evenly distributed. The mixture material was put into the oven and heated to a temperature of 200°C for 20 minutes and take in a desiccator for 24 hours before testing.

2.4. Tensile test
The tensile test equipment used in this study was a Fiber Tensile Test equipment (TechnoLab Indonesia). The shape of the specimens were referred to ASTM D638 Type V. Specimen was clamped then pull with a speed of 0.025 mm/s until break. Tensile test data was recorded thorough the Fiber Tensile Test software.

2.5. Surface morphological observation
Observation of morphology was conducted using Scanning Electron Microscope (FEI type Inspect S50). The voltage used 10.00 kV, and before the SEM process is carried out, the specimen was coated with gold metal [7]. Morphology observation was conducted at cross section surface in SEM with magnification 50x.

3. Results and Discussion

3.1 Mechanical properties analysis
The results that have been obtained in tensile testing of overall variations of cassava starch-based biocomposite foam with the addition of bacterial cellulose (0%, 0.5%, 1%, 1.5%, 2.0%wt) are shown in Figure 1 and Figure 2.
The physical and mechanical properties of biocomposite foams are correlated to the structure of foam, that is controlled by the polymerisation, bubble growth, bubble nucleation, and foam aging [8]. Cellulose have used as reinforcement in starch-based biocomposites due to influence in composite strength [9]. Both cellulose and starch have a similarity in chemical structure so that the affinity between cellulose and starch able to increase the mechanical properties of biocomposites and also produce biodegradable composite [10][11][12]. The highest value occurs in biocomposite foam with the addition of 1%wt bacterial cellulose producing an average tensile strength of 690.8 kPa (Figure 1) and elastic modulus of 5.26 GPa (Figure 2). There is a decrease in tensile strength in percentages above 1.0%wt. In the percentage of bacterial cellulose of 1.5%wt and 2.0%wt, the tensile strength of biocomposite foam
decreases to 338.70 kPa and 207.96 kPa, respectively. Moreover, the elastic modulus of biocomposite foam decreases to 2.5 GPa and 0.71 GPa, respectively. This is in line with research conducted by Boonchaisuriya (2011) showing that the higher content of cellulose palm fiber reduces tensile strength value of biocomposite foam [13]. Addition of bacterial cellulose make surface structure have a more uniform internal pore size as well as addition the montmorillonet into starch based foam [14]. Adding too much reinforcement cause interaction between the matrix and reinforcement material to be limited and result in debonding [15] results in a decrease in the tensile strength of cassava starch-based biocomposite foam. Besides, the decrease in tensile strength can also be caused by agglomeration. Starch-based biocomposite foams are brittle and stiff due to the greater intermolecular interactions between starch molecules [6].

3.2 Morphology observation

The results of SEM observation on morphology is shown in Figure 3. Bubble nucleation and growth was generated by blowing agent [16] that make porous structure. The initial stage of foaming process is the gas generated by blowing agent enters into starch matrix forms mixture of two phase. Next stage, at pressure and an elevated temperature, the starch matrix is saturated with the foaming gas then the homogeneous system expands as the pressure decreases so that the structure stabilizes [17]. After observation with SEM, the morphology of starch-based biocomposite foam without bacterial cellulose show the appearance of the cross-section of the cavity formed is less homogeneous and dominated by large cavities (438.9 μm - 1.088 mm). Overall, the percentage of the cavity area formed was 43.3%. On the surface, there is porosity giving rise to the potential for cracking and decreasing the tensile strength of biocomposite foam.

![Figure 3](image)

**Figure 3.** Morphology of starch -based biocomposite foam reinforced by bacteril cellulose with content of (A) 0.0%, (B) 0.5%, (C) 1.0%, (D) 1.5%, (E) 2.0%wt

Starch-based biocomposite foam with a percentage of 0.5% bacterial cellulose has a more homogeneous cavity with smaller cavity sizes (around 328.3μm) compared to starch-based
biocomposite foam without bacterial cellulose. Overall the percentage of the cavity area formed was 44.2%. Starch-based biocomposite foam with 1% bacterial cellulose percentage has a flatter surface, and fewer holes are formed. In the cross-section of the cavity formed homogeneous, but still elongated with a height of about 332 μm and a length of about 1 mm. Overall the percentage of the cavity area formed is 45.4%.

Starch-based biocomposite foam reinforced by 1.5%wt bacterial cellulose undergoes an imperfect foaming process that shows the appearance of cross-sections producing inhomogeneous cavities and parts that do not expand. The overall percentage of cavity area formed was 48.3%.

Starch-based biocomposite foam reinforced by 2.0%wt bacterial cellulose has a flat surface, but unfortunately there are still holes, and there are cracks that can reduce the tensile strength of the material. While in the cross-section display, the cavities are filled with fragments of biocomposite foam. The cavity formed has a relatively homogeneous size. Overall the percentage of the area of the cavity formed was 39.2%.

Porosity is formed on the surface of biocomposite foam due to air pressures trapped inside biocomposite forcing it to come out. The more porosity that forms on the surface of biocomposite foam, the less cavity is produced. When viewed in biocomposite foam reinforced by 1.5%wt biocomposite cellulose, there is a lot of porosity that is formed and the morphology of the cavities that are increasingly irregular. That is because high-pressure air tries to get out. Because of inside biocomposite foam is entirely solid, the only way is through the surface of biocomposite foam, causing porosity.

4. Conclusion
The addition of bacterial cellulose increase both tensile strength and elastic modulus of starch-based biocomposite foam-reinforced by bacterial cellulose. Starch-based biocomposite foam reinforced by 1.0% bacterial cellulose produces optimum tensile strength and elastic modulus values of 690.8 kPa and 5.26 GPa, respectively.

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