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CHARACTERIZATION OF PHYSICAL AND MECHANICAL PROPERTIES OF BIODEGRADABLE FOAM FROM MAIZENA FLOUR AND PAPER WASTE FOR SUSTAINABLE PACKAGING MATERIAL

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***Abstract*— Biodegradable Foam (Biofoam) production is an effort to reduce plastic waste in Indonesia. This product is made to replace Styrofoam, whose raw material is carcinogenic in the form of styrene which cannot be dissolved by the digestive system and is difficult to excrete through urine or feces which can trigger the growth of cancer in the long term and is harmful to the environment. Biofoam in this study is made from cornstarch with the addition of cellulose taken from paper waste. Based on the research that has been done, cornstarch-based biofoam with the addition of cellulose from paper waste as a biofiller can affect the physical and mechanical characteristics of the biofoam produced. The biofoam with a starch:cellulose ratio of 13:10 grams resulted in the best value of water adsorption in the amount 47.26%, also give the best result on tensile strength value and biodegradability value in the amount of 4.548 MPa and 11.943%. The addition of cellulose to the biofoam mixture in an appropriate amount will reduce the water absorption value of the biofoam. Because cellulose can cover the cavities generated by the starch expansion process in the biofoam. Therefore, the addition of cellulose also affects the mechanical properties of biofoam, namely tensile strength. Where the low filler composition in the biofoam will increase the tensile strength, but when the filler composition has passed an optimum point, the filler particles will experience agglomeration thereby reducing the tensile strength of the biofoam product. The variation in operating conditions in the manufacture of starch-based biofoam with the addition of a biofiller in the form of cellulose from paper waste did not significantly affect it. The variation in operating conditions only affects the visual appearance of the biofoam produced. Biofoam samples with the best visual appearance were produced at an operating temperature of 160 °C with an operating time of 30 minutes. Where high temperatures can affect the color and texture of the biofoam which is getting harder. The hard texture of the biofoam can increase the tensile strength of the biofoam.**

Keywords— **Biofoam, Cellulose, Starch, Styrofoam**

I. INTRODUCTION

Industrial revolution 4.0 provides various accesses for the public, especially its impact on the practical and hygienic lifestyle. This causes a dependency on people, especially on the use of plastics for food and beverage packaging, including Styrofoam, which is certainly not eco-friendly. Based on data from *Data Asosiasi Industri Plastik* and *Badan Pusat Statistika* [1] shows that plastic waste in Indonesia reaches 64,000,000 tons per year, of which 3,200,000 tons are plastic waste dumped into the sea. Styrofoam is food and beverage packaging made from non-recyclable and non-biodegradable chemicals that have adverse effects on human health and the environment [2], [3]. The raw material used to make Styrofoam is a carcinogenic material in the form of styrene which cannot be dissolved by the digestive system and is difficult to excrete through urine or feces which can support the growth of cancer in the long term [4]. Meanwhile, the danger to the environment is caused by the styrofoam waste combustion system which causes harmful styrene gases such as polyaromatic hydrocarbons (PAHs), hydrochlorofluorocarbon (HCFC), and carbon monoxide (CO), which will cause a pile of trash if doesn’t burn and leave it [5], [6]. Biodegradable foam (Biofoam) can be used as a way to replace Styrofoam to reduce environmental pollution and adopt a healthy lifestyle. Biofoam is an alternative Styrofoam packaging that is safe and eco-friendly with raw materials that have high biodegradability, low cost, low density, low toxicity, and water resistance [7]. That is why characteristic that is easy to form, lightweight, water-resistant, can withstand hot and cold temperatures, and low production prices are some of the parameters as the raw material to replace styrene for this biofoam [8]. Starch can be one of the raw materials for making Biodegradable Foam (Biofoam) because it has special properties such as baking expansion and easy to modify [9]. Maizena flour is fine grains derived from mashed dry corn with the largest component in the form of starch which reaches 68.2% [10], [11]. Biodegradable Foam (Biofoam) which is made from starch has deficiencies, namely that it is not resistant to water, also has poor physical and mechanical properties. Therefore, additives are needed as a modification to increase water resistance and fillers to improve mechanical properties. One of the additives that can be added in the process of making this biofoam is paper. Paper consumption in the world, especially in Indonesia, has increased over time [9]. The level of paper demand in 2011 reached 5.2 million tons in Indonesia [9]. The use of paper waste as biofiller in biofoam is very possible because the paper has a cellulose content of 69-99% weight [9]. This cellulose is useful as a filler material that can increase mechanical strength [9]. So it is hoped that the biofoam produced with raw materials from paper waste and cornstarch can meet the requirements of commercial Styrofoam and reduce environmental pollution.

II. METHODOLOGY

2.1. Materials

The main materials for this research are starch from maizena flour and cellulose from paper waste. The supporting materials to complete this research are Polyvinyl Alcohol, Magnesium Stearate, Effective Microorganisms-4, and Aquadest. The function of each material is shown in Table 1.

Table 1. Materials Function

Materials	Function
Maizena Flour (Starch)	Biodegradable raw material
Paper Waste (Cellulose)	Biofiller to increase the characteristic of biofoam
Polyvinyl Alcohol (PVA)	A biodegradable polymer which can form a transparent, strong, elastic, and well-adhered film layer (plasticizer)
Magnesium Stearate	Compound that prevents the foam from adhering to the mold
Effective Microorganisms-4 (EM-4)	Photosynthetic bacteria to speed up the decomposition of biofoam
Aquadest (H_2O)	Universal solvent

2.2. Method

This research uses the baking process method that is carried out in two steps in general: (1) starch gelatinization, expanding the mixture and forming a foam and; (2) foam drying. The baking process in the oven is controlled by modifying the time and temperature to see the effect on the biofoam. The operating variables during the research consisted of control variables and independent variables.

Control Variables

The control variables are the mass of PVA, Mg Stearate, and water with an amount equal to 5 gram, 2 gram, and 20 mL sequentially.

Independent Variables

The independent variables including the ratio of starch:cellulose and operating conditions shown in Table 2.

Table 2. Research Design

Run	Temperature (°C)	Time (Minute)	Ratio Starch:Cellulose
1	80	30	13:10
2	160	30	13:10
3	80	60	13:10
4	160	60	13:10
5	80	30	13:10
6	160	30	20.5:2.5
7	80	60	20.5:2.5
8	160	60	20.5:2.5

Experimental Process

The experimental process for making the biofoam is shown in Figure 1. Then, the product (biofoam) will be analyzed the physical characteristics including water adsorption and biodegradability, also the mechanical characteristic namely tensile strength.

The reference used to analyze water adsorption of biofoam is ABNT NBR NM ISO 535 of the year 1999 by cutting a sample in the size of 2.5 x 5 cm. Then the sample was weighed as the initial weight (M_0), then immersed in water for several minutes, and dried using a tissue to remove the remaining water that stuck to the surface of the sample. The sample is weighed again (M_t) and the added weight of the sample is calculated so that the percentage of water adsorption capacity is obtained by calculating based on the following equation [12].

$$Water\ Adsorption\ (\%) = \frac{M_t - M_0}{M_0} \times 100\% \qquad \text{(Eq. 1)}$$

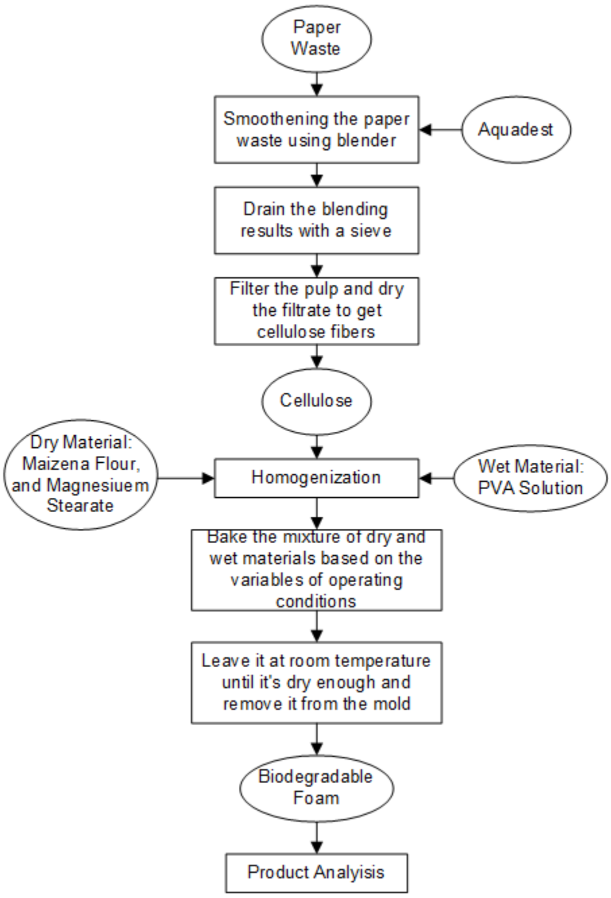

Figure 1. Flowchart of The Research

The biodegradation test was carried out to find out how many biofoam components can be decomposed by nature in the soil [13]. The analysis of the degradability was carried out by cutting the sample in the size of 2.5 x 5 cm and weighed as the initial weight (W_0). Then the sample is put into a box filled with soil with a height of 20 cm for 20 days. Then the sample is cleaned of the remaining soil and weigh the final sample (W_1). Then calculate the percentage of weight loss with the following equation [12], [14].

$$Weight\ Loss\ (\%) = \frac{W_0 - W_1}{W_0} \times 100\% \qquad \text{(Eq. 2)}$$

This test can also be added to bacteria from Effective Microorganism-4 (EM-4) which contains photosynthetic bacteria (Actinomycetes).

Tensile strength aims to determine the strength of the material against the tensile force by pulling a material until it breaks and knowing how the material reacts to the pull to the extent that the material increases in length [15]. The tensile and elongation strength of biofoam is influenced by starch content, fiber content, plasticizers, and the resulting compatibility of materials. This test is relatively simple and has been standardized throughout the world, for example in America with ASTM E8, in Japan with JIS 2241, and in Indonesia with ASTM D 638 [15]. Testing is done by clamping the two ends of the sample that has been cut according to the standard in the testing machine, then turning on the power completely and setting it up. Then set the maximum distance, load speed, and force range. The sample is drawn slowly until the sample breaks [12].

III. RESULT AND DISCUSSION

Characterization of the physical and mechanical properties of Biodegradable Foam produced by the Baking Process method with raw materials in the form of corn starch from cornstarch and cellulose from paper waste resulted in products with the results listed in Table 3. Determination of variables in this study using the factorial design method with three changing variables, namely operating temperature, operating time, and the ratio of starch:cellulose.

Table 3. Determination of Variables and Interaction

Run	Independent Variables			Interaction			
	T	t	R	Tt	TR	tR	TtR
1	-	-	-	+	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	-	+	-	-	-
5	-	-	+	+	-	-	+
6	+	-	+	-	+	-	-
7	-	+	+	-	-	+	-
8	+	+	+	+	+	+	+

Notes:

- Operating Temperature (T), involve:
  $- = 80℃$
  $+ = 160℃$
- Operating Time (t), involve:
  $- = 30$ minute
  $+ = 60$ minute
- Ratio Starch:Cellulose, involve:
  $- = 30{:}\ 10$ gram
  $+ = 20.5{:}\ 2.5$ gram

The most influential variable in this study can be determined by using the Quicker Method which calculates the main effect and interaction effect on water adsorption. The calculation result for most influence variables to the value of water adsorption can be seen in Table 4 and Table 5 below.

Table 4. Calculation Result of Main Effect and Interaction Effect to Water Adsorption of Biofoam

Effect	Score
T	13.0421227
t	30.9120769
R	100.038203 →Main Effect

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Tt	15.3407179 → Interaction Effect
TR	-4.4367081
TtR	-19.659267
tR	-22.08315

Table 4 shows that the main effect in this study is the ratio of starch:cellulose with a value of 100.038 with an interaction effect in the form of operating temperature and operating time of 15.341.

Table 5. Determination of Influential Variables on Water Adsorption of Biofoam

P (%)	Effect	Effect Identity
7.1428571	-22.08315	tR
21.428571	-19.659267	TtR
35.714286	-4.4367081	TR
50	13.0421227	T
64.285714	15.3407179	Tt
78.571429	30.9120769	t
92.857143	100.038203	R

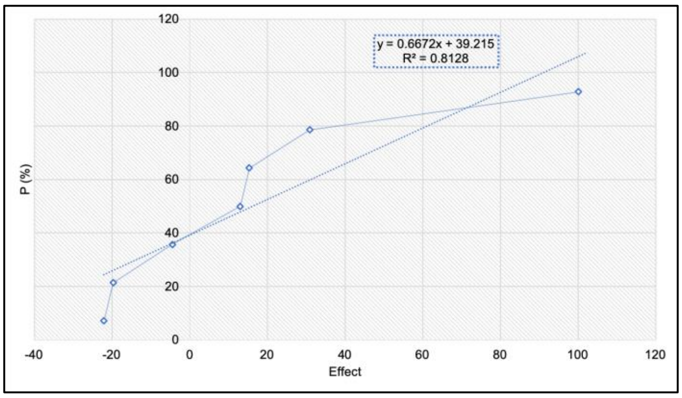

Figure 2. Normal Probability Plot on Water Adsorption Biofoam for Factorial Design 2^3

Figure 2 shows the Normal Probability Plot graph between the P-value and the effect obtained by regression (R^2) of 0.8128 by activating the Trendline feature in Microsoft Excel. This means that 81.28% of the total model variation can be represented by a regression equation. The equation that shows the correlation between the value of water adsorption and the parameters of the research process (the ratio of starch:cellulose and operating conditions) is $y = 0.6672x + 39.215$. Therefore, in the analysis of the water adsorption of biofoam, it can be concluded that the starch:cellulose ratio is the most influential variable to the water adsorption of biofoam.

3.1. Physical Properties Analysis of Biodegradable Foam

3.1.1. The Effect Ratio Starch:Cellulose on Water Adsorption of Biofoam

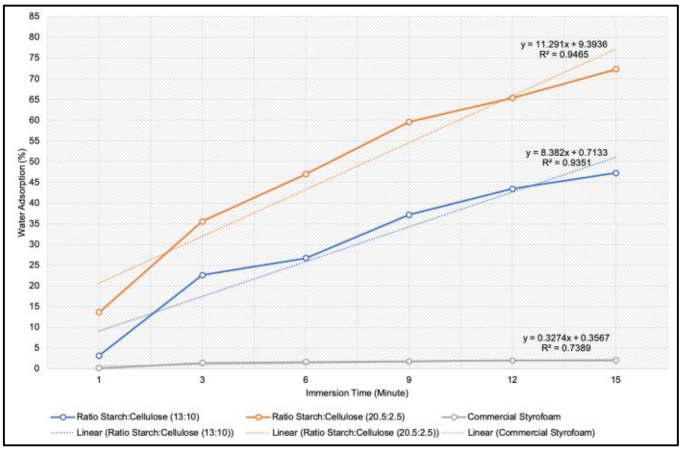

Figure 3. Relationship between Ratio Starch:Cellulose and Water Adsorption of Biofoam

Water adsorption is the amount of water absorbed by biofoam after being immersed in water with different time variations [16]. This test is carried out to show whether the biofoam immersed in water will be damaged within a certain time. When the biofoam is immersed in water with a certain time variation, the water will diffuse into the biofoam material. This needs to be avoided because water that diffuses too much will damage the structure of the material from within and reduce the quality of the biofoam produced.

Based on Figure 3, it can be seen that water adsorption increases time by time. The ratio between starch from cornstarch and cellulose from paper waste is one of the effects of increasing water adsorption in biofoam. Starch according to [17] consists of two fractions, namely a dissolved fraction called amylose and an insoluble fraction called amylopectin. The solubility of amylopectin can be seen from the polarity of the substance where water is a polar compound, while amylopectin is a non-polar compound, so the two substances cannot dissolve each other. Cornstarch contains 74-76% amylopectin and 24-26% amylose, where the amylopectin content can affect the solubility and gelatinization temperature of starch [18]–[20]. The expansion process in starch-based biofoam production will produce a hollow structure and be more easily filled with water, so it is necessary to have a filler material in the form of cellulose fibers obtained from paper waste to fill these cavities.

The water adsorption of biofoam increases with the following increase in cellulose, this is because cellulose is

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a hygroscopic compound that can dissolve in water. Although the added starch is more than cellulose, biofoam will produce a structure that tends to be more hollow and can increase the adsorption of water, due to the starch characteristic which is hydrophilic and tends to bind to water. The results of this study are in line with research conducted by [13] where the addition of suitable cellulose to the starch will reduce water adsorption in biofoam. The water adsorption of biofoam with ratio starch:cellulose in the amount of 20.5:2.5 was greater than the starch:cellulose in the ratio of 13:10, this shows that cellulose added with a suitable amount to the starch will reduce water adsorption. Biofoam with a starch:cellulose in the ratio of 13:10 when immersed in water for 15 minutes resulted in the amount of 47.26% which is thought to be better than biofoam made with a starch:cellulose in the ratio of 20.5: 2.5 with water adsorption in the amount of 72.27% at the same condition. Also, this study tested commercial styrofoam on the market with a water adsorption value of 2.036% for 15 minutes of immersion time. The results obtained in this study are very far from being compared to commercial styrofoam, this is because natural fibers such as cellulose from paper waste with high hydrophilic properties which are not added accordingly will increase the water adsorption of biofoam. This is also proven by research conducted by [21] where starch and cellulose-based biofoam will increase overall water adsorption. Because natural starch can absorb water by 0.4 the initial weight of starch and increases the absorption of water which is greater than changes the structure which are denser and high viscosity [22], [23].

3.1.2. The Effect of Operating Conditions on Water Adsorption of Biofoam

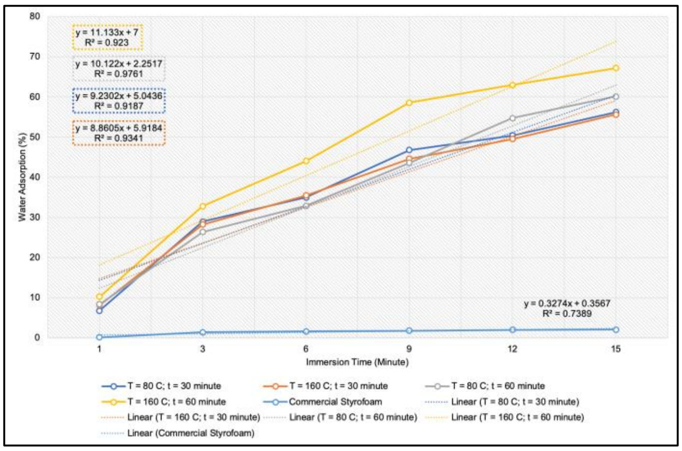

Figure 4. Relationship between Operating Conditions and Water Adsorption of Biofoam

In this study, the variation of operating conditions in the biofoam doesn't have a significant effect. This is evidenced in Table 4 which shows that the main effect on the water adsorption is the ratio of starch:cellulose with a value of 100.038. The thing that can be seen with the naked eye is the visual appearance of the biofoam that shows in Table 6.

Table 6. Visual Appearance of Biofoam

Operating Conditions		**Visual Appearance of Biodegradable Foam**	
T (°C)	t (Minute)	Ratio 13:10	Ratio 20.5:2.5
80	30	Dusty white color, soft texture, sticky with the molder.	Flourish white color, soft texture, sticky with the molder.
160	30	Dusty white color, normal texture, detached from the molder.	Flourish white color normal texture, detached from the molder.
80	60	Dusty white color hard texture, detached from the molder.	Flourish white color hard texture, detached from the molder.
160	60	Dusty white color (darker), very hard texture, hardens in the mold, and difficult to detach.	Flourish white color (darker), very hard texture, hardens in the mold, and difficult to detach.

Based on Table 6, the best-operating conditions for biofoam is 160°C for temperature that baked in the oven for 30 minutes with the ratio starch:cellulose in the amount of 13:10 grams.

Figure 5. The Result of Biofoam (Ratio 13:10) and T = 160 °C; t = 30 Minute

3.1.3. The Effect of Ratio Starch:Cellulose on Biodegradability of Biofoam

The biodegradation test was carried out on the biofoam produced from the research which was taken from the best-operating conditions, namely in sample 2. The biofoam in sample 2 was made with a starch:cellulose in the ratio of 13:10 grams that baked in an oven with a temperature of 160 °C for 30 minutes. The biodegradation test was carried out to determine the size of the sample that was broken down by microorganisms in the soil. This test is carried out by the soil burial method, where the biofoam is immersed in the soil for a certain time and weighed every day to determine the mass loss that occurs due to decomposition by microorganisms. The relationship between soil burial time and the percentage of biofoam damage can be seen in Figure 6 below.

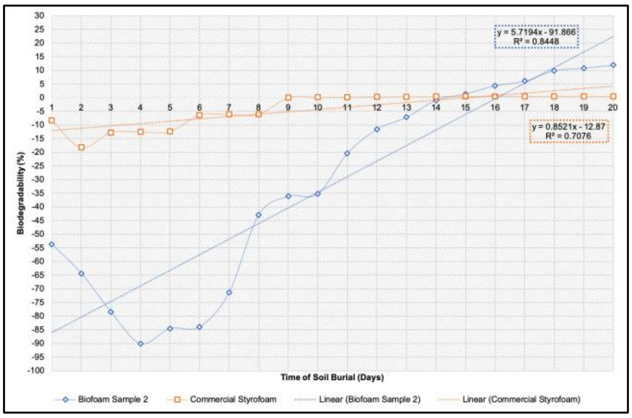

Figure 6. Relationship between Time of Soil Burial and Biodegradability of Biofoam

Figure 6 shows that the longer the immersion time of biofoam in the soil, the greater the percentage of damage or loss of mass (degradability). However, sample 2 of biofoam experienced a decrease in the percentage of damage reaching -90.126% in the first 4 days and began to increase the next day until the 15th day then showed a positive percentage, namely 1.395%. The increase in the percentage of damage to biofoam which reached a negative value was thought to be due to the Effective Microorganisms-4 (EM-4) that added to the soil and also containing photosynthetic bacteria (Actinomycetes). The results of the study which is conducted by [13], [16] show that the addition of cellulose can affect the percentage of biofoam damage in the soil because cellulose is a biofiller that causes biofoam to easily break down in the soil and organic. Besides, this study also tested commercial Styrofoam with a percentage of damage of 0.462% within 20 days of stockpiling in the soil. The degradation time of biofoam for 20 days resulted in a percentage of damage in the amount of 11.943%, which this value will continue to increase day by day until the biofoam can be completely degraded in the soil naturally.

3.2. Mechanical Properties Analysis of Biodegradable Foam

The biofoam was also tested for its mechanical property which is tensile strength. The variables that have the most influence on the tensile strength, analyzed through the calculation of the main effect and the interaction effect with the Quicker Method listed in Tables 7 and 8 below.

Table 7. Calculation Result of Main Effect and Interaction Effect to Tensile Strength of Biofoam

Effect	Score
T	5.066 → Main Effect
t	-3.356
R	-2.338
Tt	-1.88
TR	-3.702
TtR	-1.668
tR	2.204 → Interaction Effect

Table 7 shows that the main effect in this study is temperature with a value of 5.066 with an interaction effect in the form of operating time and the ratio of starch:cellulose of 2.204.

Table 8. Determination of Influential Variables on Tensile Strength of Biofoam

P (%)	Effect	Effect Identity
7.1428571	-3.702	TR
21.428571	-3.356	t
35.714286	-2.338	R
50	-1.88	Tt
64.285714	-1.668	TtR
78.571429	2.204	tR
92.857143	5.066	T

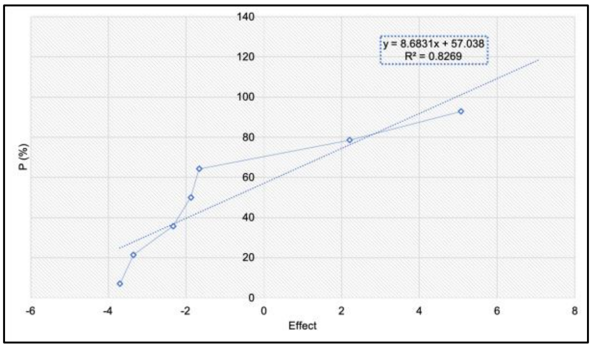

Figure 7. Normal Probability Plot on Water Adsorption Biofoam for Factorial Design 2^3

In figure 7 displays the Normal Probability Plot graph between the P-value and the effect obtained by regression (R^2) of 0.8269 by activating the Trendline feature in Microsoft Excel. This means that 82.69% of the total model variation can be represented by a regression equation. The equation that shows the correlation between the value of tensile strength and the parameters of the research process (the ratio of starch:cellulose and operating conditions) is $y = 8.6831x + 57.038$. Therefore, operating temperature is the most influential variable in the analysis of the tensile strength.

3.2.1. The Effect of Ratio Starch:Cellulose and Operating Conditions on Tensile Strength of Biodegradable Foam

Biofoam with raw materials in the form of starch from maizena flour and cellulose from waste paper are tested for their mechanical properties by performing a tensile strength test. The purpose of the tensile strength test is to determine the tensile strength of the biofoam produced by calculating the distribution of the maximum force that the material can bear against the cross-sectional area of the original material [24]. The theory of [13] states that the greater the value of tensile strength produced by a material, the greater force is needed to attract the material.

Table 9. Tensile Strength Result of Biofoam

Run	**Operating Conditions**		**Ratio**	***Tensile Strength* (MPa)**
	T (℃)	t (Minute)		
1	80	30	13:10	2.303
2	160	30	13:10	4.548
3	80	60	13:10	0.966
4	160	60	13:10	3.105
5	80	30	20.5:2.5	1.676
6	160	30	20.5:2.5	2.904
7	80	60	20.5:2.5	2.275
8	160	60	20.5:2.5	1.729

Based on Table 9, it can be seen that the biofoam with the highest tensile strength value was produced by the sample in run 2 with a starch:cellulose ratio in the amount of 13:10 grams with operating conditions in the form of a temperature of 160 ℃ for 30 minutes. The function of adding cellulose in biofoam is to fill the material to improve the mechanical properties of the biofoam. A study from [13] states that the low filler composition in the manufacture of biofoam will experience an increase in tensile strength, but when the filler composition has passed an optimum point, the filler particles will experience agglomeration, thereby reducing the tensile strength of the biofoam product. Agglomeration according to [13], [25] is very likely to occur because when the addition of excess cellulose will result in strong interactions between the fillers (filler-filler bonding), causing the interaction between the filler and the matrix to decrease. Based on data from Product Information Commercial, it is stated that commercial Styrofoam has a tensile strength of 0.1 MPa, so that the biofoam produced from cornstarch and cellulose waste paper with a ratio of 13:10 grams has greater tensile strength and meets commercial tensile strength standards.

IV. CONCLUSION

The addition of cellulose from paper waste as a biofiller can affect the physical and mechanical characteristics of the biofoam produced. The suitable amount of cellulose that is added to the biofoam will reduce the water adsorption value of the biofoam. Because cellulose can cover the cavities generated by the starch expansion process in the biofoam. Besides, the addition of cellulose also affects the mechanical properties of biofoam, namely tensile strength. Where the low filler composition in the manufacture of biofoam will experience an increase in tensile strength, but when the filler composition has passed an optimum point, the filler particles will experience agglomeration thereby reducing the tensile strength of the biofoam product. The degradation time of biofoam for 20 days resulted in a percentage of damage in the amount of 11.943%, which this value will continue to increase day by day until the biofoam can be completely degraded in the soil naturally.

V. ACKNOWLEDGMENTS

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