

AN ABSTRACT OF THE THESIS OF

Kim Michael Kadlec for the degree of Master of Science

in Forest Products presented on March 17, 1980

Title: Wetting as a Predictor of Surface Inactivation for Platen

Dried Douglas-fir Veneer

Redacted for privacy

Abstract approved: _____
Dr. J. D. Wellons

Surface inactivation continues to be a problem in the softwood plywood industry. A simple test to predict its presence would be well received by the industry. This study attempts to use various measures of wettability to predict the presence of surface inactivation.

The following techniques were studied to determine which, if any, best predicts surface inactivation after platen drying of second-growth Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] veneer;

1. absorption time for liquids on veneer surface,
2. difference between absorption time on sanded and unsanded veneer surfaces,
3. extent of liquid spread parallel to the grain,

4. contact angle for liquid on the veneer surface.

Evaluation of these tests was based on glueline quality and durability data from a companion gluability study (Sandoe and Wellons 1979). Results of these evaluations indicated that none of these test procedures were reliable indicators of surface inactivation on platen dried second-growth Douglas-fir veneer.

Wetting as a Predictor of Surface Inactivation for
Platen Dried Douglas-fir Veneer

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed March 17, 1980

Commencement June 1980

Thesis Committee

Redacted for privacy

Redacted for privacy

Redacted for privacy

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ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. J. D. Wellons for his help and guidance in preparing this thesis.

Special appreciation is extended to Weyerhaeuser Co. for supplying materials, and to the United States Forest Products Laboratory in Madison, Wisconsin, for funding and cooperating in material preparation.

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WETTING AS A PREDICTOR OF SURFACE INACTIVATION FOR
PLATEN DRIED DOUGLAS-FIR VENEER

I. INTRODUCTION

Surface inactivation is a heat-induced change in the wood veneer resulting in a loss of bonding ability (Troughton and Chow 1971). The process of drying plywood veneer or lumber laminates can result in the veneer being inactivated prior to gluing. Although the mechanism by which inactivation occurs has not been defined beyond question, a number of techniques for detecting its presence have been proposed. Unfortunately test results of these techniques usually have been confounded by other gluing variables and have not allowed a conclusive evaluation of each technique.

To appreciate the severity of the issue, one has only to look at the court cases against companies which have manufactured and sold plywood and laminated wood products produced with inactivated wood surfaces. The lawsuits against one particular Canadian firm manufacturing structural beams that failed due in part to inactivated surfaces were costly enough to force the firm into bankruptcy (Fox, et al. 1976). The claims against plywood manufacturers typically are smaller but are a persistent problem. It is evident, therefore, that simple tests allowing firms to detect the presence of inactivated wood surfaces prior to assembly would be well received by the wood products industry.

Commercial drying of veneer conventionally has been done either by gas fired or steam heated ovens. A relatively new commercial

method, platen drying, has been established and put into operation. During 1979 the Forest Research Laboratory, Oregon State University cooperated with the United States Forest Products Laboratory (Madison), and the Weyerhaeuser Company to study the gluing of platen dried second-growth Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] veneer (Sandoe and Wellons 1979). That research built a mathematical model of the durability of gluelines as a function of veneer thickness, platen drying temperature [325°F (163°C) - 460°F (238°C)] and dry veneer moisture content (1%, 5%, 9%). Because that study generated veneers having varying degrees of surface inactivation, I was presented a unique opportunity to evaluate different methods of detecting surface inactivation, i.e. to determine whether the tests were responding to surface inactivation or to other gluing variables.

The intent of my research was to determine which, if any, of the following techniques best predicts surface inactivation after platen drying of those second growth Douglas-fir veneers:

1. absorption time for liquids on veneer surface,
2. difference between absorption time on sanded and unsanded veneer surfaces,
3. extent of liquid spread parallel to the grain,
4. contact angle for liquids on the veneer surface.

The liquids used for the first three objectives were: H₂O, 0.5% aqueous NaOH, 25% phenol-formaldehyde solids in water (P/F solution), and 25% phenol-formaldehyde solids in 0.5% aqueous NaOH

(P/F/C solution). Only water and 0.5% aqueous NaOH were used in the contact angle measurements.

Evaluations of the quality and durability of gluelines were made from the gluability study (Sandoe and Wellons 1979) using wood failure and shear strength of parallel laminated veneers as criteria.

II. SURFACE INACTIVATION AND WETTABILITY OF VENEERS

Surface inactivation is a long standing problem in wood gluing operations, and much has been written about it. These studies have in general indicated that wettability of a wood surface decreases when surface inactivation occurs. The following sections review the existing information on both surface inactivation and wettability.

Surface Inactivation

The term surface inactivation refers to wood surfaces which, after being exposed to high temperatures [350°F (176°C) or higher], will not form adequate exterior bonds with phenolic resins. Inactivation is a surface phenomenon because adequate bonds will form if the surface fibers are removed completely by sanding (Northcott *et al.* 1959, Hancock 1963). The fact that we do not know the mechanisms by which phenolic resins bond to wood has hindered research aimed at establishing the definite cause of surface inactivation.

Covalent bonding and hydrogen bonding have been proposed as important factors in wood-polymer bonding (Wellons 1977, Chow 1969). Chow (1971) has proposed that surface inactivation is due to the oxidation of the alcohols on the wood surface to aldehydes, carboxylic acids, and ketones, resulting in a loss of covalent bonding ability. Chow used infrared spectrometry to analyze the changes in the functional groups on a wood surface as a result of

drying temperature and drying time. He concluded that significant amounts of oxidation do occur at temperatures of 356°F (180°C) after extended periods of time (35 minutes). The time it took to reach significant oxidation was shown to be shorter at higher drying temperatures - 15 minutes at 464°F (240°C). Oxidation will occur in the absence of atmospheric oxygen at lower temperatures but only after a much longer period of time - 75 minutes at 180°C. At higher temperatures (240°C) no significant difference in time was noted to reach significant levels of oxidation whether or not atmospheric oxygen was present. Extractives in wood did not appear to be necessary for oxidation, but did act as catalysts for the reaction.

Stumbo (1964) noted that DeBryune attributed surface inactivation to a pyrolytic process taking place during drying. At high temperatures (> 350°F) adjacent hydroxyl groups in wood are proposed to react with each other forming an ether linkage by removing a molecule of water. This reaction would result in a loss of polarity at the wood surface, reducing the wettability of the wood.

An association between extractives and surface inactivation has been shown. Hancock (1964) proposed that during the final stages of drying, migration of long chain saturated fatty acids (extractives) occurs. These fatty acids hydrogen bond to the hydroxyl groups in wood leaving a surface covered with hydrocarbons. This hydrocarbon layer results in the wood surface having a low surface tension, inhibiting wetting by adhesives. Hancock, using Douglas-fir, showed that wood which had its extractives removed prior to heat treatment did not decrease significantly in bonding ability.

Unextracted wood, when exposed to these same conditions, did show significant reductions in bonding ability. Similar tests under low oxygen conditions showed no significant differences.

Hemingway (1969) concluded that there were not enough long chain fatty acids available in yellow birchwood to form a continuous hydrocarbon layer to impede wetting of the wood by the adhesive. He proposed instead that oxidation products of the linoleic acids and esters are capable of lowering the surface tension of wood enough to reduce its wettability and therefore its gluability.

Northcott et al. (1959 and 1962) have proposed that surface inactivation is actually due to undercured gluebonds. The curing process of phenolic resins requires that water be absorbed from the resin prior to hot pressing (during assembly time). If too much moisture is present at time of pressing the condensation reactions necessary for curing the resin will be retarded.

Currier (1958) showed that Douglas-fir veneer was reduced in water absorbency (wettability) if it was dried at higher temperatures or for longer periods of time at lower temperatures. Northcott et al. (1959) showed that under normal gluing conditions wood which had its water-absorbing capacity reduced by drying did produce undercured gluebonds. In subsequent studies Northcott et al. (1962) showed that if the water absorbing capacity (wettability) was restored by either sanding or treatment with NaOH, adequate bonds could be formed. They also showed that given a sufficiently long assembly time the caustic (NaOH) in the resin was capable of

increasing the wettability enough so that water could be absorbed out of the resin by the wood and good bonding would take place.

Wettability

A prerequisite for good bond formation is wetting of the solid surface by the liquid adhesive (Zisman 1963, Patton 1970). Wetting allows the necessary intimate molecular contact to take place between adhesive and solid substrate. Patton (1970) explained the wetting phenomenon using surface energetics. He stated that three separate processes - adhesion, penetration, and spreading - must take place for complete wetting to occur. Equations 1, 2, and 3 are the work equations associated with adhesion, penetration and spreading, respectively.

$$W_a = \gamma_s - \gamma_I + \gamma_L \quad (1)$$

$$W_p = \gamma_s - \gamma_I \quad (2)$$

$$W_s = \gamma_s - \gamma_I - \gamma_L \quad (3)$$

where: W = change in energy of the system as a result of adhesion
(a), penetration (p) and spreading (s).

γ_s = surface tension (surface free energy) of the solid;

γ_L = surface tension of the liquid;

γ_I = surface tension of the interface between solid and
liquid

A positive value for work is necessary for the process to take place spontaneously; otherwise work has to be applied to the system for wetting to occur. It should be noted that spreading (Equation 3) will not occur unless $\gamma_s > \gamma_L$ (in most systems γ_I is low enough

in value that it can be ignored). Lack of spreading also hinders the adhesion and penetration processes. The above equations (1, 2, and 3) apply only to smooth surfaces; they also contain two hard-to-measure values, γ_s and γ_l . These difficult-to-measure parameters may be eliminated by substituting Young's equation, $\gamma_s - \gamma_l = \gamma_L \cos \theta$ to produce Equations 4, 5, and 6 in which a coefficient for roughness (R) is added. Theta represents the contact angle between liquid and solid (Figure 1) for smooth (θ) and rough (θ_r) surfaces.

$$R = \frac{\cos \theta_r}{\cos \theta}$$

$$W_a = \gamma_L (R \cos \theta_r + 1) \quad (4)$$

$$W_p = \gamma_L (R \cos \theta_r) \quad (5)$$

$$W_s = \gamma_L (R \cos \theta_r - 1) \quad (6)$$

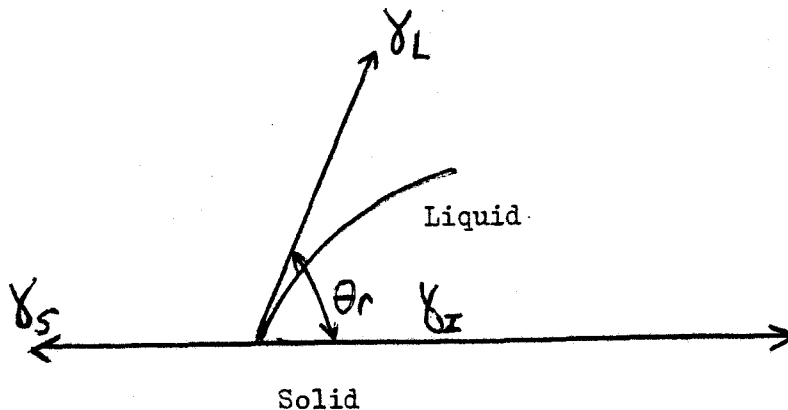


Figure 1. Equilibrium of a droplet on a solid surface.

From the above equations it is evident that when the liquid and solid form a contact angle, $\theta_r > 90^\circ$, penetration and spreading will

not occur and only partial wetting will occur due to the positive value for the work of adhesion (4). Roughness of the surface hinders the wetting process under these conditions. When $\theta_r < 90^\circ$, adhesion and penetration will occur but complete spreading will only be spontaneous if the surface roughness factor is large enough to make W_s positive.

In addition to surface roughness various other features of wood surfaces have been shown to have an influence on the wettability of wood. Herczeg (1965), Gray (1962), Nguyen and Johns (1979), and others have shown that aging of the wood surface decreases wettability. Gray, working with several species, found that most of the decrease occurs within one to two days after surface generation and levels off after three or four days. Stumbo (1964) suggests that this decrease in wettability may be due to the adsorption of gases and vapor from the air, or contaminants settling on the surface, all of which lower the surface tension (surface free energy) of the wood. Nguyen and Johns showed that the surface tension of Douglas-fir drops 43% in 84 hours - from 48 dynes/cm to 27.5 dynes/cm.

The opposite of aging is generation of a fresh wood surface. Gray (1962) and Bodig (1962) have shown that creating a fresh wood surface either by sanding or microtoming results in an increase in wettability. The fresh surface is apparently free of contaminants, adsorbed gases and vapors, or has new bonding sites exposed, all of which would increase the wettability. Gray's work showed that

sanding of Douglas-fir increased the surface tension from 47.5 dynes/cm to 72.3 dynes/cm.

The presence of extractives on the wood surface has been shown to be responsible for decreased wettability in some species (Chen 1970, Gray 1962, Nguyen 1979). This decrease in wettability is primarily due to the lower surface tensions associated with many of the extractives. If the extractives are removed, wettability increases. Nguyen and Johns found a 22% increase in the surface tension of Douglas-fir after removing the extractives. Increasing the surface tension of the solid should (according to the wetting equations) increase wettability. Water, relative to wood has a higher surface tension (72.8 dynes/cm); therefore increases in the moisture content of wood (more water present) will generally result in improved wettability. Wellons (1980) and Chen (1972) have confirmed that wettability is increased as moisture content increases.

If in the drying process wood is exposed to excessively severe conditions inactivated surfaces can result. Hemingway (1969) and Hancock (1964) have shown that these surfaces are reduced considerably in wettability.

The other component in the wetting process is the wetting liquid. Properties of the liquid also influence the wetting of wood surfaces. In general the higher a liquid's surface tension the less likely it is to wet wood which has a relatively lower surface tension. Chen (1972) has shown that as the liquid's

viscosity increases, its ability to wet decreases. It should be noted that for many liquids both surface tension and viscosity are lowered considerably by increasing temperature, therefore enabling the liquids to wet. The swelling ability of a liquid reflects its attraction to wood and its influence on wetting ability. Solutions of immediate interest in this study are aqueous (aq.) phenol, aq. formaldehyde, and aq. NaOH. Stamm (1964) has shown that all three are more capable of swelling wood than water and thereby increase the wood's wettability. Solutions containing varying amounts of these compounds should also be capable of increasing the wettability of a wood surface.

Tests For Predicting Surface Inactivation

Chow (1972) proposed using the change in color intensity of a piece of wood during drying to measure the degree of surface inactivation which has taken place. Using an infrared reflectance colorimeter, color intensities of a piece of wood are measured before and after drying. Chow has shown that as this difference in color intensity increases, bond quality decreases - indicating surface inactivation. This test method is not applicable to mill situations, however, because 1) color intensity measurements must be made on the exact same spot of a piece of veneer before and after drying, 2) the test is not reliable for veneers of very high moisture contents.

Because wettability is necessary for good bond formation, it follows that a relationship should exist between the wettability

and gluability of a wood surface in those situations where wettability is the controlling factor. Freeman and Wangaard (1960), Bodig (1962) and Chen (1970) have all shown that wettability does give a reliable indication of gluability. Because loss of wettability has been shown to accompany surface inactivation, we decided to use wettability measurements to predict that surface inactivation had occurred. Although various methods are available for measuring wettability, they vary in applicability to our study.

Corrected Water Absorption Height

Developed by Freeman (1959), this method requires filling a capillary tube with milled wood. One end of the tube is placed in water and the height of capillary rise indicates the relative wettability of the wood. Bodig (1962) used this method in his studies relating wettability to gluability for five Philippine Mahoganies. He found a high correlation between wettability and gluability. The problem with this method is that milling the wood destroys any difference between surface and interior fibers - therefore it cannot be used in studies of surface inactivation.

Liquid Absorption Time

This method consists of placing a liquid droplet on the wood surface and measuring the time it takes until the drop no longer reflects light. A longer time indicates poor wetting. Hemingway (1969) used this method in his study on surface inactivation and surface wettability. He used water as the test liquid and noted

the tests' sensitivity to changes in surface wettability brought about by heating of the wood. He also established an absorption time of 20 minutes or more as indicating non-wetting. This test appeared very applicable to our study because various solutions could be tested simultaneously. This is essentially the same test recommended by the American Plywood Association (APA) for predicting surface inactivation (Erb 1965). The APA procedure is to measure the difference in absorption time of water on adjacent sanded and unsanded spots on the dried veneer surface. A time difference of four minutes or more indicates a severely inactivated surface. This test method will be evaluated in our study.

Rate of Liquid Spread

Chen (1972) developed this alternative method of measuring wettability. In this test a liquid resin droplet is placed on the surface and photographs taken of it at intervals of 5, 7.5, 10, 20, and 50 seconds. The droplets' extension along the grain is measured from the photographs and a coefficient of spread wetting is determined. The higher the coefficient of spread wetting, the greater the wettability of the surface. Chen found a high correlation ($R = .859$) between the coefficient of spread wetting and the traditional measurement of wetting contact angle. This test as developed by Chen did not appear applicable to our study because we needed to observe several solutions at the same time. However, a modified version of the test (measuring the extent of liquid spread at the time of liquid absorption) was determined to be manageable.

Contact Angles

The most widely used measure of wettability is the liquid contact angle. The wetting equations tell us that the size of the angle formed when a liquid contacts a solid (contact angle) is an indication of whether or not wetting will occur. High contact angles are indicative of poor wetting. Two methods for determining contact angles were considered.

Inclined Plate Method of Measuring Contact Angle. This method was developed by Adams (1938). It requires that a plate of the material to be tested be partly submerged at a 90° angle to the wetting solution. The solution makes a contact angle with the plate. This angle is determined by rotating the plate until the solution is a plane at its contact with the plate. The angle between the plate and the solution is then the contact angle. Bodig (1962) used this method in establishing a relationship between wettability and gluability. He found a significant correlation between contact angles measured by this method and subsequent gluability values. This test method did not appear applicable to our study because once a surface has been tested it cannot be tested again, prohibiting use of several solutions.

Sessile Droplet Method of Measuring Contact Angle. This method consists of placing a liquid droplet on the solid surface and measuring the angle the liquid makes with the solid. Measurements are usually made with a microscope or microscope-camera apparatus. Hse (1972), and Chen (1970) have shown that wettability measurements made in this manner also indicate a surface's gluability. This

method was judged to be very applicable because various solutions on both sanded and unsanded surfaces could be tested simultaneously, with a relatively small quantity of test material.

In conclusion, the literature suggests strongly that a relationship does exist between decreased wettability and loss of gluability due to surface inactivation. However, no research to date has tested this relationship with platen dried veneer. Because platen drying is suspected to heat the wood surface more than convection drying, platen dried veneer might be more severely inactivated. On the other hand, the supply of oxygen at the wood surface during platen drying is limited. Also, platen drying causes most water in green veneer to evaporate and diffuse away from the wood surface through lathe checks and fiber lumen. This should reduce migration of extractives to the veneer surface. Reducing the amount of available oxygen and extractives at the wood surface might result in less surface inactivation or perhaps a different type of inactivation than is found in convection dried veneer. My study will verify whether the existing information on convection dried veneer can be applied to platen dried veneer.

III. EXPERIMENTAL PROCEDURES

Design of Experiment

This study was designed for a split-plot factorial analysis. Factors and levels are shown in Tables 1 and 2; analyses of variance (Tables 29, 30, 31 in the appendix) indicate where the splits occur. Two observations were averaged for each replication.

Peeling and Drying of the Veneer

Twenty-five logs of second-growth Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] were selected and shipped from the Weyerhaeuser plywood plant, Longview, Washington to the U.S. Forest Products Laboratory, Madison, Wisconsin. Upon arrival in Madison, logs were debarked and cut into four-foot long peeler blocks, vat soaked in water at 180°F for approximately eight hours, and then peeled into 24 by 48 inch strips. Both sapwood and heartwood were peeled from each block. Veneer thickness was randomized over all peeler blocks. The veneer for this study was dried in the gluability study (Sandoe and Wellons 1979). Platen drying was in a two foot by two foot steam heated single opening hot press, at the temperatures and to the moisture contents indicated in Tables 1 and 2. To assist removing water vapor from the veneer, a slotted caul plate was installed on the platen adjacent to the loose surface of

TABLE 1. Experimental design for study of factors affecting veneer wettability as measured by liquid absorption time and extent of liquid spread.

Factor	No. of Levels	Level Studied
Veneer Thickness	4	0.1", 0.2", 0.3", 0.4"
Drying Temperature	5	Platen dried - 325°F (163°C), 375°F (191°C), 425°F (218°C), 460°F (238°C) Air dried - 425°F (218°C)
Final Veneer Moisture Content	3	1%, 5%, 9%
Wood Type	2	Sapwood, Heartwood
Test Time	2	Immediately after press drying, conditioned for 30 days
Veneer Surface	2	Sanded, Unsanded
Solutions	4	H ₂ O, 0.5% Aq. NaOH, 25% phenol-formaldehyde solids in water, 25% phenol-formaldehyde solids in 0.5% Aq. NaOH
Replication	2	

TABLE 2. Experimental design for study of factors affecting veneer wettability as measured by liquid contact angle.

Factor	No. of Levels	Level Studied
Veneer Thickness	4	0.1", 0.2", 0.3", 0.4"
Drying Temperature	5	Platen dried - 325°F (163°C), 375°F (191°C), 425°F (218°C), 460°F (238°C) Air dried - 425°F (218°C)
Final Veneer Moisture Content	3	1%, 5%, 9%
Wood Type	2	Sapwood, Heartwood
Veneer Surface	2	Sanded, Unsanded
Solution	2	H ₂ O, 0.5% Aq. NaOH
Replication	2	

the veneer.¹ Drying times were determined from time-temperature curves prepared in preliminary experiments.

Sample Preparation

Each sheet of dried veneer (22" x 24") was immediately cut in two; one piece (17" x 22") for the gluability study (Figure 2A) and a corresponding piece (7" x 22") for the surface inactivation study. The 7" x 22" piece was divided into three pieces (Figure 2B, C, D), two 7" x 9" pieces to be used for liquid absorption time and extent of liquid spread tests and a 7" x 4" piece to be used for the liquid contact angle test. One of the 7" x 9" pieces (Figure 2B) was placed between two aluminum caul plates and allowed to cool. This piece was used to test for surface inactivation immediately after press drying. The other two pieces were stored in a conditioning room set to provide approximately a 5% equilibrium moisture content (temperature = 90°F, relative humidity = 24%). These samples were used for measuring absorption times and extent of spread (Figure 2D), and contact angle (Figure 2C) after conditioning.

Immediately prior to testing, the tight side of the test sample was sanded lightly parallel to the grain in two areas as shown in Figure 3 and then blown clean of dust. The sanding resulted in the sample having alternating unsanded and sanded zones. As shown, two observations for each replicate of the liquid

¹The loose-side of a piece of veneer is that surface originally facing the interior of the log. It has lathe checks present whereas the tight-side does not.

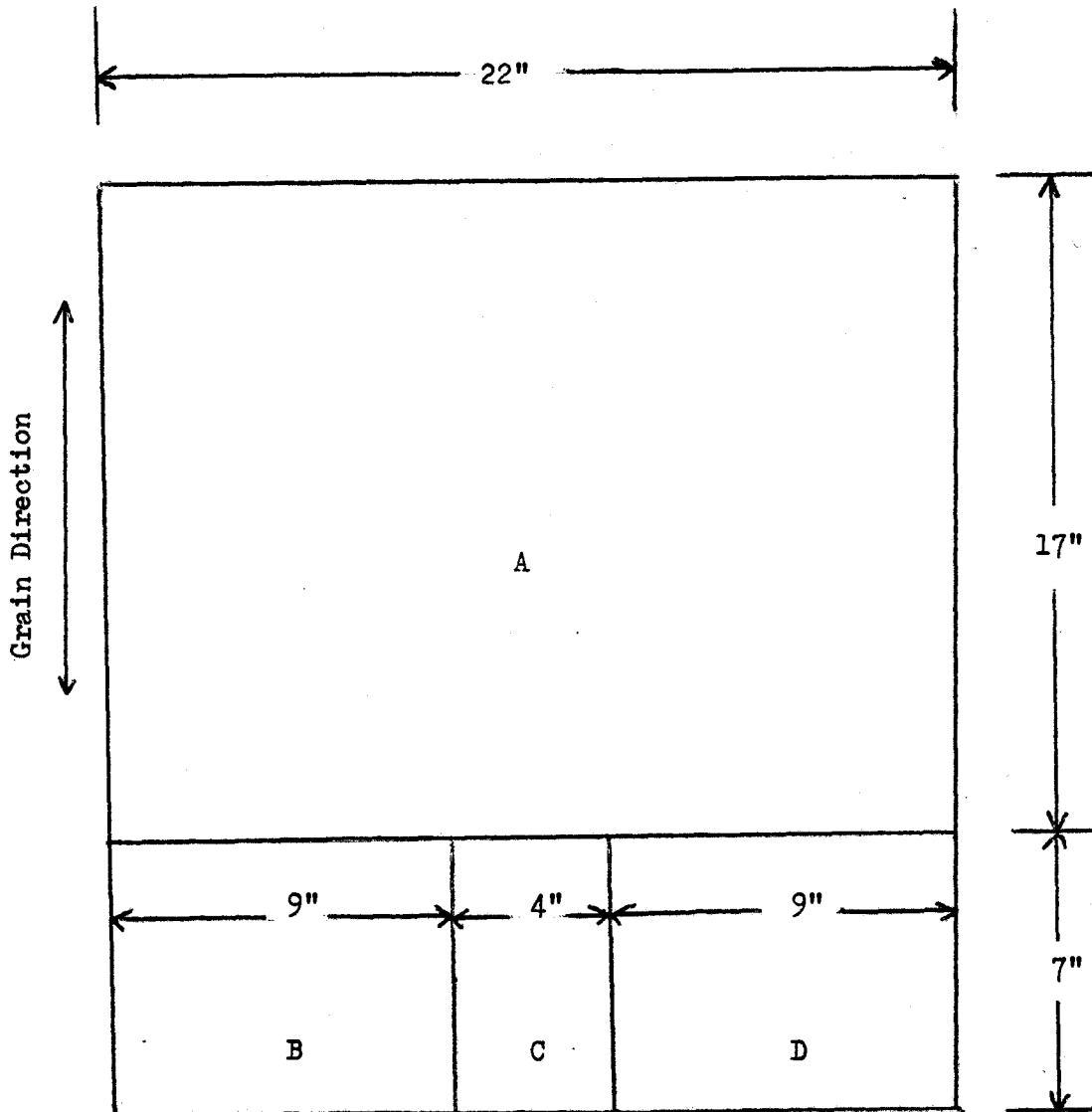


Figure 2. Diagram of cutting pattern for test samples.
A - gluability study
B - liquid absorption time/extent of liquid spread immediately after press drying
C - contact angle measurement
D - liquid absorption time/extent of liquid spread after 30 days conditioning

Figure 4 shows the test pattern resulting from the sanding of the contact angle test sample. It also had two observations for each replicate.

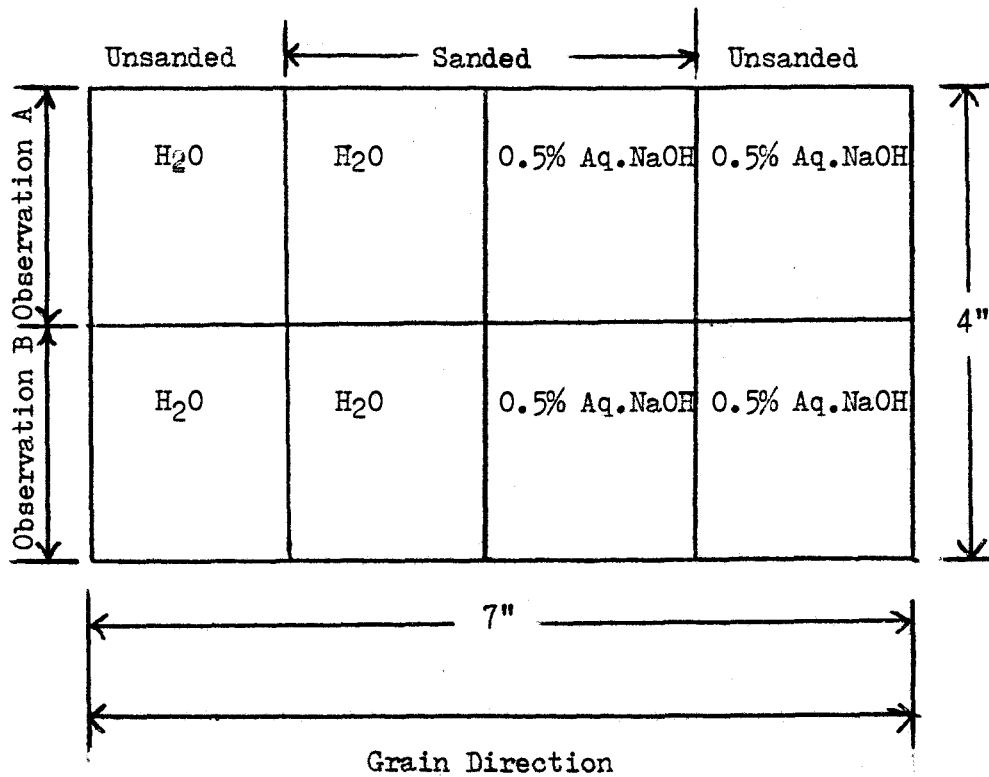


Figure 4. Test sample for contact angle after sanding of the veneer.

Liquid Absorption Time - Extent of Liquid Spread

Liquid absorption times and extents of liquid spread on the veneer surface were measured for four different solutions on both sanded and unsanded dry veneer. The liquids tested are described in Table 3.

In preparing the P/F/C-solution, the water, phenol, formalin and NaOH were mixed and heated at the rate of 5°F/minute until reflux (approximately 30 minutes). Reflux was continued for 35 minutes, after which the cook was stopped. This procedure resulted in a partly cooked resin containing some dimers and trimers of methylol phenols but only approximately ½% free formaldehyde. The other three solutions were prepared by mixing at ambient temperatures the ingredients listed in Table 3.

Each solution was randomly assigned a different zone (1-4) for every new sample (Figure 3). One droplet of each solution was placed in its zone in each of the four (two sanded and two unsanded) areas of the sample. Because the surface tensions varied between solutions, the following different gauge needles were ground to a flat tip and used to obtain droplets of approximately 12 µl:

<u>Needle Gauge</u>	<u>Solution</u>
22	H ₂ O
22	0.5% aqueous NaOH
18	25% phenol-formaldehyde solids in water (P/F)
20	25% phenol-formaldehyde solids in 0.5% aqueous NaOH (P/F/C)

TABLE 3. Ingredients and physical properties of test solutions.

Liquid	Component - weight	Surface tension (dynes/cm)	Viscosity (Cps)
25% phenol-formaldehyde in water (P/F)	50.03% Formalin	43	1
	119.9 grams		
	90% phenol		
	104.4 grams		
	Water		
	391.7 grams		

0.5% Aq. NaOH	50% NaOH	75	1
	2 grams		
	Water		
	198 grams		

25% phenol-formaldehyde in 0.5% Aq. NaOH (P/F/C)	50.03% Formalin	51	18
	365.98 grams		
	90% phenol		
	317.34 grams		
	50% NaOH		
	10.06 grams		
	Water		
	323.57 grams		

Water	Distilled water	75	1

Droplets were placed on the tight-side of earlywood only. Each droplet was monitored for the length of time it took to absorb completely, noted by its failure to reflect light. At the time of complete absorption the droplets' extent of spread parallel to the grain was marked and measured. A maximum of 20 minutes was allowed for absorption. After 20 minutes, testing was stopped and the extent of liquid spread was measured. The same procedures were followed in testing for liquid absorption time and extent of liquid spread on samples after 30 days of conditioning.

Contact Angle Measurement

A horizontally oriented 35 mm camera with a 50 milliliter lens was used to photograph contact angles. Samples were placed tight side up with the veneer surface parallel to and grain direction perpendicular to the axis of the camera. Droplets of H_2O and 0.5% Aq. NaOH were placed on both freshly sanded and unsanded zones of earlywood in the camera's field of view using 18 gauge needles that had been ground to a flat tip. The sequence of application was:

- 1 - H_2O - unsanded
- 2 - H_2O - sanded
- 3 - 0.5% Aq. NaOH - sanded
- 4 - 0.5% Aq. NaOH - unsanded

Photographs were taken at intervals of 20 seconds, 60 seconds, 120 seconds after the H_2O droplet had been applied to unsanded veneer.

A slide projector and mirror were used to project the photographs onto a table. Contact angles were measured to the nearest degree using a base-board protractor.

Bond Quality Determination

Shear specimens for determining bond quality (shear strength and % wood failure) were prepared in the gluability study (Sandoe and Wellons 1979). After conditioning the veneer, adhesive was applied to that portion of the dried veneer (Figure 2A) to be glued, and two-ply parallel laminates (13" x 11") were hot pressed with the lathe checks (loose sides) toward the glueline, using Monsanto's phenolic resin adhesive, PF 3048, at the following rates: 33, 37, 42, and 48 lbs. per 1000 sq. ft. of glueline for 0.1, 0.2, 0.3, and 0.4 inch thick veneers respectively. The closed assembly time was 20 minutes and the press times were 4, 5, 6, and 8 minutes for 0.2, 0.4, 0.6 and 0.8 inch thick panels, respectively. These times were approximately one minute longer than recommended by the adhesive supplier to insure complete curing.

Cured panels were hot stacked for at least 12 hours and then cut into shear specimens. Shear specimens from each panel were aged by one of three methods; no aging, cyclic boil-chill-dry exposure developed by Kreibich and Freeman (1968), or vacuum-pressure-soak (Anon. 1974). After aging the specimens were tested in a globe shear tester. Failure loads were recorded and percentage wood failures determined.

IV. RESULTS, DISCUSSION AND CONCLUSIONS

Effect of Test Methods

The three test methods (absorption time for liquid, extent of spread and contact angle for liquid) were examined to determine whether they were indicating changes in wettability that resulted from changes in test procedure and drying method. Tables 4, 5 and 6 show the average values obtained for each test method. The absorption time (Table 4) and the contact angle (Table 6) tests showed a wide range of values depending on test time, solution tested and whether or not the veneer had been sanded. Likewise Tables 7 and 8 show substantial changes in wettability as a function of drying variables. These results suggest that absorption time and contact angle were sensitive to changes in wettability, supporting findings by Hemingway (1969) for absorption time and Freeman (1959), Bodig (1962) and others for contact angle. Wide ranges of values were not apparent with the extent of liquid spread tests (Table 5) indicating this technique is not comparable to Chen's (1972) rate of liquid spreading test for detecting wettability. Our test measured the total distance the liquid had spread at time of complete absorption whereas Chen's test involved measuring the rate at which the liquid was spreading by taking several measurements at various time intervals. Our results depended mainly on the volume of liquid used, and we therefore did not see a large range of values. Another factor which may have added to the

TABLE 4. Absorption time for liquid on platen dried veneers.*

Test Time	Liquid	Absorption Time (Minutes)			
		Unsanded (U)	Sanded. (S)	Average	Difference U-S
Immediately After Press Drying	P/F-Solution**	0.2	0.2	0.2	0
	0.5% Aq. NaOH	2.6	0.9	1.8	1.7
	P/F/C-Solution**	11.3	6.9	9.1	4.4
	H ₂ O	13.4	3.7	8.5	9.7
	Average	6.9	2.9	4.9	
After 30 Days Conditioning	P/F-Solution**	0.1	0.2	0.1	-.1
	0.5% Aq. NaOH	5.1	1.9	3.5	3.2
	P/F/C-Solution**	14.5	10.2	12.3	4.3
	H ₂ O	17.5	6.1	11.8	11.4
	Average	9.3	4.6	7.0	
Average For Both Test Times	P/F-Solution**	0.1	0.2		
	0.5% Aq. NaOH	3.9	1.4		
	P/F/C-Solution**	12.9	8.5		
	H ₂ O	15.4	4.9		

* Averaged for all veneer thicknesses, drying temperatures, moisture contents and wood types.

** P/F = Phenol/Formaldehyde; P/F/C = Phenol/Formaldehyde/0.5% NaOH.

TABLE 5. Extent of liquid spread on platen dried veneers.*

Test Time	Liquid	Absorption Time (Minutes)		
		Unsanded (U)	Sanded (S)	Difference U-S
Immediately After Press Drying	P/F-Solution**	2.6	2.5	-.1
	0.5% Aq. NaOH	2.2	2.6	.4
	P/F/C-Solution**	2.1	2.0	-.1
	H ₂ O	1.2	2.7	1.5
After 30 Days Conditioning	P/F-Solution**	2.7	2.5	-.2
	0.5% Aq. NaOH	1.9	2.7	.8
	P/F/C-Solution**	1.8	1.8	0
	H ₂ O	.7	2.5	1.8

* Averaged for all veneer thicknesses, drying temperatures, moisture contents and wood types.

** P/F = Phenol/Formaldehyde; P/F/C = Phenol/Formaldehyde/0.5% NaOH.

TABLE 6. Contact angles for liquids on platen dried veneers.*

Liquid	Contact Angle (Degrees)		Difference U-S
	Unsanded (U)	Sanded (S)	
0.5% Aq. NaOH	17	2	15
H ₂ O	74	18	56

* Averaged for all veneer thicknesses, drying temperatures, moisture contents and wood types.

TABLE 7. Average* absorption times for liquids on platen dried veneer as a function of drying variables.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	5.7	6.0	6.7	4.7	3.9	5.8	5.4
.2	4.8	5.5	4.7	5.0	3.6	5.0	4.7
.3	5.9	5.8	6.5	8.1	6.6	6.6	6.6
.4	6.1	6.6	7.1	7.4	---	6.8	6.8
MEAN	5.6	6.0	6.3	6.3	4.9	6.1	5.9
ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	4.1	5.7	5.5	5.2	3.2	5.1	4.7
.2	5.7	4.8	5.5	5.5	4.7	5.4	5.2
.3	5.6	7.0	6.8	8.7	6.6	7.0	6.9
.4	7.1	7.1	8.0	8.8	6.0	8.0	7.4
MEAN	5.6	6.2	6.5	7.1	5.1	6.4	6.1

* Averaged for all moisture contents, test times, solutions, with and without sanding.

TABLE 8. Average* contact angles for liquids on platen dried veneer as a function of drying variables.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
CONTACT ANGLE FOR SAPWOOD, DEGREES							
.1	24	32	29	23	26	27	27
.2	20	28	26	24	15	25	23
.3	18	23	31	29	34	25	27
.4	17	27	35	33	---	28	28
MEAN	20	28	30	27	25	26	26
CONTACT ANGLE FOR HEARTWOOD, DEGREES							
.1	30	30	24	42	16	32	28
.2	23	22	32	31	22	27	26
.3	18	28	41	42	32	32	32
.4	25	30	41	45	24	35	33
MEAN	24	28	35	40	24	32	30

*Averaged for all moisture contents, test times, solutions, with and without sanding.

insensitivity of the test was the inability to accurately determine the liquid's leading edge. This problem arose because the liquid did not always spread evenly. Often the liquid would spread varying distances along its front due to the differences in the roughness of the wood surface.

Correlations of test methods (Table 9) showed that the only significant relationships were between absorption time for the liquid and extent of liquid spread. This significant correlation was to be expected (1) because both measurements were made from the same droplet, (2) because the greater the extent of spread, the greater the surface area for absorption, and (3) because spreading and absorption (penetration) are related wetting processes (Patton 1970). However, these correlations seem to contradict the prior conclusion that liquid absorption time is sensitive to changes in wettability while extent of liquid spread is not. Apparently although the range of values for liquid spread is limited, small increases in extent of spread do result in more rapid liquid absorption. The lack of any significant correlations between contact angle and absorption time suggests (1) that one or both of these techniques is not measuring true changes in wettability, or (2) that factors influencing wettability differed substantially from one location to another on the veneer surface.

Correlation between test methods were done only for those tested after 30 days of conditioning and for the water and 0.5% aqueous NaOH solutions because no contact angle tests were made immediately out of the press (due to time constraints) or with the

TABLE 9. Correlations between wettability test methods after 30 day conditioning of veneers.

Methods Correlated	Correlation Coefficients (R) for			
	Water on Unsanded Veneer	Water on Sanded Veneer	0.5% Aq. NaOH on Unsanded Veneer	0.5% Aq. NaOH on Sanded Veneer
Absorption time vs. Extent spread	-0.81	-0.66	-0.56	-0.09
Absorption time vs. Contact angle	+0.36	+0.34	+0.27	+0.19
Extent spread vs. Contact angle	-0.37	-0.08	-0.15	-0.18

P/F or P/F/C solutions. These latter two solutions were not tested for contact angle, because observations of absorption time for the liquid and extent of liquid spread tests indicated that no measurable contact angles would be formed.

Effect of Drying Variables on Wettability

The drying variables which had a significant effect on wettability were thickness of the veneer, the veneer drying temperatures, and wood type (sapwood or heartwood). See the analysis of variance tables (Appendix, Tables 29 and 31) for absorption times and contact angles. The moisture content the veneer was dried to did not significantly affect wettability as measured by liquid absorption time or contact angle.

Judgment of significance was based on a 0.001 significance level and F-ratios ≥ 10.0 . F ratios of 10 or greater were chosen because (1) given the large number of degrees of freedom, numerous factors and interactions had significance levels of 0.001, and (2) from a practical point of view, F-ratios of less than 10.0 corresponded to contact angles of 5° or less and absorption times of less than one minute, both of which are too small (short) to be relevant.²

Tables 7 and 8 show the average absorption times and contact angles as a function of veneer thickness, drying temperature, and

²Factors affecting extent of liquid spread (Appendix, Table 30) were not considered because as previously indicated, this technique appeared to be insensitive to changes in wettability.

wood type. It should be noted that although these tables of averages do reflect general trends in the data, they mask the wide range of values observed. Furthermore a few drying variables had significant interactions with testing variables, requiring that the effect of these drying variables be examined for each solution. Tables 10-15 give the corresponding values for absorption times and contact angles for each solution tested on unsanded veneer. The combination of water on unsanded veneer most strongly indicated lack of wetting.

From Tables 7, 8, 10, and 14 the following should be noted:

- as thickness of veneer increased, wettability decreased;
- these patterns were in general stronger in heartwood than in sapwood; and
- heartwood was reduced in wettability more so than sapwood.

All of the above indicate a veneer drying time-temperature relationship affecting wettability. These findings agree with other researchers (Currier 1958, Hancock 1964, Hemingway 1969) who have found that as drying temperature or time at a particular temperature increases the wettability, whether measured by absorption or contact angle, is decreased. The difference in wettability between sapwood and heartwood may be interpreted as supporting the literature which states that the presence of extractives (heartwood) can both reduce wettability (Chen 1970, Gray 1962, Nguyen 1979) and aggravate surface inactivation (Chow 1971).

TABLE 10. Average* absorption times for water on unsanded platen dried veneer as a function of drying variables.

Thickness Inches	Temperature °F				Oven	Mean	
	325	375	425	460	425	Platen	Overall
ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	14.2	15.0	17.9	13.5	12.7	15.2	14.7
.2	14.2	15.5	16.1	14.6	11.6	15.1	14.4
.3	16.3	17.6	17.9	18.3	16.7	17.5	17.4
.4	16.3	17.3	18.8	18.7	----	17.8	16.8
MEAN	15.3	16.4	17.7	16.3	13.7	16.4	16.1
ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	11.1	13.7	13.3	15.6	8.9	13.4	12.5
.2	15.0	15.1	15.9	12.9	13.7	14.7	14.5
.3	11.0	16.8	18.0	19.9	15.7	16.4	16.3
.4	16.4	18.1	19.6	20.0	15.2	18.5	17.9
MEAN	13.4	15.9	16.7	17.1	13.4	15.8	15.3

* Averaged for all moisture contents and test times.

TABLE 11. Average* absorption times for 0.5% Aq. NaOH on unsanded platen dried veneer.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	3.0	3.4	5.7	3.7	3.7	4.0	3.9
.2	3.2	4.2	2.6	3.5	1.6	3.4	3.0
.3	3.0	4.5	4.8	7.4	5.2	4.9	5.0
.4	3.4	4.5	6.3	7.1	---	5.3	5.3
MEAN	3.2	4.2	4.9	5.4	3.5	4.4	4.3
ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	1.5	2.3	3.4	2.0	1.3	2.3	2.1
.2	2.6	2.7	3.6	3.7	3.6	3.2	3.2
.3	1.8	3.0	5.5	7.7	4.8	4.5	4.6
.4	3.0	4.7	6.3	9.1	2.9	5.8	5.2
MEAN	2.2	3.2	4.7	5.6	3.2	4.0	3.8

* Averaged for all moisture contents and test times.

TABLE 12. Average* absorption times for P/F/C solution on unsanded platen dried veneer.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	18.8	15.9	15.4	10.2	7.8	15.1	13.6
.2	12.3	11.5	11.0	14.3	7.9	12.3	11.4
.3	14.2	14.1	14.6	17.6	13.5	15.1	14.8
.4	14.6	14.9	17.7	14.1	---	15.3	15.3
MEAN	15.0	14.1	14.7	14.1	9.7	14.5	13.8
ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	10.1	13.5	12.0	12.7	5.4	12.1	10.7
.2	9.4	10.3	10.1	10.6	6.2	10.1	9.3
.3	14.5	10.8	16.2	17.0	12.9	14.6	14.3
.4	16.1	13.3	15.6	15.6	13.8	15.2	14.9
MEAN	12.5	12.0	13.5	14.0	9.6	13.0	12.3

* Averaged for all moisture contents and test times.

TABLE 13. Average* absorption times for P/F solution on unsanded platen dried veneer.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	.1	.2	.2	.2	.1	.2	.2
.2	.1	.2	.1	.2	.2	.2	.2
.3	.1	.2	.2	.2	.1	.2	.2
.4	.1	.1	.1	.2	---	.1	.1
MEAN	.1	.2	.2	.2	.1	.2	.2

ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	.2	.2	.2	.2	.1	.2	.2
.2	.2	.1	.1	.1	.1	.1	.1
.3	.2	.1	.2	.2	.2	.2	.2
.4	.1	.2	.1	.2	.2	.2	.2
MEAN	.2	.2	.2	.2	.2	.2	.2

* Averaged for all moisture contents and test times.

TABLE 14. Average* contact angles for water on unsanded platen dried veneer as a function of drying variables.

Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
CONTACT ANGLE FOR SAPWOOD, DEGREES							
.1	64	75	74	65	71	70	70
.2	60	82	79	73	43	74	67
.3	58	67	83	79	84	72	74
.4	59	80	84	88	---	78	78
MEAN	60	76	80	76	66	74	72
CONTACT ANGLE FOR HEARTWOOD, DEGREES							
.1	74	79	67	83	42	76	69
.2	68	70	76	80	59	74	71
.3	51	76	101	95	82	83	83
.4	74	84	94	100	65	88	83
MEAN	69	77	85	90	62	80	77

* Averaged for all moisture contents.

TABLE 15. Average* contact angles for 0.5% Aq. NaOH on unsanded platen dried veneer as a function of drying variables.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
CONTACT ANGLE FOR SAPWOOD, DEGREES							
.1	24	34	28	14	23	25	25
.2	15	22	13	12	6	16	14
.3	4	14	23	18	23	15	16
.4	2	14	22	7	---	11	11
MEAN	11	21	22	13	17	17	17
CONTACT ANGLE FOR HEARTWOOD, DEGREES							
.1	15	21	15	36	2	22	18
.2	5	5	29	25	10	16	15
.3	1	11	37	28	21	19	20
.4	7	11	31	27	16	19	18
MEAN	7	12	28	29	12	19	18

*Averaged for all moisture contents.

Effect of Test Variables on Wettability

All three test variables--solution tested, test time (immediately after press drying and after 30 days conditioning), and sanding significantly affected wettability. In addition, these main effects interacted significantly with each other and in selected instances with the drying variables thickness, temperature, and wood type (Appendix, Tables 29, 31). These interactions require that these variables be examined simultaneously rather than separately. Again judgment of significance was based on a 0.001 significance level and F-ratios ≥ 10.0 .

Tables 4 and 6 show how absorption times and contact angles varied depending on test time, sanding and which solution was used. The main effect of solution is clearly described. The P/F solution and 0.5% Aq. NaOH had short (< 3 minutes) absorption times, indicating good wetting ability. Water and the P/F/C solution had much greater absorption times--8-12 minutes on the average--implying poor wetting. The contact angle tests used only 0.5% Aq. NaOH and water, however the same pattern existed--the caustic solution gave small contact angles (good wetting) and water gave large contact angles (indicating poor wetting).

The wide range of values between solutions can be attributed to their different physical characteristics. The P/F solution has a relatively low surface tension ($\gamma = 43.3$ dynes/cm, Table 3), also has a strong attraction to wood (Stamm 1964) and therefore readily wets wood surfaces. Northcott et al. (1962), and others have shown

that caustic solutions (0.5% Aq. NaOH) improve the wettability of wood surfaces. The P/F/C solution has a comparatively high viscosity (18 cps to 1 cps for the other solutions) which hinders in part its ability to wet wood surfaces, especially after the wood adsorbs water and caustic from the phenolic solids. Water has a surface tension of 72.2 dynes/cm and therefore does not spontaneously wet dry Douglas-fir surfaces which have been found to have surface tensions of 44-50 dynes/cm (Zisman 1963, Gray 1962). The surface tension of wood does increase with increases in moisture content, therefore the solutions should show improved wetting ability with time. Figure 5 shows that wettability (as measured by contact angle) improves with time.

The effect of solution interacted with veneer thickness in both the absorption time and contact angle measurements. For absorption time, this interaction results primarily from the fact that the P/F solution wets all thicknesses equally well whereas the other three solutions wet less effectively as thickness increases. This interaction is illustrated in Table 16 for all conditions but is also apparent in Tables 10-13 for individual conditions. For contact angle, this interaction results primarily from the fact that only subtle differences in contact angle occurred with 0.5% Aq. NaOH as thickness increases, but these differences were more pronounced with water (Table 17). These same observations are seen in Tables 14 and 15. The effect of solution interacted with wood type in the contact angle data for the same reason as above. As Table 18 shows, the difference in contact angle measured with Aq. NaOH on sapwood and

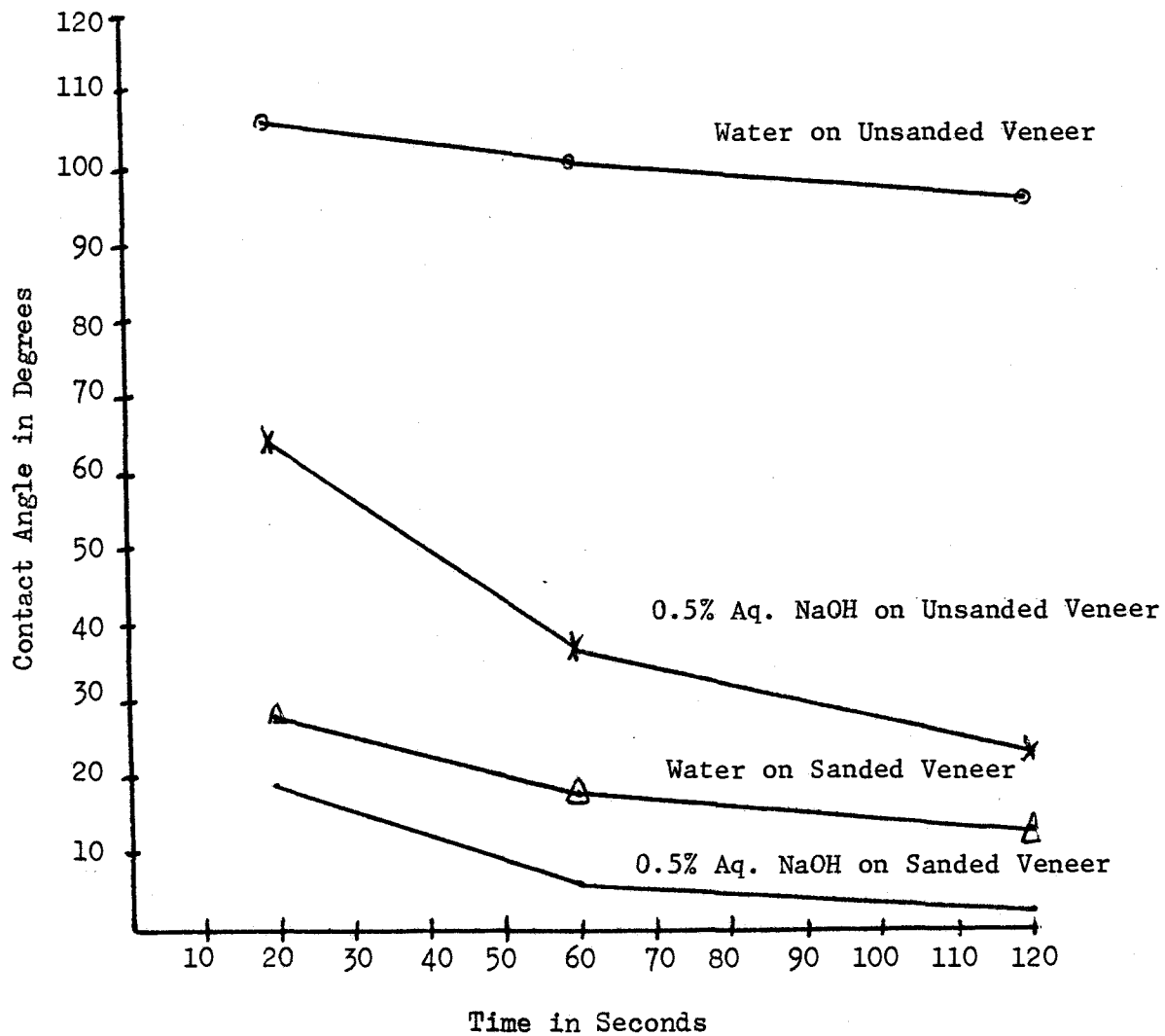


Figure 5. Contact angles for liquids on .3" heartwood veneer platen dried at 425°F.

TABLE 16. Average* absorption times for liquids on platen dried veneer as a function of veneer thickness.

Veneer Thickness Inches	Absorption Time, Minutes			
	Liquid			
	P/F	0.5% Aq. NaOH	P/F/C	H ₂ O
.1	0.2	2.0	9.9	8.3
.2	0.1	2.1	8.4	9.3
.3	0.2	3.3	12.2	11.4
.4	0.2	3.3	12.4	11.7

TABLE 17. Average* contact angles for liquids on platen dried veneer as a function of veneer thickness.

Veneer Thickness Inches	Contact Angle, Degrees	
	Liquid	
	H ₂ O	0.5% Aq. NaOH
.1	44	12
.2	41	7
.3	49	10
.4	51	9

*Averaged for all drying temperatures, moisture contents, wood types, with and without sanding.

TABLE 18. Average* contact angles for liquids on platen dried veneer as a function of wood type.

Wood Type	Contact Angle, Degrees	
	H ₂ O	0.5% Aq. NaOH
Sapwood	43	9
Heartwood	49	10

TABLE 19. Average** absorption times for liquids on platen dried veneer as a function of wood type and sanding.

Wood Type	Absorption Time, Minutes			
	P/F	0.5% Aq. NaOH	P/F/C	H ₂ O
<u>Unsanded</u>				
Sapwood	.1	4.0	13.5	15.6
Heartwood	.1	3.8	12.3	15.3
<u>Sanded</u>				
Sapwood	.1	1.1	7.3	4.4
Heartwood	.2	1.8	9.7	5.4

* Averaged for all veneer thicknesses, drying temperatures, moisture contents, with and without sanding.

** Averaged for all veneer thicknesses, drying temperatures, moisture contents.

heartwood was not significant compared to the difference in the contact angles measured with water.

Aging the surface increased absorption time significantly. Table 4 shows this effect of surface age (test time) on wettability. The absorption times for most solutions on both sanded and unsanded veneer surfaces increased with aging. This finding supports Gray (1962), Herczeg (1965), and others who have found a decrease in wettability with increased surface age.

Surface aging interacted with solution (Table 4) primarily because water and the P/F/C solution differed from 0.5% Aq. NaOH and P/F solution considerably more after aging than before aging.

Absorption times and contact angles for all solutions were much lower after sanding (Tables 4 and 6), indicating an improvement in wettability of the veneer surface with sanding, supporting findings of Gray (1962), and Bodig (1962). Sanding removes the surface fibers, eliminating any surface inactivation, exposing fresh fibers which have a higher surface tension (Gray 1962) and therefore improving wettability.

The observation that aged veneers after sanding had longer absorption times than unaged veneers after sanding indicates that light sanding was not completely effective in creating a fresh surface and therefore may not have completely eliminated the factors responsible for the decrease in wettability due to aging.

Sanding interacted significantly with solution primarily because sanding had no effect on the absorption times of the P/F solution whereas the other solutions all showed a decrease in absorption

times with sanding (Table 4). In addition, wood type influenced the sanding/solution interaction (Table 19) because 0.5% Aq. NaOH, the P/F/C solution and H₂O all had different absorption times for sapwood than for heartwood after sanding. Prior to sanding the differences were either smaller or of the opposite sign. No physical explanation is apparent for this effect.

In both the absorption time and contact angle data, sanding also interacted with the drying variable temperature (see Table 20 for example) because sanding reduced the effect of temperature on wettability. Sanding and wood type interacted in the absorption time data (Table 21) because the effect of sanding on wettability was greater for sapwood than for heartwood. Again no physical explanation for this effect is apparent.

Tables 22 and 23 show our results for the APA test for surface inactivation. They would seem to indicate that all of our samples were inactivated because the difference in absorption time of water on adjacent unsanded and sanded spots on veneer were all above four minutes. However, the gluability results (Table 24 from Sandoe and Wellons 1979) indicate little surface inactivation except for the long drying times encountered with the thickest veneers. Apparently APA's test method does not apply to platen dried veneer.

Correlations of Wettability and Gluability

Bodig (1962), Freeman (1959), Freeman and Wangaard (1960) have related the wettability of wood to its gluability. Tables 25, 26, and 27 show the results of correlations made between the various measures

TABLE 20. Average* absorption times for liquids on platen dried veneer as a function of drying temperatures and sanding.

Absorption Time, Minutes		
Drying Temperature °F	Unsanded	Sanded
325	7.7	3.5
375	8.2	3.9
425	9.0	3.7
460	9.1	4.3
OVEN 425	6.4	3.4

TABLE 21. Average* absorption times for liquids on platen dried veneer as a function of wood type and sanding.

Absorption Time, Minutes		
Wood Type	Unsanded	Sanded
Sapwood	8.3	3.2
Heartwood	7.9	4.3

* Averaged for all veneer thicknesses, moisture contents, wood types, test times, solutions.

** Averaged for all veneer thicknesses, drying temperatures, moisture contents, test times, solutions.

TABLE 22. Difference between sanded and unsanded veneer in absorption time of water -- immediately after platen drying.*

Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
DIFFERENCE IN ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	10.2	9.0	14.8	6.7	6.8	10.2	9.5
.2	5.8	8.8	11.6	9.6	8.7	9.0	8.9
.3	9.9	14.2	14.0	11.2	9.3	12.3	11.7
.4	6.8	13.8	14.7	11.1	---	11.6	11.6
MEAN	8.2	11.5	13.8	9.7	8.3	10.8	10.3

DIFFERENCE IN ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	8.2	7.5	10.3	10.7	3.6	9.2	8.1
.2	7.7	11.2	10.5	6.5	6.0	9.0	8.4
.3	2.9	9.1	12.4	14.9	7.2	9.8	9.3
.4	10.6	12.6	13.8	13.7	10.8	12.7	12.3
MEAN	7.4	10.1	11.8	11.5	6.9	10.2	9.5

* Averaged for all moisture contents.

TABLE 23. Difference between sanded and unsanded veneer in absorption time of water -- after 30 day conditioning.*

Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
DIFFERENCE IN ABSORPTION TIME FOR SAPWOOD, MINUTES							
.1	14.6	11.7	12.1	14.0	13.2	13.1	13.1
.2	17.0	12.2	16.5	15.4	9.1	15.3	14.0
.3	12.8	13.6	12.6	10.2	10.3	12.3	11.9
.4	16.3	15.0	14.0	11.2	---	14.1	14.1
MEAN	15.2	13.1	13.8	12.7	10.9	13.7	13.1

DIFFERENCE IN ABSORPTION TIME FOR HEARTWOOD, MINUTES							
.1	9.2	14.7	9.9	14.1	10.1	12.0	11.6
.2	8.9	11.3	10.9	10.5	8.0	10.4	9.9
.3	7.5	7.2	15.0	8.9	10.5	9.7	9.8
.4	6.1	12.4	9.4	7.6	10.8	8.9	9.3
MEAN	7.9	11.4	11.3	10.3	9.9	10.3	10.2

* Averaged for all moisture contents.

TABLE 24. Shear strength of parallel laminated veneers after vacuum-pressure aging.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
BREAKING LOAD FOR SAPWOOD, PSI							
.1	450	437	455	430	412	443	437
.2	443	427	487	390	413	437	432
.3	385	362	383	380	432	378	388
.4	304	342	323	397	---	342	342
MEAN	396	392	412	399	419	400	404

BREAKING LOAD FOR HEARTWOOD, PSI							
.1	395	482	438	410	440	431	433
.2	503	475	498	427	447	476	470
.3	467	463	455	420	533	451	468
.4	338	346	367	365	310	354	345
MEAN	426	442	440	406	433	429	429

TABLE 25. Correlations of bond strength with absorption time after vacuum-pressure (V-P) and boil aging on sanded (S) and unsanded (U) veneer.

Test Time	Liquid	Correlation Coefficients (R) For			
		V-P Aging		Boil Aging	
		Sanded	Unsanded	Sanded	Unsanded
Immediately After Platen Drying	P/F Solution*	+0.05	+0.13	---	+0.06
	0.5% Aq. NaOH	-0.13	-0.15	---	-0.18
	P/F/C Solution*	-0.01	-0.15	---	-0.16
	H ₂ O	-0.02	-0.22	---	-0.25
	H ₂ O Difference U-S		-0.22		-0.22
	0.5% Aq. NaOH Difference U-S		-0.12		-0.12
After 30 Day Con- ditioning	P/F Solution*	+0.00	-0.02	---	---
	0.5% Aq. NaOH	-0.22	-0.17	-0.24	-0.18
	P/F/C Solution*	-0.08	-0.09	---	-0.06
	H ₂ O	-0.06	-0.14	---	-0.19
	H ₂ O Difference U-S		-0.05		-0.05
	0.5% Aq. NaOH Difference U-S		-0.10		-0.10

* P/F = Phenol/Formaldehyde; P/F/C = Phenol/Formaldehyde/0.5% NaOH.

TABLE 26. Correlation of bond strength with extent of liquid spread after vacuum-pressure (V-P) and boil aging on sanded (S) and unsanded (U) veneer.

Test Time	Liquid	Correlation Coefficients (R) For		
		V-P Aging		Boil Aging
		Sanded	Unsanded	Unsanded
Immediately After Platen Drying	P/F Solution*	+0.02	+0.05	---
	0.5% Aq. NaOH	+0.05	+0.19	+0.20
	P/F/C Solution*	+0.10	+0.12	---
	H ₂ O	+0.10	+0.20	+0.27

After 30 Days Con- ditioning	P/F Solution*	+0.01	+0.06	---
	0.5% Aq. NaOH	+0.04	+0.21	+0.19
	P/F/C Solution*	+0.06	+0.07	---
	H ₂ O	+0.08	+0.15	+0.21

* P/F = Phenol/Formaldehyde; P/F/C = Phenol/Formaldehyde/0.5% NaOH.

TABLE 27. Correlation of bond strength with contact angle after vacuum-pressure and boil aging on sanded (S) and unsanded (U) veneer.

Solution	Surface	Vacuum-Pressure	Boil
H ₂ O	U	-.07	-.13
H ₂ O	S	-.002	-.07
0.5% Aq. NaOH	U	.07	.06
0.5% Aq. NaOH	S	.02	-.02

of wettability in this study and the strength values obtained in the gluability study. As can be seen from these tables, none of the wettability tests had any significant correlations with the bond strengths obtained. All wettability tests were correlated first with the strength after vacuum-pressure-soak aging because this was determined to be the best indicator of bond quality (Sandoe and Wellons 1979). Several correlations also were made with the bond strength values after boil-dry-boil aging. The results showed slight improvement in correlation, but none were significant. A limited number of correlations were made using the dry shear strength values, but these results also were not significant.

No correlations were made between the % wood failure values because all the wood failure values were extremely high (Table 28 from Sandoe and Wellons 1979).

I checked the possibility that the wood fiber had been severely damaged during drying, resulting in abnormally low shear strength values by comparing the shear strengths of platen dried veneer with shear strengths of solid wood which had been air dried at 90°F. The shear strength values for platen dried veneers (average of 474 PSI) were not found to be significantly different from the shear strength values for the air dried wood (average of 489 PSI). Therefore it was concluded severe damage to the wood fibers had not occurred.

Implications

All these findings appear to contradict the theory that wettability is a good indicator of gluability. Even though we do

TABLE 28. Percent wood failure after vacuum pressure aging.

Veneer Thickness Inches	Temperature °F					Mean	
	325	375	425	460	Oven 425	Platen	Overall
% WOOD FAILURE FOR SAPWOOD							
.1	92	91	79	90	89	88	88
.2	92	92	84	88	91	89	89
.3	85	87	77	88	81	84	84
.4	90	87	90	90	---	89	89
MEAN	90	89	83	89	87	88	88
% WOOD FAILURE FOR HEARTWOOD							
.1	98	94	98	99	98	97	97
.2	95	96	97	97	98	96	97
.3	89	89	89	89	82	89	88
.4	85	85	90	90	94	88	89
MEAN	92	91	94	94	93	93	93

see a significant change in wettability of the veneer surface, especially with water, due to some drying variables, the often cited relationship between wettability and gluability does not seem to exist in this study of platen dried veneer. A possible explanation that agrees with Bodig (1962) may be that at pressing conditions the P/F-resin is capable of overcoming any apparent lack of wetting ability observed at ambient temperatures. This may occur because the resin components possibly dissolve away surface contaminants at the high temperatures occurring in the hot press. At these temperatures no major viscosity effect should be seen as with the P/F/C solution used in this study. Instead the resin should act like the 0.5% Aq. NaOH and P/F solutions, readily wetting the wood.

Conclusions

1. None of the following tests
 - liquid absorption time on veneer surface,
 - difference between liquid absorption time on sanded and unsanded veneer surface,
 - extent of liquid spread parallel to grain of veneer, or
 - contact angle of liquid on veneer surfaceappear to predict surface inactivation after platen drying. No significant correlations could be found between any of the test methods and the bond quality data from the companion gluability study (Sandoe and Wellons 1979).

2. Wettability is related to veneer drying time and temperature. Wetting appears to decrease as drying temperature increases and as veneer thickness (i.e. longer drying time) increases.

3. Aging reduces wettability. Absorption times increased significantly between tests made immediately after press drying and after 30 days of conditioning.

4. Sanding of the veneer surface increased wettability considerably in all tests.

5. After platen drying, heartwood appears to be less wettable than sapwood. In general, both absorption times and contact angles were greater for heartwood than sapwood.

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APPENDIX

Appendix

TABLE 29. Analysis of variance--absorption times for liquids.

Source	Sum of Squares	df	Mean Square	F-ratio	pI (%)
Thickness (TH)	3,128.4	3	1,042.8	38.09	< 0.1
Temperature (TE)	1,444.8	4	361.2	13.19	< 0.1
TH*TE	1,070.4	12	89.2	3.26	< 0.1
Moisture Content (MC)	333.6	2	166.8	6.09	< 0.5
TH*MC	62.4	6	10.4	.38	> 50.0
TE*MC	232.8	8	29.1	1.06	< 50.0
TH*TE*MC	612.0	24	25.5	.93	> 50.0
Sap/Heart (SH)	82.5	1	82.5	3.01	10.0
TH*SH	338.7	3	112.9	4.13	1.0
TE*SH	63.2	4	15.8	.58	> 50.0
TH*TE*SH	250.8	12	20.9	.76	> 50.0
MC*SH	107.6	2	53.8	1.97	< 50.0
TH*MC*SH	73.8	6	12.3	.45	> 50.0
TE*MC*SH	150.4	8	18.8	.69	> 50.0
Repetition	58.5	1	58.5	2.14	< 50.0
Error 1	3,918.2	143	27.4		
Test Time (TT)	4,112.5	1	4,112.5	287.56	< 0.1
TH*TT	14.1	3	4.7	.33	> 50.0
TE*TT	116.8	4	29.2	2.04	1.0
TH*TE*TT	291.6	12	24.3	1.70	1.0
MC*TT	14.2	2	7.1	.50	> 50.0
TH*MC*TT	129.6	6	21.6	1.51	< 50.0
TE*MC*TT	138.4	8	17.3	1.21	< 50.0
SH*TT	34.8	1	34.8	2.43	< 50.0
TH*SH*TT	218.1	3	72.7	5.08	0.5
TE*SH*TT	120.4	4	30.1	2.10	1.0
MC*SH*TT	29.8	2	14.9	1.04	< 50.0
Error 2	2,774.2	194	14.3		
Sanded/ Unsanded (SU)	17,939.7	1	17,939.7	1746.94	< 0.1
TH*SU	32.7	3	10.9	1.07	< 50.0
TE*SU	586.0	4	146.5	14.27	< 0.1
TH*TE*SU	218.4	12	18.2	1.77	1.0
MC*SU	50.4	2	25.2	2.45	1.0
TH*MC*SU	84.6	6	14.1	1.38	< 50.0
TE*MC*SU	104.8	8	13.1	1.27	< 50.0
SH*SU	516.2	1	516.2	50.27	< 0.1
TH*SH*SU	129.9	3	43.3	4.22	1.0

TABLE 29 (continued)

Source	Sum of Squares	df	Mean Square	F-ratio	p ¹ (%)
TE*SH*SU	172.4	4	43.1	4.20	0.5
MC*SH*SU	13.8	2	6.9	.67	> 50.0
TT*SU	135.3	1	135.3	13.17	< 0.1
TH*TT*SU	212.7	3	70.9	6.91	< 0.1
TE*TT*SU	101.6	4	25.4	2.47	5.0
SH*TT*SU	48.1	1	48.1	4.69	5.0
Solution (SL)	81,532.2	3	27,177.4	2646.50	< 0.1
TH*SL	1,887.3	9	209.7	20.42	< 0.1
TE*SL	757.2	12	63.1	6.14	< 0.1
TH*TE*SL	1,260.0	36	35.0	3.41	< 0.1
MC*SL	202.8	6	33.8	3.29	.5
TH*MC*SL	163.8	18	9.1	.88	> 50.0
TE*MC*SL	309.6	24	12.9	1.26	< 50.0
SH*SL	39.0	3	13.0	1.27	< 50.0
TH*SH*SL	223.2	9	24.8	2.42	0.5
TE*SH*SL	68.4	12	5.7	.56	> 50.0
MC*SH*SL	318.0	6	53.0	5.16	< 0.1
TT*SL	173.1	3	57.7	56.22	< 0.1
TH*TT*SL	238.5	9	26.5	2.58	1.0
TE*TT*SL	577.2	12	48.1	4.68	< 0.1
MC*TT*SL	41.4	6	6.9	.67	> 50.0
SH*TT*SL	67.8	3	22.6	2.2	10.0
SU*SL	14,552.1	3	4,850.7	472.35	< 0.1
TH*SU*SL	33.3	9	3.7	.36	> 50.0
TE*SU*SL	714.0	12	59.5	5.79	< 0.1
MC*SU*SL	53.4	6	8.9	.87	> 50.0
SH*SU*SL	419.4	3	139.8	13.62	< 0.1
TT*SU*SL	166.5	3	55.5	5.40	0.5
Error 3	31,909.4	3098	10.3		
TOTAL		3839			

¹Probability that difference occurred by chance rather than by the result of treatment.

Appendix

TABLE 30. Analysis of variance--extent of liquid spread.

Source	Sum of Squares	df	Mean Square	F-ratio	p ¹ (%)
Thickness (TH)	29.7	3	9.98	20.99	< 0.1
Temperature (TE)	33.6	4	8.44	17.76	< 0.1
TH*TE	20.4	12	1.70	3.59	< 0.1
Moisture Content (MC)	7.6	2	3.81	8.00	< 0.1
TH*MC	6.0	6	1.01	2.13	> 5.0
TE*MC	2.1	8	.26	.55	> 50.0
TH*TE*MC	12.5	24	.52	1.1	< 50.0
Sap/Heart (SH)	56.6	1	56.60	119.05	< 0.1
TH*SH	22.2	3	7.37	15.49	< 0.1
TE*SH	1.08	4	.27	.56	> 50.0
TH*TE*SH	26.6	12	2.22	4.68	< 0.1
MC*SH	.3	2	.17	.35	> 50.0
TH*MC*SH	1.7	6	.28	.60	> 50.0
TE*MC*SH	7.8	8	.97	2.03	2.5
Repetition	1.6	1	1.60	3.37	10.0
Error 1	68.6	143	.48		
Test Time (TT)	19.9	1	19.90	58.28	< 0.1
TH*TT	3.2	3	1.05	3.07	5.0
TE*TT	1.8	4	.44	1.30	< 50.0
TH*TE*TT	5.2	12	.43	1.27	< 50.0
MC*TT	1.8	2	.88	2.58	10.0
TH*MC*TT	3.1	6	.52	1.52	2.5
TE*MC*TT	1.5	8	.19	.55	> 50.0
SH*TT	2.0	1	1.96	5.75	2.5
TH*SH*TT	4.5	3	.76	2.21	10.0
TE*SH*TT	2.7	4	.68	1.98	< 50.0
MC*SH*TT	1.3	2	.66	1.92	< 50.0
Error 2	66.0	194	.34		
Sanded/ Unsanded (SU)	259.2	1	259.17	1184.70	< 0.1
TH*SU	.6	3	.19	.87	< 50.0
TE*SU	24.0	4	5.99	27.38	< 0.1
TH*TE*SU	7.2	12	.60	2.77	< 0.1
MC*SU	3.3	2	1.63	7.46	< 0.1
TH*MC*SU	1.4	6	.23	1.07	< 50.0
TE*MC*SU	1.6	8	.20	.91	> 50.0
SH*SU	.2	1	.20	.91	< 50.0
TH*SH*SU	2.6	3	.87	3.97	1.0
TE*SH*SU	3.6	4	.89	4.04	0.5
MC*SH*CU	.8	2	.38	1.73	< 50.0

TABLE 30 (continued)

Source	Sum of Squares	df	Mean Square	F-ratio	p ¹ (%)
TT*SU	5.2	1	5.24	23.94	< 0.1
TH*TT*SU	1.1	3	.37	1.69	< 50.0
TE*TT*SU	5.0	4	1.26	5.77	< 0.1
SH*TT*SU	.2	1	.21	1.73	< 50.0
Solution (SL)	388.3	3	129.44	591.72	< 0.1
TH*SL	13.9	9	1.54	7.04	< 0.1
TE*SL	20.8	12	1.73	7.91	< 0.1
TH*TE*SL	22.3	36	.62	2.84	< 0.1
MC*SL	3.1	6	.51	2.31	5.0
TH*MC*SL	4.3	8	.24	1.10	< 50.0
TE*MC*SL	8.6	24	.36	1.64	2.5
SH*SL	2.8	3	.94	4.30	0.5
TH*SH*SL	4.9	9	.54	2.48	1.0
TE*SH*SL	5.0	12	.42	1.92	5.0
MC*SH*SL	2.3	6	.39	1.80	10.0
TT*SL	2.4	3	.80	36.51	< 0.1
TH*TT*SL	6.2	9	.69	3.18	< 0.1
TE*TT*SL	9.7	12	.81	3.71	< 0.1
MC*TT*SL	2.2	6	.37	1.69	< 50.0
SH*TT*SL	.5	3	.18	8.44	< 0.1
SU*SL	.5	3	.16	716.17	< 0.1
TH*SU*SL	7.3	9	.81	3.69	< 0.1
TE*SU*SL	1.3	12	.11	5.25	< 0.1
MC*SU*SL	2.2	6	.37	1.69	< 50.0
SH*SU*SL	.8	3	.28	1.27	< 0.1
TT*SU*SL	1.1	3	.38	1.73	< 50.0
Error 3	681.6	<u>3098</u>	.22		
TOTAL		3839			

¹Probability that difference occurred by chance rather than by result of treatment.

Appendix

TABLE 31. Analysis of variance--contact angles.

Source	Sum of Squares	df	Mean Square	F-ratio	p ¹ (%)
Thickness (TH)	9,623.1	3	3,207.7	8.85	< 0.1
Temperature (TE)	37,450.0	4	362.5	25.83	< 0.1
TH*TE	23,866.8	12	1,988.9	5.49	< 0.1
Moisture Content (MC)	5,444.6	2	2,722.3	7.51	< 0.1
TH*MC	5,289.6	6	881.6	2.43	5.0
TE*MC	5,420.8	8	677.6	1.87	10.0
TH*TE*MC	16,020.0	24	667.5	1.84	2.5
Sap/Heart (SH)	7,893.5	1	7,893.5	21.78	< 0.1
TH*SH	1,256.4	3	418.8	1.16	< 50.0
TE*SH	11,298.0	4	2,824.5	7.79	< 0.1
TH*TE*SH	9,434.4	12	786.2	2.17	2.5
MC*SH	1,209.6	2	604.8	1.67	< 50.0
TH*MC*SH	4,986.0	6	831.0	2.29	5.0
TE*MC*SH	5,194.4	8	649.3	1.79	10.0
Repetition	2,118.9	1	2,118.9	5.85	2.5
Error 1	51,823.2	143	362.4		
Sanded/ Unsanded (SU)	597,735.0	1	597,735.0	4998.66	< 0.1
TH*SU	815.1	3	271.7	2.27	10.0
TE*SU	11,478.8	4	2,869.7	24.0	< 0.1
TH*TE*SU	7,868.4	12	655.7	5.48	< 0.1
MC*SU	1,456.6	2	728.3	6.09	< 0.5
TH*MC*SU	1,992.6	6	332.1	2.78	2.5
TE*MC*SU	3,552.0	8	44.0	3.71	< 0.1
SH*SU	668.6	1	668.6	5.59	2.5
TH*SH*SU	2,005.8	3	1,209.9	10.12	< 0.1
TE*SH*SU	2,751.6	4	687.9	5.51	< 0.1
MC*SH*SU	523.6	2	261.8	2.19	< 50.0
Solution (SL)	640,101.0	1	640,101.0	5352.95	< 0.1
TH*SL	7,843.2	3	2,614.4	21.86	< 0.1
TE*SL	4,251.2	4	1,062.8	8.89	< 0.1
TH*TE*SL	4,065.6	12	338.8	2.83	< 50.0
MC*SL	427.4	2	213.7	1.79	< 50.0
TH*MC*SL	904.8	6	150.8	1.26	< 50.0
TE*MC*SL	2,027.2	8	253.4	2.12	5.0
SH*SL	3,027.6	1	3,027.6	25.32	< 0.1
TH*SH*SL	417.3	3	139.1	1.16	< 50.0
TE*SH*SL	2,419.2	4	604.8	5.06	< 0.1
MC*SH*SL	448.8	2	224.4	1.88	< 50.0
SU*SL	201,864.0	1	210,864.0	1688.12	< 0.1

TABLE 31 (continued)

Source	Sum of Squares	df	Mean Square	F-ratio	p ¹ (%)
TH*SU*SL	2,947.2	3	982.4	8.22	< 0.1
TE*SU*SL	1,867.2	4	466.8	3.90	< 0.5
MC*SU*SL	191.8	2	95.9	.80	< 50.0
SH*SU*SL	169.8	1	169.8	1.42	< 50.0
Error 2	188,609.2	<u>1577</u>	119.6		
TOTAL		1919			

¹Probability that difference occurred by chance rather than by result of treatment.