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Determination of wood wettability properties of oil palm trunk, *Shorea* sp. and *Paraserianthes falcataria* by contact angle method

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Abstract. The aim of this study was to determine the wettability of the inner part of oil palm trunk (OPT), the outer part of OPT, OPT that densified 50%, *Shorea* sp. and *Paraserianthes falcataria* wood, as raw material for laminated beams. The wettability of the wood was measured by using cosine-contact angle (CCA) method, which is measuring the angle between dripped resin liquid and the wood surface. The resins that used in this study is phenol formaldehyde (PF) and urea formaldehyde (UF). The results showed that the *Shorea* sp. and P. *falcataria* woods have the smallest contact angle or the best wettability properties than OPT. *Shorea* sp. has the best wettability on PF resin (83.00°), while P. *falcataria* on UF resin (90.89°), this is due to the levels of starch and extractive substances in *Shorea* sp. and P. *falcataria* wood are smaller than OPT. Furthermore, *Shorea* sp. and P. *falcataria* wood surfaces are flatter and smoother than OPT, so that the resin will flow easier and wetting the wood surface. In this condition, the liquid resin will flow easier and formed a smaller contact angle. The good wettability of wood will enhance the adhesion properties of laminated beams.

1. Introduction

Oil palm trunk (OPT) has a potential as as a raw material substitute for wood. In the other hand, OPT has many weaknesses, such as variations in the density, high shrinkage-swelling, high moisture content and low strength. The efforts to improve OPT quality has been done by compressed using close system compression [1] and by impregnated of phenol formaldehyde [2]. Through compression and impregnation of phenol formaldehyde into OPT can improve the physical and mechanical properties.

The other effort to improved OPT quality was make a laminated board. One of the properties that need before make the laminated board was to determine wettability properties. The wettability is a surface condition that determines the extent the fluid will be drawn by the surface, affecting absorption, adsorption, penetration and spread of adhesive [3]. By knowing the wettability properties of the wood, we can surmise any kind of wood that is suitable for done a gluing process, or what type of treatment can be done to increase the wettability properties of the wood so that the quality of gluing wood become better.

Wettability of the wood can be measured by the two methods, namely the method of Cosine-Contact Angle (CCA) and Corrected Water-Absorption Height (CWAH). CCA method and CWAH method has advantages and disadvantages of each. The weakness of the CWAH among other is the measurement results do not reflect the quality of the wood surface that will be glued, because the wood crushed into particles, so it can't be distinguished piece of wood surface to be glued or not to be glued. The advantage of CCA method among other its wettability measurement result is the wettability value of the wood surface that will be glued so that relatively more accurate if used to estimate the gluing strength.

In this study, wood wettability measurement was conducted by CCA. The wettability of wood depends on its wood species [4]. One of the easiest ways to determine wettability of the wood is a method of contact angle. Contact angle is done by measuring the angle formed between the surface of the wood with adhesive liquid that dripped in the board surface [5].

Smaller contact angle, indicating that the wood more easily wetted by adhesive.

The wood used is oil palm trunks (OPT). The OPT is comprised of three types, namely outer part of OPT, the inner part of OPT and the inner part of the OPT that is compressed to 50%. Meanwhile, as the comparison are meranti merah (*Shorea Sp.*) and Sengon (*Paraserianthes Falcataria*). The OPT included the monocots, while *Shorea* and *P. Falcataria* wood included the hardwood.

This study aims to analyze the nature of wettability of the inner and the outer of OPT and OPT that compressed, and also the wettablity of meranti merah and Sengon wood. The type of wood is the raw material that will be used for the manufacture of laminated beams.

2. Materials and Method

Materials used are OPT, *Shorea* sp, *P. Falcataria*, phenol formaldehyde (PF) resin and urea formaldehyde (UF) resin. Oil palm trunks used consisted of three types of oil palm trunk, there are outer part of OPT, inner part of OPT and compressed by 50% of OPT. Tools to be used are a saw, tape measure, calipers, oven, hot press machine, scales, moisture meter, digital camera and tripod, pipette, computer and Iconico Screen Protactor Software Version 4.0.

The size of sample (OPT, Shorea sp. and *P. falcatarial)* were 30 cm x 4 cm x 2 cm, in length, width, and thickness, respectively. The inner part of OPT for compressed sample was 30 cm x 4 cm x 4 cm and after compressed by 50% became 30 cm x 4 cm x 2 cm, using a hot press machine at a temperature of 120 °C and a pressure of 25 kgf for 30 minutes. Furthermore OPT board, *Shorea* sp. and *P. falcataria* wood dried in an oven at a temperature of 60 ° C until the moisture content of air dried. Sample test for the measurement of the contact angle is three boards per type of wood, with three measurements on each board. Total sample test is 30 boards (5 types of wood x 2 types of adhesive x 3 replications = 30 sample test).

Board was measured the moisture content and density. Measurements of water content using moister meter. The water content is denoted in percent (%). Density measurements were made by weighing the weight of the board (M) and measuring the average length, width and thickness to calculate the volume of the board (V). Density is calculated using dividing board's weight with board's volume, and it is denoted in units of g/cm^3.

Board wettability properties were measured using the Cosine-Contact Angle (CCA). Determination of board wettability is done by measuring the contact angle between the adhesive liquid that dripped in the board surface [5]. The trick is to do preparation beforehand in the form of a camera mounted on a tripod and eye lenses arranged parallel to the surface of the wood that will be dripped adhesive. The distance between camera lens with the wood is about 20 cm. The camera comes with a micro lens to produce an image that is clear and sharp. Dripping a liquid adhesive is done by using pipette and it is dripping on the surface of the wood that is flat and smooth. High of dripping adhesive is about 2 cm above the surface of the wood with a droplet volume of about 0.01 ml. Photo shoot is done 5 seconds after dripping. The magnitude of the contact angle was measured by the angle formed between the curved lines of the adhesive liquid to wood horizontal surface. Contact angle measurements using software Iconico Screen Protactor Version 4.0.

3. Results and Discussion

The value of the contact angle (CA), moisture content (MC) and the density (ρ) of OPT, *Shorea sp.* and *P. falcataria* wood are presented in Table 1. The results of these measurements show that the

OPT board, *Shorea sp.* and *P. falcataria* has a water content of 12.27~19.70%. Density board of OPT, *Shorea sp.* and *P. falcataria* is 0.26~0.78 g/cm^3. While, the contact angle OPT board, *Shorea sp.* and *P. falcataria* amounted to 83.00~108.78°.

Table 1. The contact angle value, moisture content and density of oil palm trunk, *Shorea sp.* and *P. falcataria*

No.	The type of wood	PF Adhesives			UF Adhesive		
		CA (^{o})	MC (%)	ρ (g/cm^3)	CA (^{o})	MC (%)	ρ (g/cm^3)
1.	Outer part of OPT	105.44	17.90	0.39	98.11	17.13	0.38
2.	Inner part of OPT	108.78	19.00	0.26	93.67	19.70	0.27
3.	OPT that compacted 50%	98.89	12.27	0.38	107.33	13.83	0.38
4.	Meranti merah	83.00	14.57	0.78	93.56	14.10	0.78
5.	Sengon	90.11	16.20	0.46	90.89	15.67	0.49

Description: OPT = trunks of oil palm; PF = phenol formaldehyde; UF = urea formaldehyde; CA = contact angle; MC = moisture content; **ρ**= density

Wood moisture content is the content or the amount of water contained in the wood compared with the dry weight of the oven or the wood dry weight and expressed in percent. Wood is a hygroscopic material that has the ability to absorb and release water, either in the form of water or vapour. The greatest board water content is the board of the inner part of OPT is equal to 19.70%, while the water content of the smallest board is the OPT board that compressed 50% in the amount of 12.27%.

Wood moisture content was influenced by the wood itself and environmental factors. Wood moisture content is inversely proportional to its density. Smaller density of the wood, then the moisture content of the wood will be even greater, and vice versa. Board of the inner part of OPT that has a large water content, namely 19.70% is a board that has a small density is 0.27 g/cm^3. More decrease of wood density means that the wood is more porous and bulky or large volume. Low density wood is characterized by soft wood and large cell cavity. The magnitude of cell cavity can be a place to hold water in the wood. Water on the wood is contained in the wood cells. There are two types of water in the wood cells, the water in the cell walls of wood is called bound water, and water in the cell cavities is called free water. In the cell cavities are also saturated water vapour.

The contact angle was affected by wood moisture content [6]. All contact angles for all liquids increased with increasing wood moisture content. Accordingly that OPT have high moisture meter, especially the inner part and the outer part of OPT. The contact angle of inner part and outer part of OPT more higher from the other samples (Table 1).

Wood for contact angle measurements have been dried in an oven until the moisture content of air dried, the moisture content range of 15~20%. The water content of the dry air in wood occurs when an empty cell cavities and cell walls still contain some of the water. The OPT board that compacted 50% with a density of 0.38 g/cm^3 has the smallest water content, and it is equal to 12.27%. This is due to the OPT board has been experiencing a warming in hot press machine at a temperature of 120° C and a pressure of 25 kgf for 30 minutes. The warming has pulled out all the water from the cavity cells and some of the water from the cell walls of the wood. The compression process is able to improve the quality of the wood, lower water content and increase its density, such as compression of 50% on inner part of OPT being able to improve the physical and mechanical properties of OPT [7].

The highest density of the board is meranti merah board that is equal to 0.78 g/cm$^{3.}$ The density of the lowest board is the board of the inner part of OPT is 0.26 g/cm$^{3.}$ The results are consistent with other research. The density of meranti merah wood is 0.30-0.86 g/cm^3 with average 0. 52 g/cm^3 and density of sengon wood is 0.24-0.49 g/cm^3 with average 0.33 g/cm^3 [8]. In this type of OPT [9] suggested that a density value of OPT is 0.14~0.60 g/cm^3. In the oil palm trees aged 40 years, Hartono et al. [10] stated that OPT density is 0.23~0.74 g/cm^3. In this study of OPT was found that the density of the inner part of OPT lower than the density of the outer part of OPT. Then, all the physical and mechanical properties of the part near the bark decreases towards the central of trunk.

Compression of the inner part of OPT 50% able to improve OPT density of about 0.12 g/cm^3, so that the density of compressed OPT equivalent to the density of the outer part of OPT is 0.38 g/cm^3. OPT compression will be optimal if the known properties of the OPT, especially the radial distribution of its density value. The study of heat treatment [11] reported that heat treatment caused the wood more hydrophobic characteristics. Its mean that the contact angle values of the wood materials increased with the thermal modification. From data (Table 1) shown that contact angle of compressed OPT using FP resin was decreased if compare with the inner part and the outer part of OPT. The other hand, the contact angle of compressed OPT using UF was increased if compared with the inner part and the outer part of OPT.

The highest density of OPT is at the outer part near the bark, then decreased in the middle and the lowest in the central part of trunk. It is caused by distribution of vascular bundles, which is denser at the edges and tapers off towards the central [9], [10]. The other research [12] reported that horizontally the outer OPT density is higher than the inside. This is caused 1) on the outer is dominated by the vascular bundles (51%) which have a high density, while the inner part is dominated by the parenchyma tissue (70%) which having low density; and 2) the cell walls of parenchyma tissue of the outer is thicker than the inner.

Density of *Shorea* sp. include in the category of high density, due to its constituent cells has a thicker cell walls with a smaller cell cavity. Meranti merah has a robust class III~IV and suitable to use as a raw material of veneer, plywood, building materials, doors and windows, timber shipping, coffins, musical instruments, household furniture and crates wrapping [8].

Contact angle of OPT board, *Shorea* sp. and P. *falcataria* using phenol formaldehyde (PF) and urea formaldehyde (UF) resin is approximately 83.00~108.78°. The greatest contact angle is inner OPT by using PF resin, which amounted to 108.78°, whereas the smallest contact angle is *Shorea* sp. wood by using PF resin, which amounted to 83.00°. Contact angle of oil palm trunk, *Shorea* sp. and P. *falcataria* with PF and UF resin are presented in Figure 1.

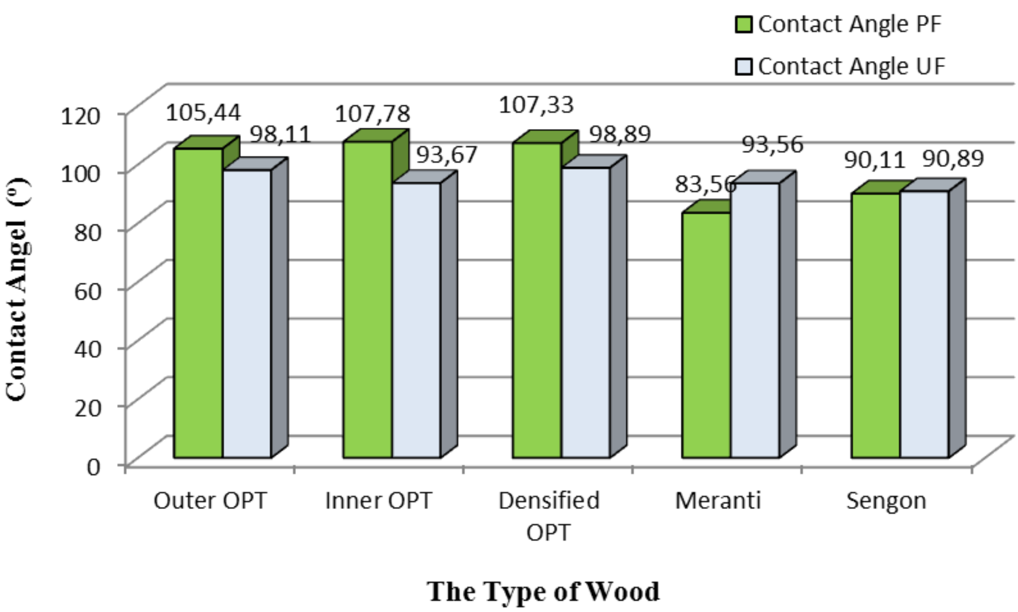

Figure 1. The contact angle of oil palm trunk, *Shorea* sp. and P. *falcataria*

The greater the contact angle formed between the wood and adhesive, then the lower the wettability properties of the wood. The results showed that *Shorea* sp. and P. *falcataria* wood have the most excellent wettability properties compared with OPT wettability. *Shorea* sp. and P. *falcataria* has the smallest contact angle or the best wettability properties than the wettability of oil palm trunk (OPT), both the outer part of OPT, the inner part of OPT, as well as OPT that compressed 50%. *Shorea* sp. wood has the best wettability for the adhesive properties of PF (the contact angle of 83.00^o), while P. *falcataria* wood has the best wettability properties for UF resin (contact angle of 90.89^o).

The results of wettablity several wood [13] showed that the wettability of P. *falcataria* wood higher than acacia and gmelina wood. The study also showed that the wettability of P. *falcataria* wood better than acacia wood, and acacia wood wettability is better than gmelina wood. This was caused by wood density and extractives deposit on the surface of the wood. The average density of acacia is 0.69 *(A. mangium)* and 0.61 *(A. auriculiformis)* and gmelina density is 0.42~0.61 [8]. In this study P. *falcataria* wood density is 0.46 ~ 0.49 (Table 1).

The study of contact angle [14] reported thath the contact angle dependant on wood species, resin type and on the location of the drop on the wood surface. Such as, the contact angle on sapwood is greater than that on heartwood for southern pine, but is smaller for Douglas-fir, and also for type resin, that contact angle difference between PF resin on southern pine and PMDI resin on Douglas-fir. From data (Fig 1), Contact angle of FP resin more higher than UF on inner part, outer part of OPT and compressed OPT. The otherwise, contact angle of UF is higher than PF on Sengon and Meranti wood.

The great of OPT contact angle or poor wettability properties allegedly caused by extractive substances that contained in it. In addition OPT has more rough wood surface and uneven than *Shorea* sp. and P. *falcataria*, so that the adhesive more difficult to flow and wetting the surface of the wood. In this condition, the liquid adhesive is more difficult to flow so that the contact angle was formed smaller. Good wettability properties of wood that will enhance the adhesion properties of the laminates beam to be made. The weakness of OPT are its starch contents, extractive and fatty acids are high, as well as hygroscopic properties is higher than wood [15]. Solubility of extractive substances of OPT in alcohol-benzene, cold water, hot water and NaOH 1% were 8.9%, 12.02%, 16.37% and 24.87%, respectively [16]. Then, solubility of extractive substances of P. *falcataria* wood in alcohol-benzene, cold water, hot water and NaOH 1% were 3.4%, 3.4%, 4.3% and 19.6% [17] and solubility of extractive substances of *Shorea* sp. wood in alcohol-benzene, cold water and hot water were 4.84%, 4.98% and 7.16%, respectively [18]

Solubility data of extractive substances on OPT, *Shorea* sp. and P. *falcataria* showed that the content of extractive substances in OPT is the greatest. The extractive agent has an enormous influence in decreasing hygroscopic, permeability and also increasing wood durability. Although its few in number, extractive influential in gluing of wood, which affect pH, contamination, and penetration [19]

The extractive substances occupy a place in the cell wall that it is usually occupied by water. Decreasing levels of extractive substances can raise the value of wettability due to the reduction of substances that block the absorption of fluid by the cell wall [20]. Also, the extractive substances composed of various substances differ in structure and chemical composition such as gum, fats, resins, sugar, oil, starch, and tannins the components are dissolved in cold water are tannin, gum, carbohydrate and pigment. Components that dissolved in hot water are the same as that dissolved in cold water plus starch component [21]

The presence of large extractive substances could interfere in the gluing process, especially from non-carbohydrate group (oils, fats, resins, salt, and etc) [22]. Therefore, if extractive substances that used quite a lot, wood should be treated to eliminate extractive substances by submersion, boiling or evaporation so that the wood was glued with satisfactory results.

Figure contact angle of outer part of OPT, inner part of OPT, OPT that compressed 50%, *Shorea* sp. and P. *falcataria* using PF and UF resin are presented in Figure 2 and Figure 3.

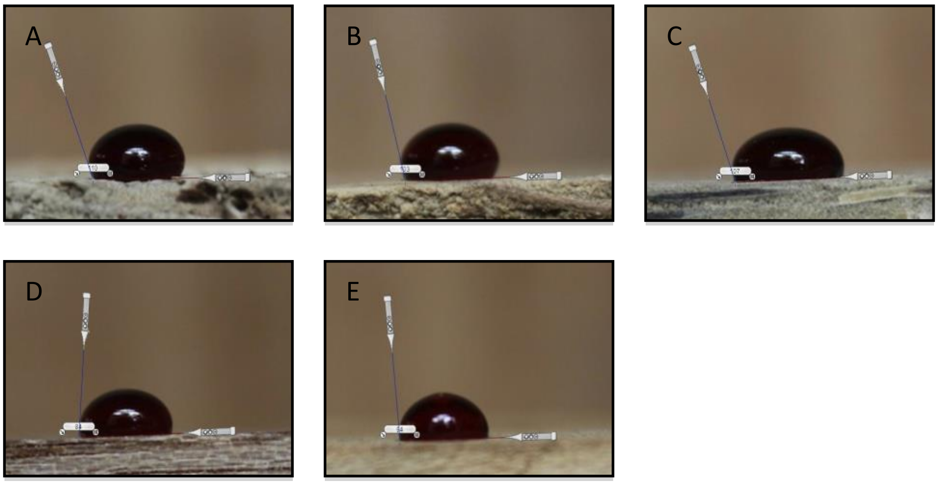

Figure 2. The contact angle of inner part of OPT (A), outer part of OPT (B), OPT that compressed 50% (C), *Shorea* sp. (D) and P. *falcataria* (E) using PF resin

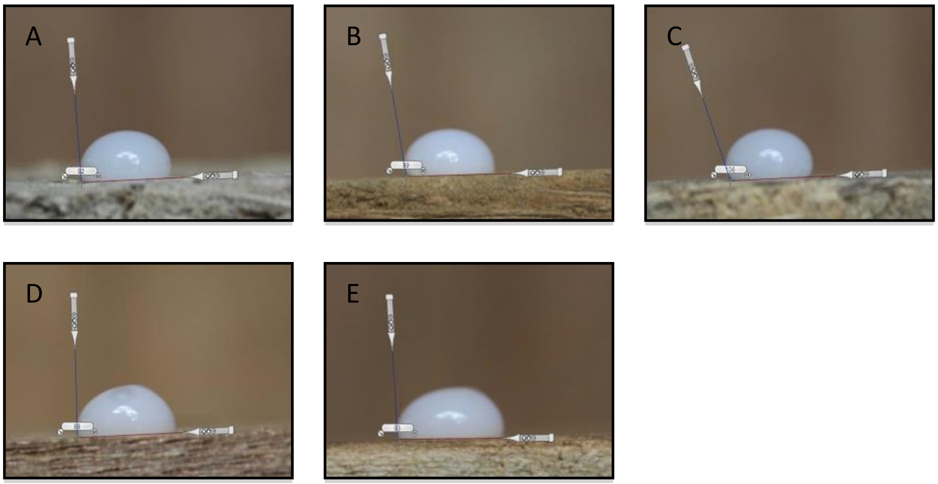

Figure 3. The contact angle of inner part of OPT (A), outer part of OPT (B), OPT that compressed 50% (C), *Shorea* sp. (D) and P. *falcataria* (E) using UF resin

The wettability is affected by the submersion treatment, either cold water or hot water submersion [23]. Wettability properties of wood that measured by the method of Corrected Water-Absorption Height (CWAH) rising after the levels of extractive substances reduced. Extractive substances out of the wood due to submersion treatments with cold water, hot water and steaming process. Reduced extractive substances cause a rise in the value of the absorption of water, which means also raise the value of wettability.

Then, wood extractives have correlation with the wettability of wood surfaces to be bonded by adhesives [24, 25]. Wettability is the ability of a material to absorb liquid (liquid system). Wettability properties can be used as an indication of the nature of its gluing. This is in line with the other research [26] that the wettability of wood by better adhesive will produce a stronger adhesiveness. This is shown with greater percentage of damage to the wood (not on the adhesion lines) and more resistant to delamination. At the time of adhesion process, the bond between the adhesive with adhered surface allows occurs because the first adhesive liquid wetting the surface.

Good wetting occurs when the contact angle (θ) between the adhesive and substrate is lower than 90°. Perfect wetting occurs when the molecular bond between liquids and solids (adherend) is greater than the molecular bonds in the liquid. Success or failure of a liquid wetting solid depends on the surface tension of both sustain, for example polymers and substrates. Increased surface energy which affected by water level, occurs due to the development of wooden structure that releases polar hydroxyl group will develop a liquid and the adhesive polymer. Liquid adhesive may cause the development of wood substantially. Thus, some of the wood adhesive has the capacity to convert wood surface with low energy become much higher. Sapwood transition process into heartwood will reduce surface energy, due to the non-polar extractives. Liquid adhesive with low pH such as UF has difficulty wetting and adhere to the surface. While the alkaline liquid adhesive (pH>8) as PF for plywood adhesive, can solve the extractive non-polar, and increase the surface energy which is sufficient to forming a good bond [27].

Wettability is affected by various factors, which are associated with an adhesive (surface tension, temperature, viscosity) and wood (density, porosity, extractive). Wood with low density (high porosity) has better wettability properties, while extractive in excessive amounts, like non-polar extractive such as terpene and fatty acids, having a bad influence. Wettability is also influenced by the cleanliness of the wood surface and the conditions of machining. For example, a blunt knife can cause the wood surface becomes overheating or compaction occurred (hardened surface). Veneer drying at high temperatures, above 160^o C resulted in a decreased wettability [21].

The correlation between the glue ability index (adhesion strength) and wettability strengthen the theory of specific adhesion [28]. It is possible to predict the values of relative adhesion strength of a type of wood that is not recognized by measuring its wettability simply.

Based on these studies, it is possible to make laminated beams by using raw materials of OPT, *Shorea* sp. and P. *falcataria* wood. Laminated beams made of OPT with a combination of *Shorea* sp. and P. *falcataria* wood. On the one hand, it can utilize waste of oil palm plantations and on the other hand laminated beams that produced higher quality with better adhesive properties. To improve the gluing properties that will impact on the quality of laminated beams, it is necessary to pre-treatment in the form of submersion in hot water or in cold water. Most of extractive substances that can be disrupt the bonding process between adhesive and wood will be dissolved through the pre-treatment, so that the nature of its adhersion and the quality of the resulting laminated beams will increase.

4. Conclusion

Shorea sp. and P. *falcataria* wood have the smallest contact angle or the best wettability properties than the wettability of oil palm trunk (OPT), both outer part of OP, inner part of OPT, as well as OPT that is compressed 50%. *Shorea* sp. wood has the best wettability properties to phenol formaldehyde resin (contact angle of 83.00^o), while P. *falcataria* wood has the best wettability properties for urea formaldehyde resin (contact angle of 90.89^o).

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