Gluability of Two Veneer Thickness Following Microwave Heat Gun Drying

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Abstract

Faster drying, higher in drying rate and uniformity in moisture of dried veneer are key factors in assessing successful wood veneer drying. Microwave drying differs from conventional drying in the way that microwave energy causes excitation and friction (dissociation) of water molecules or water in wood, which manifest itself as heat. It is superior penetration and can enhance the rate of moisture evaporation. Heat gun is employed to absorb evaporated wood water from being humid. In contrast to microwave drying, conventional drying relies on heat conduction from outer surface wood layers towards the inner layers; so that the thicker the wood cross-section the slower the rate of evaporation. Successful wood drying are determined by faster drying, higher drying rate and uniformity in final moisture content. One of key factors in assessing further veneer drying is veneer gluability, which can be evaluated using percentage of wood failure and glueline shear strength.

This research is aimed to investigate the effect of microwave heat gun drying on veneer gluability, using percentage of wood failures and glueline shear strength test as estimators. Three treatments were employed, plywood made of microwave heat gun, conventional and mixed dried-veneers, using ten replicates. The results indicated that no difficulties were found in gluing dried veneer, either pure microwave, conventional or mixed dried veneers. Surprisingly, it is also reported that microwave heat gun drying result in better veneer gluability.

Key words: microwave heat gun drying, veneer gluability, glueline shear test and percentage of wood failure.

Introduction

A properly dried veneer is the most critical requirement for glue spreading. Over-dried or re-dried veneer generally leads to insufficient bonding between veneer and wood adhesive which then results in poor glueline performance (Resch *et al*. 1970). Veneer gluability is one parameter for assessing the success of veneer drying, and it is a major mechanical factor to be considered in plywood assembly. It is measured by the plywood shear test (Loos 1971). There are two ways in which such test can be conducted: namely glueline shear strength and percentage of wood failure on the shear areas of test specimen surfaces (Northcott 1955; Koran and Vasishth 1971; Zink and Kartunova 1998).

Many experiments have been carried out to investigate wood gluability and understand the factors involved. Stumbo (1964) identified the causes of poor adherence between wood veneer of Douglas fir and Redwood when using Phenol Resorcinol Formaldehyde and Casein. The causes varied from excessive drying/over heating, physical, chemical and photochemical contamination of veneer surfaces to the environment, and to surface inactivation due to wood extractives. Hancock (1963) investigated the effect of heat treatment on the surface of Douglas fir veneer; Resch *et al.* (1970) investigated the effect of two veneer drying methods (microwave and hot air temperature up to 150˚C) on glueline quality of many wood species: Douglas fir, Western larch, Western hemlock, etc. Gluability of earlywood and latewood in Loblolly pine has been well documented by Biblis and Chiu (1972), while Goto *et al.* (1982) investigated the gluability of Red seraya (*Shorea spp*) veneer using a Scanning Electron Microscopic (SEM).

Microwave heat gun drying is a 900 Watt domestic microwave connected with cavity and assembled with heat gun. Heat gun is targeted to absorb evaporated moisture released from wood veneer during drying to prevent humidity turbulence in microwave cavity. Microwave cavity is a rectangles hole, 10 cm in height, 20 cm in width and 100 cm in length and made of dense aluminum (nonmagnetic material). Microwave energy is transmitted through cavity; wood veneer is placed vertically and rotated against microwave energy.

The aim of this research is to assess the gluability of two veneer thicknesses, A and B (3 and 1.5 mm in thickness, respectively) dried by microwave heat gun and conventional drying, glued with Phenol Formaldehyde (PF) using both glueline shear strength and percentage of wood failure as estimators of veneer gluability. The detailed goals of this experiment presented in this paper are to determine the gluability of two dried veneer of two thicknesses and; to examine the relationships between percentage of wood failures and glueline shear strength.

Materials and Method

Two peeled-veneer thickness of Radiata pine (*Pinus radiata* D Don) were used in 3 and 1.5 mm thick, and marked as veneer A and veneer B, respectively. These two veneers have two different physical properties, veneer A has rough surfaces, full of peeled checks and any wood knots are presented. Whereas veneer B has very smooth surface, containts juvenille wood and peeled checks is absent. Both veneer thickness have 200 mm and 150 mm in length and width respectively. Phenol Formaldehyde (PF) was used to glue both dried-veneers to assembly three layers plywood. A two factorial design was used in this investigation. Factor C is two veneer samples A and B, veneer thickness of 3 and 1.5 mm for C_1 and C_2 respectively. Factor D is the drying treatment (microwave dried (D_1) and conventionally dried (D_2) and mixed plywood (D_3). The two veneer samples A and B were dried by microwave heat gun and conventional drying to obtain the dried veneer reached 5 $\pm$ 3% of moisture content.

Sheets of three-layered plywood were manufactured from each of two veneers A and B. Five sheets of 3-ply plywood were made from each veneer thickness. Wood adhesive was applied by hand using a paintbrush over the dried veneer surfaces (double spreading). The spread rate of glue was calculated using an electronic balance with an accuracy of 0.01 gr. The glue spread rate is the veneer weights differences before and after been srpreating out with phenol formaldehyde. The assembly times (open and close times) were around 10~15 minutes. A steel-platen plate was used to press (clamp) the plywood sheets and then oven heated at 102 $\pm$ 3°C for 22 hours to cure the PF.

The dimensions of samples used in the glueline shear strength test were 30 mm and 80 mm in width and length respectively and ten replicates were used to represent all experimental variables. The pattern of samples used for glueline shear strength and percentage of wood failures based on Australian Standard 2098.2 (Anonymous 1977). Three plywood samples, namely conventional, microwave, and mixed were manufactured for each experimental variable. In addition, mixed plywood samples were manufactured from microwave drying veneers for face and back veneer layers, whereas conventional drying was used for core layers for both veneer thicknesses.

Two variables were used to assess the bonding quality for three plywood samples namely glueline shear strength and percentage of wood failures. The maximum load where failure occurred was recorded as breaking strength (kN). The measurement of wood failures percentage is based on Australian Standard 2098.2 (Anonymous 1977). It is calculated as percentage of adhering wood fiber to the total area of bonded shear areas. Glueline shear strength is the ratio of maximum load (kN) to total area of bonded shear area (sum of both shear areas) in cm^2. Glueline shear strength was conducted using the Universal Testing Machine (UTM) Instron 1185 100 kN. The density of plywood was determined in accordance to Australian Standard 2098.7 (Anonymous 1977), namely 'high precision methods', which is the mass of plywood samples divided by its volume (g/cm^3).

Results and Discussion

Average Glue Spreading Rates (GSR) for the two sets of dried veneer samples A and B dried by microwave heat gun and conventional drying are summarized in Table 1.

Table 1. Glue spreading rate (GSR) for two dried veneer thicknesses dried by two drying methods.

GSR (g/m^2)	Conventional		Microwave	
	Veneer A	Veneer B	Veneer A	Veneer B
*x	277	149	263	204
Max	378	228	383	270
Min	205	63	181	139
St. dev.	48	53	57	35
CV (%)	17	36	22	17

*x = average from 5 plywood sheets

Table 1 indicates that the highest GSR (383 g/m^2) was recorded from the microwave heat gun-dried veneer A, while conventionally dried veneer B had the lowest GSR (63 g/m^2). Microwave drying resulted in higher average GSR for veneer sample B, while conventionally drying had higher GSR for veneer A. The sets of A dried veneer had higher GSR (270 g/m^2) than B veneers (177 g/m^2). In addition, an interaction between drying methods and veneer thickness was found to affect GSR.

The means density for the three plywood samples namely conventionally dried, microwave dried and mixed, manufactured with two veneer thickness are summarized in Table 2.

Table 2. Summary of density for three plywood samples manufactured from two veneer thicknesses.

Density (g/cm^3)	Conventional		Microwave		Mixed	
	Veneer A	Veneer B	Veneer A	Veneer B	Veneer A	Veneer B
x	0.52	0.54	0.55	0.53	0.46	0.57
Max	0.54	0.60	0.60	0.60	0.49	0.60
Min	0.47	0.42	0.50	0.50	0.43	0.53
St. dev	0.03	0.07	0.03	0.03	0.02	0.02
CV (%)	5.8	13	5.50	5.70	4.30	3.50

Table 2 indicates that the three plywood samples, except mixed veneer A, manufactured from two dried veneer thickness had similar densities. Plywood made with conventionally dried veneer (B) had the highest coefficient of variation (13%) for density compared to other plywood samples. Although plywood samples made with veneer B (conventional, microwave and mixed plywood) had higher mean density (0.55 g/cm^3) compared to those from veneer A (0.51 g/cm^3). This table also indicates that three plywood types (conventional, microwave and mixed) resulted in a significant difference in the densities and interaction was found between veneer samples and treatments for density.

Average Glueline Shear Strength (GSS) and Percentage of Wood Failures (PWF) for the three plywood samples made from the two different thicknesses of veneer A and B dried by microwave and conventional drying are tabulated in Table 3 and Table 4, respectively.

Table 3. Summary of glueline shear strength (GSS) for the three plywoods made from two veneer thicknesses.

GSS (kN/cm^2)	Conventional		Microwave		Mixed	
	Veneer A	Veneer B	Veneer A	Veneer B	Veneer A	Veneer B
x	0.14	0.14	0.16	0.11	0.15	0.10
Max	0.15	0.28	0.20	0.20	0.24	0.12
Min	0.11	0.08	0.10	0.10	0.10	0.09
St.dev	0.01	0.06	0.05	0.03	0.04	0.01
CV (%)	7.14	42.90	31.30	27.30	26.60	10.00

Table 4. Summary of percent wood failures (PWF) for the three plywoods manufactured from two veneer thickness.

PWF (%)	Conventional		Microwave		Mixed	
	Veneer A	Veneer B	Veneer A	Veneer B	Veneer A	Veneer B
x	55.3	73.8	79.51	54.2	69.4	71.17
Max	99.1	98.1	98.3	98.8	99.5	95.8
Min	0	50	53.2	0	26.3	0
St. dev	35	17.2	18	47.4	26.8	30.43
CV (%)	63.3	23.3	22.7	87.5	38.6	42.8

Table 3 shows that GSS resulted from three plywood samples are ranging from 0.08 ~ 0.28 kN/cm^2. Although, there could be some differences in GSS, the balanced analysis of variance for GSS for the three plywood samples which are not differently significant.

Table 4 shows that the highest PWF arose for plywood samples made with mixed veneer A (99.5%). Mixed plywood veneer A and B also had a higher (70.3%) PWF compared to microwave plywood samples (66.9%) and conventionally plywood (64.4%). This table also highlights that nil values rising from plywood made with conventionally dried veneer A, microwave and mixed veneer B respectively were due to wood failures. The numbers of failed replicates are two, four and one of ten for conventional veneer A and microwave and mixed veneer B, respectively. This is supported by higher values for the coefficients of variation (63.3%, 87.5% and 42.8% for conventional veneer A, microwave and mixed veneer B respectively) compared to other plywood samples.

Two variable used for bonding quality of plywood assessment, GSS and PWF, indicate that higher in PWF do not result in the higher GSS.

The GSR for dried veneer A is higher than veneer B irrespective of the drying method. The possible cause is probably due to the rough surface and presence of peeler checks on veneer A. Glue penetrates veneer through peeler checks and heavier glue spreading is needed to occupy rougher veneer surfaces. Haskell and Blair (1966) stated that rough veneer surfaces need more adhesive/glue because of low and high topography of veneer surfaces. The presence of earlywood on veneer A is also a possible cause of higher glue spreading rates. They found that earlywood from Southern pine veneer had greater absorptivity than latewood and needs 30 ~ 50% higher adhesive spreading rates. Another possible explanation for the high glue spreading rate for veneer A lies in the higher the coefficient of variation (45%) for initial moisture content (IMC) of the dried veneer being prepared for gluing compared to veneer B (39%). Although, average GSR for microwave heat gun dried veneer is lower than conventional samples, the maximum and minimum values for GSR for microwave veneer A and B are higher than conventionally dried veneer samples. This indicates that GSR for both dried veneer thicknesses improves following microwave drying. For example, GSR for conventional veneer A increases from 378 kg/m^2 to 383 kg/m^2 following microwave drying, while it increases from 228 kg/m^2 to 270 kg/m^2 for veneer B. GSR found in this experiment are lower than those reported by Goto *et al.* (1982). These workers obtained averages of 330 g/m^2 in investigating the gluability and adhesion mechanisms using Polypropylene as hot melt wood adhesive and phenol formaldehyde for bonding plywood. Biblis and Chiu (1972) gained an average of 401.2 g/m^2 for GSR of PF when investigating the gluability of Loblolly earlywood and latewood. However, the GSR from this experiment are higher than reported by Zavala and Humphrey (1996) where they obtained 250 g/m^2 for bonding veneer-based products (5 layers of LVL) using PF.

In terms of plywood density, the three plywood types, (except mixed plywood veneer A), manufactured from two dried veneer thicknesses A and B had similar density. However, further analysis of variance indicates that plywood made of microwave dried veneer A and B had higher density compared to conventional and mixed plywood. This is related to a higher glue spreading rates following microwave veneer drying (Table 1). No causes are found to explain higher coefficient of variation of density for plywood samples made with conventionally dried veneer B. The density of the three plywood types is higher than the density of parent veneer (0.45 g/cm^3 and 0.48 g/cm^3 for conventional and microwave drying respectively). The density of plywood is usually higher than the parent wood due to pressing and glue spreading rate (Morley 1988).

Three plywood types manufactured with two veneer thicknesses A and B dried by microwave and conventional drying resulted in different GSS. Plywood samples made with veneer A (0.15 kN/cm^2) had higher GSS than those from veneer B (0, 12 kN/cm^2). This is possibly related to higher GSR for veneer A. Rough surfaces of veneer A are also thought to cause higher GSS. Combining microwave and conventionally dried veneer A can improve GSS from 0.14 kN/cm^2 for conventional to 0.15 kN/cm^2 for mixed plywood. However, this did not occur for veneer B, where the highest GSS (0.14 kN/cm^2) arose for conventional samples. The mixed plywood samples resulted in lower GSS than plywood made with conventional veneer and equal to those made from microwave samples. It is probably due to over drying of veneers following microwave drying in which wood failures occurred on the back veneer layers, three and one of ten replicates for microwave and mixed plywood sample made with veneer A, (see Table 4). Over dried veneer tends to have low strength due to its rigidity. Haskell and Blair (1966) reported that over dried veneer has a dark colour related to physical and chemical changes in the surfaces of veneers. These workers reported that over drying of veneer resulted low in GSS of 0.11 kN/cm^2 and 59% wood failure compared to properly dried veneer, which had 0.17 kN/cm^2 and 94% GSS and PWF respectively, for Southern pine plywood glued with PF.

Figure 1 shows that plywood made from microwave dried veneer A and mixed veneer A resulted higher in GSS than those plywood made from dried veneer B. This figure also indicates that both plywoods made from either veneer A and B dried by conventional drying resulted a similar value of GSS. Even though, this figure shows a wide range of GSS, interestingly, a balanced analysis of variance for GSS for samples and treatments was found not to be significantly different.

In addition, an interaction was not found between veneer's thickness and treatments for GSS. Low average GSS arose for plywood samples made with conventionally dried veneer A, microwave dried veneer B and mixed veneer B. This is attributed to nil values arising during strength test (*see Table 3*). These values represent wood failures, which failed on the back of veneer layers (non-shear areas). This results in lower maximum loads and influences GSS. This is probably due to over-dried veneer, which leads to increase veneer rigidity and brash failures. This is supported by Figure 1. This figure illustrates that plywood samples made with conventionally dried veneer A and B had similar GSS (probably properly dried veneers). Whereas microwave and mixed plywood samples made with veneer B resulted in lower GSS than conventional plywood samples. Another possible cause is the result of exposing all plywood samples at oven temperatures (102 $\pm$ 3^{o}C) for 22 hours for adhesive curing. Fischer and Bensend (1969) stated that an excessive long hot pressing can lead to low plywood bond quality. The veneer can be over dried and cause severe stress during pressing and conditioning processes.

The GSS plywood made from Radiata pine glued with PF, ranging from 0.10 ~ 0.16 kN/cm^2) reported from this research are agree to the GSS of Radiata pine glued with Isocyanate resin (MDI) reported by Subarudi (1995). He reported that GSS ranging from 0.101 ~ 0.159 kN/cm^2 for five-layer plywood made with Radiata pine veneer treated with soaking with 50%, 60% and 70% solid content MDI and using low-high pressure.

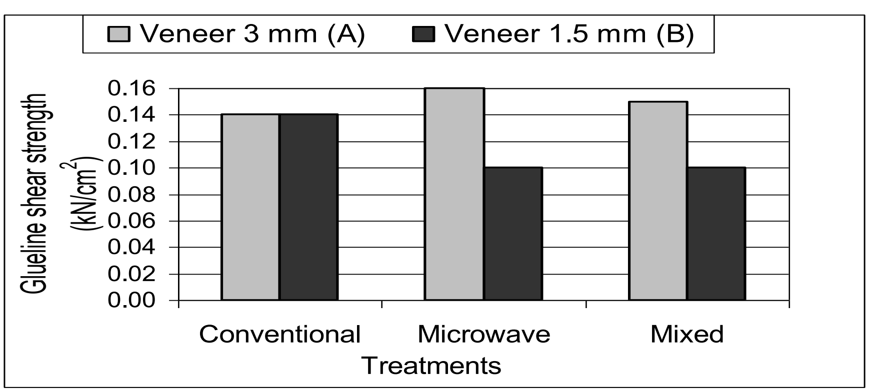

Figure 1. Glueline shear strength for three plywood samples.

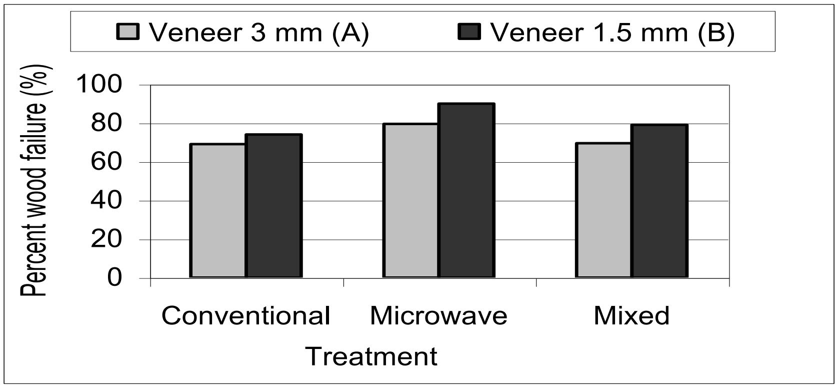

Figure 2. Percent wood failures for three plywood types (excluded the failed replicates).

In terms of percentage of wood failures, plywood samples manufactured with veneer A had higher PWF than those of veneer B. Low PWF for veneer B (Table 4) is attributed to the nil values obtained for these samples, where wood failures occurred on the back veneer layers rather than in shear areas. However, a comparison of PWF for three plywood types excluded the nil values given in Figure 2. This figure clearly shows that plywood samples made with veneer B had a higher PWF for three types of plywood. Plywood made from microwave-dried veneer A and B had higher PWF compared to the other plywood types (conventional and mixed). This is probably due to a higher GSR and dried veneer gluability following microwave conditioning. GSR plays an important role in wood gluing due to its effect on bonding strength and a major contribution to plywood moisture content. Fischer and Bensend (1969); and Zavala and Humphrey (1996) point out that GSR has a linear response for GSS and PWF for Southern pine veneer glued with Phenolic resin using fresh blood as a modifier. A balanced analysis of variance for PWF for three plywood samples and veneer samples (Table 4) clearly indicates that the three plywood types and two veneer thicknesses did not result in significantly different PWF. No interaction was found between veneer samples and treatments.

The percentages of wood failures recorded from this experiment agree with those reported by Subarudi (1995) He reported a range of PWF from 79% to 98% for Radiata pine plywood (5 layers) treated with 50%, 60% and 70% solid MDI with soaking and three levels of pressure (low, high and average respectively). An attempt was made to estimate the PWF using GSS and maximum load values. However, no correlation was found between these variables. In other words, the PWF is independent of GSS and the GSS values are also independent of PWF. In addition, the GSS did not represent the quality of plywood bonding. These results agree with those reported by Chow and Hancock (1969). They reported that the relationship between PWF and GSS is not linear. The PWF is more sensitive to initial bond degradation than to breaking load or maximum load (Northcott 1955; Chow and Hancock 1969). If PWF is used as an estimator of plywood bonding quality, a correlation between PWF and mechanical test results must be established (Northcott, 1955).

No difficulties were found in gluing within and between two veneer thicknesses A and B dried by microwave heat gun and conventional methods, using estimated values of GSS and PWF. These results agree with those reported by Resch *et al*. (1970). These workers found no difficulties for gluing veneers of several western species using microwave and hot air temperature up to 150^{o}C. They concluded that the gluability of re-dried veneer is equal to or better than primary dried or hot air re-dried veneer.

Microwave dries wood veneer by transmitting a radio frequency wave and rotating wood water molecule (free and bond waters) directions. These wood water molecules rotations are manifested as heat. Heat evaporates wood water into wood surface. Microwave dries wood from inner to outer part of wood and this leads to moisture uniformity of dried wood. This mechanism is contrast with conventional drying, which dry wood from outer section (surface) to the inner (middle) of wood surface.

Conclusion

Microwave drying resulted in better veneer gluability determined using PWF and GSS as estimators. Combining microwave with conventionally dried veneer for both samples thicknesses A and B to form mixed plywood can improve GSS and PWF compared to the pure conventional plywood samples.

Higher in PWF do not linearly represent higher in GSS. In other words, PWF is independent from GSS as well as otherwise.

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