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Potential of Local Fast-growing Wood for Alternative Hull Materials: Epoxy Bond Strength Test and its Durability

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ABSTRACT

It has been claimed that wood species suitable for wooden boat is decreasing fast. Boat maker has been hardly looking for wood species for traditional wooden boat. In order to find potential wood species for wooden boat production, this research was conducted. The objectives of the research was to obtain the epoxy wood bonding behavior of several wood species. Eight wood species were procured form Pekanbaru, Riau. They were glued by epoxy with three glued spread. The bonding durability was tested by cyclic boiling test. It was concluded that dry epoxy bonding strength of behaved differently than wet epoxy bonding strength. The dry epoxy bond strength is influenced by wood species factor and glue spread. Jabon show the highest dry strength of 436 kg/cm^2, while the lowest is shown by trembesi species. Low glue spread of 30#/MSGL produced highest bond strength. The glue spread showed negative correlation to bond strength. Wet strength is affected by interaction of wood species and glue spread factor. The highest wet strength (44kg/cm^2) is shown by mahang species combined with 50 pound/MSGL glue spread.

Key words : *Fast-growing wood, Epoxy, Bond strength, Ship hull*

Introduction

Traditional wooden boat maker has been facing difficulties of wood species suitable for boat production nowadays. The supply of locally wood species for wooden boat such as dark red meranti, laban, teak, mahang has been decreasing fast. This low supply of wood species suitable for wooden boat has caused higher boat production cost. Consequently, several traditional wooden boat makers have stopped their boat production. They have been asking for help to find the wood species substitution suitable for wooden boat to wood research institution. In 1976, the Indonesian government had issued a standard of wood species suitable for wooden boat (Anonym, 2006), however those species have become scarcity due to low supply.

Many local types of wood are found in community gardens, planted or grown wild, this type of wood is not used as a component of wooden boats because the community believes it is of low quality and is not resistant to attacks by marine life. Wood

as one of the ship's raw materials will be affected by changes in weather, especially on the ship's hull. Resin coating can increase the strength and durability of wood (Fakhri, *et al.,* 2020). Therefore, it is necessary to conduct further research on the bond strength of resin with wood as an alternative material for ship components.

Basically, the wood is easy to bond, however, there is only a small amount of adhesive that creates a bond that can withstand exterior conditions. In wood, generally the most severe conditions involve wet stress or a water immersion cycle followed by rapid drying due to the wood shrinking process, whereas most adhesives do not change in volume significantly. Thus, there is a large stress-strain gradient in the wood / adhesive interface (Frihart, 2003).

Study about the effects of adhesives (PVAc, Desmodur-VTKA and phenol formaldehyde) on Uludag fir (*Abies bornmüllerina* M.) and Oriental beech (*Fagus orientalis* Lipsky) cut tangentially and exposed to heating tests (40, 60, and 80 °C) and heating duration (30, 60 and 90 days) and controls. Obtained that when compared to control samples, the highest decrease of 26.2% in average with Oriental beech and 18.5% in average with Uludag fir was obtained with the samples bonded with D-VTKA adhesive kept for 90 days (Uysal *et al.,* 2010b).

The positive relationships of glue-bond quality and adhesive penetration into the wood structure. The positive relationships glue-bond quality and wettability of the wood structure. Chain link analogy for adhesion and cohesion has a strong influence on optimum conditions for good bonding (Ülker, 2016).

Many studies on the bond strength of epoxy resin to wood have been carried out, among others (Frihart, 2003a; Yalçin, *et al.,* 2004; Ahmad, *et al.,* 2011; Jin *et al.,* 2015; Raftery, 2009). Some local wood species that are coated with epoxy resin are eligible for hull component materials. Resin coating can improve the physical, mechanical properties, and resistance of wood to attack by marine life and the influence of external weather (Fakhri *et al.,* 2020).

Epoxies are normally durable adhesives, except in the case of wood bonding. The cause for this weakness has not been previously investigated but has been attributed to poor interfacial adhesion. Specimens from the cyclic water soak, heat-drying method were cut open to look at the delaminated surfaces (Frihart, 2005).

The shear and compression strength of epoxy formulations are greater than those of timber, and therefore this material can be used for connexion with other materials and to substitute deteriorated timber under compression. The increase in the shear strength of epoxy formulations over time after setting is remarkable. The strength at 1 and 7 days is at least 50 and 80 %, respectively of the strength at 21 days, which is favourable for practical applications. The influence of contact surface roughness (planed or unplaned) exists but have not been statistically confirmed. The results are slightly better for rough surfaces, and timber planed surfaces do not give rise to an advantage. Regarding the bonding shear strength between composite material and the epoxy formulation, surface treatment of simple cleaning with solvent is enough, and it is not necessary to sand (Arriaga *et al.,* 2011).

Materials and Methods

The 8 (eight) wood samples were procured in Pekanbaru Riau Sumatra, Indonesia, namely: Akasia (*Acacia mangium),* Trembesi *(Samanea saman* Merr.), Ekaliptus *(Eucalyptus*_spp.*),* Mahang *(Macaranga gigantea* Mull. Arg*),* Jabon *(Antthocephalus cadamba)*, Geronggang *(Cratoxylon arborencens),* Laban *(Vitex pinnata)*, and Meranti batu *(Shorea leprosula* Miq). Wood samples were air dried and cut into 5 cm × 2.5 cm × 80 cm. Adhesion block test followed the British standard. Two component of epoxy resin was used in adhesion test. Three glue spread of 30, 40 and 50 pound per MSGL were employed. Three replication was used for each treatment. The curing was conducted by cold press in laboratory room for 24 hours. The adhesion strength was tested by compression shear forces along the glue line. The durability of epoxy bonding was tested following cyclic boiling test, twenty-four test samples of adhesion blocks were boiled for 4 hours followed by drying in an oven at a temperature of 60 ± 3 °C for 20 hours and followed by boiling for 4 hours and soaking in cold water for 30 minutes and then subjected to compression shear strength test while wet.

Results and Discussion

The research result of adhesion strength of epoxy wood bonding and its durability by cyclic boiling test were shown on Table 1. The ANOVA of adhe-

sion strength on dry and wet condition were presented in Table 2.

It was shown in Table 2 that interaction between wood species and glue spread factors did not influence the dry strength. The single factor of wood species and glue spread affected significantly on epoxy wood bond strength. It was observed that the highest dry bond strength was shown by jabon followed by eucalypt, laban, dark red meranti, acacia, mahang, geronggang and trembesi. The glue spread factor show negative correlation to bond strength. It meant that higher glue spread lower bond strength of epoxy bonded wood. It seems that epoxy resin adhesive requires very thin glueline to produce high strength (Fig. 1).

On the other hand, the wet strength was influenced significantly by interaction of two factors involved in the research. This finding is different to dry strength that is affected only by single factor of wood species and glue spread. Wet epoxy bond strength was obtained by cyclic boiling procedure, meaning the adhesion block test was boiled for 4 hours followed by drying in an oven at 60 ± 3°C for 20 hours and followed again by 4 hours boiling and soaked in cold water for 30 minutes and then subjected to compression shear strength test while wet. This condition accelerates the glue line degradation to exterior condition and showing the glue line durability. The highest wet epoxy bond strength ($44 kg/cm^2$) was shown by mahang species combined with 50 pound /MSGL glue spread (Fig. 2).

In dry epoxy bond strength, the jabon species

Table 1. Epoxy bonding dry and wet strength of several wood species

Wood Species	Bonding Strength ($kgcm^{-2}$)	Glue Spread (pound/MSGL)		
		30	40	50
Jabon (*Antocephalus* sp)	Average Dry	436.32	169.76	135.86
	Average Wet	4.19	5.69	2.80
	Drop Ratio	0.99	0.97	0.98
Trembesi (*Samanea* sp)	Average Dry	170.66	69.88	69.94
	Average Wet	11.65	5.49	6.40
	Drop Ratio	0.93	0.92	0.91
Akasia (*Acacia* sp)	Average Dry	271.01	150.92	86.04
	Average Wet	7.35	5.49	3.59
	Drop Ratio	0.97	0.95	0.95
Eukaliptus (*Eucalypt* sp)	Average Dry	389.39	241.46	135.96
	Average Wet	7.43	2.73	3.06
	Drop Ratio	0.98	0.99	0.98
Geronggang (*Cratoxylon* sp)	Average Dry	176.55	130.11	97.76
	Average Wet	11.55	24.60	19.33
	Drop Ratio	0.93	0.78	0.81
Mahang (*Mahogany* sp)	Average Dry	250.80	90.51	89.81
	Average Wet	20.66	34.85	44.40
	Drop Ratio	0.91	0.61	0.51
Dark Red Meranti (*Shorea* sp)	Average Dry	293.58	118.16	101.51
	Average Wet	27.32	19.61	24.32
	Drop Ratio	0.89	0.83	0.76
(Laban) *Vitex* sp	Average Dry	328.33	128.40	122.61
	Average Wet	33.12	11.85	9.09
	Drop Ratio	0.89	0.91	0.92

Table 2. Analysis of epoxy bonding dry and wet strength

SV	DF	Dry Strength Prob	Wet Strength Prob	Shear Strength Drop
Wood Species (WS)	7	.000	.000	.000
Glus Spread (GS)	2	.000	.761	.000
WS x GS	14	.371	.007	.014

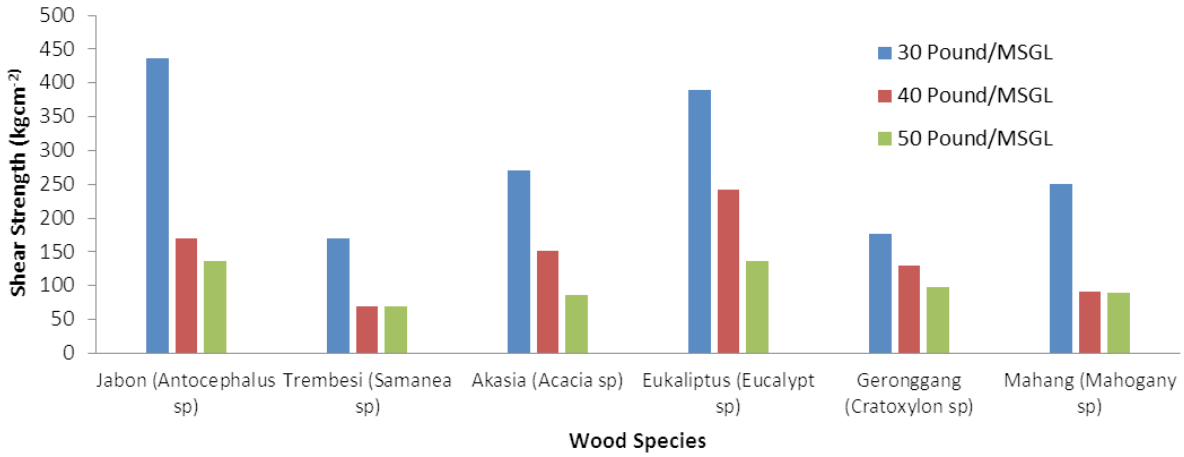

Fig. 1. Dry epoxy bond strength of several wood species

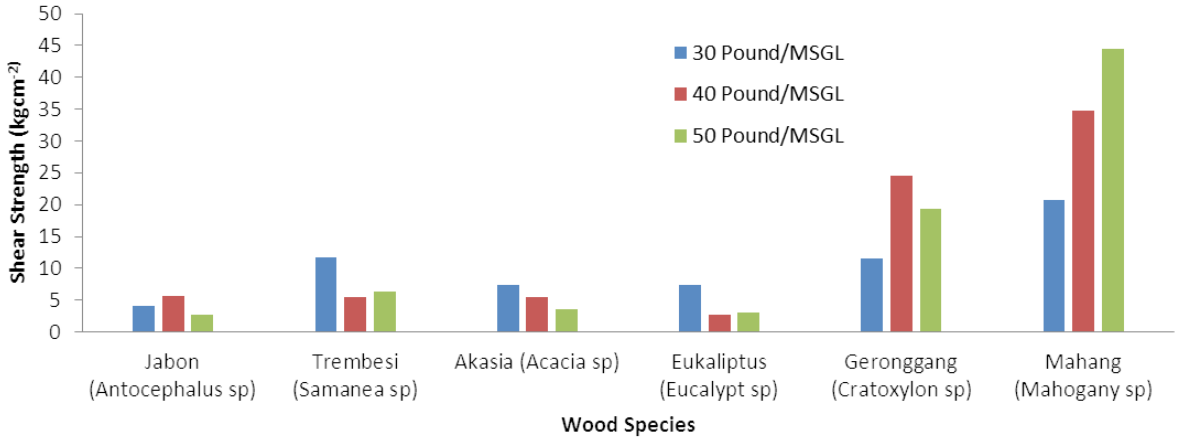

Fig. 2. Wet epoxy bond strength of several wood species

shows the highest values, while glue spread of 30 pound/MSGL produces the higher dry strength compare to 40 and 50 pound/MSGL. In wet epoxy bond strength which influenced by interaction of wood species and glue spread, the highest value is shown by mahang and 50 pound/MSGL. This results emphasize that heat treatment (boiling at 100 °C) has affected wood species strength and epoxy glue line as well. The durability of epoxy glue line against accelerated exterior condition has been shown the epoxy bond strength drop from dry to wet condition. Analysis of varians shows that this shear strength drop influenced by all single factors but interaction factors. The highest strength drop was shown by jabon followed by eucalypt, acacia, geronggang, trembesi, mahang, dark red meranti and laban for 30 pound /MSGL glue spread. On the other hand the glue spread factor influenced the shear strength drop almost the same as in the dry shear strength. The glue spread showed a negative correlation to shear strength drop (Fig. 3).

Conclusion

The emphasis on wood bond strength has been on interface interaction between the wood and the adhesive, with some discussion on the chemical weak boundary layer of the wood due to extractives. Alternative failure mechanisms, other than interfacial and cohesive failure in the bulk wood and adhesive, need to be considered. These alternative failure modes include mechanical failure of the adhesive and wood interphase regions. Epoxies are normally durable adhesives, except in the case of wood bonding. The cause for this weakness has not been previously investigated but has been attributed to poor

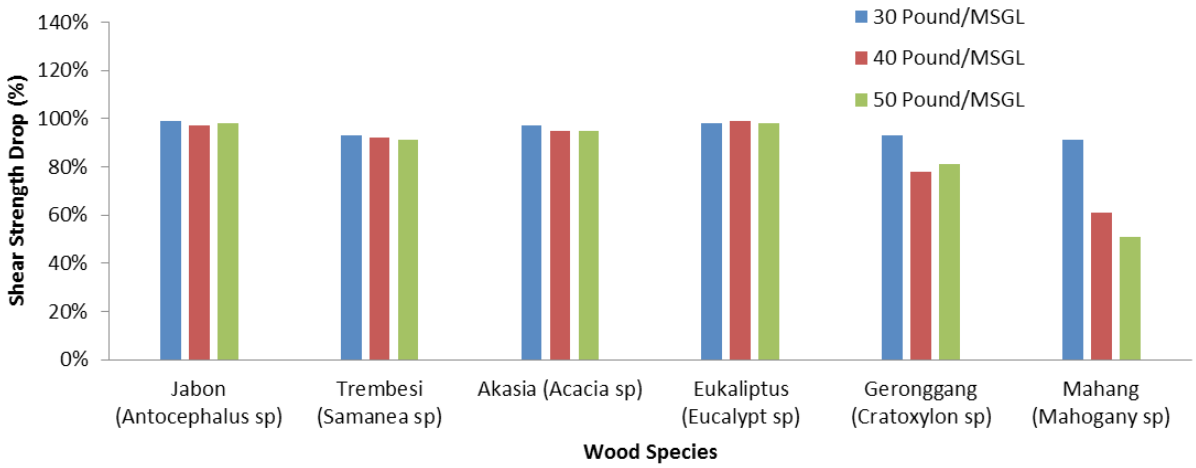

Fig. 3. Shear strength drop of several epoxy bonded wood

interfacial adhesion. Specimens from the cyclic water soak, heat-drying method were cut open to look at the delaminated surfaces (Frihart, 2003a). The adhesion of the glue depends on the wood-adhesive bonding chain. Adhesive bonding performance between wood elements is presumed to be significantly influenced by the degree of penetration of the adhesive into the porous network of interconnected cells (Ülker, 2016).

It was concluded that dry epoxy bonding strength of behaved differently than wet epoxy bonding strength. The dry epoxy bond strength is influenced by wood species factor and glue spread. Jabon shown the highest dry strength of 436 kg/cm^2, while the lowest is shown by trembesi species. Low glue spread of 30#/MSGL produced highest bond strength. The glue spread showed negatively correlation to bond strength. Wet strength is affected by interaction of wood species and glue spread factor. The highest wet strength (44kg/cm^2) is shown by mahang species combined with 50 pound/MSGL glue spread.

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