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Hybrid Particleboard Made of Corn Husk (*Zea Mays* L.) and Sembilang Bamboo (*Dendrocalamus Giganteus* Munro): Effect of Adhesive Type and Particle Composition

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Abstract

Particleboard is a panel product made of wood particles or other lignocellulosic materials added with adhesive then pressed. The development of particleboard manufactured using non wood biomass has become important due to the decreased of wood as main raw material for the particleboard industry. Corn husk (*Zea mays* L.) and Sembilang bamboo (*Dendrocalamus giganteus* Munro) are lignocellulosic biomass that has potential as renewable materials for hybrid particleboard. The purposes of this study were to determine the suitability, the effect of adhesive type, and particle composition on physical and mechanical properties of hybrid particleboard made of corn husk and Sembilang bamboo particles. The adhesive types used were urea formaldehyde (UF) and phenol formaldehyde (PF) with 10 wt% adhesive content and the composition of corn husk : Sembilang bamboo was set at 100 : 0, 75 : 25, 50 : 50, 25 : 75, 0 : 100 (% w/w). The target density of hybrid particleboard was set at 0.80 g/cm^3. The boards were manufactured at 130 °C for UF and 150 °C for PF press temperature, 10 minutes and 2.5 MPa for the pressure of the hot press. The results showed that hybrid particleboard properties improved with increasing the amount of Sembilang bamboo particles in the board. Hybrid particleboard properties affected in ascending order were modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) and screw holding power (SHP). Generally, hybrid particleboard bonded PF adhesive has better properties than bonded UF adhesive. Results indicated that the addition of Sembilang bamboo particles in the mixture resulted in better properties of hybrid particleboard.

INTRODUCTION

Global demand on wood-based panel especially particleboard rises each year. There has been an increase in particleboard consumption in the world from 2015-2018 ranging from 85.033.084-95.301.946 m^3 per year (Food and Agriculture Organization, 2018). Particleboard described as a wood-based composite consisting of particles of various shapes and sizes (Hashim et al., 2011). It is produced by simultaneously compressing small particles of wood and bonding them with an adhesive (Shmulsky & Jones, 2011), into sheets (Valarmathi et al., 2013). There are a number of factors that affect the properties of particleboard such as type of raw material, type of particle generated, binder type, hot pressing process condition etc.

The particleboard industry uses mostly wood chips from natural or plantation forest, resulting in a higher quality product due to better control of the homogeneity of raw material. Related to the rise in consumption of particleboard in the world, causing the search for alternative renewable lignocellulosic materials for particleboard

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manufacturing that may efficiently meet the demand.

Considering these condition, some studies researched suitability of hybrid particleboard made of non-wood or agricultural by-products biomass such as oil palm trunk, corn biomass, sorghum bagasse, corn stalk and bamboo Belangke and corn stalk (Baskaran et al., 2013; Theng et al., 2015; Kusumah et al., 2016; Guler et al., 2016 and Iswanto& Anjarani, 2018). Thus, agricultural by-products and non-wood biomass are potential as renewable materials with comparatively good suitabilities in the design of hybrid particleboard manufacturing.

Biomass from corn husk is quite abundant in Indonesia and has not been used optimally. From corn harvested, the weight of corn husk which can obtained ranged from 10 to 38.38% (McCuctcheon & Samples, 2002; Dirgantara, 2013). When calculated from the production of corn fruit in 2018 is around 30.06 million tons, corn husk are also produced around 3-9 million tons (BPS, 2018). In the period of October 2019 to September 2020, the national area of the corn field was 5.5 million hectares with the harvested area approximately 5.16 million hectares. This area resulted in national corn production for around 24.95 million tonnes of dry kernels in 2020 (Ministry of Agriculture, 2020). Furthermore, Indonesia has 143 types of bamboo and 60 species are grown on Java Island. One type of well-known bamboo is Sembilang bamboo (Widjaja, 2001). Corn husk and Sembilang bamboo are a source of lignocellulose that is renewable, biodegradable and has the potential as hybrid particleboard raw materials.

Corn husk biomass has α-cellulose (38.66%), hemicellulose (29.33%) and lignin (10.11%) (Prasetiyo et al., 2018). The chemical contents of Sembilang bamboo also are similar to other agricultural by-products, wood and annual fiber plants. The combination of those two materials is expected to produce hybrid particleboard that has excellent properties and is comparable to particleboard from wood particles.

Particleboard performance is mostly related to the properties of adhesives and their compatibility with particles. More than 90% of particleboards manufacturing is bonded with urea formaldehyde (UF) and phenol formaldehyde (PF) adhesives. In addition, among other adhesives used in particleboard manufacture, UF and PF are the most economical and useful glue because of their low cost and easy application (Kariuki et al., 2019). A recent study by Bekhta et al., 2021 found that particleboard fabricated using pure UF outperformed the particleboard properties compare to those using lignosulfonates and pMDI (Bekhta et al., 2021). PF resins is used to produce particleboard which is applied as exterior furniture because of its water resistance. Meanwhile, UF is used to produce particleboard for indoor furniture.

Even though corn husk has been investigated as raw material for hybrid particleboard, yet its combination with Sembilang bamboo has never been conducted before. Therefore, the purpose of this study was to investigate the influence of the composition between corn husk and Sembilang bamboo particles and to evaluate the influence of different adhesive types on the physical and mechanical properties of hybrid particleboard.

MATERIALS AND METHODS

Materials

Corn husk and Sembilang bamboo biomass were collected from Cibinong, Bogor. Corn husk and Sembilang bamboo were processed into particle by a chipper and ring flaker machines. The particles were then screened by utilizing a horizontal vibration sieve. Particles size were used in this research passed through 4 mesh and retain at 14 mesh. All particles used in this research were dried at 100-105 °C in a technical oven until 5% moisture content to be reached.

A liquid phenol formaldehyde (PF) adhesive (45% solids and pH 8.0) and urea formaldehyde (UF) adhesive (50% solids and pH 7.6) were obtained from PT Pamolite Adhesive Industry at Probolinggo East Java. The adhesive was applied 10 wt% for hybrid particleboard based on oven dry weight. Prior to hybrid particleboard production, chemical components of Sembilang bamboo were characterized according to TAPPI 257:2002 test method.

Methods

Hybrid particleboard with a target density of 0.8 g/cm^3 were manufactured using composition of corn husk : Sembilang bamboo particles were 100 : 0, 75 : 25, 50 : 50, 25 : 75, 0 : 100 (% w/w). The dimensions of hybrid particleboards were 30 x 30 x 0.9 cm (length, width, thickness). The pressing conditions were as follows; hot-press temperature

(130°C for UF adhesive and 150°C for PF adhesive), press pressure (2.5 MPa) and press time (12 min).

All the boards were post-cured for one week at room temperature of 27°C and 65% relative humidity (RH). Test samples (5 replications) were prepared and tested based on JIS A 5908:2003 standard for physical and mechanical properties of particleboard.

Physical properties testing for the hybrid particleboards was conducted for its density, water absorption and thickness swelling. The testing specimens of hybrid particleboard were immersed in the water for 24 hours for water absorption and thickness swelling investigation. Mechanical properties testing for hybrid particleboard was carried in terms of flexural strength (modulus of rupture and modulus of elasticity), internal bonding and screw withdrawal. Mechanical testing was conducted using universal testing machine.

RESULTS AND DISCUSSION

Physical Properties

The targeted density of hybrid particleboard for this study was 0.80 g/cm^3. The range density of hybrid particleboard in this study was 0.80-0.86 g/cm^3 (Figure 1). The boards bonded with UF and PF adhesive had high density, which even exceeds the target density. This condition is related to the compatibility of particles which will affect the mechanical properties. The low standard deviation indicates that the density values of the test samples were uniform enough so that the average density data is acceptable.

Particle size and density distribution strongly influence the board performance (Valarmathi et al., 2013). Therefore, the quality of bonding between the particles is a major factor that affects performance, which in turn depends on the amount and type of adhesive used (Veigel et al., 2012). Generally, the particle size of Sembilang bamboo had a good slenderness ratio (more than 150) compared to corn husk particle which affect the properties of boards.

Figure 2 and 3 show the effect of the adhesive type and composition between corn husk and Sembilang bamboo particles on thickness swelling (TS) and water absorption (WA) properties. The increase of Sembilang bamboo particle in hybrid particleboard able to improve TS and WA values. The TS value of the board ranged from 21.03-118.98% (Figure 2). Overall, the TS value of the board does not met JIS A 5908:2003 which mention the maximum value of 12%. The observed results indicated that the adding of Sembilang bamboo particles of more than 50% w/w in the mixture resulted in better TS. While, the WA value of board ranged from 42.23-159.82% (Figure 3).

Pardosi et al. (2012), argued that the particle size of the material can affect the strength of the bonds between particles and the water absorption of the resulting particleboard. The low-density particleboard is easily penetrated by moisture. Therefore, the larger the volume of cavities that are formed, the more water will be contained in the hybrid particleboard. The water content of the hybrid particleboard is very significantly affected by the particle size, the smaller the particle size the lower the water content.

The value of TS and WA were also affected by the density target achievement. Overall, the value of density target (0.80 g/cm3) from board has reached. The real density value of hybrid particleboard was 0.80-0.86 g/cm3 as shown in Figure 1.

The standard deviation of test samples bonded with PF were lower than of test samples bonded with UF. It indicates that the thickness swelling values of test samples bonded with PF were more uniform than of thickness swelling values of test samples bonded with UF. Particleboards bonded with UF were more susceptible to environment moisture so that the thickness swelling values were more varied.

This condition can be affected by the density of Sembilang bamboo which is higher compared to the corn husk. The hygroscopicity properties of material also had important role in determining of TS and WA value (Zhang & Hu, 2014). The results from analysis of chemical content show that Sembilang bamboo particle has α-cellulose (39.04%), holocellulose (54.67%), hemicellulose (15.63%) and lignin (10.22%). As a lignocellulosic material, corn husk and Sembilang bamboo contains a significant amount of cellulose that have hydroxyl group which easier to absorb water. However, the presence of PF and UF adhesives on particleboards can reduce the hygroscopic properties of particles. Compatibility between particles and adhesive able to improve the dimensional stability from particleboard.

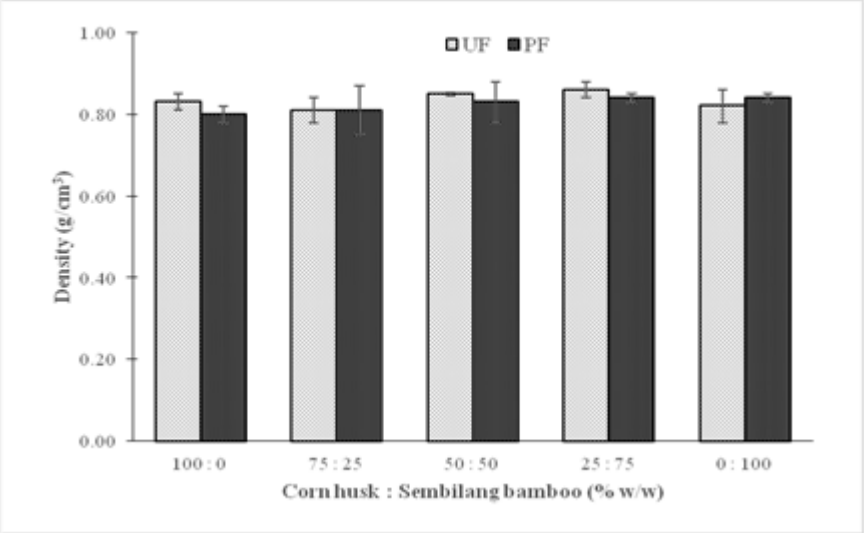

Figure 1. The density of hybrid particleboard.

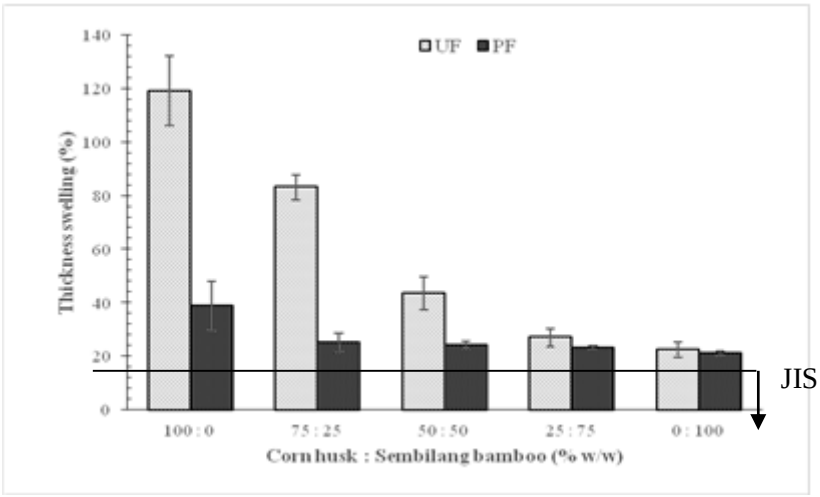

Figure 2. Thickness swelling value of hybrid particleboard.

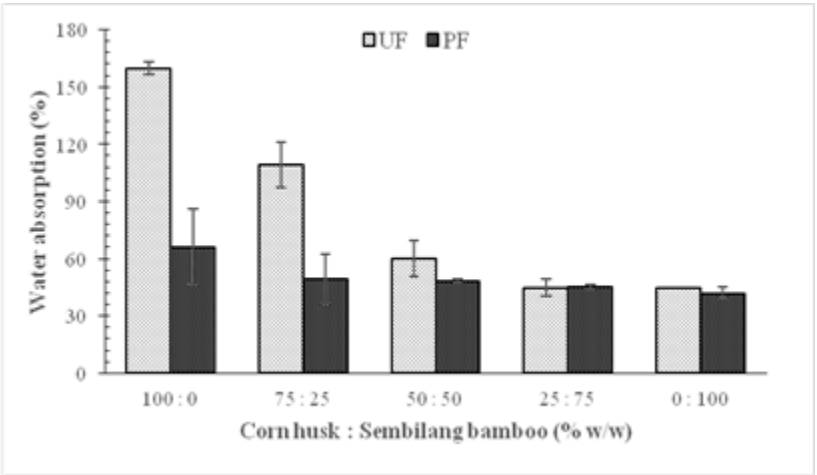

Figure 3. Water absorption values of hybrid particleboard .

The principal factors that affecting the TS value of particleboards are the type of adhesives used and the resin content and compressibility of the boards (Kelly et al., 1977). Commonly, particleboard bonded using PF adhesive has better TS and WA values compared to particleboard bonded UF adhesive. In this research, the board which bonded using PF adhesive has better TS and WA values than board bonded using UF adhesive. This result was also confirmed by Astari et al. (2019) who investigated the thickness swelling properties of particleboard from cornstalks using PF and UF. The result shows that particleboard with PF gives 21.5% lower thickness swelling compare to particleboard with UF. This can be caused by UF adhesive properties that easily absorb water and moisture (Maloney, 1993). Furthermore, this probably due to interference in the curing of PF adhesive, reduced wettability of the particle surface or limitation of diffusion and/or spreading of the adhesive within the particles and over the particle surface (Prasetiyo et al., 2018).

Mechanical Properties

Figures 4-7 show the results of mechanical properties such as modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and screw holding power (SHP) for produced hybrid particleboards.

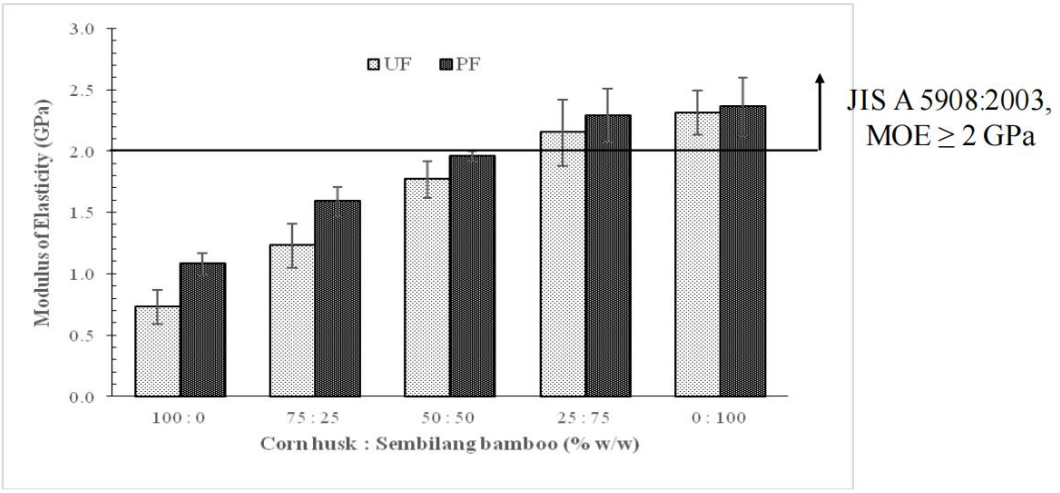

Figure 4. Modulus of elasticity from hybrid particleboard.

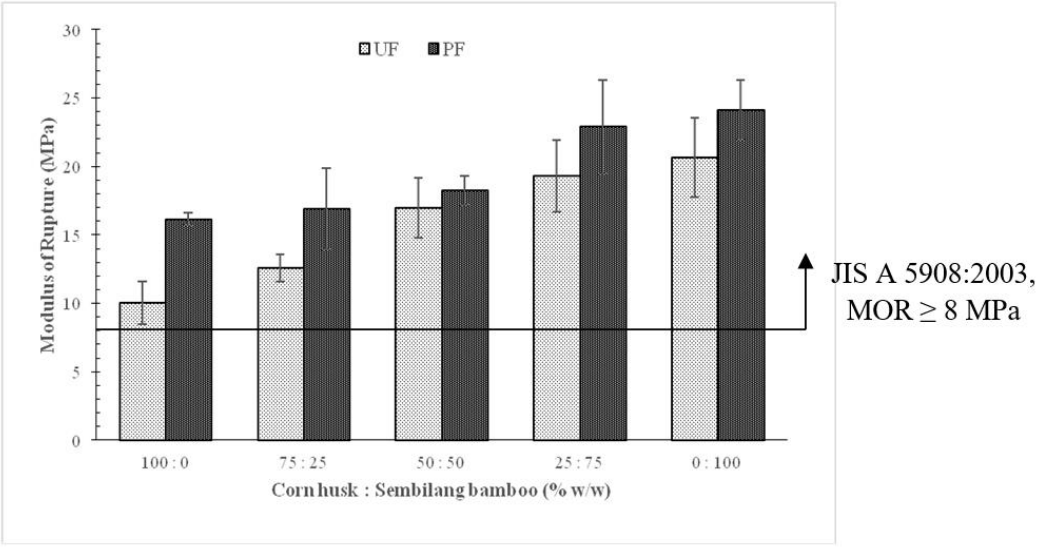

Figure 5. Modulus of rupture from hybrid particleboard.

Generally, the bending properties (MOE and MOR) values from corn husk hybrid particleboard using PF adhesive are better than hybrid particleboard using UF. Results indicated that Sembilang bamboo amount in particleboard manufacturing affects MOE and MOR of boards. Increasing Sembilang bamboo particles from 0 to 100% w/w increased the MOE and MOR values (Figure 4-5). Nearly, the value of MOE was below the JIS standard which mention the minimum value of 2.0 GPa, except on board with a mix of 75 to 100% Sembilang bamboo particles that met the JIS standard. The highest MOE (2.36 GPa) and MOR (24.13 MPa) values were only obtained from hybrid particleboard manufactured using 100% Sembilang bamboo particles, respectively. On the other hand, the lowest MOR and MOE values were observed when 100% corn husk particles were utilized in the hybrid particleboard production.

Overall, MOR values of hybrid particleboard that ranged from 10.03 to 24.13 MPa met JIS A 5908:2003 which mention the minimum value of 8 MPa (type 8), moreover until requirement type 13 (value of 13 MPa) and type 18 (value of 18 MPa) for base particleboard standard. Particle geometry differences between corn husk and Sembilang bamboo particle is affected MOR and MOE values of hybrid particleboard were obtained. Sekaluvu et al. (2014) reported that particle size and adhesive content affecting the board density, MOE and MOR from particleboard using maize cobs.

The differences between MOE and MOR values from hybrid particleboard that were obtained also influenced by the chemical reaction between adhesive type and lignocelluloses materials, thus lowering the bondability of these materials (Kelly, 1977). It is known, corn husk has higher hygroscopic properties than Sembilang bamboo particles. Thus, corn husk particle is easier to absorb water than Sembilang bamboo particle which affect on wettability properties and moisture content. The utilization of particles with a high moisture content resulted in particleboards with inferior mechanical properties due to the poor adhesion between adhesive and particles (Ndazi et al., 2006).

Figure 6 shows the results from the relationship between adhesive type with IB properties of hybrid particleboards. As expected, the IB value of hybrid particleboards increased in line with the increase of Sembilang bamboo content from 0 to 100 % w/w. The IB value of hybrid particleboards bonded using PF adhesive (0.57-1.37 MPa) was slightly higher and met JIS A 5908:2003 than hybrid particleboards manufactured with UF adhesive (0.09-0.95 MPa). Most of the variations in material composition results IB values are satisfied with the JIS standard which requires 0.15 MPa for type 8 even until met type 13 (0.20 MPa) and type 18 (0.30 MPa), except on board from 100% corn husk particle. The IB values of the hybrid particleboard also were superior to sandwich particleboard made of bamboo Belangke and corn

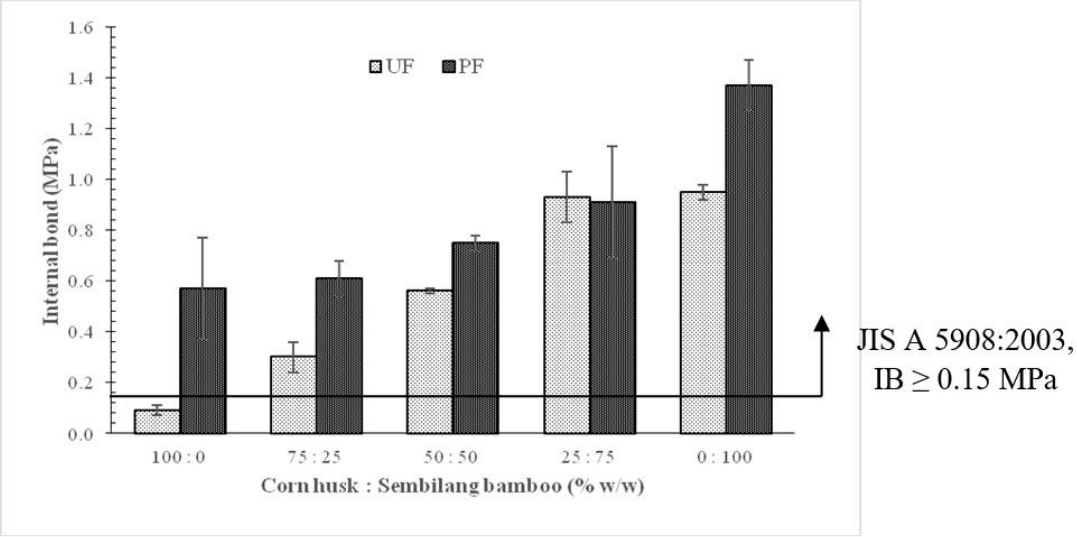

Figure 6. Internal bond value of hybrid particleboard.

stalk particles bonded isocyanate resin (4 to 10%) that ranged from 0.048 to 0.067 MPa and did not met JIS A 5908:2003 standard (Iswanto et al., 2018).

This condition is similar to the test results of MOE and MOR from hybrid particleboard. The IB values of boards were also influenced by the distribution of the adhesive used. As the distribution of the adhesive is evenly distributed, the value of the IB will be higher. However, the distribution of the adhesive is not evenly distributed then the IB properties will be lower.

The screw holding power (SHP) is the ability of the particleboard to hold the screw implanted in the particleboard (Kasim et al., 2001). The measurements of SHP show the maximum force exerted on the particleboard in a given area until the screw is released. The value of SHP from hybrid particleboard is shown in Figure 7. The result showed the SHP value of hybrid particleboard with PF adhesive higher than hybrid particleboard bonded UF adhesive. The SHP values of hybrid particleboard with UF adhesives ranged from 156.77 to 523.18 N, while hybrid particleboard bonded PF adhesive ranged from 222.66 to 698.70 N. Only from hybrid particleboard with a composition between corn husk and Sembilang bamboo particles above 50% is able to produce SHP value that fulfilled the JIS A 5908: 2003 standard which sets a minimum SHP value at 300 N (type 8) and included in the category type 13 (400 N) and 18 (500 N). This SHP also was superior to particleboard from 100% corn stalk particle bonded using UF and PF adhesives (8, 10 and 12 wt%) that ranged from 201.17 to 254.95 N and could not meet JIS A 5908:2003 standard (Prasetiyo et al. 2019).

In addition, the value of SHP also influenced by the density and surface bonding area of a particle. Particles with surface bonding area caused contact between the particles with the adhesive to be larger that causing the value of SHP to increase (Melo et al., 2014). The completeness and ease of the adhesive distribution to the particles and particle geometry were also affected the SHP value of particleboard (Juliana et al., 2012; Astari et al., 2018).

The value of SHP also can be attributed to the geometrical properties of corn husk and Sembilang bamboo particles. As we know, Sembilang bamboo is larger and longer compared to corn husk particles. During the mixing process with adhesive, the smaller corn husk particles will fill voids space between Sembilang bamboo particles and makes the board more compact than the board made of 100% corn husk particle.

Cheng et al. (2016) studied the effect of particle geometry and adhesive percentage in mechanical and physical properties of particleboard from peanut hulls. It is reported that particle geometry, adhesive type and adhesive mass percentage directly affecting the mechanical performance of the board. It is also reported that the type of adhesive consequence to the suitable of

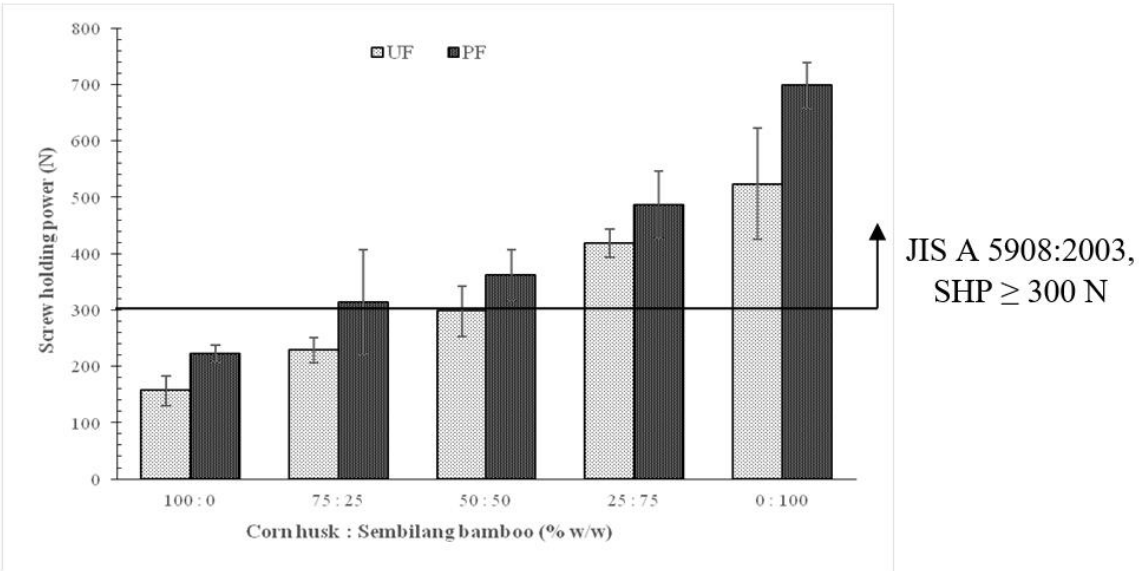

Figure 7. Screw holding power value of hybrid particleboard.

particle source (wood or non-wood) with the adhesive which further affecting the properties of the board.

Generally, the MOE, MOR and IB values of hybrid particleboard made of corn husk and Sembilang bamboo particles bonded UF and PF adhesive are better to compare to hybrid particleboard made of bamboo and rubberwood particles bonded UF reported by Nurhazwani et al. (2016).

CONCLUSION

Corn husk (*Zea mays* L.) and Sembilang bamboo (*Dendrocalamus giganteus* Munro) as renewable materials can be processed into particles that are suitable for hybrid particleboard manufacture. The results indicated that corn husk and Sembilang bamboo can be mixed using UF and PF adhesive. Generally, the hybrid particleboard that bonded using PF adhesive and comprise with higher contents of Sembilang bamboo particles had superior properties. Nearly, the properties of hybrid particleboards comply with the minimum requirements in JIS A 5908:2003 standards for general grade particleboards except for TS properties and some values from MOE. In the future, this product has the opportunity to be used as a material for non-structural building components such as partitions.

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