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Research Paper

Optimisation of Biodegradable Plastic from Cassava Peel Starch with Additional Materials of Sugarcane Bagasse Cellulose

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ABSTRACT: *The use of plastic in large quantities causes environmental pollution because it is not easily decomposed. One way to overcome this is to make bioplastics from natural materials that are easily decomposed such as cassava peel starch. However, the use of starch in making bioplastics still has low mechanical properties. Therefore, cellulose is added as an additive to improve the mechanical properties of bioplastics. This study investigated the potential of cassava peel starch modified with bagasse cellulose as a base material for bioplastics. The aim is to improve the mechanical performance and biodegradability of bioplastics to reduce the environmental impact of conventional plastics. The resulting bioplastics were evaluated based on water absorption, biodegradability, tensile strength, elongation, and elastic modulus tests. Variations in cellulose content showed a significant effect on the physical and mechanical properties of bioplastics. The addition of 18% cellulose provided the best water resistance, while 3% cellulose content resulted in the highest biodegradability. Optimal mechanical properties were achieved at 9% cellulose addition, with a tensile strength of 10.48 N/mm², elongation of 7.92%, and elastic modulus of 3.43 N/mm². However, these results are still below the standards for environmentally friendly plastics based on SNI 7188.7:2016 and SNI 7818:2014, which set higher parameters for water resistance, tensile strength, and elasticity. This bioplastic has the main advantage of being easily biodegradable, making it a potential alternative for certain applications.*

Keywords: *Bagasse; Biodegradability; Bioplastic; Cassava peel; Mechanical properties;*

1. INTRODUCTION

Biodegradable plastic (bioplastic), also known as environmentally friendly plastic, is a viable solution to the issue of conventional plastic waste that resists decomposition [1][2]. This bioplastic is produced from natural materials, including plants and animals, that contain polymer compounds, including starch [3], cellulose, lignin, and alginate. Starch is a material with significant potential due to its renewable nature and its widespread availability in Indonesia [4].

In Indonesia, cassava, sago, potatoes, and maize are among the numerous sources of starch that are frequently encountered [5]. Sago and cassava serve as staple foods in certain areas. However, processing cassava into food products generates significant waste, particularly cassava peels, which amount to millions of tonnes each year. Due to their abundant starch content, this waste shows promise for use as a raw material in bioplastic production. [1][6].

It has been demonstrated in prior research that the mechanical properties of starch present challenges when used in bioplastics. Research has demonstrated the brittleness and low tensile strength of bioplastics produced from purified starch [7]. To enhance their flexibility and durability, additional materials such as plasticisers are required [1]. Moreover, it was found that the tensile strength reached its highest value with the addition of cellulose, but it still fell short of the minimum standard set by SNI 7818:2014 [8]. This suggests that, despite the potential for modifications to enhance the mechanical properties of bioplastics, there is still a

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substantial void to be filled in order to comply with industry standards. Additional research into various composite materials and additives may result in solutions that enhance the flexibility and durability of bioplastics, potentially rendering them a more suitable option for a variety of applications.

Bagasse, a byproduct of the sugar production process, is one of the most prevalent sources of cellulose [9][10]. Despite its abundant availability and high cellulose content, bagasse has not yet reached its full potential [11]. The delignification process of bagasse yields pure cellulose up to 43.41% and isolated cellulose up to 87.94%, making it suitable for use as an infill in bioplastics [12]. Research also indicates that bioplastics made from a mix of cassava starch and cellulose from bagasse are stronger than those made from pure cassava starch [13]. Additionally, cassava peel residue has been explored as an alternative starch source, demonstrating properties similar to cassava tuber starch, thus making it suitable for bioplastic production [14]. It has also been shown that cassava peel starch can produce bioplastics with a faster biodegradation rate compared to traditional plastics [15]. Observations from the Bone Sugar Factory further suggest that bagasse waste can be utilized as a reinforcing material in bioplastics, reducing waste and enhancing the value of sugar industry by-products.

This study focuses on producing bioplastics using cellulose from sugarcane bagasse and starch from cassava peels. A key aspect of the research is to analyze how the addition of cellulose influences the bioplastic's properties. Cassava peels, sourced from culinary waste such as fried cassava and chips, are cleaned and processed to extract starch. Meanwhile, sugarcane bagasse, obtained from the Bone Sugar Factory, undergoes a delignification process to remove lignin and produce pure cellulose for use as a filler. This research aims to develop bioplastics with enhanced mechanical performance while promoting sustainable waste management by utilizing these organic by-products.

2. RESEARCH METHODS

2.1 Materials and Tools

This research was conducted at the Process Control Laboratory of Politeknik ATI Makassar. Key tools used included an oven, 20 x 20 cm mould, autoclave, and universal testing machine. The materials consisted of cassava peels sourced from fried food vendors in Makassar City, sugarcane bagasse, glycerol, distilled water, polyvinyl alcohol (PVA), and sodium hydroxide (NaOH). All chemicals used were of analytical grade to ensure accurate results. The design of the main tool can be seen in Figure 1.

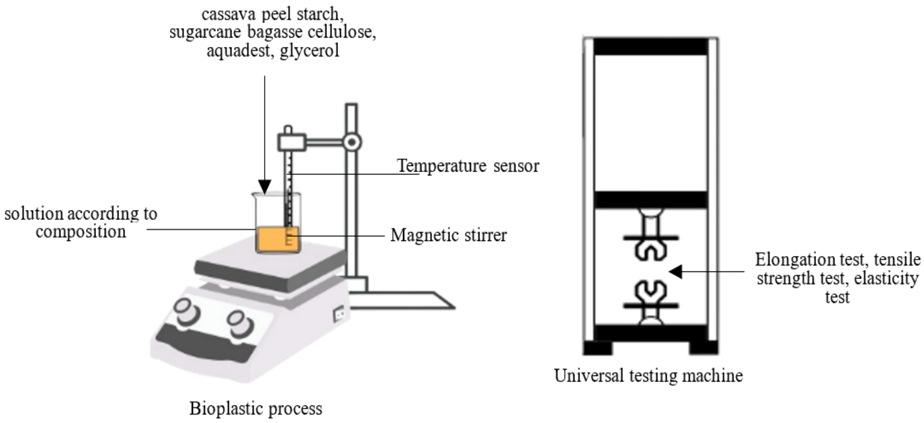

Figure 1. Production of Bioplastic and testing Biodegradable

2.2 Methods

2.2.1 Preparation of Cassava Peel

Cassava peel was cleaned and extracted to obtain wet starch. Subsequently, the starch was dried in an oven at 70°C for 30 minutes. Once the starch had been dried, it was ground with a blender and filtered through an 80 mesh sieve.

2.2.2 Preparation of Bagasse

The bagasse was cleaned, dried, and ground using a blender. Next, the bagasse was sieved with a 40 mesh sieve. The sieved bagasse was mixed with 17.5% NaOH solution with a ratio of 1:15 (bagasse) and heated in an autoclave at a pressure of 0.05 MPa for 60 minutes. After this process, the bagasse was filtered and washed with distilled water until neutral, then dried in an oven at a temperature of 105°C for 1 hour. After drying, the bagasse was ground again and sieved with a size of 80 mesh to obtain pure cellulose.

2.2.3 Production of Bioplastic

The 5 grams of cassava peel starch was mixed with 5 grams of PVA and bagasse cellulose in various concentrations (3, 6, 9, 12, 15, and 18%). The mixture was added with 100 ml of distilled water and stirred until homogeneous. Then, 0.25 grams of glycerol was added as a plasticizer. This solution was heated at a temperature of 75-80 °C for 40 minutes while continuing to stir. After being homogeneous, the solution was poured into a 20 x 20 cm mold as much as 100 ml and allowed to dry at room temperature for 48 hours. After drying, the bioplastic was released from the mold and ready to be analyzed.

2.2.4 Bioplastic Testing

Bioplastic testing is carried out to determine its quality and mechanical properties. Various bioplastic tests carried out were:

a. Water resistance test

The water resistance test aims to determine the level of bioplastic resistance to water [16]. This test procedure began by cutting the bioplastic into 2 x 2 cm sizes, then weighing the initial weight of the sample (W_o). After that, the sample was placed in a container containing 10 mL of distilled water for 1 minute. After that time, the sample was lifted and the water attached to the surface of the bioplastic was removed using tissue. Furthermore, the sample was reweighed to obtain the weight after the test (W). The test results are then calculated using equation 1 and 2:

$$\text{Water absorption capacity } (\%) = \frac{W_1 - W_o}{W_o} \times 100\% \quad \ldots\ldots (1)\ [16]$$

$$\text{Water resistance } (\%) = 100\% - \text{water absorption capacity } (\%) \quad \ldots\ldots (2)$$

where W_o is the weight of the sample before dipping (mg) while W_1 is the weight of the sample after dipping (mg).

b. Biodegradability test

Biodegradability test was conducted to determine the length of time required for bioplastic to decompose, using the soil burial test method [17]. Bioplastic was cut into 2 x 2 cm sizes, then stored in a desiccator for 24 hours before being weighed. The bioplastic samples were then buried in the soil at a depth of 5 cm for 6 days. After this period, the samples were taken, washed using distilled water, and dried again in a desiccator for 24 hours. The weight of the samples was then reweighed, and the weight loss was calculated using equation 3 and 4:

$$\text{Losing weight } (\%) = \frac{W_o - W_1}{W_o} \times 100\% \quad \ldots\ldots (3)\ [18]$$

$$\text{Degradability} = \frac{W_o - W_1}{6 \text{ days}} \times 100\% \quad \ldots\ldots (4)$$

where W_o is the weight of the sample before burial (mg) while W_1 is the weight of the sample after burial (mg).

c. Elongation and tensile strength test

Elongation test and tensile strength test were conducted using universal testing machine instrumentation. In the elongation test, the sample was cut to a length of 8 cm and a width of 2 cm and then its thickness was measured. Next, the sample was tested for its tensile strength [17]. The elongation and tensile strength values are calculated according to equations 5 and 6 respectively:

$$\text{Elongation } (\%) = \frac{\text{Bioplastic length extension (mm)}}{\text{Initial length of bioplastic (mm)}} \times 100\% \quad \ldots\ldots (5)\ [19]$$

$$\sigma = \frac{F}{A} \quad \ldots\ldots (6)\ [19]$$

where σ is tensile strength (N/mm^2), F is required force (N), and A is Surface area (N/mm^2).

d. Elasticity test

Elasticity (Young's modulus) is obtained from the comparison between tensile strength and elongation [19] with equation 7.

$$\text{Elasticity (N/mm}^2\text{)} = \frac{\text{Tensile strength test value (N/mm}^2\text{)}}{\text{Elongation test value (\%)}} \quad \text{.. (7) [19]}$$

3. RESULTS AND DISCUSSIONS

The successful production of bioplastic from cassava peel starch has been achieved through the incorporation of bagasse cellulose. The objective of this investigation was to evaluate the impact of bagasse cellulose on the quality of bioplastic derived from cassava peel starch. Furthermore, in order to enhance the elasticity of the product, polyvinyl alcohol (PVA) and glycerol were incorporated as plasticisers during the production of this bioplastic [20][21]. The materials were mixed according to a predetermined composition concentration: (A) 3%, (B) 6%, (C) 9%, (D) 12%, (E) 15%, and (F) 18%. and heated at a temperature of 75-80 °C for 40 minutes while being stirred with a magnetic stirrer.

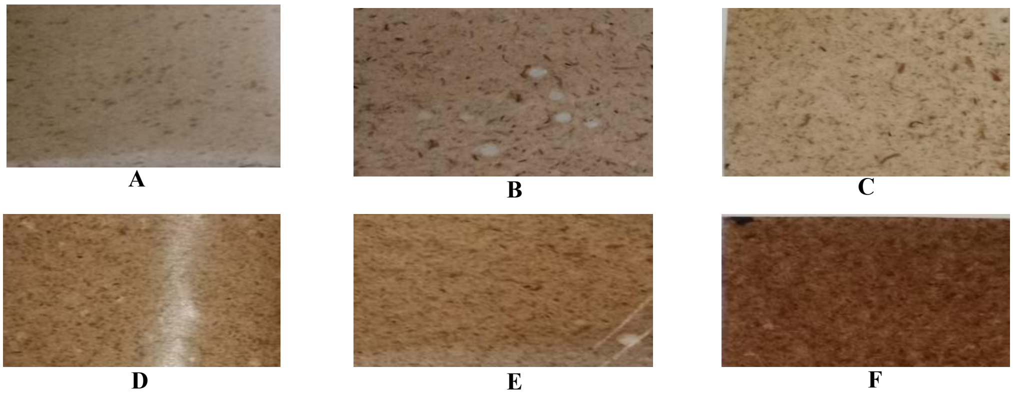

Figure 2. Biodegradable plastic resulting from synthesis with variations in sugarcane bagasse cellulose

The gelatinisation temperature of cassava peel starch was 63°C, at which point the starch molecules undergo a transformation into gel [22]. In the interim, prior research had demonstrated that the optimal temperature for bioplastic agitation was 80°C for a duration of 40 minutes [23]. PVA achieves its optimal solubility at temperatures exceeding 60°C, with the most favourable conditions occurring at temperatures around 70°C, at which point it can dissolve completely and achieve its optimal state [24]. Consequently, the bioplastic mixture was heated in this investigation at a temperature of 75-80°C to guarantee that all components were thoroughly mixed and dissolved. The bioplastic solution was permitted to dry at room temperature for 48 hours following the conclusion of the heating procedure. The bioplastic that results is illustrated in Figure 2. The quality of the bioplastic was evaluated by testing it for water resistance, biodegradability, and mechanical resistance after it had been dried. This was done to ensure that the resultant bioplastic product complies with the biodegradable plastic standards.

3.1 Water resistance test

Figure 3 shows the effect of increasing the content of bagasse cellulose on the water absorption capacity of bioplastics. The higher the concentration of bagasse cellulose added, the more the water absorption capacity of bioplastics tends to decrease. Bioplastics with a 3% bagasse cellulose content recorded the highest water absorption capacity, 62.93% while bioplastics with an 18% bagasse cellulose content showed the lowest water absorption capacity, 31.05%. Thus, bioplastics with a bagasse cellulose content of 18% showed the highest water resistance, which was 68.95%.

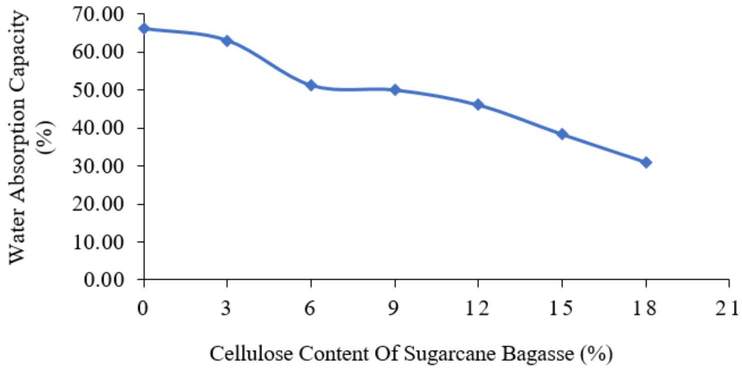

Figure 3. Water absorption test results

Permana et al. [25] have determined that the greater the water absorption capacity of a bioplastic, the lower its resistance to water. Consequently, the material is more susceptible to damage and dissolves more readily. The hydrophilic properties of starch are intended to be reduced by incorporating bagasse cellulose into bioplastic, as per Fadilla et al. [8]. This is due to the fact that cellulose is incapable of dissolving in water and creates robust hydrogen bonds, which complicates its interaction with water molecules. This is evident in the comparison of bioplastics that are devoid of cellulose (0%) and those that contain cellulose. The water absorption capacity of bioplastic without the addition of cellulose is higher, resulting in a reduced resistance to water compared to bioplastic containing cellulose [26]. Nevertheless, the Indonesian National Standard (SNI 7188.7:2016) stipulates that bioplastic should exhibit a water resistance of 99%. Thus, the bioplastic generated from cassava peel starch and bagasse cellulose in this investigation has failed to satisfy the established water resistance standards.

3.2 Biodegradability test

The biodegradability test aims to determine how quickly bioplastic samples can be decomposed by microorganisms in the soil [27]. Figure 4 shows the effect of adding bagasse cellulose on the percentage of bioplastic weight loss during 6 days of planting. The results showed that the level of bioplastic degradation decreased with increasing bagasse cellulose content. Bioplastic with 3% cellulose content experienced the highest weight loss, which was 81.00%. In contrast, bioplastic with 15% cellulose content only experienced a weight loss of 17.00% in the same period.

The decrease in the level of bioplastic degradation with increasing cellulose content is caused by a decrease in water absorption [28], as shown in the results of the water absorption test (Figure 3). Bioplastics with high water absorption are more easily overgrown by microorganisms, so that the degradation process takes place faster [29]. Cellulose with high concentrations forms strong hydrogen bonds, causing bioplastics to become stiffer and less absorbent, thus inhibiting the activity of microorganisms needed for the degradation process [30].

The presence of hydroxyl groups (OH) in the polymer structure, which are polar, facilitates the bioplastic degradation process by microorganisms. Microorganisms break down polymer compounds into small pieces until they completely break the polymer chain bonds, leading to the natural decomposition of the material [8]. The rate of degradation slows down in bioplastics that have a lot of cellulose in them. However, the bioplastics used in this study met the ASTM D5338 standards for biodegradability, which mean they broke down in less than 60 days.

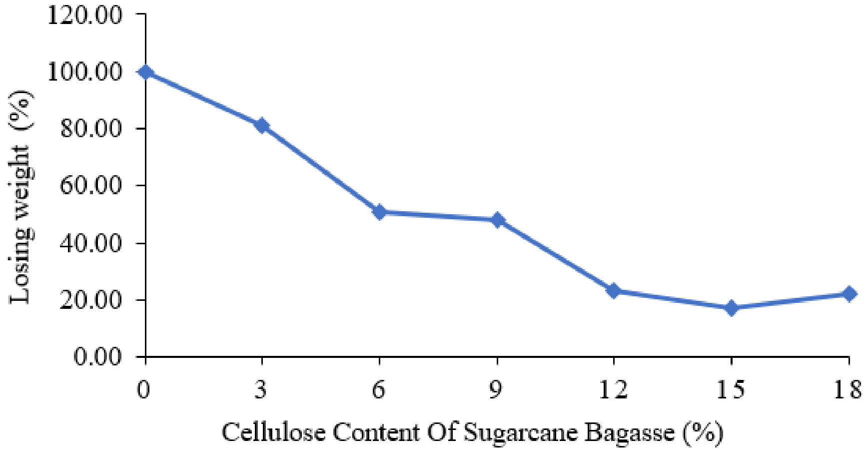

Figure 4. Biodegradability test results

3.3 Elongation test

An elongation test was conducted to evaluate the effect of adding bagasse cellulose on the toughness or elasticity of bioplastics when pulled [20][31]. Based on Figure 5, the addition of bagasse cellulose affects the elongation value of bioplastics. With the addition of 3, 6, and 15% cellulose, the elongation value of bioplastics was relatively similar, with no significant changes. However, the addition of cellulose up to 9% resulted in an increase in elongation value compared to bioplastics without the addition of cellulose. This increase is due to the formation of more hydrogen bonds between the hydroxyl (OH) groups in cellulose and starch. These bonds lengthen the polymer chain, thereby increasing the ability of bioplastics to stretch [31].

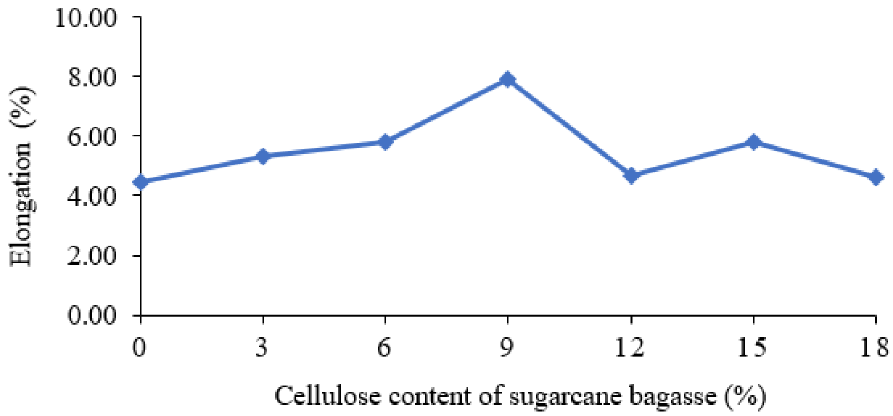

Figure 5. Elongation test results

However, the elongation value decreased again with the addition of 12 and 18% cellulose. This is attributed to the bioplastic's increased stiffness and hardness [32], as the high concentration of cellulose creates a denser and stiffer structure, thereby reducing the material's flexibility and ductility [33]. The addition of 9% cellulose achieved the highest elongation value of 7.92%. However, according to the Indonesian National Standard (SNI 7188.7:2016), the elongation standard for bioplastics is in the range of 21-220%. Therefore, this study's bioplastic failed to meet the established elongation standard. This shows that, although the addition of cellulose increases mechanical strength, bioplastics still require further optimisation to achieve the expected elasticity standard.

3.4 Tensile strength test

A tensile strength test was conducted to evaluate the effect of adding bagasse cellulose on the tensile strength of bioplastics [32][34]. The addition of bagasse cellulose changed the tensile strength value of bioplastics, as shown in Figure 6. The highest tensile strength value was achieved in bioplastics with the addition of 9% bagasse cellulose, which was 10.5 N/mm², while the lowest tensile strength value was found in bioplastics with 6% cellulose content, which was 7.0 N/mm². In general, bioplastics with the addition of cellulose have higher tensile strength values than bioplastics without cellulose (0%), indicating that cellulose plays a role in increasing mechanical strength [31].

The formation of hydrogen bonds between the hydroxyl (OH) groups of starch and the hydroxyl (OH) and carboxyl (COOH) groups in bagasse cellulose causes this increase in tensile strength. These hydrogen bonds strengthen the structure of the bioplastic, although on the other hand they reduce its elasticity. Bagasse cellulose also has a long and regular linear polymer chain that makes the bioplastic stiff and hard [34]. However, Figure 6 also shows that the addition of cellulose more than 9% causes a decrease in the tensile strength value. This is due to the high intermolecular forces and crystallinity of cellulose, which inhibit optimal interaction and dispersion with other components in the bioplastic mixture [35]. As a result, the addition of excessive cellulose actually reduces the tensile strength of the bioplastic.

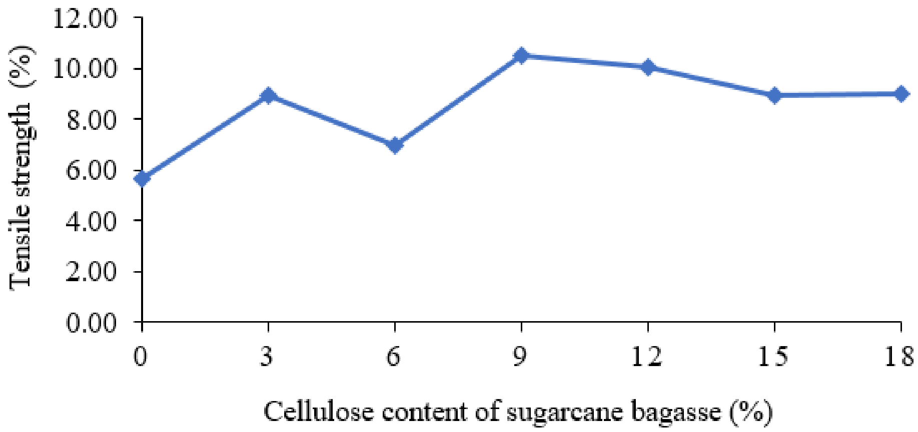

Figure 6. Tensile strength test results

Several previous studies also found that the tensile strength of bioplastics decreased with increasing fibre content. The study showed that tensile strength decreased with the addition of fibre [36]. However, in some cases, the addition of cellulose actually increased the tensile strength, such as in bioplastics based on banana stem cellulose and taro starch [37]. Based on SNI 7818:2014, the minimum tensile strength standard for bioplastics is 13 N/mm². Therefore, this study's bioplastic did not meet this standard. However, according to the Japanese Industrial Standard (JIS), bioplastics must have a tensile strength of more than 3.92 N/mm², so the results of this study have met this standard.

3.5 Elasticity test

Figure 7 shows the elasticity level of bioplastic with the addition of bagasse cellulose. The test results show that bioplastic without the addition of cellulose has a higher elasticity value compared to bioplastic containing cellulose [26]. Although the variation of cellulose addition shows differences in elasticity values, the difference between variations is not significant. However, in general, the elasticity value tends to decrease along with the increase in the concentration of bagasse cellulose [38].

The stronger interaction between cellulose and the polymer matrix in bioplastics causes this decrease in elasticity [39]. The addition of more cellulose leads to the formation of more hydrogen bonds, enhancing the material's stiffness and strength while diminishing its flexibility [40]. As a result, bioplastics become stiffer and less elastic. The addition of 18% bagasse cellulose to bioplastics yielded the lowest elasticity value.

According to SNI 7818:2014, the elasticity standard for biodegradable plastic bags is in the range of 400-1120%. Therefore, this study's bioplastic failed to meet the established elasticity standards. This demonstrates that while the inclusion of cellulose enhances the mechanical strength of bioplastics, additional optimisation is necessary to attain elasticity that satisfies the established standards.

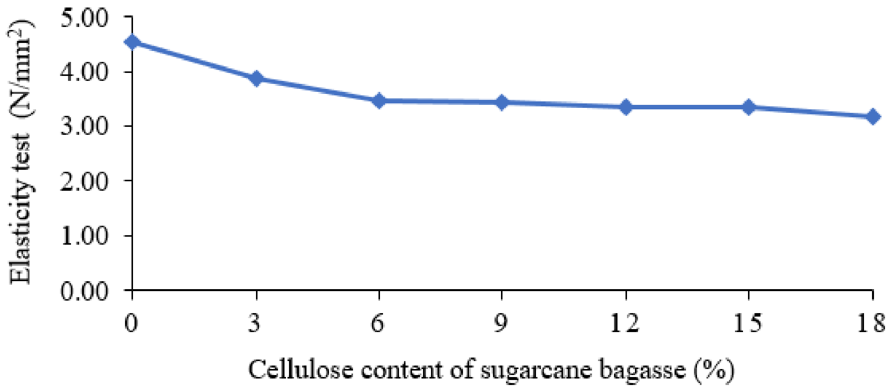

Figure 7. Elasticity test results

4. CONCLUSION

The research results indicate that the addition of bagasse cellulose influences the quality of bioplastics. The water absorption test revealed that the higher the bagasse cellulose content in bioplastics, the lower the water absorption level. This is different from the biodegradability test, where the more bagasse cellulose content, the longer the bioplastic degrades. In the mechanical properties test, the addition of bagasse cellulose resulted in an increase in tensile strength and elongation values, which eventually decreased due to saturation. The addition of bagasse cellulose resulted in a decrease in the elasticity value.

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