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The Properties of Particleboard Composites Made from *Pleurotus ostreatus* Baglog Waste Using Citric Acid and Sucrose Adhesive

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Abstract

Pleurotus ostreatus (PO) is one of the edible mushrooms cultivated in baglog as the medium. Baglog's productive age is around 4-5 weeks. The more PO produced, the amount of baglog waste also increases. The main component of baglog is wood sawdust, which contains lignocellulose; therefore, baglog has great potential to be used as a raw material for making particleboard. This research aims to make particleboard from baglog waste and determine the effect of the type and adhesive concentration on the physical and mechanical properties of the particleboard that is produced. Particleboard is made by mixing baglog waste, whose particle size is 40 mesh, with citric acid and sucrose adhesives whose concentrations are varied between 50%, 60%, and 70%. Furthermore, the particleboard was formed using a hot press machine (200 °C, 10 MPa) for 15 minutes. The obtained particleboard will be analyzed for its physical properties, including density, moisture content, water absorption, thickness swelling, morphology, and mechanical properties, including modulus of rupture (MOR) and modulus of elasticity (MOE). The test refers to the JIS A 5908-2003 type 8 standard. As a result, particleboard made using citric acid adhesive (citric acid 70%; C70) has a better physical and mechanical properties compared to sucrose adhesive, with a density value of 0.86 g/cm³, moisture content of 4.118%, thickness expansion of 3.992%, water absorption capacity of 36.89%, 13.456%, MOR 9.682 MPa, and MOE 1.455 GPa.

INTRODUCTION

Pleurotus ostreatus is an edible mushroom that is popular and favored by the consumers. In the 100 g dried mushroom of PO, contains of 32 g protein, 50.9 g carbohydrate, 3.1 g fat, 6.2 g crude fiber, 0.32 g thiamin (vitamin B1), 0.58 g riboflavin (vitamin B2), 8.72 g niacin (vitamin B3), 0.052 g folic acid acid (vitamin B9), 12.52 g ascorbic acid, and micronutrients such as selenium, zinc, iron, magnesium, potassium, calcium, and sodium (Raman et al., 2021). The high market demand for PO creates business opportunities for mushroom farmers in various regions of Indonesia. According to BPS, it is known that in 2017, PO production reached 3,701.956 tons, and in 2018, it reached 31,051.571 tons (Jumar et al., 2021).

Cultivating PO can be done using baglog as a growing medium for mushroom seeds, with a productive period of about 4-5 months. After the productive period is over, the baglog must be replaced with a new one, which causes the accumulation of baglog waste. When PO production increased, the amount of baglog waste

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also increased. According to the results of an interview with the production manager of CV. Asa Agro Corporation (AAS), it is known that in Cianjur, West Java, the amount of baglog waste produced by CV. Asa Agro Corporation (AAS) reaches 80-100 tons per month. Baglog waste generated from the cultivation process will be disposed of at the final disposal site (garbage dump) so that it does not cause contamination of the fungal growth process in the cultivation area due to the emergence of contaminating microorganisms. However, baglog waste containing mushroom mycelia that can produce methane gas (CH_4). If the amount of baglog waste increases and waste accumulates in the TPA, the methane gas produced can pollute the environment. In addition, baglog waste that is not treated immediately will rot and cause an unpleasant odor, which has the potential to become a breeding ground for disease-causing bacteria.

According to Jumar et al. (2021) baglog waste from the PO cultivation process contains 49% carbon, 0.6% nitrogen, 0.02% potassium, and 0.7% phosphorus, so that baglog waste is widely used as fertilizer (Prabowo et al., 2020; Ayu et al., 2021; Jumar et al., 2021) and growing media (Widhiantara et al., 2017; Sugianto et al., 2020). One of the compost fertilizers from baglog waste developed by Jumar et al. (2021) known to have fulfilled SNI with parameters of 40.07% water content, 14.38% carbon, 19.43 C/N ratio, 0.74% nitrogen, 0.5% phosphorus, 8.08% potassium, 6.38% calcium, 0.22% magnesium, and 0.0017% aluminum. Apart from being used as fertilizer and planting medium, baglog waste can also be used as a raw material for making briquettes (Dewanta et al., 2017; Tranggono et al., 2021) and carboxymethyl cellulose (CMC) (Dimawarnita & Tri-Panji, 2018). However, various efforts to utilize baglog waste that have been carried out have not been able to reduce the accumulation of baglog waste. Therefore, there is a need for alternative utilization of baglog waste, such as processing baglog waste into particleboard.

Particleboard is a composite material made by lignocellulose-containing materials bound together with adhesives and compressed by heat (Kusumah et al., 2017). In recent years, a lot of work has gone into the development of bioadhesive-based particleboards. The purpose is to reduce the use of formaldehyde-based adhesives because they can cause health and environmental problems (Zhang et al., 2018). Some of the bio-adhesives used in the particleboard manufacture are dextrins (Alamsyah et al., 2020), sucrose and citric acid (Umemura et al., 2013; Umemura et al., 2015; Widyorini et al., 2016; Santoso et al., 2020), and natural rubber latex (Islam et al., 2021). Moreover, according to previous research, the use of sucrose and citric acid as adhesives in the manufacture of particleboards is proven to be able to increase the dimensional stability of particleboard, making the particleboard more resistant to water (Umemura et al., 2013; Santoso et al., 2020).

As previously explained, baglog waste is a lignocellulosic material because baglog is made from wood sawdust, bran or rice bran, calcium, and gypsum in a certain ratio (Pertanian, 2010). Hence in this study, baglog waste was used as the raw material for making particleboard with the addition of citric acid and sucrose adhesives with varying concentrations of 50%, 60%, and 70%. Particleboard from baglog waste was made by the hot press method and then analyzed for its physical and mechanical properties, including density, moisture content, water absorption, thickness swelling, biodegradable test, bending tests, and morphology. These parameters were also intended to determine the effect of the type and concentration of adhesive on the particleboard quality.

RESEARCH METHODOLOGY

Preparation of Particles and Adhesive

Pleurotus ostreatus baglog waste was dried under the sun light for about 4 days and then dried in the oven for 24 hours at 80 °C. Next, the dried baglog will be ground using a grinding machine (Honda GX-200) and sieved using a sieve (Maksindo MKS-AYK45) until the particle size reaches 40 mesh. Furthermore, the citric acid and sucrose adhesives were prepared in various concentrations (50%, 60%, and 70%) using distilled water as a solvent.

Manufacture of Particleboard

The manufacture of particleboard in this study was carried out by Widyorini et al., (2016) with some modifications. Baglog, which will be processed into particleboard, is mixed with adhesive in a ratio of 1:1 by spraying. Furthermore, the mixture was dried at 80 °C for 12 hours, then formed using a hot press machine (Shinto Compression Moulding Machine NF-50HH) at 200

°C and a pressure of 10 MPa for 15 minutes with the targeted particleboard density of 0.8 g/cm^3. Then, before determining the physical and mechanical properties, the particleboard samples need to be conditioned for 2 days. In this study we have 7 particleboard sampels, which is one sample as a control, 3 samples made from baglog with citric acid adhesive (C50, C60, C70), and 3 samples made from baglog with sucrose adhesive (S50, S60, and S70. Control sample was made from baglog and without adhesive.

Characterization of Particleboard

Density

The density test was carried out based on the JIS A 5908-2003 standard to determine the density of particleboard. Samples with a size of 25 x 25 mm were measured for it length, width and thickness using a caliper (Taffware SH20) and calculated the volume (V). Sample weight was also measured using a digital balance (Fulgid DJ Series GS602B) to determine its mass (m_1). Then, the density of the sample was determined using the following Eq. (1).

$$density\left(\frac{g}{cm^3}\right) = \frac{m_1}{V} \quad (1)$$

Moisture content

The water content in the samples was measured using the gravimetric method, which refers to the JIS A 5908-2003 standard. The sample was cut, and its mass (m_0) was determined. The sample was then put into an oven at 103 °C for 24 hours, and its mass (m_1) was determined. The water content of the sample can be calculated using the following Eq. (2).

$$moisture\ content\ (\%) = \frac{m1 - m0}{m0}\ x\ 100 \quad (2)$$

Water Absorption and Thickness Swelling

The water absorption and thickness swelling test were done based on the JIS A 5908-2003 standard. The water absorption test was carried out by measuring the mass of the sample before (m_1) and after (m_2) it was soaked in water for 24 hours at 25 ºC, while the thickness swelling test was carried out by measuring the thickness of the sample before (T_1) and after (T_2) it was soaked in water for 24 hours at 25 ºC. Water absorption and thickness swelling can be determined using Eq. (3).

$$water\ absorption\ (\%) = \frac{m2 - m1}{m1}\ x\ 100 \quad (3)$$

Mechanical test

At this stage, measurement of the flexibility of the sample was carried out to determine the ability of the particleboard to withstand loads in a dry state. This bending test refers to JIS A 5908-2003. The fracture toughness (MOR) and flexural strength (MOE) tests were carried out by measuring the length of the support (L), width (b), and thickness (t) of each test sample, then placing it horizontally on the sample support and applying a load to the sample center using the Shimadzu AG-IS 50 kN Universal Testing Machine (UTM). MOR and MOE can be determined by entering the deflection (d) and maximum load (P) data obtained from the test results into Eqs. (4) – (5).

$$Fracture\ toughness\left(\frac{N}{mm2}\right) = \frac{3PL}{2\ bh^2} \quad (4)$$

$$Flexural\ strength\ (Gpa) = \frac{PL^3}{4bh^3d} \quad (5)$$

Where, P is the maximum load (N), L is the pedestal length (mm), d is the deplacement or deflection (mm), b is the sample width (mm) and h is the sample thickness (mm).

Biodegradadable test

The biodegradable test was carried out to find out how long the sample would degrade in the soil. The biodegradable test on this particleboard refers to the EN13432 soil burial test method (Darni et al., 2022), in which the sample with a size of 2.5 cm x 2.5 cm was measured for its mass before (W_0) and after (W_1) it was planted in the soil for 14 days. The percentage of the sample decomposing in the soil is determined using the Eq. (6).

$$Weight\ loss\ (\%) = \frac{W1 - W0}{W0} \quad (6)$$

Morphology

Sample morphology tests were carried out using Field-Emission Scanning Electron Microscopy (FE-SEM, Thermo Scientific Quattro S) to determine the surface morphology of the samples. The test was carried out by attaching the sample to the holder using carbon tape (Sutiawan et al., 2022) and the sample's morphology will be observed at 150x and 1000x magnification.

RESULTS AND DISCUSSION

Density

In this research, the target density of the particleboard is 0.8 g/cm^3 due to according to Umemura et al. (2015), the board with a density of 0.8 g/cm^3 has the best physical and mechanical properties, which include water absorbtion, thickness swelling, MOR, MOE, and internal bond (IB) strength. Figure 1 showed that the densities of the particleboards obtained in this research were 0.811-0.959 g/cm^3, while the density of control sample was 0.838 g/cm^3. At the same adhesion concentration, the density of particleboard using citric acid was higher than that using sucrose. This indicated that citric acid is better at binding the baglog waste particles than sucrose. Based on JIS A 5908:2003, the particleboard density is 0.4-0.9 g/cm^3. Therefore, among the six samples of particleboard from baglog waste, only the C50 sample does not meet the JIS standard.

These results were related with the research conducted by Santoso et al. (2020), which found that nipa fronds particleboard using sucrose and citric acid has a density of 0.84 g/cm^3 and 0.81 g/cm^3, respectively. Particleboard made from teak wood and citric acis-surcose adhesive has densities ranging from 0.85 to 0.94 g/cm^3 (Widyorini et al., 2016).

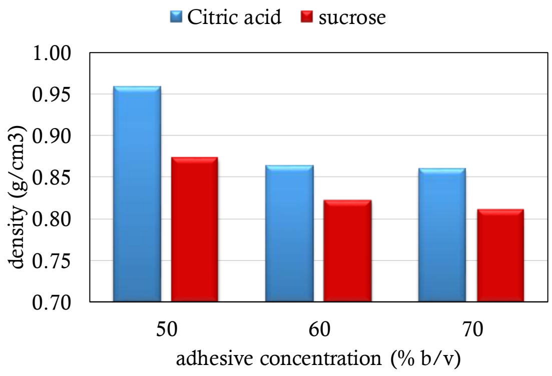


Figure 1. Density of particleboard made from *Pleurotus ostreatus* baglog waste.

Moisture Content

Figure 2 showed that the moisture content of particleboards were about 3.637-4.382%, while the moisture content of control sample was 5.616%. For each type of adhesive, the lowest moisture content was obtained from a sample using 60% citric acid and 60% sucrose adhesive. The moisture content of nipa fronds particleboard using sucrose and citric acid adhesive produced by Santoso et al. (2020) is 6.99% and 4.41%, respectively. Based on JIS A 5908:2003, the moisture content of particleboard is around 5-13%, therefore the particleboards obtained in this research did not meet JIS standard.

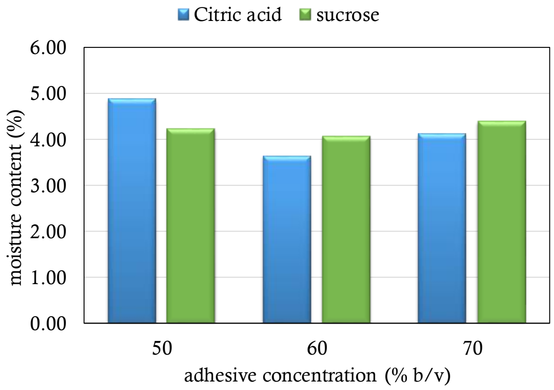


Figure 2. Moisture content of particleboard made from *Pleurotus ostreatus* baglog waste.

Water Resistance Properties

The water resistance properties of particleboard can be analyzed through the results of water absorption and thickness swelling. Control sample can not be determined that water absorption and thickness swelling due to it was broken when immersed in the water at 1 minute. Figure 3 showed the water absorption and the thickness swelling of particleboard affected by the type and concentration of adhesive used. The use of citric acid can be obtained the particleboard with lower water absorption and thickness swelling compared to sucrose. Moreover, the higher the adhesive concentration used, the lower the water absorbtion and thickness swelling.

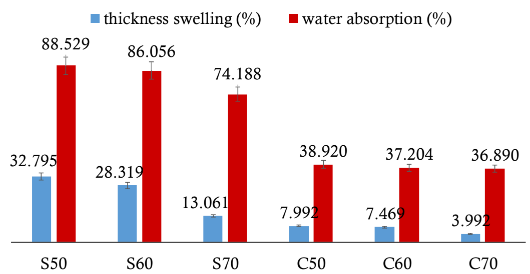
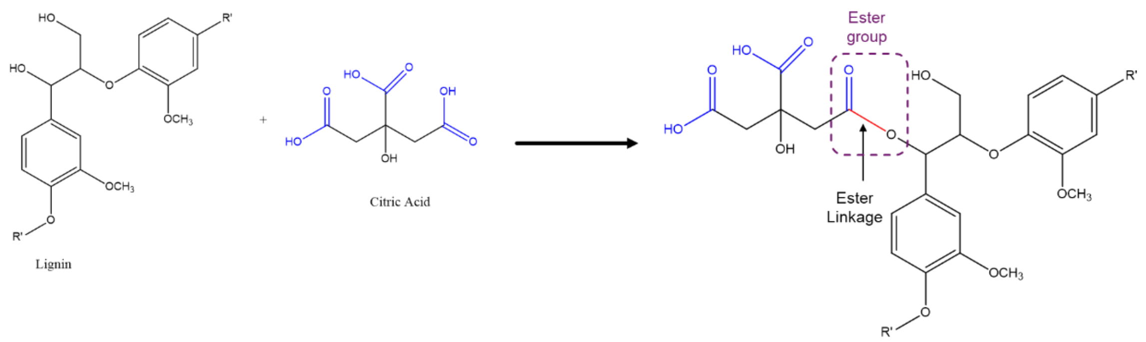
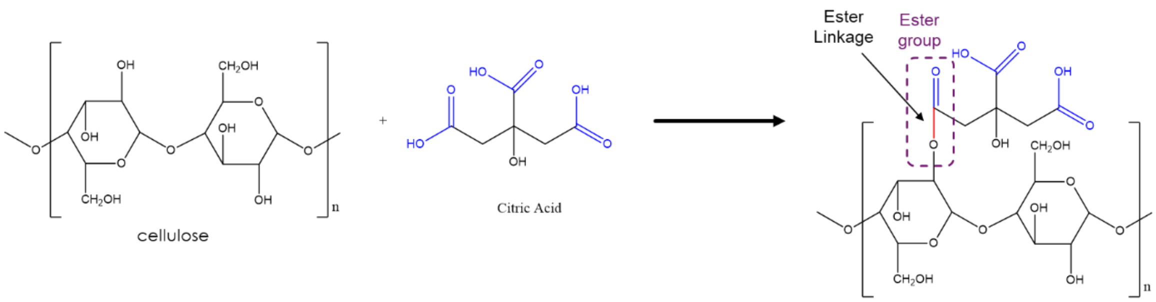


Figure 3. Water absorption, and thickness swelling of particleboard made from *Pleurotus ostreatus* baglog waste.

The results of this study are related to the research conducted by Widyorini et al. (2016),



(a)



(b)

Figure 4. Ester lingkage formation between (a) lignin and citric acid and (b) cellulose with citric acid

which showed that teak wood particleboard using citric acid adhesive has lower water absorption and thickness swelling compared to sucrose. Nipa frond particleboards using sucrose have a water absorption and thickness swelling of 49.22% and 59.52%, respectively. While the water absorption and thickness swelling of nipa frond particleboards using citric acid adhesive are 34.20% and 2.82%, respectively (Santoso et al., 2020).

Citric acid adhesive can reduce the water absorption during the soaking process due to citric acid is able to form the ester linkage that is more hydrophobic (Widyorini et al., 2016). That ester group (-COOR) is formed by the reaction between the carboxyl group (-COOH) in the citric acid and the hydroxyl group (-OH) from lignocellulose in the biomass content (baglog waste), as shown in Figure 4.

JIS A 5908:2003 does not provide requirements for the water absorption value, but the requirement for thickness swelling of particleboard is maximum of 12%. Thus, the particleboard made from *Pleurotus ostreatus* baglog waste using citric acid adhesive complies with the JIS A 5908:2003 type 8 standard.

Mechanical Properties

Modulus of rupture (MOR) is the fiber strength that occurs in the maximum load (when the object failure), and it incicates of the maximum sample strength. While modulus of elasticity (MOE) indicates of the sample stiffness. Figure 5 showed that the MOR and MOE value of particleboard without adhesive (control sample) are lower than the particleboard sample using adhesive. Figure 5 also showed that the type and concentration of adhesive used in the particleboard manufacturing process has an effect on the MOR and MOE. MOR and MOE value of particleboards obtaining by citric acid adhesive increase with increasing citric acid concentration. In other words, increasing the concentration of citric acid adhesive can make the particleboard stronger and stiffer. Increasing the concentration of citric acid will be made the more ester linkage formed, therefore the particleboard become stronger and stiffer. In contrast, when using sucrose adhesive, the higher the concentration of sucrose, the lower the MOE of particleboard. A sucrose molecule has eight hydroxyl group (-OH), so if the concentration of sucrose increased, the hydroxyl group in the particleboard also increased. Hydroxyl group able to enhance the elasticity of material (Ningrum et al., 2016), in this study is particleboard. The optimum MOR of particleboard using sucrose at an adhesive concentration of 60%, which is 6.278 MPa. In addition, at 60% and 70% adhesive concentration, particleboard using citric acid had a higher MOR and MOE than particleboard using sucrose. So it can be concluded that citric acid causes the strength and stiffness of particleboard increase while sucrose causes the strength and stiffness of particleboard decrease.

This result study are similar to the research conducting Widyorini et al. (2016), which is the MOR and MOE of teak wood particleboard using citric acid greater than those of sucrose. Meanwhile, the result of Santoso et al. (2020) showed that the MOR of nipa frond particleboard using citric acid was lower than sucrose. It is in contrast with the value of MOE, which is nipa frond particleboard using citric acid is higher than sucrose.

According to JIS A 5908:2003, the minimum MOE for type 8 particleboard is 2000 MPa (equal to 2 GPa), while the minimum MOR is 8 MPa. Thus, the particleboard that meets the JIS A 5908:2003 type 8 standard for MOR is C60 and C70, while for MOE, all of the samples obtained for this study have not met the standard yet. Some factors influencing MOR and MOE are the type and concentration of adhesive, the degree of adhesiveness of particleboards surface layer (Santoso et al., 2020), and the time and temperature of pressing (Umemura et al., 2015; Kusumah et al., 2017).

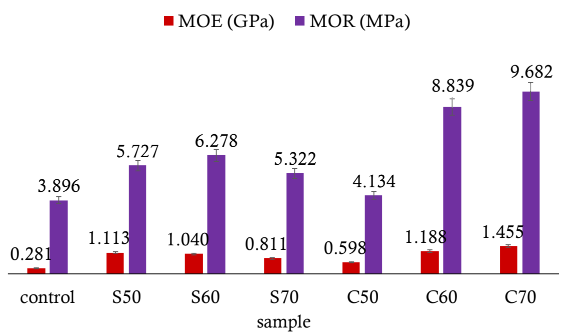


Figure 5. MOR and MOE of particleboard made from *Pleurotus ostreatus* baglog waste.

Biodegradability of Particleboard

The degradability of particleboard made from baglog waste ranges from 4.992% to 43.297% within fourteen days (Figure 6). Particleboard made from baglog waste and sucrose adhesive can be degraded faster than citric acid adhesive. This is because sucrose is a carbohydrate that can be used by microorganism as a carbon source. Basically, microorganism need carbon, nitrogen, and phosphorus for the process of synthesis, cell growth, and the production of enzymes used to degrade a material (Zhang & Elser, 2017). Carbon is used by microorganism as a source of energy for their activities, while nitrogen and phosphorus are constituents of important compounds in cells that determine the growth activity of microorganism. The amount of carbon in sucrose ($C_{12}H_{22}O_{11}$) is more than citric acid ($C_6H_8O_7$) therefore particleboard using sucrose degrades faster than citric acid.

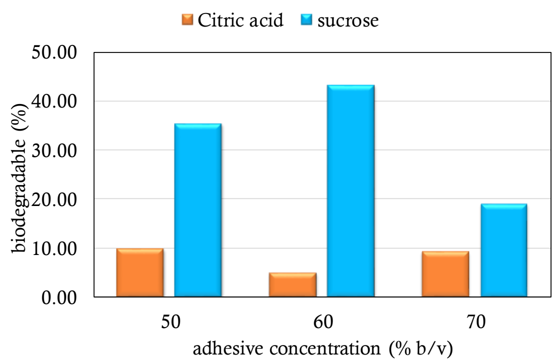


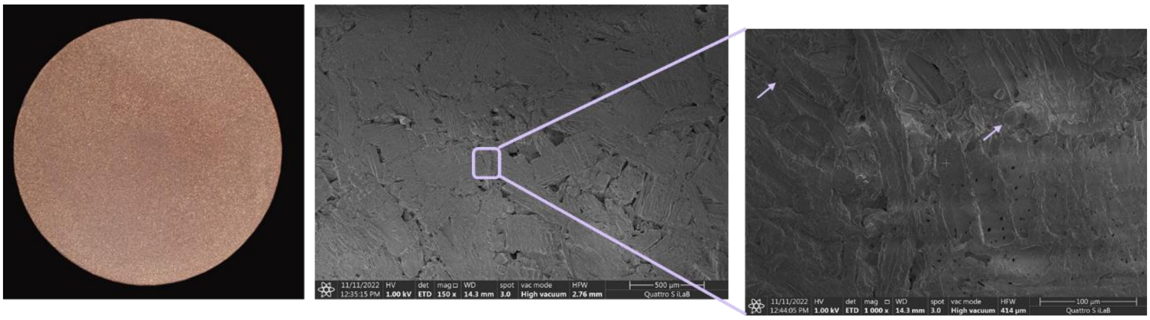
Figure 6. Biodegrable of particleboard made from *Pleurotus ostreatus* baglog waste.

The biodegradability of control sample was 56.168%. Particleboard which made from baglog waste will be disintegrated faster when it made without adhesive. Adhesive able to bind the baglog particles therefore making it more difficult to decompose. When the bond between baglog and adhesive stronger, the degradation time is also longer.

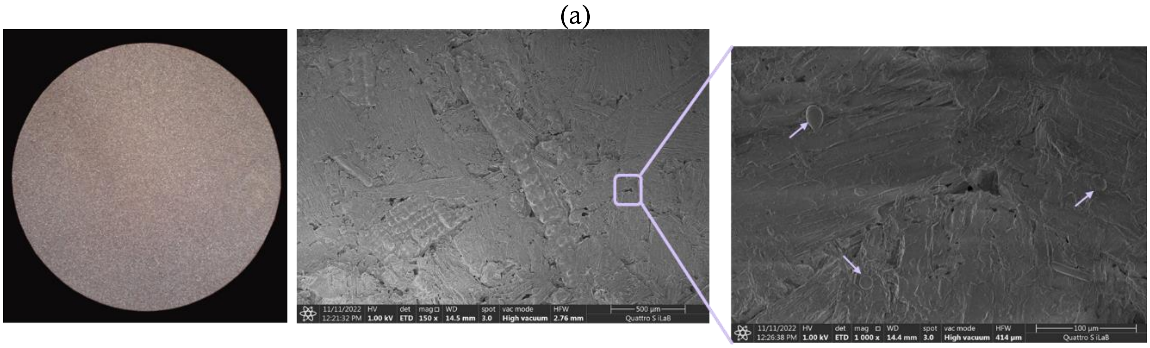
Factors affecting the degradation process of a material are temperature, pH, water content, and the available nutrients (Zhang & Elser, 2017). While some factors affecting biodegradability of particleboard as the biodegradable material are size, shape, composition, molecular weight, and diffusion coefficiency of the material (Papadopoulou & Chrissafis, 2017).

Morphology of Particleboard

Figure 7 showed that the surface morphology of particleboard made by *Pleurotus ostreatus* baglog waste using citric acid and sucrose. When using citric acid, the particleboard's color is sharper than that of sucrose. In addition, the observation using FESEM showed that there are small cavities on the surface of particleboard. These cavities are the passageways for water to enter the particleboard, causing the water absorbtion to be relatively high. When observations were made at 1000x magnification, *Pleurotus ostreatus* spores were visible (shown by arrows). This proves that baglog waste contains of *Pleurotus ostreatus* spores.



(a)



(b)

Figure 7. Morphology of particleboard made from *Pleurotus ostreatus* baglog waste using (a) citric acid and (b) sucrose adhesive.

CONCLUSION

Pleurotus ostreatus baglog waste can be used as a raw material for particleboard with the addition of citric acid and sucrose adhesive. Citric acid can enhance the water resistance of particleboard, which is characterized by low the water absorption and thickness swelling and also increases the strength (MOR) and stiffness (MOE) of particleboard. In contrast, sucrose can decrease the water resistance of particleboard, which is characterized by high water absorption and thickness swelling, and also reduce the strength (MOR) and stiffness (MOE) of particleboard. The biodegradability of particleboard made by adding sucrose is higher than that of citric acid. The adhesive concentration also affects the physical and mechanical properties of particleboard, where water absorbstion and thickness swelling will be lower when the the additive concentration is enhanced.

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