Mechanical Properties of 3 Ply Plywood Made from *Acacia Mangium* Veneers and Green Starch-based Adhesives

Kang Chiang Liew[1,*] , and *Genevieve* En Yee Chin[1]

[1]Faculty of Science and Natural Resources, Forestry Complex, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

Abstract. Recently, starch has attracted great consideration as a raw material on wood adhesives in the wood industry. Cassava and sago starch-based adhesive are renewable, biodegradable and environmental friendly product when compared with other petroleum-based adhesives. In this study, different starches-based adhesive has been produced. Mechanical properties of plywood made from *Acacia mangium* veneers with different starches-based adhesives (cassava and sago) as binder cured at different curing temperatures (100°C, 120°C and 140°C) has been determined. All materials (starch, vinegar, water and glycerol) were cooked and stirred until the mixture reached 70°C - 80°C which become sticky and whitish. After that, starch-based adhesives were applied on the veneers by using spreader, and the plywood were pre-pressed for 30 minutes with 20 kg load before hot-press. Cassava starch-based adhesive showed the highest Modulus of Elasticity which was 12410.56 N/mm² than sago starch-based adhesive, while Modulus of Rupture of the cassava starch-based adhesive at 100°C showed highest mean value at 74.19 N/mm². Sago-starch based adhesive at 140°C showed the highest shear strength with 1.11 N/mm². In short, cassava and sago starch-based adhesives gave good performance in mechanical properties such as bending for pressed temperature (100°C and 120°C), and shear at 140°C pressed temperature.

1 Introduction

Adhesive is used and applied on any surface of the material, glued together and resist separation. Most of the wood adhesives are derived from petroleum source, called as synthetic adhesive or petroleum-based synthetic adhesive. Petroleum-based adhesives are non-renewable resource and limited such as melamine formaldehyde, urea formaldehyde resin, phenol formaldehyde and ethylene vinyl acetate based adhesive. These types of adhesive are widely available in different type of material, good in performance, excellent in durability and resistance in moisture and heat. In manufacturing and end use of these synthetic adhesives, low molar mass of toxic compounds were emitted largely. Negative effects on the human health and environment, for example, end product made from

* Corresponding author: liewkc@ums.edu.my

plywood in the interior, formaldehyde will be emitted to the surrounding and effects on the human health [1].

There have been renewed interests in more environment-friendly adhesive such as bio-based adhesive or "green" adhesive from biological sources. There are some natural substances, which was extracted and derived from variety of organic or inorganic sources such as starch, casein, soy bean, protein, and blood [2]. In short, wood industries continuously looking for green product which renewable, biodegradable and non-toxic gas emitted into the environment and low price for adhesive. Therefore, the aim of this study was to evaluate the mechanical properties (bending test and shear test) of plywood made from *Acacia mangium* veneers with different starches-based adhesives (cassava and sago) as binders cured at different curing temperatures (100^{o}C, 120^{o}C and 140^{o}C). Results expected that the starch-based adhesives would give comparable properties to the conventional adhesive of urea formaldehyde.

2 Materials and Methods

Acacia mangium was selected as the raw material where their logs were peeled and veneers cut into size at 19.5 cm in width and 20 cm in length. Starch-based adhesives from cassava flour and sago flour, vinegar, glycerol and water were cooked on hot plate. During the cooking process, the mixture was constantly stirred until it became sticky and whitish, which took around 30 minutes, at 70^{o}C - 80^{o}C. Urea formaldehyde adhesive was used as Control in this study.

Gluing process was performed after the completion of the process of preparation of veneers and adhesives. Starch-based adhesives and urea formaldehyde with 16.79±2 g of adhesives were applied onto each side of the veneers manually. Arrangement of the veneers was glued together at 90^{o} on each layer prior to pre-pressed for 30 minutes with 20 kg of load before hot press. Hot press process was carried out by using temperature of 100^{o}C, 120^{o}C, and 140^{o}C for a duration 30 minutes with pressure 0.5 MPa, for each 3-ply plywood. After hot press process, plywood was conditioned (relative humidity: 50±2 %, temperature: 23±2^{o}C for a period of 7 days) to obtain constant moisture content before cutting into test pieces.

Bending test (JAS No. 233:2003) was done to determine Modulus of Elasticity and Modulus of Rupture between plywood and adhesive. The dimension of test pieces was 170 mm in length X 35 mm in width. Shear test (JAS No. 233:2003) with modification on the shear speed with 1 mm/s was done to determine the strength of adhesion between the layers of plywood. The test pieces were 79 mm in length X 25 mm in width. The groove were cut by using bandsaw at the top and back of the test piece with 2 mm in width. Test pieces were immersed into the water bath for 3 hours at 60^{o}C before putting on towel to absorb excessive water. Then, Universal Testing Machine was used to test shear of test piece. Figure 1 showed the experimental design.

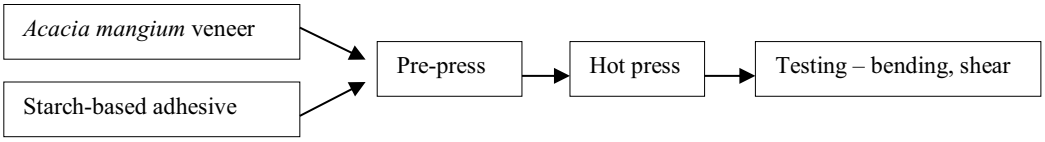

Fig. 1. Experimental design of study.

3 Results and Discussion

There were two mechanical test done throughout this study, which is bending test and shear test. The average of the mechanical test for Modulus of Rupture of plywood with different pressed temperatures recorded in the range 56.37 N/mm^2 to 78.95 N/mm^2, whilst the Modulus of Elasticity of in the range 7779.53 N/mm^2 to 12410.56 N/mm^2 and the shear test 0.28 N/mm^2 to 2.8 N/mm^2.

Figure 2 presented average of Modulus of Elasticity of the starch-based adhesives. Cassava starch-based adhesive with 100^{o}C of hot press temperature in making plywood showed the highest Modulus of Elasticity among all starch-based adhesives and temperatures, noted as 12410.56 N/mm². This is due to structure of cassava at 100^{o}C is good in performance as a binder and high elasticity compared with others starch-based adhesives in plywood. It also showed that structure and elasticity of the cassava starch-based is being destroy when temperature increasing to 140^{o}C. Uthumporn *et al*. [3] stated that different starches have different gelatinization temperature and while the starch under alkali and acid treatment with increasing temperatures could influence gelatinization temperature of starch. According to Yu *et al.* [4], granules morphological changes is effected by heating temperature than compared with heating time, while increase in alkali concentration, gives a strong impression on the swollen granules than neutral and acid conditions.

At the same temperature, sago starch-based adhesive in plywood showed the lowest Modulus of Elasticity recorded as 7779.23 N/mm². On the other hand, at 120^{o}C of hot press temperature showed the better results in starch-based adhesives in plywood when compared with urea formaldehyde. Sago starch-based adhesive showed the highest Modulus of Elasticity recorded as 12376.34 N/mm² which was higher than cassava starch-based adhesive at 57.78 N/mm² and urea formaldehyde about 2010.06 N/mm².

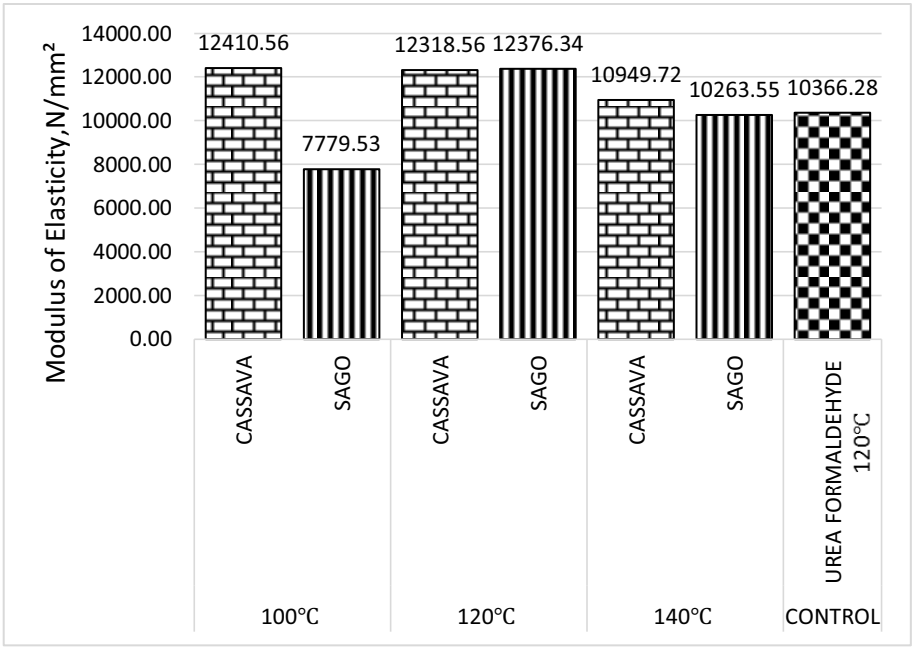

Fig. 2. Graph shows Modulus of Elasticity (N/mm²) for different starch-based adhesives and urea formaldehyde as binder in plywood pressed at different temperatures.

Figure 3 presented cassava starch-based adhesive in plywood with hot press temperature at 100°C recorded highest mean value of Modulus of Rupture which was 74.19 N/mm². At the same hot press temperature, sago starch-based adhesive in plywood showed the lowest mean value of Modulus of Rupture 56.37 N/mm². By comparison of mean value of Modulus of Rupture between the different adhesives with hot press temperature at 120°C, sago starch-based adhesive showed slightly lower than urea formaldehyde about 5.36 N/mm². In short, cassava and sago starch-based adhesives in plywood at 120°C of hot press temperature showed lower mean value of Modulus of Rupture when compared with urea formaldehyde. This was probably due to pure starch-based adhesives do not give good performance in strength and bonding between veneers and starch-based adhesive. According to Akbari *et al*. [5], the same testing was used for medium density fiberboard where there was no increment in loading at higher starch content due to lowest composition of natural rubber latex in the starch-based adhesive. Hence, pure starch-based adhesive has no ability to resist the loading strength except adding natural latex which tends to reduce brittle failure of the blend [6].

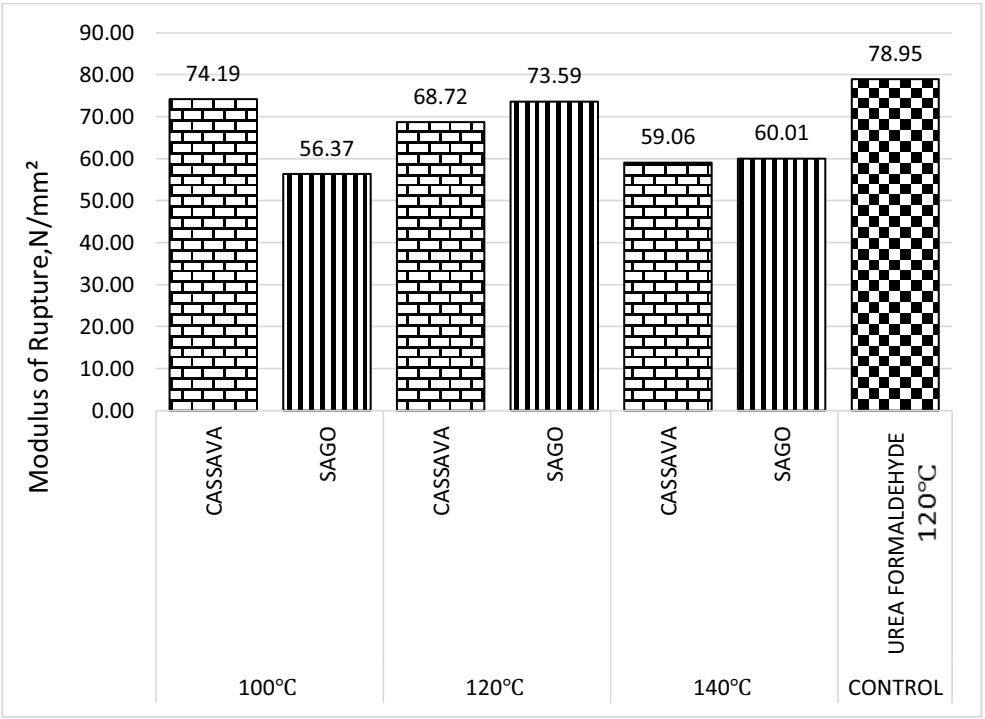

Fig. 3. Graph shows Modulus of Rupture (N/mm²) for different starch-based adhesives and urea formaldehyde as binder in plywood pressed at different temperatures.

Referring to Figure 4, sago starch-based adhesive in plywood with different hot press temperature at 140°C showed the highest mean value of shear strength which recorded 1.11 N/mm², while the lowest mean value of shear strength noted as 0.28 N/mm², which was starch-based adhesive at 120°C. As showed in bar graph, as the hot press temperature increased, the sago starch-based adhesive in plywood also increased in strength. With this situation, the structure of starch granules was broken and separated molecules of starch which is able to create an excellent adhesion to the veneer surface. According to Mohamed *et al.* [7], a high heating rate was achieved and the final temperatures was high enough to limit α-amylase activity. Hence, firmness of the starch gel was not reduced and a good

cohesion was achieved. In contrast, bar graph showed fluctuation when cassava starch-based adhesive in plywood increased with hot press temperature, bond strength decreased first, then increased again. Yu *et al.*[4] mentioned that treatment temperature of starch-based adhesive was increased and bond (shear) strength of starch-based adhesive between veneers also increased first, and then decreased in bond strength. This is because of the amount of free hydroxyl groups was presented on starch molecular chain.

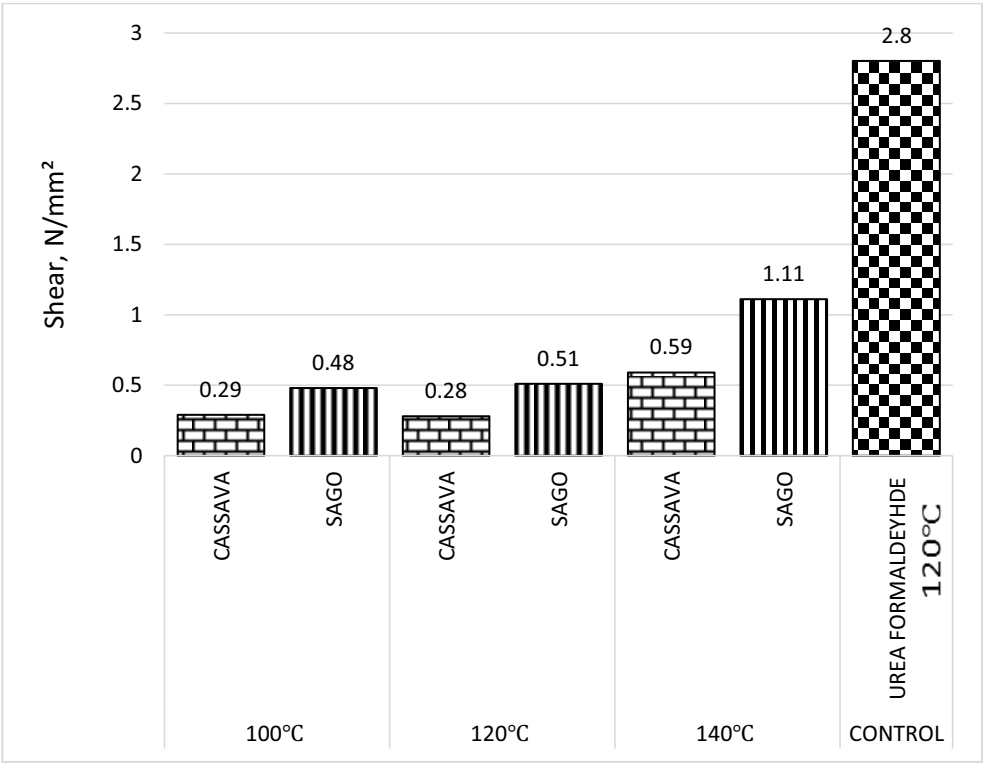

Fig. 4. Graph shows shear strength (N/mm²) for different starch-based adhesives and urea formaldehyde as binder in plywood pressed at different temperatures.

4 Conclusions

Mechanical testing were carried out with bending test and shear test to study bonding of starch-based adhesives with veneers. Cassava and sago starch-based adhesive in plywood with 120°C had higher elasticity and more elastic than urea formaldehyde as Control about 12318.56 N/mm² and 12376.34 N/mm². By comparison with starch-based adhesives and urea formaldehyde as Control in plywood at 120°C hot press temperature, sago starch-based adhesive showed slightly lower than urea formaldehyde was about 5.36 N/mm². At 120°C hot press temperature, cassava and sago starch-based adhesives showed mean value in shear strength as 0.28 N/mm² and 0.51 N/mm² when compared with urea formaldehyde recorded as 2.8 N/mm² due to pure starch-based adhesives were no good performance in shear test. In short, starch-based adhesive is an environmental friendly product, but in the process of making starch adhesive is expensive than urea formaldehyde. Hence, for the consumer who is consider environmental friendly can buy and use starch-based adhesive of plywood for making furniture or for floor and wall.

The authors sincerely thanked and acknowledged the Faculty of Science and Natural Resources, Forestry Complex, Universiti Malaysia Sabah for kindly supporting and providing the assistance and equipment throughout this research.

References

1. A.J. Kinloch, *Adhesion and Adhesives: Science and Technology* (Springer Science and Business Media, 1987)
2. L.F.M. da Silva, (ed.), *Handbook of Adhesion Technology: with 97 tables* (Springer Science & Business Media, 2011)
3. U. Uthumporn, Y.N. Shariffa, A. Fazilah, A.A. Karim, Colloid and Polym. Sci., **290**, 15 (2012)
4. H. Yu, Y. Cao, Q. Fang, Z. Liu, Bioresources, **10**, 2 (2015)
5. S. Akbari, A. Gupta, T.A. Khan, S.S. Jamari, N.B.C. Ani, P. Poddar, J. Ind. Acad. Wood Sci., **11**, 2 (2014)
6. J. Shey, S.H. Imam, G.M. Glenn, W.J. Orts, Ind. Crop. Prod., **24**, 1 (2006)
7. S.A. Mohamed, A.L. Al-Malki, T.A. Kumosani, Aust. J. Basic & Appl. Sci., **3**, 3 (2009)