Research Article

Eka Mulya Alamsyah*, Sutrisno, Arif Nuryawan, Ragil Widyorini

# Identifying best parameters of particleboard bonded with dextrin-based adhesives

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**Abstract:** The objective of this study was to evaluate the best parameters of particleboard manufacturing throughout the physical and mechanical properties' test under Japanese Industrial Standard. Particleboard panels were manufactured from veneer waste of sengon wood (*Paraserianthes moluccana*) bonded with dextrin-based adhesives (DAs) and urea formaldehyde (UF) adhesives at the density target of 0.70 g/cm$^2$ under various manufacturing parameters of adhesives composition, load pressure and pressure temperatures. The results showed that an increase in the value of physical and mechanical properties occurred on particleboards which were glued with DAs added with UF. As the addition of UF adhesive increases, the physical and mechanical properties of the particleboard also gradually increase. This confirms that a good bonding occurs when adding UF adhesives compared to using only dextrin. The particleboard manufacturing parameters demonstrated the best properties when 40% DA was mixed with 60% UF adhesives (DA–UF = 40:60 pbw; P12) for the physical test and 20% DA mixed with 80% UF (DA–UF = 20:80; P13) for the mechanical test for both particleboards under the load pressurized at 40 kgf/cm$^2$ for 30 min at a temperature of 105°C.

**Keywords:** particleboard bonded, dextrin, adhesives

*** Corresponding author: Eka Mulya Alamsyah,** Department of Post Harvest Technology, School of Life Sciences and Technology Institut Teknologi Bandung, Jl. Ganesa 10, Bandung, Indonesia, e-mail: ekamulya@sith.itb.ac.id
**Sutrisno:** Department of Post Harvest Technology, School of Life Sciences and Technology Institut Teknologi Bandung, Jl. Ganesa 10, Bandung, Indonesia
**Arif Nuryawan:** Department of Forest Products Technology, Faculty of Forestry, Universitas Sumatera Utara, Medan, Indonesia
**Ragil Widyorini:** Department of Forest Products Technology, Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia

## 1 Introduction

Until now, formaldehyde-based adhesives such as urea formaldehyde (UF), melamine-formaldehyde (MF), melamine urea formaldehyde (MUF), and phenol formaldehyde (PF) are still dominantly used as adhesives for wood composite products due to several advantages, including easily and cheaply produced, the nature of its optimal attachment for the final purpose of use (interior or exterior) and easy application because their viscosity/thickness can be regulated, of their fast cure (mature) by adjusting the pH conditions and of their pressing temperature. But unfortunately, formaldehyde-based adhesives will continuously release formaldehyde emissions (due to hydrolysis that is reversible) both during production and have been applied as an adhesive on wood products/wood composites that have a negative effect on users/humans, which results in sick house syndrome (SHS; the inconvenience of living inside a building that is filled with furniture glued by formalin-based adhesives). The World Health Organization (WHO) even reports that the long-term effects of SHS are carcinogenic (International Agency of Research Cancer 2006). Proposing researchers also recently reported that although formaldehyde levels were lowered to a minimum in UF adhesives, they still have a negative effect on mice, namely, increased white blood cell contents and thickened mucous membrane lining in the respiratory organs of mice (Nuryawan et al. 2017). The production of composite wood mainly relies on the petrochemical-based and formaldehyde-based adhesives such as UF, PF and MUF, which can cause under certain conditions problem for health and environment (Moubarik et al. 2010). Therefore, in order to substitute these formaldehyde-based resins as well as based on environment awareness, bioadhesives have been re-used nowadays even though their strength and durability are limited (Matting and Brockmann 1968; Frihart and Hunt 2010; Umemura et al. 2013; Ferdosian et al. 2017). Bioadhesives are definitively advantageous in terms of health and environmental issues because the parents of these adhesives are natural renewable resources (such as animals and botanical plants; Mathias et al 2016). Despite the raw materials of bioadhesive are mainly used for human food consumption, some available sources are utilized as feedstock of bioadhesives, such as waste of skin, bone, fish, blood (from animals) and residue of bark, rind and seed (from plants; Ulker 2016).

The dextrin adhesive (DA) was chosen because it is made without formalin and is relatively easily produced because it is starch based and the thickness can be adjusted, so that it can be applied as a composite product adhesive by spraying. Starch-based and protein-based adhesives commonly called as bioadhesives derived from plant-based materials such as durian, corn, cassava, wheat, etc. (Yang et al. 2006; Jarusombuti et al. 2012; Liu et al. 2012; Nikyash et al. 2012) for the manufacturing of wood composites. Durian is a famous and popular native fruit of Southeast Asia, also known as the king of fruits. It is considered exceedingly delicious. Durian is a climacteric fruit that undergoes rapid postharvest changes resulting in a short shelf life at ambient temperature. These changes are essential for consumption. The fruit is usually consumed fresh, but it can be processed into different products. Nowadays both fresh and processed durians have become popular in both local and export markets, possibly because the new ways of eating the fruit have been well received. In addition, a huge amount of inedible husk left has created biomass that can be developed into many innovative products (Ketsa 2018). The inedible durian seeds are also obtained in huge amounts, which in turn can be developed into DA materials, and they are environmentally friendly (Nuryawan et al. 2019). On the other hand, the information on the utilization of durian DA for particleboard production are still limited.

Dextrin in this study is produced from durian seeds. Those durian seeds came from North Sumatera Province with the consideration that durian fruit production in North Sumatra Province is the largest in Indonesia so it can be concluded that as an area that produces a lot of durian fruits, there are many post-consumption durian seed waste. One main utilization of durian seed is as a source of starch that is mixed with polyethylene in plastic bag production (Cornelia et al. 2013). Another utilization of durian seed starch is as the filler of material based on its tensile strength and biodegradation polymer polysterene (Sudi 2013). The quality of durian starch through the addition of sodium metabisulfite and duration in solution resulted in low quality (Suarti et al. 2013). Furthermore, the durian seed starch contains high amylopectin, which is known for its high binding capacity compared to other vegetable starches. To anticipate starch durability and starch adhesive durability as wood composite product adhesives, the water-soluble wood preservatives (boric acid/H3BO3) at various concentrations are introduced into DAs based on the weight of the solid DAs applied, so that ultimately the product is not overgrown with fungus and not attacked by termites.

Some previous studies on the utilization of starch-based adhesive for manufacturing wood composites have been done by some researchers. Dextrin can be used as an economic feedstock for the synthesis of curing agents for waterborne epoxies in an effort to develop formaldehyde-free adhesives (Liu et al. 2011). Hosseinpourpia et al. (2019) reported the potential use of dextrin-based wood adhesive which is cross-linked *in situ* with glyoxal and polymeric diphenylmethane diisocyanate (pMDI) for medium-density fiberboard (MDF) manufacturing. It was possible to utilize selected starch-based products as bioadhesive for the production of particleboard (Janiszewska et al. 2015). Galvas (2011) reported that the utilization of protein-based adhesives gives the best characteristic compared to the starch-based adhesive formulations as wood adhesives. Ninjan et al. (2018) chose latex-based adhesive to develop the natural adhesives. Generally, these research outputs showed that good quality bonding occurred when starch or dextrin was mixed with a synthetic adhesives such as UF or cross-linkers compared to starch or dextrin alone.

The waste wood from MDF, medium-density particleboard, plywood and timber after reduction of these wood product residues to particles could be made particleboards (Azambuja et al. 2018). Similarly bamboo and woody waste are used as wood composite products (Chung and Wang 2019). In the current study, sengon wood veneer waste from plywood and laminated veneer lumber (LVL) industry were chosen as particle materials.

The objective of this study was to evaluate the best parameters for manufacturing particleboard of sengon wood (*Paraserianthes moluccana*) veneer waste bonded with DA throughout its physical and mechanical properties' test under Japanese Industrial Standard (JIS 2003).

# 2 Materials and methods

## 2.1 Materials

### 2.1.1 Adhesives

In this study durian seed starch DAs obtained from the Faculty of Forestry, University of North Sumatra (Surti 2019) and commercial UF resin adhesives were used, which were provided by PT. Sumber Graha Sejahtera, a plywood and LVL company in Balaraja Tangerang, Indonesia.

### 2.1.2 Particle

Particles used in this study were sengon wood (Paraserianthes moluccana) veneer waste obtained from PT.

Sumber Graha Sejahtera, a plywood and LVL company in Balaraja Tangerang, Indonesia.

## 2.2 Methods

### 2.2.1 Preparation of DA

Dextrin flour is diluted in water at a ratio of 1:20 (w/v) and heated in boiling water for 15 min. After chilling, DAs are ready to be used as particleboard adhesives (Surti 2019). Figure 1 showed the preparation of DA in laboratory.

### 2.2.2 Preparation of wood particle

Wood particles are made in a simple way through splitting of the veneer waste as shown in Figure 2. After being converted into small sizes, the particles are then cooled until they reach a moisture content (MC) of approximately 5%. After that, they are stored in different plastic bags according to their size. The manufacture of wood particles is carried out at the School of Life Sciences and Technology, Institut Teknologi Bandung and brought to PT. Sumber Graha Sejahtera.

### 2.2.3 Manufacturing of particleboard

For preliminary test of making DA particleboard of medium density (0.70 g/cm$^3$), 15% adhesive content based on the weight of the solid adhesive content, hot pressing was carried out at pressures of 10, 25 and 40 kgf/cm$^2$ for 2 × 15 min (open and close) at temperatures of 105°C, 140°C and 150°C. The complete manufacturing parameters of particleboards are presented in Table 1.


**Figure 1:** Durian seed starch dextrin.

**Figure 2:** Particle from veneer waste.

### 2.2.4 Testing parameters

In the testing stage, some particleboards did not met the requirements for testing and show failures, such as the absence of adhesive bonding with particles, the occurrence of bubbles or blisters and the lack of felt load when making boards. These particleboard failures occurred on boards P1, P2, P4, P6, P7, P8, P9, P10 and P11. While the successful particleboards were obtained from P3, P5, P12 and P13, as shown in Figure 3. From Figure 3 it could be seen that the appearance of the board ready to test, no bubbles or blister so that the boards were continued to the physical and mechanical properties test. The physical property tests include measurements of density, MC, thickness of swelling and water absorption. Tests for mechanical properties include measurement of modulus of rupture (MOR), modulus of elasticity (MOE), screw holding strength and internal bond (IB) strength. The testing parameters were based on JIS (Japanese Agricultural Standard 2003).

# 3 Results and discussion

## 3.1 Particleboard performance

All the particleboards made may not be of good quality and not all of them can be continued with the testing process because they demonstrated failure before being tested (worst and failed before tested). This was possible because the adhesive weight, the temperature and the

**Table 1:** Manufacturing parameters of particleboards

| Code | Adhesives compositions (pbw) | Glued spread (g) | | Pressing temperature (°C) | Load pressure (kgf/cm²) | Pressing time (min) |
|---|---|---|---|---|---|---|
| | | DA | UF | | | |
| P1 | DA control 1 (100) | 70 | 0 | 150 | 25 | 30 |
| P2 | DA control 2 (100) | 70 | 0 | 150 | 10 | 30 |
| P3 | DA control 3 (100) | 70 | 0 | 140 | 40 | 30 |
| P4 | UF control 1 (100) | 0 | 100 | 140 | 10 | 30 |
| P5 | UF control 2 (100) | 0 | 100 | 105 | 40 | 30 |
| P6 | DA–UF (80:20) | 56 | 20 | 150 | 25 | 30 |
| P7 | DA–UF (80:20) | 56 | 20 | 150 | 10 | 30 |
| P8 | DA–UF (60:40) | 42 | 40 | 150 | 25 | 30 |
| P9 | DA–UF (60:40) | 42 | 40 | 150 | 10 | 30 |
| P10 | DA–UF (40:60) | 28 | 60 | 140 | 10 | 30 |
| P11 | DA–UF (20:80) | 14 | 80 | 140 | 10 | 30 |
| P12 | DA–UF (40:60) | 28 | 60 | 105 | 40 | 30 |
| P13 | DA–UF (20:80) | 14 | 80 | 105 | 40 | 30 |

Note: pbw, part by weight; DA, dextrin adhesive; UF, urea formaldehyde adhesives.

P3 P5 P12 P13

**Figure 3:** Appearance of the performance of the successful particleboards P3, P5, P12 and P13.

pressure and the load pressure used were not optimal, causing failures such as the absence of adhesive bonding with particles, the occurrence of bubbles or blisters and the lack of felt load when making boards. These criteria show that the parameter applied to particleboard manufacturing could not meet the best parameters. Therefore, it was important to separate the specimen for board testing before applying physical and mechanical testing. The decision for carrying out the testing of the particleboard is presented in Table 2.

## 3.2 Physical properties

Physical test results for particleboards P3, P5, P12 and P13 are presented in Table 3. The MC test results showed that all particleboards met the JIS requirements because their values were still below 14%. While the board density values range from 0.58 to 0.69 g/cm$^3$. The highest density of 0.69 g/cm$^3$ was obtained by particleboard bonded with 40% DAs mixed with 60% UF (P12). This value is nearest to the target density value of 0.70 g/cm$^3$, and this is presumably because the particles used have a non-uniform size, so that some areas on the board are not filled with adhesives and particles. Suggestions for improvement are aimed at making particles of even smaller sizes. For shrinkage and thickness swelling values, the sample particleboard test with 100% DAs (P3) failed because before testing the sample was damaged or dispersed when immersed in water. This shows that the 100% dextrin adhesive has not been able to meet the requirements of shrinkage values.

## 3.3 Mechanical properties

The results of mechanical properties' testing of particleboards P3, P5, P12 and P13 are presented in Table 4.

Table 2: Decision for testing particleboards

| Code | Board performance | Decision |
|---|---|---|
| P1 | Worst | Not tested |
| P2 | Worst | Not tested |
| P3 | Good | Tested |
| P4 | Worst | Not tested |
| P5 | Good | Tested |
| P6 | Worst | Not tested |
| P7 | Worst | Not tested |
| P8 | Worst | Not tested |
| P9 | Worst | Not tested |
| P10 | Worst | Not tested |
| P11 | Worst | Not tested |
| P12 | Good | Tested |
| P13 | Good | Tested |

The highest MOE test results 1014.72 N/mm$^2$ were obtained by particleboard bonded with 100% UF adhesives (P5), while the smallest 494.44 N/mm$^2$ were obtained by particleboard bonded with 40% DAs mixed with 60% UF adhesives (P12). The same condition was observed in MOR test results, where the highest value 9.66 N/mm$^2$ was obtained with P5 and the lowest 5.41 N/mm$^2$ obtained with P12. These results are the same as the previous research wherein the particleboard bonded with UF adhesives has the highest MOE and MOR compared to particleboard bonded with wheat starch and oil palm starch (Salleh et al. 2015). The screw holding strength ranges from 138.28 for P3 (the lowest) to 680 N for P13 (the highest). For the IB strength, the values range from 0.11 for P3 (the lowest) to 0.57 N/mm$^2$ for P5 and P13 (the highest). Another study shows that the IB values of the particleboard ranged 0.74 ± 0.92 kgf/cm$^2$ (Nuryawan et al. 2019). It was predicted that the uneven distribution of DA presumably making less strength of the IB.

Relating to the MC values among the particleboard, it can be predicted that the high mechanical test values were obtained by the more dried particleboard. By far, among the DAs used, it can be found that the best mechanical properties were obtained by the particleboard bonded with 20% dextrin mixture with 80% UF (P13). This confirms that a good bonding quality occurs when adding UF adhesives compared to using only dextrin.

Table 4: Mechanical properties of particleboards

| Code | Bending strength 200 (N/mm$^2$) | | Screw withdrawal (N) | Internal bond (N/mm$^2$) |
|---|---|---|---|---|
| | MOE | MOR | | |
| P3 | 915.67 | 5.68 | 138.28 | 0.11 |
| P5 | 1014.72 | 9.66 | 582.03 | 0.57 |
| P12 | 494.44 | 5.41 | 298.44 | 0.47 |
| P13 | 548.51 | 6.57 | 680.08 | 0.57 |

Previous study confirmed that the utilization of cassava starch-based adhesive only in MDF manufacturing showed lower quality of bonding compared to the MDF bonded with cassava starch mixed with UF adhesive (Jarusombuti et al. 2012). Another study of DA for particleboard stated that the use of additive materials, for example, cross-linker agent into DA could improve the mechanical properties of MOR and IB compared to using dextrin only (Hosseinpourpia et al. 2019). Both the previous studies supported the current study that starch and dextrin only cannot improve bonding. Therefore, in the future studies it is necessary to understand ways to improve the quality of the particleboard, which are of two kinds: one is improving the characteristics of DA and the other is improving the parameters of manufacturing including using particles of smaller size than the particle size used in the current study.

## 4 Conclusion

From the 13 composition parameters tested, particleboards that meet the requirements and whose physical properties can be further developed, i.e., a particleboard

Table 3: Physical properties of particleboards

| Code | Parameters | | | | |
|---|---|---|---|---|---|
| | MC (%) | Density (g/cm$^3$) | Radial shrinkage (%) | Tangential shrinkage (%) | Thickness of swelling (%) |
| P3 | 5.93 | 0.58 | NT | NT | NT |
| P5 | 11.56 | 0.62 | 0.54 | 0.55 | 44.44 |
| P12 | 11.87 | 0.69 | 0.63 | 0.67 | 45.34 |
| P13 | 12.71 | 0.62 | 0.75 | 0.71 | 33.09 |

NT: not tested, boards failed before testing.

that can be bonded using a mixture of 40% DA and 60% UF adhesives (DA–UF = 40:60) (P12) and pressurized at 40 kgf/cm$^2$ for 30 min at 105°C. While in the mechanical properties' test, particleboards that meet the requirement and have the opportunity to be further developed, i.e., a particleboard that can be bonded using a mixture of 20% DAs and 80% UF adhesives (DA–UF = 20:80) (P13) and pressurized at 40 kgf/cm$^2$ for 30 min at 105°C. These results indicated that the use of DAs at the level of 40% is the maximum when mixed with UF adhesives as the binder. Further, these confirm that a good bonding quality occurs when adding UF adhesives compared to using only dextrin.

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