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COMPARATIVE STUDY OF ADHESIVE STRENGTH IN MAHOGANY WOOD LAMINATED COMPOSITES

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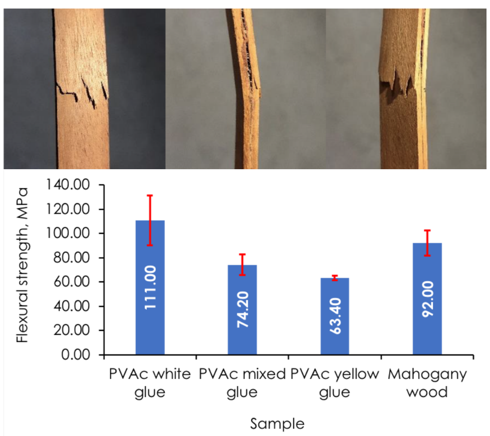
Graphical abstract



Abstract

Adhesive technology has seen significant advancements in recent years. Compared to welding or threaded joints, adhesives provide a straightforward mechanism for joining material interfaces. Due to practicality allows for the potential development of adhesives with strengths comparable to those of traditional joints. In this study, a modified type of Polyvinyl Acetate (PVAc) adhesive was utilized as a binder for mahogany wood surfaces. The choice of PVAc adhesive is due to its common use in everyday applications, particularly in the woodworking industry. Additionally, this adhesive is relatively safe for both health and the environment. The study examined three types of adhesives: PVAc white adhesive, PVAc yellow adhesive, and a combination of the PVAc white and yellow adhesive. These adhesives were used to bond the wood surfaces, and the bond strength at the interface was evaluated through a flexural test. The results showed that the adhesive strength of white adhesive reached 111 MPa, while the mixed adhesive and yellow adhesive exhibited flexural strengths of 74.2 MPa and 63.4 MPa, respectively. Notably, the presence of white glue was found to enhance the flexural strength of mahogany wood even in the absence of adhesive.

Keywords: PVAc adhesive; flexural strength; wood interface

Abstrak

Teknologi perekatan mengalami perkembangan yang menarik akhir-akhir ini. Perekat memiliki mekanisme yang simpel dalam menyatukan antarmuka material jika dibandingkan dengan sambungan las maupun ulir. Karena kepraktisannya, maka perekat memiliki potensi untuk dikembangkan hingga memiliki kekuatan yang mendekati dengan tipe sambungan yang lainnya. Dalam studi ini digunakan modifikasi jenis lem PVAc (Polyvinyl Acetate) sebagai pengikat antarmuka permukaan kayu mahoni. Pemilihan lem PVAc ini didasari oleh keluasannya perekat ini digunakan dalam industri kayu. Lem ini juga relatif tidak membahayakan bagi lingkungan dan kesehatan. Tipe perekat yang digunakan adalah lem putih PVAc, lem kuning PVAc dan kombinasi antara keduanya. Jenis lem ini digunakan untuk merekatkan permukaan kayu kemudian diuji kekuatan ikatan antarmukanya melalui uji lentur. Dari studi ini diketahui bahwa kekuatan perekat yang menggunakan lem putih memiliki kekuatan lentur sebesar 111 MPa, kemudian diikuti lem campuran dan lem kuning dengan kekuatan lentur 74.2 MPa dan 63.4 MPa. Temuan menariknya adalah keberadaan lem putih dapat meningkatkan kekuatan lentur kayu mahoni yang tanpa perekat.

Kata kunci: perekat PVAc; kekuatan lentur; antarmuka permukaan kayu

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1.0 INTRODUCTION

Adhesives play a crucial role in the wood industry, as they must ensure structural stability [1]. They need to maintain their strength and resistance under load. The strength of the adhesive bond is influenced by humidity levels and ambient temperature. An increase in temperature can lead to a reduction in the bond strength of wood joints [2]. Heat treatment of wood prior to bonding with polyvinyl acetate (PVAc) significantly affects its shear strength [3]. Mahogany wood laminated with PVAc adhesive showed a reduction in flexural strength when exposed to a wet environment, while the flexural modulus of samples exposed to vegetable oil actually increased [4].

The development of adhesives for the forestry product industry must prioritize health and safety considerations. Polyvinyl acetate (PVAc) is a wood adhesive known for its excellent bonding capabilities; however, its adhesion can be compromised by humidity and high temperatures [5]. To enhance the adhesive strength of PVAc, various approaches have been employed, including improving heat resistance, water resistance, and drying speed, as well as enabling its application in low-temperature environments [6]. Additionally, hybridizing PVAc emulsion with gelatin and latex can create a more robust bond, resulting in increased thermal stability and enabling use in high ambient temperatures [5].

The thickness swelling ratio of the test specimens decreased with the addition of pMDI to the PVAc adhesive. Specifically, using 8% pMDI can enhance thickness swelling resistance in humid environments [7]. Additionally, incorporating water and 0.96% cellulose nanofibrils (CNF) into the PVAc adhesive can increase the strength of overlap joints from 6.5% to 74.5% when compared to pure PVAc [8].

The properties of PVAc can be enhanced by incorporating nanoparticles such as silicon dioxide (SiO_2) and titanium dioxide (TiO_2). Using PVAc combined with nano TiO_2 results in a faster curing time for the adhesive [9]. The mixing duration of PVAc with nano SiO_2 and TiO_2 significantly influences the shear strength of the bond; mixing for 5 to 10 minutes can improve the shear strength in single-layer joints [10].

Overall, the addition of nano SiO_2 and TiO_2 tends to have a beneficial effect on PVAc. Furthermore, acetylated hornbeam can effectively be bonded using PVAc adhesive, and polyurethane (PUR) is suitable for applications in wet and humid environments [11]. Additionally, extending pressing times leads to improved adhesion. The incorporation of 1% TiO2 and 2% SiO2 into PVAc enhances the flexural strength of laminated composite joints [12].

Modifying PVAc with nano-clay can enhance both the shear strength and the percentage of wood failure in both wet and dry conditions [13]. Additionally, nanowollastonite can serve as a reinforcement in PVAc adhesives, further increasing the shear strength of wood joints [3].

At ambient atmospheric temperatures, PVAc adhesives are highly effective for wood bonding. However, they are not suitable for use in wet or humid conditions [14]. Modifications using 35% melamine-formaldehyde (MF) and 50% phenol-formaldehyde (PF) are ideal for humid environments. Additionally, 50% urea-formaldehyde (UF) and 50% MF are appropriate for hot conditions. Interestingly, other studies have shown that adding 50% UF to PVAc adhesives does not affect the resin hardening or the joint shear strength [15].

Adding tannin to polyvinyl acetate (PVAc) can improve its wettability, leading to enhanced bond strength, water resistance, and heat resistance [16]. Tannin modifies the adhesive properties, resulting in an increase in adhesive viscosity. This change is attributed to cross-linking reactions, which accelerate the interaction of tannin with the adhesive.

The investigation of modified PVAc white and yellow glues is intriguing, as both types of adhesives are commonly used in the woodworking and home industries. This study will examine how the bonding strength between wood changes when white glue and yellow glue are applied to bond the surface of mahogany wood.

2.0 METHODOLOGY

Mahogany Wood. In this study, nine samples of mahogany wood were collected from Sobang, Pandeglang. Each test sample was measured at a length of 100 mm, a thickness of 4 mm, and a width of 15 mm. The mahogany wood selected for this study was relatively old.

PVAc white glue is an adhesive with a density of 1.05 g/cm³, a viscosity of 14400 ± 800 cps, a solid content of 51 ± 1%, and a minimum film formation time of 10 minutes at 20 °C. The pH level is between 5 and 6, and the glue line pressure for hardwood ranges from 9 to 12 kg/cm².

PVAc yellow glue has the following properties: density 1.175 g/cm³, viscosity 5000 cps, pH 4 to 5.5, and solid content: 47% ± 2%.

(a) (b)

Figure 1. PVAc adhesive (a) white glue and (b) yellow glue

Sample making process

The flexural test samples were made from old mahogany wood, characterized by its reddish colour.

Eighteen samples were prepared, each measuring 100 x 15 x 2 mm, in accordance with ASTM D790 standards. The adhesives used included PVAc white glue, PVAc yellow glue, and a mixture of the white and yellow glue.

To create the samples, two wooden boards were glued together using different types of adhesive and subjected to a pressure of 2 MPa for 30 minutes. Once the compaction process was completed, the samples were left to dry in the sun for 4 hours.

Flexural strength test

The flexural test samples conformed to ASTM D790 standards, with dimensions of 100 x 15 x 4 mm. Flexural testing was conducted using a Zwick/Roel testing machine, with three replicates for each sample. The data collected from these tests included the flexural modulus of elasticity, flexural strength, and strain of the laminated wood.

3.0 RESULTS AND DISCUSSION

Flexural strength

This flexural strength test follows the ASTM D790 standard, utilizing test samples with dimensions of 100x15x4 mm. The test was replicated on three samples. The results indicated that the flexural strength of mahogany wood laminates bonded with white PVAc adhesive was 111 MPa, which is higher than that of the mahogany wood itself. In contrast, when the wood interface surface is bonded with a mixture of white and yellow glue, the flexural strength decreases to 74.2 MPa. Additionally, when yellow glue is used exclusively to bond the mahogany wood, it produces the lowest strength, measuring at 63.4 MPa.

Figure 2 illustrates that the flexural strength of PVAc white glue can surpass that of wood. This is due to the presence of a series of organic chemical compounds where carbon atoms are arranged in an open chain. To achieve maximum strength, the distance between the wood surfaces should be 0.006 inches.

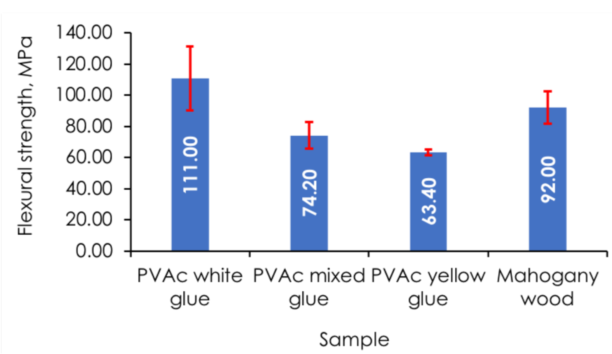


Figure 2. Flexural strength of laminated composites with different types of adhesives

The findings of this study align with the report published by Prabawa [17], which indicates that the adhesive strength of white glue is twice as high as that of yellow glue. Furthermore, white glue demonstrates excellent stability during aging [18]. Consequently, the PVAc adhesives from both the white and yellow glue exhibit flexural strength values that fall in between those of the two, specifically at 74.20 MPa.

Flexural modulus

The flexural modulus is a mechanical parameter that indicates a material's ability to resist elastic deformation when subjected to a bending load. The average flexural modulus of laminate wood boards is 8.94 GPa. For mahogany wood laminates bonded with yellow PVAc adhesive, the flexural modulus is 2.60 GPa. In contrast, when using a mixed glue, the flexural modulus increases to 5.11 GPa.

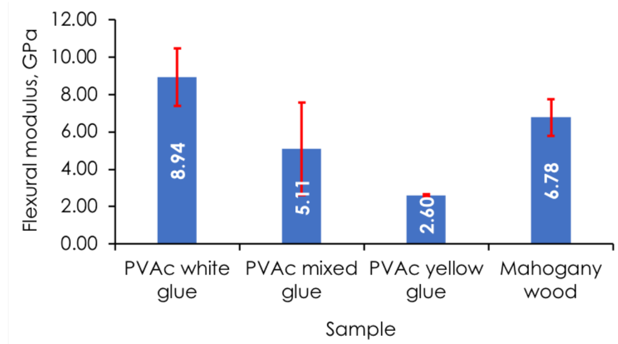


Figure 3. Flexural modulus of laminated composites with different types of adhesives

Flexural strain

Flexural strain refers to the deformation that occurs in a material when a bending force is applied. It is measured at the point of maximum stress, which is located on the material's outer surface. Figure 4 illustrates that laminated wood bonded with white glue exhibits the lowest flexural strain. This finding contrasts with the material's flexural strength and flexural modulus. Conversely, yellow PVAc adhesive results in a higher flexural strain. Therefore, if the goal is to achieve strength and stiffness, white glue is the preferred option. However, if the objective is to enhance the laminated wood's ability to withstand deformation, yellow glue would be the better choice.

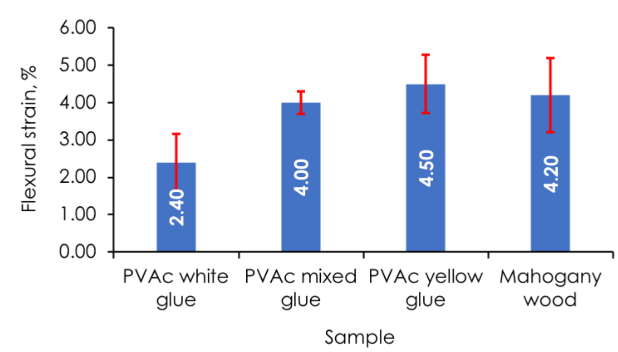
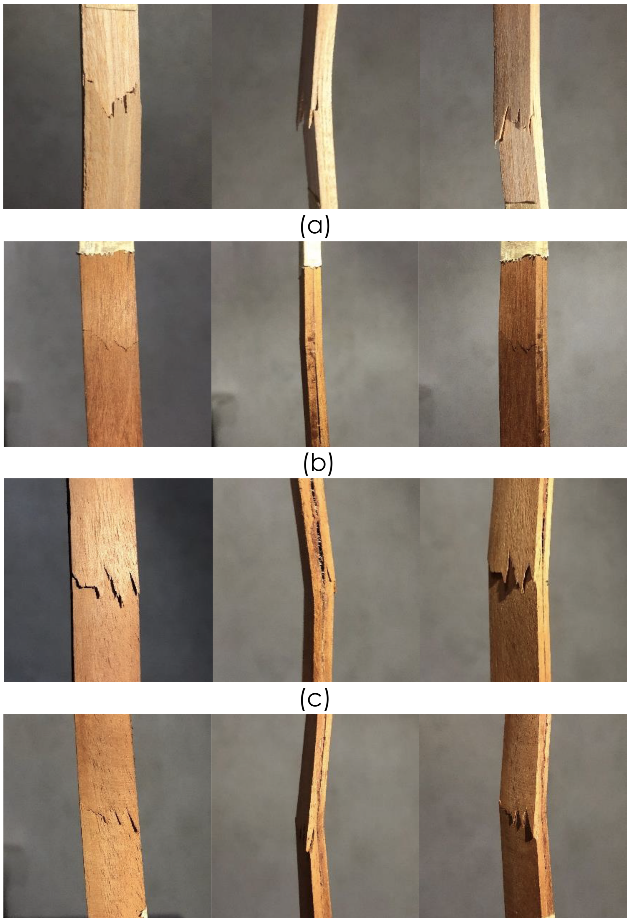


Figure 4. Flexural strain of laminated composites with different types of adhesives

Fracture Surface

Figure 5 illustrates the fracture surface of laminated wood glued with various adhesives, alongside unglued mahogany wood. Visually, laminated wood bonded with PVAc white glue exhibits a superior physical appearance.



(a) (b) (c) (d)

Figure 5. Macro images of cracks in laminated mahogany wood using different types of PVAc adhesives: (a) mahagony wood without adhesive, (b) white glue, (c) mixed glue, and (d) yellow glue.

The presence of PVAc adhesive can significantly change the fracture pattern of laminated wood. Samples glued with white glue often demonstrate a brittle fracture pattern, which can weaken the overall structure. In contrast, samples that used mixed glue or yellow glue tend to exhibit a more ductile fracture. This macro photograph of the fracture surface supports the findings from the bending tests.

4.0 CONCLUSION

The use of PVAc adhesive demonstrates excellent performance when bonding two mahogany wood surfaces. Test results indicate that the adhesive made with white glue achieves the highest flexural strength at 111 MPa, followed by mixed glue at 74.2 MPa and yellow glue at 63.4 MPa. Notably, the flexural strength of the PVAc white glue exceeds that of the mahogany wood itself.

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