



The utilization of sugarcane bagasse, cassava peels and corn husks in handmade paper production



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ABSTRACT

High demands for trees as the raw material of paper can disrupt the stability of the environment. It is necessary to find alternatives from other materials which are more environmentally friendly. This study aims to determine the quality of paper made from combining sugarcane bagasse with cassava peels or with corn husks using PVAc or tapioca starch adhesives. A completely randomized 2 x 2 factorial design with five times replication was used. The parameters tested were the tensile and tear resistance of the paper using a micrometer and a universal testing machine. A sensory analysis from panelists was also conducted. The combination of JIPI produced a paper with the highest tensile strength (11.30 MPa) and the highest tear strength (1.82 MPa). The combination of J2P2 produced a paper with the lowest tensile strength (10.35 MPa) and the lowest tear strength (1.62 MPa). Variance analysis showed that the type of adhesive used showed a significant result on both tensile and tear resistance but material choices and interaction between materials and adhesive choices was not significantly different from the result on both tensile and tear resistance. Sensory testing shows that the combination of JIPI was preferred the most. It can be concluded that the combination of JIPI appeared to be the best combination.

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INTRODUCTION

Wood is the major source of material used to make paper. Wood is 39% fibres and contains high amounts of cellulose and hemicellulose. In 2017, the total installed capacity of the national paper industry was 12.98 million tons. The higher the need is for paper, the more wood is needed. This causes the rate of deforestation to increase, and this is a major environmental issue in today's

world. As much as 42% of all the timber harvested globally is for making paper (Suraj & Khan, 2015). Therefore, efforts are needed to find alternatives to the use of forest wood as a raw material for making pulp and paper. One alternative is the utilization of neglected biomass waste (Bahri, 2015).

Neglected biomass waste that can be used as a raw material for making paper includes waste paper, banana stems, water hyacinth, corn cobs, straw, empty fruit bunches of oil palms, peanut skins, elephant grass, palm fibres, Siam weed, sugarcane bagasse, cassava peels, and corn husks. All these contain cellulose, which, in the form of fibres, is the basic raw material for making pulp. Almost all plants that contain cellulose can be used as a raw material to produce a pulp that can be used in the production of paper.

One type of neglected biomass waste used as a raw material in the production of paper is banana stems (*Musa paradisiaca*), which have their specific fibres (cellulose) content. Paper made from banana stems is brown with a long-fibres appearance and is often used in paper art (Sucipto, Wijana & Wahyuningtyas, 2009). The exact composition between the volume of certain solutions, such as NaOH, and the mass of banana stems creates higher pulp yield. Several studies have shown that the pulp produced from banana stems can be used as paper pulp on an industrial scale because it contains more than 80% cellulose, which meets the required standard (Bahri, 2015).

The use of sugarcane is still limited to processing its juice into products such as sugar or MSG, and sugarcane bagasse has not been utilized maximally. It is usually either rejected as waste or used as a potting medium for plants. Sugarcane bagasse contains 35% cellulose, 25% hemicellulose, 20% lignin, and 20% other substances (Rainey & Covey, 2016). Abundantly available sugarcane bagasse has a high percentage of cellulose and therefore great potential to be used as a substitute for wood fibres in paper production.

Cassava peels are also an industrial waste product that is available in large amounts and has not been widely used. So far, cassava peels have only been used as fodder for animals. Cassava peels have a higher cellulose content than sugarcane bagasse at 43.43%. Moreover, cassava peels also contain 10.38% hemicellulose, 7.65% lignin, 36.58% starch, and 1.76% other substances (Artiyani, 2011).

Yet another type of agricultural waste, the corn husk, has also not yet been maximally used, and up until now, it has usually been used as one of the components for making compost. In some areas, corn husks are burned, posing a danger to the environment. The chemical composition of corn husks is 44.085% cellulose, 15% lignin, 5.09% ash, and 4.57% cyclohexane (alcohol) (Fagbemigun, Fagbemi, Otitoju, Mgbachiuzor & Igwe, 2014).

The pulp is the main substance used in the process of paper-making. In general, wood is processed into pulp in several stages, and the process is called pulping. A sodium hydroxide (NaOH) solution is used to dissolve lignin during the pulping process to speed up the fibre-separation process. The use of a five percent NaOH obtained the highest pulp yield of 54.875%, while the use of a ten percent NaOH produced the highest cellulose content, with 83.0367% (Surest & Satriawan, 2010).

The dissolution of lignin in NaOH causes the lignin to react and, as a result, the cellulose is degraded and the fibres are broken down (Asngad, Inna & Siska, 2016). The concentration of the NaOH solution also affects the tensile and tear resistance. The lower the concentration is of NaOH, the higher the tensile and tear resistance is of the paper (Ikhsan & Anggono, 2018). A ten percent NaOH solution produced a tensile resistance of 0.3733 MPa and a tear resistance of 0.5192 MPa. There is also another study that shows the differences in tensile resistance, tear resistance, and organoleptic test results between art paper made from elephant grass that uses NaOH and that uses CaO in the chemical pulping process (Asngad, Trisnawati & Sanastri, 2014).

Paper production requires the use of an adhesive to hold the fibres together to increase tensile and tear resistance. The PVAc glue is one of the commonly used adhesives since the homogeneity of the PVAc glue affects the tensile and tear resistance of the paper. The longer the pulp is ground up with the adhesive, the more homogeneous the resulting mixture is, which means that the bond between the fibres is stronger. The most effective concentration of the PVAc glue is 5%, with the results of a tensile resistance test is 0.53 N/mm² and a tear resistance test is 23.97 N/mm².

Besides PVAc, tapioca starch also functions as an adhesive, and it can be used in making paper. The more tapioca starch there is in a mixture of bio plastic-making, the higher the tensile strength is of the hydrogel formed (Haryanto & Titani, 2017). When tapioca starch is used, its concentration needs to be exact to obtain the best results. The use of five percent tapioca starch increases the tensile and tear resistance indices (Syamsu, Roliadi, Candra & Arsyad, 2014).

Based on this background, the aim of this research had to do with determining what quality the paper, produced from the combination of sugarcane bagasse with cassava peels and with corn husks using PVAc and tapioca starch adhesives, had in terms of tensile and tear resistance. This study aims to identify the quality of this paper regarding these two characteristics. Two types of material were combined with sugarcane bagasse, namely cassava peels, and corn husks, and two types of adhesives were used, namely PVAc and tapioca starch.

RESEARCH METHODS

Research Design

The research was conducted from March to September 2019 in the laboratory of biology education study program in the faculty of teachers' training and education at Surakarta Muhammadiyah University. This study used the experimental research method. A completely randomized factorial design (CRFD) and five replications were used as the environmental design. There were two factors involved. Factor 1 was the combination of materials (J) consisting of two standards, namely J1 [sugarcane bagasse and cassava peels (60%: 40%)] and J2 [sugarcane bagasse and corn husks (60%: 40%)]. Factor 2 dealt with the types of adhesive (P), namely P1 (PVAc 5%) and P2 (tapioca starch 5%). The treatments given were the combination of sugarcane bagasse and cassava peels using 5% PVAc (J1P1); sugarcane bagasse combined with cassava peels using 5% tapioca starch (J1P2); sugarcane bagasse combined with corn husks using 5% PVAc (J2P1); and the combination of sugarcane bagasse and corn husks using 5% tapioca starch (J2P2).

Population and Samples

The raw materials/samples used were sugarcane bagasse, corn husks, and cassava peels. These different types of raw material were combined by using two types of glue namely PVAc and tapioca starch. The chemical compound used for neutralizing acid was NaOH. Other compounds that were also used were ethanol and distilled water.

Instruments

The instruments consisted of eleven items. The instruments used were blenders, ziplock bags, digital scales, stoves, pans, filter cloths, printing paper screen, plywood, shelves, dumbbells, and a universal testing machine.

Procedures

The research procedure included two stages, namely the paper-making stage and the testing stage. The first step in the paper-making process was grinding the raw material, namely sugarcane bagasse, corn husks, and cassava peels. In this stage, the raw materials were cut into small pieces and blended. Next, the pulp was produced in the delignification process, in which the raw material was



cooked in 1000 ml solution of 40% ethanol and 10% NaOH (1:1) for 60 minutes at a temperature of 80°C. The result of the pulp delignification was soaked in 350ml of distilled water for 24 hours to remove the remaining ethanol. After this, the pulp was filtered and then mixed with a five percent adhesive solution-either PVAc or tapioca starch, depending on the treatment. Lastly, the paper was formed using a series of moulds. The procedures of the experiment can show in Figure I.

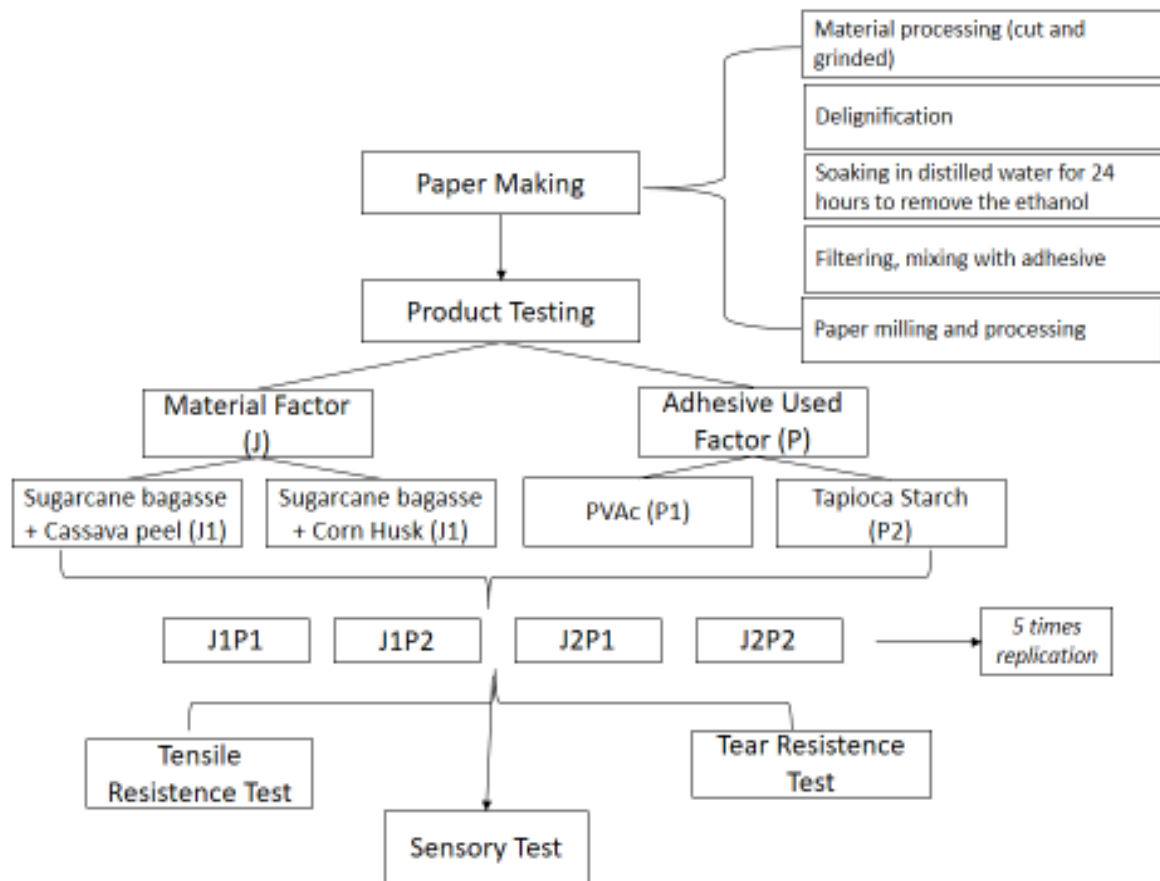


Figure I. Research procedures

Data Analysis

The testing phase was conducted to examine three categories of paper products. The three examinations included: first, tensile resistance testing; second, tear-resistance testing; and third, sensory testing. Tensile and tear resistance testing was carried out using the universal testing machine, while sensory testing was conducted using the questionnaire method to 10 panelists. In the sensory testing, three factors were examined, namely fibres texture, color, and attractiveness. For tensile and tear resistance, variance analysis was done by using IBM SPSS Statistics version 20.

RESULTS

There were two paper products produced in this research (Figure 2). The paper made from sugarcane bagasse and cassava peels was of a darker color (Figure 2a), while the paper made from a combination of cassava peels and corn husks had a lighter color (Figure 2b). Both types of paper share the same characteristics in terms of their surface texture and color. The surface texture was rough and the color was between beige and yellow, which is fine for art paper.



Figure 2. a) Sugarcane bagasse and cassava peels; b) Cassava peels and corn husks

Table 1 shows the sensory test results of the quality of the paper produced from the combination of sugarcane bagasse with cassava peels and corn husks using PVAc and tapioca starch adhesives, conducted after the tensile and tear resistance tests. It can be seen from the bar chart in Figure 3 that, based on the quantitative sensory tests of the four treatments, J1P1 had the highest index whereas J2P2 had the lowest index.

Table 1. The qualitative data of paper quality (tensile and tear resistance)

	Sensory Tests				Notes
	Texture	Fibres Appearance	Color	Level of Likeness	
J1P1	Rough**	Visible **	Brown **	Very good	A combination of 60% sugarcane bagasse and 40% cassava peels with 5% PVAc
J1P2	Rough	Visible	Brown	Good	A combination of 60% sugarcane bagasse and 40% cassava peels with 5% tapioca starch
J2P1	Smooth	Not so Visible	Yellow	Adequate	Combination of 60% sugarcane bagasse and 40% corn husks with 5% PVAc
J2P2	Smooth#	Not so Visible	Light Yellow *	Adequate	Combination of 60% sugarcane bagasse and 40% corn husks with 5% tapioca starch

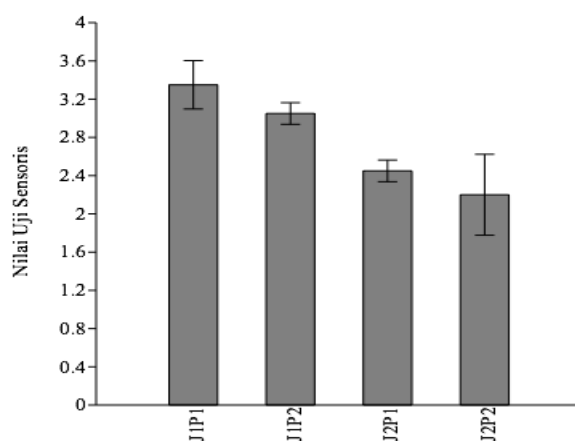


Figure 3. Sensory test index of paper quality (tensile and tear resistance)

Tensile and tear resistance tests were carried out using the universal testing machine. Table 2 shows that the combination of sugarcane bagasse with cassava peels (60%: 40%) using 5% PVAc (J1P1) produced paper performed the strongest tensile resistance, with an average of 11.30 MPa. In contrast, the combination of sugarcane bagasse with corn husks (60%: 40%) using 5% tapioca starch (J2P2) produced the paper which had a slightly weaker tensile resistance, with an average of 10.35 MPa.

Table 2. Tensile and tear resistance data on quality of paper

Treatments	Tensile Resistance (MPa)	Tear Resistance (MPa)	Notes:
N J1P1	11.30*	1.82#	*: Strongest tensile resistance **: Weakest tensile resistance #: Strongest tear resistance ##: Weakest tear resistance
J1P2	10.40	1.68	
J2P1	11.23	1.75	
J2P2	10.35**	1.62##	

The determine significance of material and adhesive used as factors compared in this experiment, analysis of variance was done with a confidence level of 95%. The result is showed in Table 3. Variance analysis showed that the type of adhesive used showed a significant result on both tensile and tear resistance but material choices and interaction between materials and adhesive choices was not significantly different from the result on both tensile and tear resistance.

Table 3. Variance analysis of tensile and tear resistance of experiment

Factor	df	Mean Square	F	sig
Tensile resistance				
J (material factor)	1.000	0.017	0.039	0.845
P (adhesive factor)	1.000	3.978	9.310	0.008
J*P	1.000	0.001	0.002	0.968
Tear resistance				
J (material factor)	1.000	0.019	1.973	0.179
P (adhesive factor)	1.000	0.085	8.676	0.010
J*P	1.000	0.000	0.033	0.858

DISCUSSION

Both types of paper as the product of this research share the same characteristics in terms of their surface texture and color. The surface texture was rough and the color was between beige and yellow, which is fine for art paper. The results of the four treatments on average show that the paper produced from the combination of sugarcane bagasse with cassava peels using PVAc and tapioca starch adhesives produced a rough texture in comparison to the combination with corn husks. This rough texture is caused by the long fibres of the cassava peels, which make the fibres bonds solid so that they are difficult to break. Besides, cassava skins contain a high percentage of cellulose, with 43.43%. Thus, this causes the texture of the paper to be rough (Artiyani, 2011). Meanwhile, sugarcane bagasse contains 37% cellulose (Yosephine, Gala, Ayucitra & Retnoningtyas, 2012).

Based on the quantitative sensory tests of the four treatments, J1P1 had the highest index whereas J2P2 had the lowest index (Figure 2). This is because the paper made from the combination of sugarcane bagasse with corn husks and 5% tapioca starch shows the lowest sensory



performance. Glue characteristics also affect the bonds between the components (Campione, Orlando, Fileccia, & Pauletta, 2019). In the process of making paper manually, which is using a screen, the resulting paper is uneven in thickness, unlike paper in stores that involves a pressing method in its production. Also, grinding time affects the texture of the paper. The longer the grinding time, the more homogeneous the resulting pulp, so that the pulp texture appears smoother than the pulp that had the shorter grinding time. This is consistent with research of Asngad et al (2016) stating that a long pulp-grinding time improves the quality of the texture of the paper. In this case, it is smoother.

The combination of sugarcane bagasse with cassava peels produced a paper that had more visible fibres when compared to the combination that uses corn husks. That is because sugarcane bagasse combined with cassava peels form fibres bonds that appear long. The long fibres bonds cause the fibres in the paper to become visible when the paper is formed. This visible fibres appearance also occurs because sugarcane bagasse and cassava peel fibres are hard to break. This process of paper making affects the appearance of fibres in the paper. Sugarcane bagasse pulp more minutely like hardwood eucalypt pulp rather than softwood as its fiber length is around 1.0–1.2 mm in diameter (Rainey & Covey, 2016). Rao, Prasanthi, Kumar, Ram & Kumar (2020) added that position of fiber of sugarcane bagasse affects the tensile resistance of the product. The tensile resistance of the paper in which bagasse fibers are aligned in 0° positions has more bearing capacity when compared to the other aligned composite specimens (45° and 90°). Aripin, Kassim, Daud & Hatta (2013) reported that the characteristic of chemical properties and morphological cassava peel indicated that this raw material is suitable to be used as an alternative fibres source for the pulp and papermaking industry, especially in countries with limited wood resources. Cassava peels that contain a relatively high content of holocellulose, cellulose, and hemicelluloses and lower content of lignin from cassava pees are acceptable for papermaking application (Reddy & Young, 2005).

The appearance of fibres can also be influenced by the chemicals (NaOH and ethanol) that play a role in the separation and termination of the fibres. These chemicals are alkaline solutions that are not able to perfectly separate the fibres. Because sugarcane bagasse and cassava peels are difficult to break down, the fibres remain visible after the forming process. This is supported by the research of Qodri (2016), which states that the more solution is used in the cooking process, the more visible the fibres appearance.

Figure 1b shows that the resulting paper color in the four treatments ranged from brown (sugarcane bagasse with cassava peels) to light yellow (sugarcane bagasse with corn husks), using PVAc and tapioca starch adhesives. The different color is influenced by the raw material used. Cassava peels are brown, while corn husks are yellow. The paper resulting from the combination of sugarcane bagasse and cassava peels using the PVAc adhesive had the most attractive color of the four treatments. The panelists also thought that brown was a better color so that they liked it the most. Color differences can also be caused by different temperatures (the temperature in the morning is different than in the afternoon or evening) and the duration of the drying process. The longer the duration is of the drying process, the darker the color is of the paper.

As can be seen in the test results, how well the paper is liked depends on the texture, fibres appearance, and color of the paper. The panelists showed different preferences for the paper produced from the combination of sugarcane bagasse with cassava peels or with corn husks using PVAc or tapioca starch adhesives. The panelists on average liked the paper made from the combination of sugarcane bagasse with cassava peels the most. They were attracted to the paper's texture, fibres appearance, and color of the paper.

It can be concluded that the paper resulted from the combination of sugarcane bagasse and cassava peels using the PVAc adhesive was preferred. In addition to the fact that it received the

most votes from the panelists, it showed the highest sensory test index in all categories. This paper had a rough texture, visible fibres appearance, and attractive color. These results were affected by the combination of the raw materials, the manufacturing process, and the drying time.

The tensile resistance of each treatment did not show significant differences because, in each treatment, the ratio of the raw material combined was the same, which was 60% sugarcane bagasse and 40% cassava peels or 40% corn husks. Cassava peels and corn husks contain almost the same proportion of cellulose, which is higher than that in sugarcane bagasse. Cassava peels contain 43.43% cellulose (Artiyani, 2011) whereas corn husks contain 44.09% cellulose (Fagbemigun et al., 2014). Meanwhile, sugarcane bagasse contains 37% cellulose (Yosephine et al., 2012).

Cassava peels and corn husks contain more cellulose than sugarcane bagasse, so the proportion of sugarcane bagasse used in this study was higher than that of cassava peels or corn husks to balance the composition of cellulose so that the fibres bonds produced were longer. The paper that contains a balanced composition of fibres and cellulose has longer fibres bonds. The composition of cellulose in the mixture determines the length of the resulting fibres. Long fibres increase the tensile resistance of paper. The length of fibres affects the quality of forming and paper stiffness. The length of the fibres formed in the pulping process affects the bonds between the fibres. Short fibres have a lower binding capacity than long fibres, and the bonds between the formed fibres affect tensile resistance. The stronger the bonds between the fibres, the stronger the tensile resistance (Paskawati, Susyana, Antaresti & Retnoningtyas, 2010; Asngad et al, 2016; Sadiku & Abdulkareem, 2019).

The chemical solvents used also affect the tensile resistance. The function of the solvents is to dissolve lignin, which then makes it easier for the fibres of each raw material to be broken in the grinding process so that the fibres of the raw material bind with each other more easily. In this study, the chemicals used as lignin solvents were 10% NaOH and 40% ethanol solutions.

The lower the concentration of NaOH and ethanol, the more perfect the fibres, and when the fibres bind to each other more easily, the tensile resistance of the paper is stronger. In contrast, when higher concentrations of NaOH and ethanol are used, the reaction with lignin is stronger, and this causes the cellulose to degrade, so the fibres are damaged, which means they cannot be completely bonded. When this happens, the bonds between the fibres weaken so that the tensile resistance is also weaker. The low concentration of NaOH used (10%) creates strong paper tensile resistance (Ikhsan & Anggono, 2018). The higher the concentration of ethanol is used in the cooking solution, the more lignin is dissolved. The maximum concentration of ethanol is 40% (Agustina, Wulandari & Romy, 2009).

Technical factors such as uneven paper thickness during manual paper-making can also influence the tensile resistance of paper. Other factors that affect paper tensile resistance are the grinding process and the homogeneity as well as the type of adhesive. If the pulp and adhesive are mixed homogeneously, the bonds between the fibres are stronger. This is because the adhesive fills in the space between the fibres, and the tensile resistance of the paper is stronger. The grinding process aims to homogenize the adhesive and to increase the quality of the bonds between the fibres. The more the pulp is ground up homogeneously, the stronger the bonds are between the fibres, which means the tensile resistance of the paper will be higher. Since every combination was given the same grinding treatment, the adhesive type had more influence on the tensile resistance in this study. The use of adhesives causes each sheet of paper to be strong and not easily torn when stretched and pulled from opposite sides.

The tensile resistance index of the PVAc adhesive is higher than that of the tapioca starch in each combination. However, the difference in tensile strength between the combinations using the PVAc and the tapioca starch is not significant. Tapioca starch is a good alternative adhesive material (Ozemoya, Ajisegiri & Idah, 2007; Opara, Ossi & OkoUdu., 2017). Moreover, tapioca

starch possesses the chemical properties and characteristics that are suitable to be used as an alternative source of fibres (Aripin et al., 2013). The use of cassava flour as a binder in paper-based composites provides bending properties (Oluwole & Awwersuoghene, 2015). Tapioca starch can be used as an alternative adhesive material that is more environmentally friendly. Tapioca has quite a large amount of starch (13.12%) so that it can fill in the space between the fibres of the paper (Murtiningrum, Bosawer, Istalaksan & Jading, 2012).

The tear resistance of each treatment is not significantly different. This is due to the same ratio of raw material combined in each treatment, which was 60% sugarcane bagasse, 40% cassava peels, or 40% corn husks. Cassava peels contain nearly the same proportion of cellulose as corn husks, which is higher than that of sugarcane bagasse. Artiyani (2011) states that cassava peels contain 43.43% cellulose. Fagbemigun et al. (2014) states that corn husks contain 44.09% cellulose. Meanwhile, Yosephine et al. (2012) state that sugarcane bagasse contains 37% cellulose.

In this study, the proportion of sugarcane bagasse used in the mixture was higher than that of cassava peels or corn husks to create a balanced cellulose composition so that longer fibres bonds could be produced. A balanced composition of cellulose and fibres produces a paper that has more solid fibres bonds. The more solid the bonds, the stronger the tear resistance. The long fibres of cassava peels and corn husks balance out the short fibres of sugarcane bagasse so that the bonds between the fibres of the combined materials are longer and create greater tear resistance.

The composition of celluloses and fibres of the mixtures must be balanced to form longer fibres bonds. Long fibres strengthen the tear resistance of paper products (Asngad et al., 2016). The length of the fibres formed during the pulping process also affects the bonds between the fibres of the different materials. Short fibres have a higher binding capacity than long fibres, and the bonds between the fibres affect the tear resistance. The greater the bond strength between the fibres, the higher the tear resistance.

Tear strength is also affected by the chemicals used. The purpose of the chemicals is to dissolve lignin, and this causes the fibres to break apart easily during the grinding process so that new fibres bonds are formed with the different types of raw material. However, the dissolution of lignin by NaOH and ethanol can cause the degradation of the cellulose and damage the fibres. If this happens, the fibres cannot be completely interwoven. Damage to the fibres affects the bonds between the fibres of different substances. If the fibres bonds between the substances are weak, the resistance of the paper is also weak, so the bonds between the fibres formed affect the strength of the paper. The lower the concentration of NaOH, the stronger the tear resistance of the paper (Ikhsan & Anggono, 2018). The higher the concentration of ethanol used in the cooking solution, the more lignin is dissolved. The cellulose will not be degraded if the ethanol concentration does not exceed the maximum limit, which is 40% (Agustina et al., 2009).

The addition of adhesives can also affect the strength of the paper tear resistance. Adhesives help to strengthen each sheet of paper and so it is not easily torn when stretched and pulled on from its opposite sides. The function of the adhesives is to glue and form bonds between fibres. The more homogeneous the adhesive in the pulp, the stronger the bonds between the fibres and the stronger the tear resistance of the paper. The adhesive used fills in the space between fibres. The addition of adhesives in paper making strengthens the bonds between fibres, thus improving the quality of physical properties of paper such as tensile and tear resistance.

The grinding process between the pulp and the adhesive also affects the bonds between fibres. The more the pulp is ground up homogeneously, the stronger the tear resistance. Tear resistance is influenced by the length of fibres, bonds between fibres, and cohesiveness of fibres (Eltahan, 2018). Furthermore, the addition of starch, which is often called the surface sizing method, also increases tear resistance. For this reason, the tapioca starch adhesive was used in this

study. In this research, the difference in tear strength could also come about due to the uneven thickness of paper in the forming process, since the process was carried out manually.

CONCLUSION

The quality of the paper from the combination of sugarcane bagasse with cassava peels or corn husks using good PVAc and tapioca starch adhesives was not significantly different. However further analysis showed that the type of adhesive gave a significant result on both tensile and tear resistance. The sensory test states that there were qualitative differences in a paper in terms of texture, color, and panelist preference for paper products. The combination of sugarcane bagasse and cassava peels with adhesive of PVAc performed the highest tensile strength (11.30 MPa) and the highest tear strength (1.82 MPa) of paper. Sensory testing shows that the combination of sugarcane bagasse and cassava peels with adhesive of PVAc was preferred the most. It can be concluded that the combination of sugarcane bagasse and cassava peels with adhesive of PVAc appeared to be the best combination.

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