Colourability of Wood and Its Effect on Bonding Strength of Laminated Wood for Handicraft Material

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Abstract. The wood has a high decorative value that can be turned into handicraft products. To optimize the use of small dimensions wood, handicraft products can be made into laminated wood. An attempt to improve the aesthetic value of wood is by adding dyes into the wood. This study aimed to analyse the ability of *Gmelina arborea* (hardwood) and *Pinus merkusii* (softwood) to absorb dyes and the effect of dyeing on bonding strength of laminated wood. Wood planks members (lamellae) that form laminated wood were soaked into direct dyes liquid with soaking time of 0 hours, 1 hour, 6 hours, 12 hours and 24 hours. The results showed retention and penetration dyes of *Pinus merkusii* ranged between 0.00013 g/cm³-0.0003 g/cm³ and 2.98%-8.22%, while retention and penetration of *Gmelina arborea* ranged between 0.00004 g/cm³-0.00018 g/cm³ and 1.59%-4.77%. Retention and penetration tend to increase at dyeing time up to 12 hours. Bonding strength of *Pinus merkusii* ranged between 26.61 kg/cm²-90.05 kg/cm² while bonding strength of *Gmelina arborea* ranged between 66.97 kg/cm²-96.12 kg/cm². Based on the result of statistical analysis, type of wood, and the coloration have a real effect on bonding strength of laminated wood. Based on the consideration of resource, efficiency and the results of statistical analysis, 6 hours of dyeing is more efficient in planning of laminated wood material for handicraft products.

1. Introduction
Wood as a lignocellulose material can be turned into various purposes, such as raw material of building construction, pulp and paper, composite panel, furniture, handicraft, etc. Handicraft products that utilized small dimension wood are limited to making large size product. Laminated wood is one of developing wood technology in this era because it could utilized small dimension wood that glued together thus becoming large dimension wood. Laminated wood are more efficient because they can be made by combining low-quality wood and high-quality wood [1].

One of the selling points of handicraft product is on its aesthetic value. Wood has a high decorative value that formed from colour, fibre, and pattern on wood [2]. In addition to increase the aesthetic value of wood is by adding dyes into wood to make a different colour of wood natural colour. The effectiveness dyeing will be affected by wood anatomy structure. On the wood, dyes deposited into cavity and micro pore on wood fibre network and suspected can formed hydrogen bonds with hydroxyl group in chemistry component of wood wall cell [3].

Based of this research is to learn the possibility coloration of hardwood and softwood that significantly different in its anatomy. The anatomical structure of wood affected to the ability of a solution penetrate into the wood [4],[5]. Wood that used in this research is *Gmelina arborea* from hardwood group and *Pinus merkusii* from softwood group. Because the wood that has coloured will be
processing in different shape, there is a possibility that bonding strength would be affected by dyeing process. Based on that consideration, research about dyeing effect of lamellae on laminated wood bonding strength is deemed necessary.

This research aimed to analyse dyes retention ratio on hardwood and softwood, and analyse the effect of dyeing on bonding strength of laminated wood. The results of this research are expected to be a reference material for laminated wood products innovation. In addition, the results of this research are expected to improve the quality of laminated wood handicrafts products.

2. Materials and Methods
Gmelina (Gmelina arborea), pine (Pinus merkusii), polyvinil acetat (PVAc), epoxy, aquades, and direct dye (Dylon). The tools that used is table saw, pressing machine, digital scales (0.01 g), oven, stereo microscope, water bath, and universal testing machine.

2.1 The preparation of material
Gmelina and Pine wood was cut and cleaved into 2 × 5 × 20 cm sized. Sized and quality is cultivated same and visually defect free. After that, every field of wood is sanded and dried into oven with 60˚C until its water content less than 16%.

2.2 Coloring the lamellae
Axial orientation side of each lamellae are covered with epoxy adhesive to avoid the penetration from longitudinal side. After the epoxy adhesive dried, each lamellae of gmelina and pine are soaked into dyes liquid with concentration of 0.1%. Soaking is done with different time, it is during 0 hours (as control), 1 hour, 6 hours, 12 hours, and 24 hours on water bath with temperature of 100˚C. After soaked, each lamellae are dried during 72 hours for each different time of soaked and dried into oven in temperature of 60˚C until the water content less than 16%.

2.3 Laminated wood making
Surface of lamellae that already coloured are spread with PVAc adhesive in two sides of bond sides (double glue spread) with 400 g/m² of glue spread and then assembled. Each laminated wood is formed by two lamellae with same species. After that, laminated wood is pressing during 8 hours under the pressure of 10 kg/cm².

3. Results and Discussions
3.1. Retention and penetration of dye
Retention and penetration of dye on gmelina and pine have different results. Retention and penetration of dye on pine is higher than gmelina, as seen in Figure 1 and Figure 2. This occurs because Pine is more homogeneous in its anatomical structure and has an intercellular canals that allows dye solutions to penetrate into several cell types. But overall retention and penetration in both wood types in this study are very small. This is presumably because the molecular weight of the dye that used is bigger than the pit on the wood and make the dye cannot penetrate into wood. In gmelina, dye is only on the surface of the wood because gmelina does not have an intercellular canals and the pit are very small. The results of Barly and Neo's research of the retention of preservatives in wood showed an increase in solution concentration and the addition of soaking time tends to increase retention with significant differences in the same wood species [6].

In order for dyeing process to take place the molecules of dye should penetrate into the polymer structure. For this (i) the concentration of the dye on fibre surface must be higher than inside the fiber; (ii) the polymer structure should have spaces large enough for the dye molecules to move into fibre interior or, alternatively, the dye molecules should be sufficiently small for this to happened and (iii) molecular chains of fibre polymer should have sufficient freedom of movement in order to facilitate the movement of dye molecules [7]. Low retention and penetration indicate that the second prerequisite is not achieved. The dye polymer is large enough to penetrate the cell wall and move to the next cell wall which is located deeper. Based on GCMS test results of the dye that used, the highest components of
dye is $C_{17}H_{34}O_2$ (Hexadecanoic Acid, Methyl Ester) and $C_{19}H_{36}O_2$ (Octadecanoic Acid, Methyl Ester) with molecular weight 270 g/mol and 296 g/mol, these compounds are fatty acid group. This fatty acid is also thought to slow the penetration of dye into wood.

![Figure 1](image1.png)

**Figure 1.** The average of dye retention on *Pinus merkusii* and *Gmelina arborea* lamellae

![Figure 2](image2.png)

**Figure 2.** The average of dye penetration on *Pinus merkusii* and *Gmelina arborea* lamellae
The data in Figure 3 and Figure 4 show a tendency to increase retention and penetration with increasing soaked time. However the rate of increasing and variability are different. Pine shows the retention and penetration increased from 0 hours to 12 hours of soaked time, then decreased in 24 hours. It could be due to the lamellae at 24 hours of soaked was dominated by heartwood and the radial orientation wood. While the retention of gmelina at 6 hours of soaked is drastic increased. It could be due to the lamellae at 6 hours of soaked was dominated by sapwood and the penetration shows an increase from 0 hours to 24 hours. The wood orientation side (axial, transverse, and longitudinal) of lamellae are vary and the ability to absorb a solutions is also different, because each of these orientation side has a different anatomical structure.

The presence of sapwood and heartwood on the wood also affected to retention and penetration of preservative solution. Heartwood is more difficult to preserve than sapwood, because of its anatomical, physical, and chemical changes that occur during the change of sapwood into heartwood. This change is followed by the death of the sapwood parenchyma cell and the accumulation of resins, tannins and others which provide a permanent colour on the heartwood. This situation make vessel cavity and resin vessel being covered, thus inhibiting the movement of preservatives on wood [8]. Because the concept of the colouring wood is same as preservation of wood, this process is assumed to be same. The differential penetration of a stained solution (for example, 0.5 per cent alcoholic safranin) into the end grain of dried timber allows reasonable detection, the stain being absorbed more readily by the sapwood than the heartwood [9].

To analyse more deeply about how significant the difference of retention and penetration between gmelina and pine, and soaked time, then the variance analysis is carried out. Based on variance analysis results, the retention and penetration of dye is significantly different between wood species. This is because each species of wood has various anatomical structures and physical properties. This is because each species of wood has various anatomical structures and physical properties. The anatomical structure of wood that affects retention and penetration is the tracheid, pores (vessels), cells of wood fingers, resin ducts, and wood parenchyma [8]. Based on statistical analyse, 6 hours of soaked time is the best soaked time because the laminated wood would be turned into handicraft product and another further processes (shaved, sanded, etc.), it is expected that the dye penetrates deep into the wood so the colour of dye on wood still could be found.

3.2 Bonding strength and damage percentage of laminated wood

The results of average bonding strength test showed the difference on each soaked time and species wood. As seen in Figure 3, bonding strength of gmelina is more higher than pine for each soaked time. It is because in dyeing process using high temperature and make the resin on pinewood is running out and covered lamellae surface and prevent interlocking process between adhesive and wood surface. There are generally three steps in the process of adhesive bonding, the first is usually preparation of the surface to provide the best interaction of the adhesive with the substrate, the second step is that the adhesive needs to form a molecular-level contact with the substrate surface and the third step is the setting, which involves the solidification and/or curing of the adhesive [10]. In this case, the second step does not occur perfectly.
Figure 3. The average of bonding strength of *Pinus merkusii* and *Gmelina arborea*

The results of variance analyse showed that soaked time have significant effect on bonding strength of laminated wood. In *gmelina*, soaking time from 0 hours until 12 hours showed a decrease on bonding strength and at 24 hours of soaking time the bonding strength is increased. While in pine, soaking time from 0 hours until 6 hours showed a decrease on bonding strength and from 12 hours until 24 hours the bonding strength are increased. It is expected caused by dissolution of extractive substances on pine wood after 6 hours of soaked time. Extractive substances is one of the factors that affected on bonding strength, according to research result from Malik and Adi boiling treatment in 35% ethanol solution to extracting extractive substances on Keruing wood could increase the bonding strength of laminated so the results meet the standard requirements for use as indoor components [11]. When wood is treated with inorganic salts, such as boric acid, diammonium phosphate, ammonium sulfate, these chemicals alter the pyrolysis of wood, increasing the amount of char and reducing the amount of volatile, combustible materials. Acidic fi re-retardants can catalyze dehydration of glucose units and depolymerization of cellulose [12]. Pressure treatment with wood preservatives has been known to interfere with the bond integrity of solid wood glued specimens.

The effect of soaking time on bonding strength in this case is more affected by dissolution of extractive substances of wood. Preservative type, preservative retention, and interaction with the surface were reported as highly significant factors affecting shear strength of glue bonds in solid wood samples [13]. Because the method of the colouring method that used is same as preservation method, this system is assumed to be the same. Extractive substance on soaking time of *gmelina* under 12 hours and pine under 6 hours is expected not reached the wood surface and at the same time the pore is filled with dye thus making the interlocking between adhesive and wood surface. Extractives affected in chemical adhesion by acidity and physics by the condition of the wood surface [14]. Based on JAS 234: 2003 [15], the requirement for bonding strength of laminated wood is at least 54 kg/cm², pine with soaked time of 6 and 12 hours does not meet the standard.
Figure 4. The average of wood damage percentage of *Pinus merkusii* and *Gmelina arborea*

The percentage of wood damage in bonding strength test (Figure 4) showed that gmelina has a higher percentage of wood damage than pine in soaking time from 1 hour until 24 hours. While in 0 hour of soaking time (control) gmelina has a lower percentage of wood damage compared to wood. It is because of the resin that covered pine surface prevent the interlocking process between the adhesive and wood surface. The quality of the bonding is stated if the damage mostly occur in wood [16].

4. Conclusion

Retention and penetration of dye on pine (softwood) is higher than gmelina (hardwood) for each soaking time. Soaking time of lamellae is affected on bonding strength of laminated wood. Based on the results of statistical analysis and resource efficiency, soaking time for 6 hours is more efficient for material planning of laminated wood as handicraft products.

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