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FACTORS INFLUENCING THE QUALITY OF WOOD ADHESION—PART 2: GLUE SPREADING

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INTRODUCTION

Close monitoring on the manufacturing parameters is imperative in production management of wood lamination. This is to ensure that the quality of adhesion in lamination is well maintained. Some of the processing parameters such as the amount of glue spread, laminating temperature, type of laminating materials, type of adhesive and clamping pressure are essential to be considered. In this article, glue spreading is chosen to be the topic of discussion.

The understanding on glue spread is important in relation to adhesion. Glue spread refers to the amount of glue required in weight for a unit square area on the joining surface. It is usually specified in gram per square metre ($g.m^{-2}$). Recommendation on glue spread rate can be found in the adhesive manufacturer's technical data sheet, and they are usually grouped into softwood and hardwood species. Information on the suggested glue spread will enable the laminating manufacturers in costing. This information is also handy for market comparison.

Nonetheless, suggestion in glue spread on the technical data sheet is purely a recommendation based on certain assumptions and criteria, which will vary from one to another application. In this context, the material of interest for lamination is cellulosic (i.e. wood) and non-homogeneous. Considering that the variability of the physical properties across a group of species can be large, it is necessary to identify the specific spread rate according to wood species in each fabrication attempt. This is achievable by running an in-house trial. Estimation of the quantity of adhesive should also consider the type of glue spreading facility in the existing production line.

SELECTED FACTORS AFFECTING WOOD ADHESION

Adhesion in wood is dictated by: i) the anatomical, ii) chemical, iii) mechanical, and iv) physical properties of the species. On the other hand, the adhesion mechanism can be divided into: 1) mechanical interlocking, 2) physical bonding, and 3) chemical bonding [6]. The ability of the adhesive to form a strong adhesion varies by species and the changes of the state of physical properties of the wood during adhesion. The following segments discuss some of the physical properties which will influence the capacity of adhesion.

Anatomical Characteristics of Wood

The size of the pores in wood and the density of porosity have a direct relationship with adhesion. The porosity of the wood can be translated into density of lumen present in a unit surface area. Freshly planned wood will have larger amount of lumen for the glue to fill in, thus provides stronger adhesion strength [1]. This explains the need of wood surface to be freshly cut prior to adhesion to attain good adhesive bonding.

The size of the wood pores varies between softwood and hardwood, as well as between species.

From a microscopic point of view, the cellular structure of wood varies between softwood and hardwood. In softwood, over 90 percent of the tree volume is made of longitudinal tracheid [2] and the structure of the cell lumens resembles honeycomb. The diameter of softwood vessels ranges between 30 and 40 μm [3].

On the other hand, hardwood contains mainly woody fibers which provide the mechanical strength to the tree. Hence, the main structure of the wood composition is made up of fiber with large diameter vessels (also known as pores) for transportation of water and nutrients within the standing tree. The range of these vessels diameter can be large, ranging from 20 to 300 μm [3].

However, good adhesion is not solely warrant by the size of lumen of a wood species, but the combination of physical properties and the condition of the wood surface will also affect the quality.

Surface Roughness

The surface roughness of wood is quantifiable by the amount of deviations in the direction of its surface from its ideal form of smoothness. When the magnitude of deviations is large, the surface is rough.

Wettability

Wettability refers to the tendency of the liquid to be spread on or adhere onto a solid surface. The wettability of a solid surface to be in contact with liquid adhesive is depending on the degree of its preference. In other words, the level of preference of the fluid to be in contact to the solid surface will subsequently determine its ability to displace another drop of the fluid, and eventually spread over the entire surface [4]. Suitable wettability allows the glue spread in a favourable manner. Hence, the adhesive performance is closely related to wettability of the substrate. Wettability of a liquid on the adherend surface can be measured and quantify by running the contact angle test (Figure 1). Liquid which forms a contact angle of less than 90° will enable spreading on pores and scratches of the solid surface. The strongest adhesive bonds are obtainable when the contact angles for water are low [1].

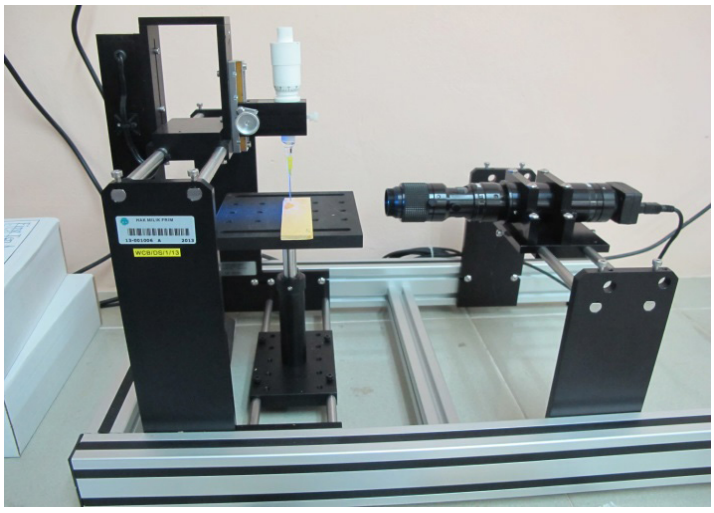

Figure 1 Determination of the contact angle by a contact angle meter

Wood Extractives

Wood extractives are the low molecular weight organic chemicals, which mainly dominates the wood surface during drying. A typical range of wood extractives in the wood composition is between 4 and 10 % [1]. The degree of extractives contain in wood differs within species,

between species, as well as between trees [2]. There have been findings on surfacing of extractive which show creation of weak boundary layer of adhesion inhibiting optimal interaction between the glue and the wood, as a result, creating weaker bonding strength [4]. Mirabelle explained that extractives present in wood can be located either inside of the capillary structure or in the cell wall structure. However, only those that are residing in the cell wall structure will give the effects to swelling of cell wall when the extractives migrate to the surface [2]. In short, only the extractives that will migrate to the surface will affect the gluability of the adhesion.

ESTIMATE THE GLUE MIXTURE BASED ON GLUE SPREAD RATE

Glue spread is commonly suggested in single or double spread. Single spread indicates the amount of glue that will be spread only on one side of the laminate while double spread is on the top and the bottom of a laminate.

There are two types of synthetic adhesive mixture: one-part pre-mixed adhesive or two-part mixture. A one-part adhesive requires no mixing and the mixture is ready to be used. In the case of a two-part mixture, combination of the parts according to the specified ratio is required. The mixing process shall be done just before the glue spreading process begun. This is to avoid the lost of surface wetness due to evaporation, which will result in increase in resin viscosity; meanwhile, this will also induce hardening before the adherend surfaces are glued. As a result, the effect on spreading process will eventually lead to poorer lamination.

One of the common mixing compositions in a two-part phenol resorcinol formaldehyde (PRF) mixture requires a 3 parts PRF resin with 1 part of the prescribed hardener.

The first step in computing the amount of spread is to identify the total surface area needed for lamination. The suggested glue spread recommended for each substrate surface can be computed by equating the two ratios, i.e. between the recommended weight of adhesive per surface area, and the substrate surface in proportion, followed by cross multiplication in getting the amount required for lamination.

An example of calculation based on the 3:1 PRF: hardener composition

Adhesive Specifications:

Adhesive type	:	PRF
Ratio of Mixture	:	3 parts PRF : 1 part hardener (or 750g PRF : 250g Hardener)
Double Spread Glueline	:	300 $g.m^{-2}$

Step 1: Identify Laminating Surface Area

Surface Area per laminate	:	$300cm^2$
Number of laminates	:	5
Number of gluelines	:	4

Step 2: Compute the amount of mixture for the total laminating surface area

Based on the above recommendation, $1m^2$ of the wood laminating surface area requires a single side of 150g or double sides of 300g mixture; therefore $300cm^2$ would require 9g of mixture on both laminating sides in a glueline. In this case, a total of 36g mixture is required for 4 gluelines.

Step 3: Compute the weight of each mixture component based on the specified ratio

The 36g mixture is made of 3 parts PRF and 1 part hardener. 75% of the total mixture amounts to 27g PRF and 25% amounts to 9g hardener.

TYPE OF GLUE APPLICATOR

There are two methods in glue application - manual by hand or by mechanical means. In a manufacturing environment, it can be either one or both methods.

An example of a manual applicator is by using the hand roller (Figure 2). There are several types of roller width depending on the needs of the roller spread. The material of the roller is an important factor which will affect the spreadability of glue. Some of the common rollers are made from polyvinyl acetate (PVA) or polyurethane (PU). Selection of the right choice of roller based on the type of adhesive will ensure even glue spread and minimal wastage.

Figure 3 depicts a non-integrated and independent glue spreading machine. Figure 4 is the integrated glue spreader as one of the components in the manufacturing line. Computation of glue spread based on the figured rate provides the clue of glue consumption. However, the actual consumption is depending on the type of glue applicator based on the type of adhesive in use. Different type of adhesive requires different type of glue spreader and grooving for optimum glue spreading. The grooving space per unit area can be obtained from glue manufacturer.

Figure 2 A typical 200mm PU hand roller

Figure 3 An independent glue spreading machine

Figure 4 A continuous manufacturing line with an integrated glue spreader (Photo taken from a finger-jointed manufacturing plant at Klang, Malaysia)

GUIDELINE ON EXAMINATION OF GLUE SPREAD

1. Pre-lamination
   - Examination on the viscosity of the glue can be conducted using a viscometer. The viscosity of the resin shall fall within the range of recommendation. In the case of a two-part adhesive, this shall be checked prior to mixing.

   - Trial in determining the glue spread rate for a specific wood species can be conducted on small patches of samples. Information provided by the adhesive manufacturer can be the good basis of spread to begin with. Figure 5 indicates slightly inadequate glue spread. Figure 6 shows suitable spread for the yellow balau species.

Figure 5 Slightly inadequate glue spread

Figure 6 Experimental trial determining suitable spread rate for balau

2. Post lamination

   Examples of laminated end product will leave us a clue whether the applied glue is sufficient.

Figure 7 The amount of squeeze-out adhesive indicates sufficient amount of glue spread is being applied

Figure 8 Excessive squeeze-out of glue spread indicating excessive application of glue, too high of clamping pressure, and/or too short of assembly time

3. Quality of Bonding

   The quality of the adhesive bonding can be quantitatively determined via laboratory testing. There are two types of testing measures:

   a. Durability of bonding
      The durability of bonding in the laminated samples can be tested by using the accelerated aging tests under extreme testing conditions. For example, by soaking samples under water maintained at ambient temperature (e.g. JAS 1152:2007 Appendix 3(1)), boiling in water (e.g. JAS 1152:2007 Appendix 3(2) - Figure 9), soaking in an enclosed water soaking

vessel which are subjected to specified vacuum and pressure (e.g. MS758:2001 Appendix B - Figure 10), or a temperature-relative humidity controlled chamber (e.g. *iFT* HO 1-10 Para 4 - Figure 11).

b. Adhesion strength
The strength of glueline can be determined via block shear test (Figure 12). The strength of shear accompanied by visual examination on the percentage of wood failure (Figure 13) would enable meaningful assessment of the quality of adhesive bonding. It has been reported that by having both results present to be more conclusive on adhesion than based on shear strength alone [5].

Figure 9 Delamination test based on water boiling soak test

Figure 10 Delamination test using vacuum pressure method

Figure 11 Cyclic delamination using conditioned water storage method

Figure 12 Block shear strength test

Figure 13 Measurement of percentage of wood failure

CONCLUSION

The knowledge of glue spreading plays a vital role in the manufacturing of high quality lamination. Hence, the underlying science in relating the glue spreading and good bonding is interdependent on one another, and upon many other factors including the properties of the adherend and the facilities in application. This paper has briefly discussed the contributing factors and has provided necessary knowledge about glue spreading.

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The paper provides guidance on some of the manufacturing factors that are pertinent to glue spreading. Some of the tips on the determination of glue spread and guidelines on examination of the quality of adhesion are discussed. Lastly, the paper has included some of the testing methods that can be used by the industry in quantifying the quality of lamination.

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