THE EFFECT OF AN ADHESIVE ON PALLET JOINT STIFFNESS

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(ABSTRACT)

An Investigation was conducted to find an adhesive that could bond green red oak. The adhesive found to bond best was a modified amine based epoxy resin. This adhesive was used to construct pallet joints in two of the three conditions: 1) nailed, 2) glued, 3) nail/glued, to determine the effect of an adhesive on pallet joint strength and stiffness.

It was found that the adhesive increased the initial strength and stiffness of the pallet joints but a brittle failure by the glue indicates the need for a more flexible adhesive.

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INTRODUCTION

Currently, the primary fasteners used in pallets are nails and staples. The use of these fasteners enables high rates of production. Metal fasteners have drawbacks in their use by increasing the potential for splitting during assembly or seasoning of pallets, which can severly effect joint rigidity. Another problem involves protruding nails as a result of wood shrinkage during seasoning. These prodruding nails may damage goods placed on the pallet. Also, nails interfere with pallet disposal. The nails or metal fasteners interfere with the chipping or grinding process. If the pallets are to be burned metal fasteners further interfere with with combustion performance. To remove metal fasteners may increase handling time, thus, increasing costs and making pallet disposal a less desirable operation.

Assembling pallets to aid disposal programs or increasing pallet stiffness may be accomplished by using a suitable adhesive. Such an adhesive must be able to bond satisfactorily to rough and green lumber and be resilient to impact loading. These conditions are not condusive for bonding using conventional gluing procedures or binders. The gluing procedures and binders need to be developed.

OBJECTIVE

The objectives of this project were to first, obtain and test a variety of traditional wood adhesives, and synthetics resins, to determine their suitability for bonding green red oaks (Quercus spp.). Second, once a suitable adhesive was accquired, it would be used to manufacture pallet joints in two of these three treatments: 1) nailed, 2) glued, and 3) nailed and glued (nail/glued). Pallet joints were tested dynamically as well as statically to determine the effect of an adhesive on pallet joint strength and stiffness.

LITERATURE REVIEW

Research on gluing of unseasoned green wood has been met with varied results. A reason for this is that the high moisture content (MC) in the wood may interfere with the curing reaction of the adhesive. Murphey and Nearn (1956) laminated red oak with moisture contents ranging from 6-50 percent using a resorcinol-formaldehyde resin. The shearblock specimens with moisture contents below 14 percent performed satisfactorily. The higher MC samples experienced adhesive migration from the glue joint resulting in reduced bonding strength. Currier (1960) glued scarf and finger joints from Douglas-fir studs with melamine and phenol-formaldehyde resin. The MC at the time of assembly ranged from 14-20 percent. Specimens were then seasoned to an average MC of 12 percent. One group was maintained at a MC of 20 percent. The glued studs were tested in static bending, loaded on the center with a crosshead speed of 0.1 inch/min. Moduli of rupture and elasticity (MOR and MOE) were calculated directly from test data. Specimens tested at their assembled MC of 20 percent had the highest stiffness. Specimens seasoned to 12 percent MC had a maximum strength reduction of 28 percent. Wood shrinkage from seasoning may have accounted for poor bond quality.

Strickler (1970) end glued green Douglas-fir, western larch, Grand-fir, and western red cedar with MC's ranging from 30 to 200 percent. The adhesives employed were resorcinol, phenol-resorcinol, melamine-urea, and casein. Joints mated cold followed by a cold-cure (drying at room temperature) were significantly weaker than joints that were glued hot or subsequently heated following assembly. It was concluded that when finger joints are mated in green wood, moisture soon migrates into the area dried during the initial heating of the joint. Without this initial cure from the hot wood surfaces, the moisture would interfere with the proper cure of the adhesives. Murphey et al. (1971) studied the feasibility of gluing red oak (6-24 and green MC) using phenol-resorcinol, casein, and melamine adhesives. Their method employed the use of a hot platten or hot air jet to surface dry the planed sample prior to gluing and assembly. Wet pockets caused by uneven drying result in spreading and adhesion problems. In order to maximize bonding strength, the adhesives should be spread immediately after heat treatment and assembly times should be as close to zero as possible. The surface temperature of the lumber can be 100 degrees C when the adhesive is spread, causing it to cure as soon as it is applied. If assembly time is not minimized precure is likely to occur. The assembled specimens were either clamped at room temperature for 24 hours or further hot pressed for 15 minutes. An immediate cure of the glue allows formation of a cured adhesive-wood interface before additional moisture can migrate to the surface. In this study, phenol-resorcinol out-performed urea, casein and melamine for both methods.

Further use of heat to dry joint surfaces has been developed by Troughton and Chow (1980). Unseasoned white spruce 2 x 12 x 48 inch boards with moisture contents ranging from 30 to 90 percent were used. Finger joints were dried for 15 minutes at 150 degrees C with air speeds of 500 feet/minute. A phenol-formaldehyde resin was then applied followed by assembly within 20 seconds. The specimens were then cut in half with both sections kiln dried. Specimens were then tested in static bending loaded on the wide face. The average bending strength was 5320 pounds per square inch (psi). Troughton and Casilla (1983), used preheating techniques to edge glue unseasoned spruce-pine-fir with phenol-resorcinol resin. The preheated wood acts as a heatsink for adhesive curing reactions. Edge-pressure time at 50 psi, and heating time at 150 degrees C, were all found to effect bond quality. Using suitable bonding conditions, edge-joints could be made from unseasoned S-P-F lumber with wood failure greater than 80 percent indicating very good adhesion between the glue and wood.

Kurata and Nagahara (1977), used green structural spruce lumber to manufacture finger joints with epoxy and isocyanate adhesives. The MC's of the samples ranged from 30 to 120 percent. These samples were divided in half. One group was tested green while the other was seasoned until it was air dried. In the two MC conditions, flexural properties of samples glued with epoxy were affected by moisture content. Properties obtained in the air dry condition were superior to those in the green condition. It was concluded that the epoxy adhesive could be applied to finger joints of structural softwood timber with a high MC. Nakamura et al. (1979), conducted experiments in which isocyanate mixed with polyvinyl acetate (PVA) emulsion was applied to finger joints of spruce lumber. The moisture contents ranged from 15 to 120 percent. It was found that when specimens were assembled with air dried lumber, moisture content does not significanly affect flexural properties of the jointed timber. It was found that flexural properties are significantly affected when tested in the green condition though the modulus of elasticity (MOE) was the same as specimens tested in the air dry condition. Nakamura et al. (1979) worked on finger joints of spruce (Picea jezoensis) and birch (Betula maximowicziana) glued at MC's ranging from 12 to 80 percent. The adhesives used were epoxy resin, resorcinol, and vinyl urethane. It was found that under 40 percent MC, resorcinol, epoxy and vinyl urethane adhesives were effective for laminating wood for non-structural uses. At a MC of 60 percent epoxy and vinyl urethane were usable. At 60 percent MC, only vinyl urethane was suitable for use in structural purposes. Polyvinyl acetate mixed with isocyanate did not provide adequate flexural strength for structural purposes at any moisture content.

The use of adhesives in pallets has been limited to elastomeric adhesives common to construction of plywood, panel floor, roof and wall systems. Kurtenacker (1969) used elastomerics based of synthetic rubber to assemble pallets from green lumber. The pallets were tested immediatly or allowed to air dry prior to testing. In rough handling tests, wood density influenced the type of failure mode. In high density species, i.e., oak and hickory, failure was of a cohesive nature occurring in the adhesive zone. With low density species, i.e., yellow-poplar, most of the failure was in the wood itself. Moisture content was found to directly influence bond performance. Further work by Kurtenacker (1975) included four synthetic elastomeric adhesives for assembling pallets, two with organic solvents as a transporting agent and two without solvent. Pallets were assembled green and conditioned to an air dry moisture content. Three tests were employed as follows: 1) static load on corner test, 2) dynamic impact load on corner test and 3) free-fall-oncorner-drop test from a height of 40 inches repeated six times. The two organic solvent borne adhesives had voids and crazing occurring in the glueline from loss of solvent during the curing process. This severely reduced strength performance and it was recommended that such adhesives not be used in pallet manufacture. The two non-solvent borne adhesives both out-performed mechanical fasteners (nails or staples) in impact tests, though moisture did significantly affect bonding. Density also affected the type of bond failure as found earlier by Kurtenacker (1969). It was concluded that synthetic elastomeric adhesives of the non-solvent type may be used under certain conditions such as moderate handling or where protruding nails may damage goods.

An in-service test of pallets assembled with non-solvent borne synthetic elastomeric adhesives was conducted by Kurtenacker (1975). Forty pallets were used in a brick and cement yard for 18 months. Of these forty, fifteen were recovered for laboratory testing by use of the free-fall-on-corner-drop test. Since the conditions of exposure to the pallets were severe, both nailed and glued pallets sustained heavy damage. It was concluded that the adhesive assembled pallets did not resist severe handling as effectively as nailed or stapled pallets. Moisture content and density had an influence on bonding strength. The mode of failure occurred mainly in the adhesive layer since oak, a high density species was used.

Adhesives that are to be used in pallet manufacturing need to have gap-filling capabilities. This may be accomplished by adding fillers to control viscosity. China clay has been used with elastomeric adhesives along with finely divided asbestos (Hemming, 1960). Titanium dioxide was added to modified epoxy with excellent results (Olsen and Blomquist, 1962). Vick (1973) used wood flour, walnut shell flour, and chrysotile absestos to control viscosity of a commercial resorcinol-formaldehyde resin. Of the three, asbestos gave good results without affecting strength. The amount of asbestos used was 1.8 parts weight basis of mixed resin.

In assembling pallets with adhesives, there must be certain properties of the adhesive favoring its use. Since the lumber is usually rough and unplaned the gluing results in uneven gluelines. Maintaining consistant clamping pressure after assembly may be difficult to control. Castor et al., (1973) glued rough planed lumber to manufacture laminated powerline transmission poles. With the glueline ranging up to 1/16 inch thick, special properties are needed in such an adhesive. Some of these glue characteristics developed by Castor also pertain to pallet assembly.

1) Gap filling capabilities up to 1/16 inch, since lumber may be rough planed or rough sawn.
2) Low shrinkage and no crazing during or after cure, to maintain full integrity in the glueline.
3) Zero sag for maintaining fill and enable lumber or pallets to be turned up on edge during lay up.
4) Full exterior durability for thick and thin glue lines.
5) Good substrate penetration with low clamping pressure, while maintaining a constant viscosity to insure adequate glueline coverage.
6) Low odor during laminating operations to meet mill, state and federal guidelines.
7) Capable of being metered, i.e., both components in liquid form.

The adhesives pertaining to pallet assembly should also have these following additional characteristics.

8) Short cure time to enable handling of pallets soon after assembly.

9) Costs competitive with other alternatives.

10) Resilient to impact loading.

11) Ability to bond under high moisture conditions.

An investigation was conducted to determine the effect of bonding green white oak with both epoxy and an isocyanate adhesive (Zito, 1983). Bentonite and Carboxylmethyl Cellulose (CMC) were used as a filler and dessicating agent. The purpose of the bentonite or CMC was to absorb excess moisture that may interfere with adhesive curing and reduce migration of glue from the joint. The percent of weight to total adhesive of bentonite or CMC was 0, 5, 10, and 15 percent. In shearblock tests, the epoxy out-performed the isocyanate adhesive, though problems with squeeze out occurred. The addition of either compound was not found to significantly increase bond performance in green wood.

MATERIALS AND METHODS

This project is divided into two major parts. Part I is a preliminary investigation using shearblock tests to determine a suitable adhesive for gluing green wood, while Part II involves comparative testing two types of pallet joints subject to three treatments (nailed, glued, and nail/glued) to determine the effect of an adhesive on pallet joint strength and stiffness. The pallet joints were subjected to the following three different tests:

1) Joint rotation test
2) Static load on corner test
3) Impact load on corner test

Part I Obtaining an Adhesive

Using Chemical Week buyer's guide (1982), a list of approximately 100 companies that specialize in resorcinol, phenolic, isocyanate, hotmelt, and epoxy resins was compiled. These companies were contacted to determine if their product line carried adhesives suitable for use in high moisture content conditions. A total of 25 samples were obtained in this manner. The list of donating companies can be found in Appendix A. Two of these adhesives needed external heat sources for proper curing and were not used in this study since the application of heat is considered impractical in pallet manufacture.

The remaining twenty-three adhesives were tested in shear using a modified shearblock test. One inch rough sawn green oak was used for shearblocks. The grain orientation of the shearblocks was perpendicular to the opposite face (see Figure 2) to approximate the cross-lap joint found in pallets.

Assembly of Shearblocks

To determine the performance of the various adhesives in bonding green wood, a modified shearblock test was developed. Rough sawn 4/4 green red oak boards were initially cut into 2 x 25 inch strips and stored in plastic bags or wrapped in 6 mil polypropylene sheets to prevent moisture moisture loss. Material that could not be used within three days was frozen to maintain a green condition. Since shearblock specimens were assembled at room conditions, these strips were thawed to room temperature before gluing. The strips, randomly selected, were cut into two 2 x 10 inch panels and ten 2 x 2 inch blocks. A 1-2 inch section was cut from the center of each strip and used for MC determination (see Figure 1). These cut panels were stored in plastic bags to prevent moisture loss while the glue was mixed.

Adhesives were prepared according to manufacturer's specifications. Since the gluing of rough lumber is not a common practice in the wood industry, a rate of glue spread needed to be determined. The laminating of rough planed lumber with a modified resorcinol was developed by Castor et al. (1973) in which glue spread rates of up to 200 pounds per thousand square feet of glueline (#/MSGL) were

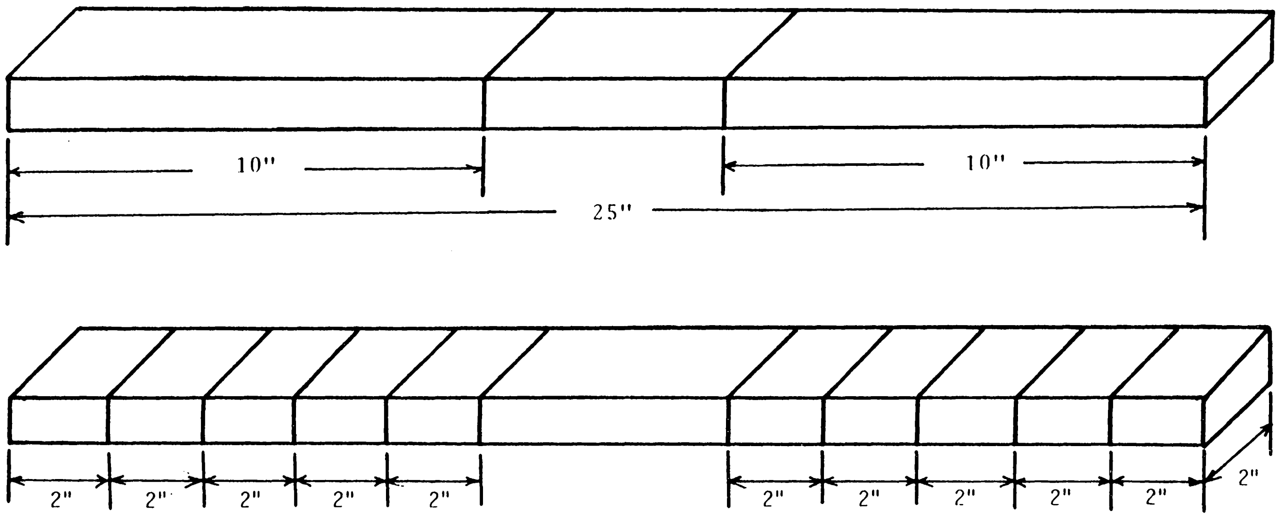

FIGURE 1. Schematic Diagram for Cutting Material for Shearblocks

recommended. Use of this heavy spread rate for the shearblock test specimens gave good glueline coverage. Since a low clamping pressure was also desired, 75 psi was chosen as a reasonable value. The viscosity of the adhesives did vary somewhat and the spread rates were adjusted in a few cases. If the spread rates were increased or decreased they were judged adequate if squeezeout occurred on all edges of the pressed specimens.

During assembly, the glue spread rates were controled by placing the 2 x 10 inch panels on a Mettler P10 scale, and adding adhesive to the nearest gram to achieve a spread rate equivalent to 200 #/MSGL. The grain of the 2 x 2 inch blocks was oriented perpendicular to the grain of the bottom panel as seen in Figure 2. This configuration simulates the cross-lap joints found in pallets. Pressing the glued samples was accomplished by sandwiching the glued panels between two boards of 2 inch kiln dried red oak, and using a Reihle universal testing machine to apply load equivalent to 75 psi. Samples were pressed for twelve hours or overnight and allowed to further cure and dry for 48 hours at room conditions. Prior to testing, shearblock specimens were machined according to Figure 2. The area of glueline tested in shear was 3 square inches. Ten replicate shearblocks were manufactured for each adhesive. Leftover glue was kept

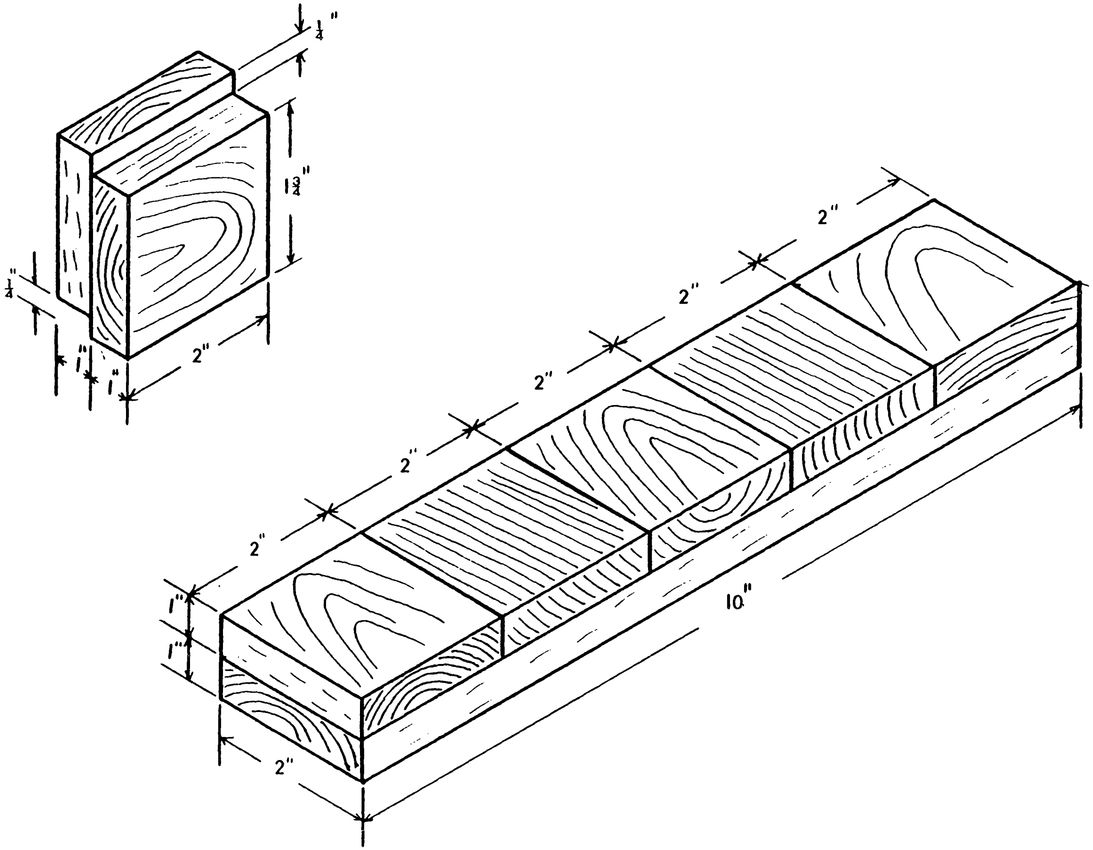

FIGURE 2. Schematic Diagram of Layed Up Panel for Glued Shearblocks and Machined Shearblock

in the mixing cans for comparison to that of the glueline in the shearblocks.

Testing Procedure

All specimens were tested in shear using a standard shear device on the Tinius Olsen universal testing machine (max. capacity 12,000 pounds). The crosshead speed was .015 inches per minute. The maximum load at failure and percent wood failure were recorded. The area of the glued surface was measured to the nearest 0.1 inch squared and used to calculate shear strength in pounds per square inch (psi). If discoloration in the cured glueline occurred compared to the cured glue in the mixing container there was reason to suspect improper curing caused by wood moisture.

Analysis of Shearblock Tests

The best performing adhesive was selected using a one-way analysis of variance (ANOVA) to determine if there was a significant difference between at least one pair of adhesives. Duncan's multiple range test was then used to rank the adhesives according to shear strength in psi. The initial moisture content of the shearblocks was also tested using ANOVA to check for any differences between specimen groups which could bias the selection process. The adhesive ranked highest according to shear strength by Duncan's procedure was selected for further testing in pallet joints.

Results and Discussion of Shearblock Tests

The results of the Duncan's procedure can be seen in Table 1. Most of the adhesives performed poorly because the saturated wood did not permit a good contact surface for adhesion. In a few cases the moisture interfered with the curing reaction. This was evident since a majority of the glues had zero percent wood failure. Migration of adhesive from the glueline caused by high moisture content was not found to be a major factor. With the exceptions of W87B, R14, and L1200, adhesives with bonding strengths over 200 psi cured properly in the glueline. The adhesives that cured properly were also those that had some wood failure. Below 200 psi, most of the adhesives had cohesive failures which occurred in the glueline.

The moisture content of the shearblock specimens at the time of assembly ranged from 68.0 to 88.8 with an average of 81.3 percent and with a standard deviation of 3.5 percent. Statistical analysis using ANOVA showed that there was no significant difference in MC between shearblock specimens at the time of assembly. A complete listing of the individual statistics for each adhesive and the ANOVA procedure can be found in Appendix B.

TABLE 1

Duncan's Multiple Range Test Showing
Ranking of Adhesives According to Shear Strength

DUNCAN	GROUPING			PERCENT WOOD FAILURE	MEAN strength (psi)	ADHESIVE
		A		27	439	Marpoxy C2-31
		A				
B		A		4	392	Epoxylite 3351
B						
B				6	360	Sikadur-31
		C		13	286	W87B
		C				
D		C		7	252	88 x 1632
D		C				
D		C		10	242	88 x 1630-1
D						
D		E		4	220	TU-902
D		E				
D		E		21	203	DER-331
D		E				
D		E		0	201	R-14
D		E				
D		E		0	201	LE-1200
		E				
F		E		11	161	Marpoxy C2-30
F						
F		G		6	122	Leebond 23-205
		G				
H		G		4	96	Epoweld 3673
H		G				
H		G		0	92	Epon 282/V40
H		G				
H		G	I	0	89	RP-20
H		G	I			
H		G	I	11	88	Scotch Grip 5230
H		G	I			
H	J	G	I	0	71	Capcure 3-800
H	J	G	I			
H	J	G	I	5	64	HM 964
H	J		I			
H	J	K	I	0	51	Scotch Weld 2216
	J	K	I			
	J	K	I	0	27	Kwik-Plus/BA-77
	J	K				
	J	K		0	26	Plionail
	J	K				
	J	K		0	18	Sikadur 33
		K				
		K		0	0	WP-2200

Since Marpoxy C2-31, a modified amine based epoxy performed with the highest bonding strength of 440 psi with 27 percent wood failure, it was selected for further testing with pallet joints.

Part II Pallet Joints

The second part of this investigation involved testing pallet joints to determine if an adhesive could increase pallet joint stiffness. Joint rotation and pallet corner specimens were assembled with three conditions: 1) nailed, 2) glued, and 3) nailed and glued. The factorial design can be seen in Figure 3.

The fastener used in the joint construction was a 0.113 x 2.25 inch hardened steel helically threaded nail (VPI nail number 1875) with a average crest diameter of 0.132 inches and an average MIBANT (Stern 1970) angle of 19 degrees (see Appendix C). Three nails were used in each joint. During initial joint construction splitting occurred when driving nails even though the red oak was in the green condition. This was seen as a source of variability in the experiment. With a maximum of 8 specimens per test a significant difference between treatments due to reduced strength in joints could have resulted. Predrilling holes in the deckboards was seen as a solution to the splitting problem. Since the portion of the nail driven into the stringer contributes most to the joint strength, predrilling deckboards was not anticipated to effect the outcome of the experiment.

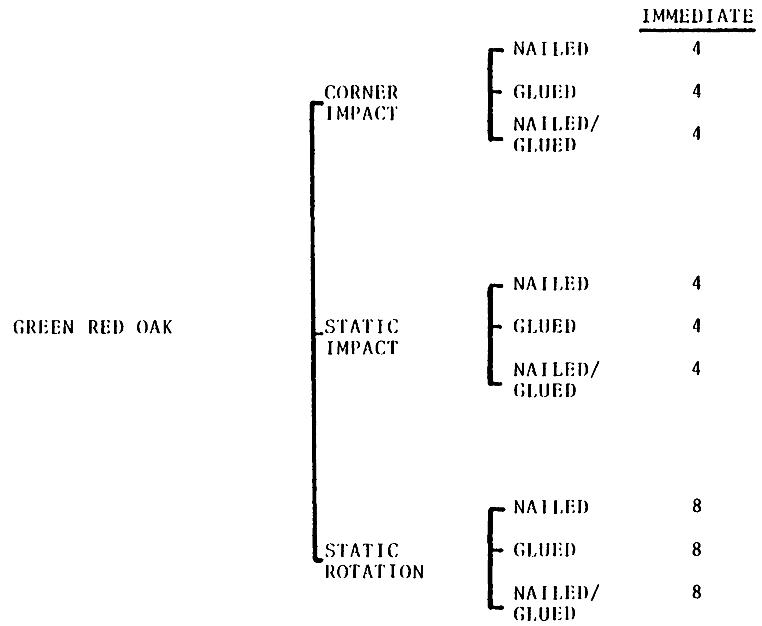

FIGURE 3. Experimental Design for Testing of Pallet Joints

Stern (1983) recommended that if holes are predrilled in the deckboards prior to nailing, the hole should not exceed 70 percent of the nail shank diameter. Therefore predrilling was done to prevent splitting during assembly. This substantially reduced the occurrence of splitting but did not eliminate it. As will be shown later, even with predrilling significant differences were found between the three treatments in all the tests.

The adhesive used was Marpoxy C2-31, a modified amine based epoxy mixed on a weight basis of 100 parts resin to 26 parts hardener, and having a pot-life of 1.25 hours with a 150 gram mass. A technical data sheet on Marpoxy C2-31 can be found in Appendix D. Glued joints were constructed with a minimum open assembly time. The spread rate was equivalent to 200 #/MSGL. Pressure applied to the glued only specimens was 75 psi using the Reihle universal testing machine. Press time was 12 hours or overnight.

During assembly of pallet joints pieces of trimmed lumber were randomly selected and used for determination of the initial moisture content. Following assembly all specimens were stored at room conditions 20 degrees C and 50 percent relative humidity for 48 hours.

Assembly and Testing of Pallet Corner Joints

To evaluate the performance and strength of the three fastening systems, pallet corner joints were assembled according to Figure 4. The corners were rounded to minimize compression of the wood at the bearing points so deflection would be measured more accurately.

The pallet corners were subjected to a static or impact impact compressive force applied to the apex (Figure 4). The static compressive force was applied using the Tinius Olsen universal testing machine at a crosshead speed of 0.3 inches per minute (Kurtenacker, 1975). A roller bearing surface was used to reduce friction during deformation. Load deflection curves were plotted during testing to provide information for maximum load and maximum deflection values. Four pallet corners of each treatment were tested.

In the dynamic drop on corner test two different procedures have been developed. Stern (1974) calls for an initial drop height of 4 inches incremented by four inches after each successive drop up to a a maximum height of 28 inches. Kurtenacker's (1975) procedure has a one inch initial drop height which is incremented by one inch for each successive drop up to a maximum height of 24 inches. Since Stern's approach produces a more severe condition, it was used in this experiment.

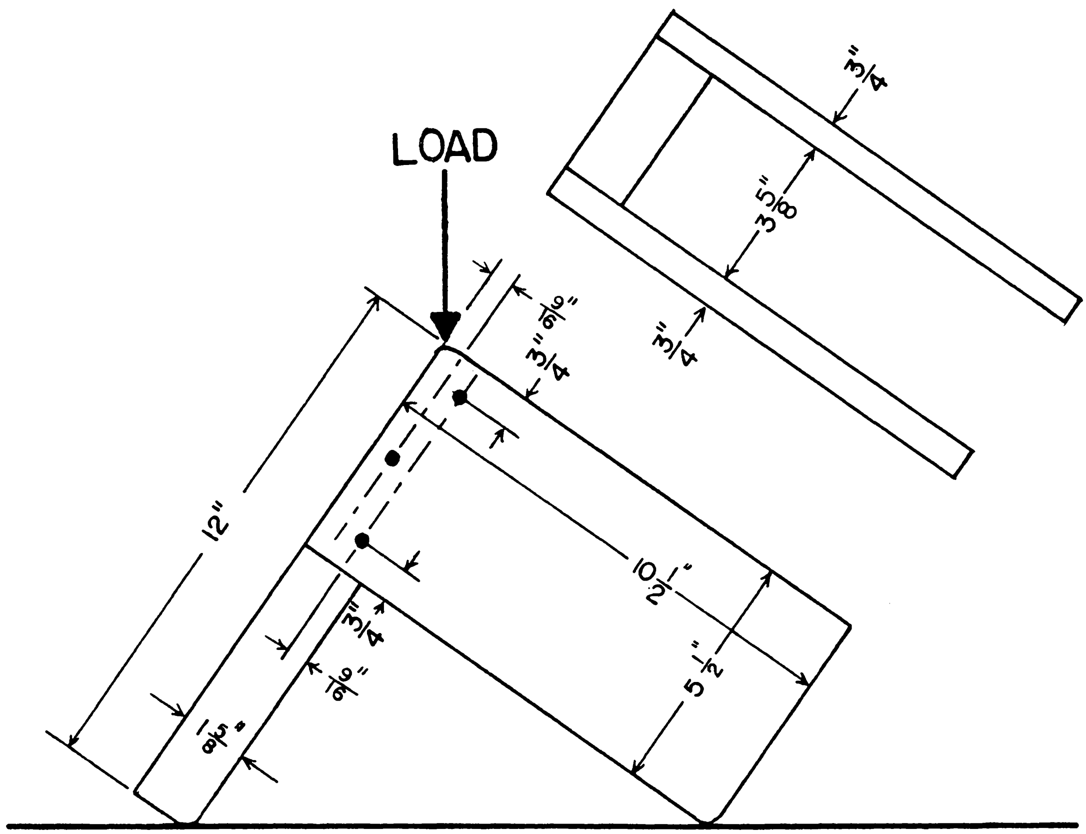

FIGURE 4. Diagram of Pallet Corner Joint for Static and Impact Tests

According to Stern (1974) a 30 pound weight falling freely between guides from sucessively increasing height increments generates the impact compressive force. The test procedure calls for the first drop of the impacting weight to be located 4 inches between the bottom of the weight and the top of each specimen. The procedure is repeated, with the drop height being increased each time by 4 inches. After the first drop from 28 inches, the weight is dropped from the 28 inch position until failure. Failure is considered to have taken place in nailed joints after the original 90 degree angle between the deckboards and stringer has increased to 120 degrees. In the case of glued only joints, failure was considered when the specimen collapsed, since no deformation up to failure, was observed during testing. Angle deformation changes between the deckboard and stringer were recorded following each drop.

After testing of pallet joints, sections were removed from stringers and deckboards for MC determination at time of testing. Specific gravity was determined based on oven dry weight and volume.

Assembly and Testing of Joint Rotation Specimens

To determine the joint modulus (stiffness), eight joint rotation specimens were manufactured for each treatment according to the dimensions in Figure 5. Following assembly, specimens were stored at room conditions 20 degrees C and 50 percent relative humidity for 48 hours, afterwhich they were tested.

Static testing of all the joint rotation specimens was conducted using the Tinius Olsen universal testing machine. The stringer was clamped rigidly to prevent movement (see Figure 6). A load was applied four inches from the edge of the stringer with a crosshead speed of 0.45 inches per minute (Kyokong, 1979). A deflectometer was used to measure vertical displacement during testing. A plot recording load verses deflection was charted for each test. Using ROTMOD, a computer program written by Mulheren, rotation moduli were calculated. What ROTMOD does is correct for the vertical displacement caused by shear and bending of the deckboard. This calculated deflection is subtracted from the total deflection and the resulting deflection is used to calculate the rotation modulus. The moment arm for the nail joint used in the calculation of the rotation modulus is the distance from the applied load to the leading edge of the

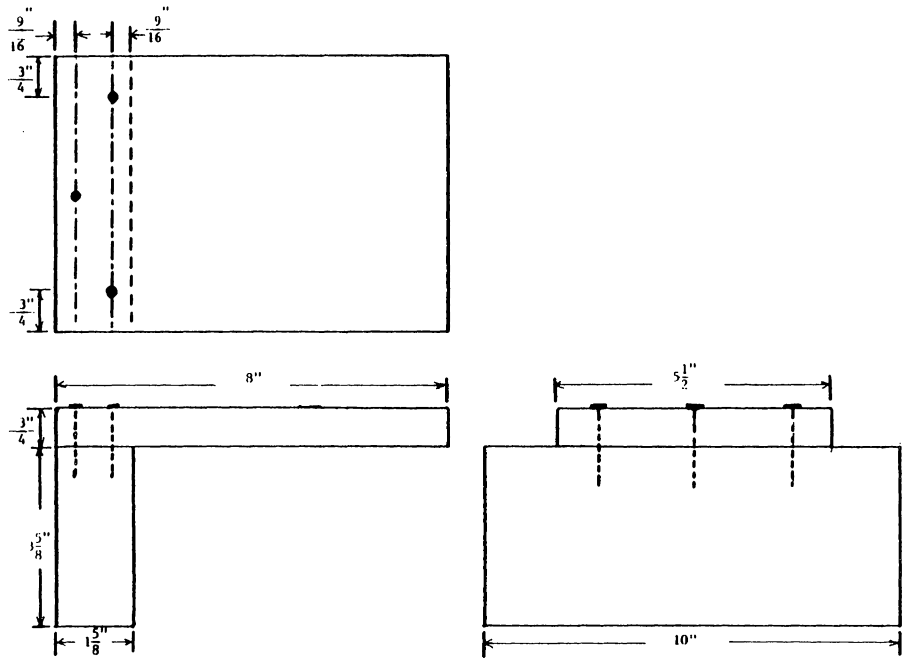

FIGURE 5. Diagram of Joint Rotation Specimen

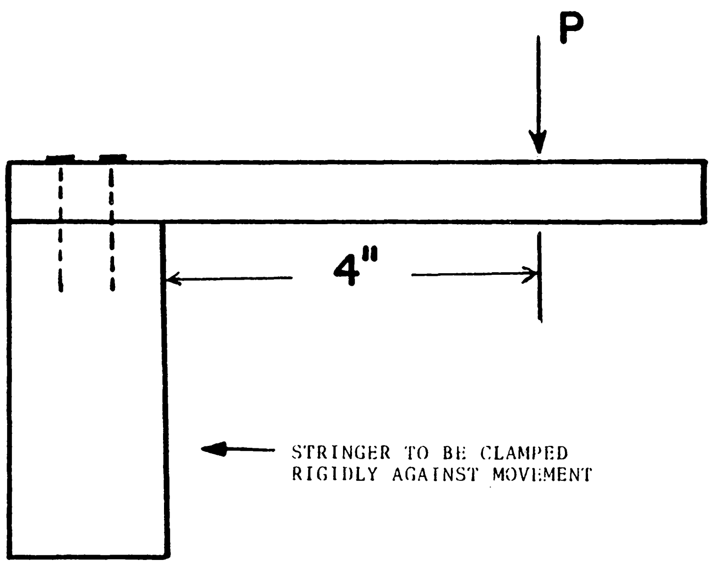

FIGURE 6. Loading Arrangement for Joint Rotation Specimen

stringer. The second moment arm is the distance from the leading edge of the stringer to centerline of the stringer (or one-half the stringer width). In the glued and nail/glued specimens the stringer width was increased by 33 percent to account for the difference in location of the centroid axis. (Which was assumed to be two thirds the distance in from the leading edge of the stringer.) Following testing, sections were cut from each specimen for moisture content determination at time of testing as well as specific gravity based on oven dry weight and volume.

Analysis of Pallet Joint Test Results

For each test procedure an ANOVA was used to determine if there were differences in mean values for maximum load, deflection at maximum load, and joint moduli. The gerneral null hypothesis for each test was:

Ho: There is no significant difference inproperties between mean values u of each of the three treatments ie., u =u =u where u =nailed, u =glued, and u =nail/glued.

With the alternate hypothesis stating:

Ha: There is a significant difference between at least one pair of mean treatment values.

If the null hypothesis was rejected at an alpha level= 0.05 for a particular test, then Duncan's multiple range test could be used to rank the mean values to determine which were significantly different. Cumulative absorbed energy mean values will be used as the basis for discussion of the dynamic load on corner test.

RESULTS of PALLET JOINT TESTS

The average moisture content of all pallet joints at the time of asembly was 77.4 percent (=6.1). After storage for 48 hours at room conditions and following testing the average moisture decreased to 66.1 percent (=9.1) for the pallet corner joints and 64.8 percent (=10.1) for the joint roation specimens. Table 2 shows mean values of moisture content and specific gravity for deckboard, stringer, and overall specimens. A one way analysis of variance for both moisture content and specific gravity, between treatments was performed. From these analyses it was found that there was no statistical difference in MC or specific gravity between treatments for either the pallet corner joints of joint rotation specimens. Therefore it was concluded that these two factors were independent of the strength factors measured in this study. Appendix E has the individual data and ANOVA test results.

Static Load on Corner Test

Table 3 is a summary of the mean results for maximum load. The result of the ANOVA for maximum load showed that there was a signigicant difference treatments at an 0.05 alpha level. From the Duncan's procedure it was found that

TABLE 2

Moisture Content and Specific Gravity for Pallet Joints

Specimen Type	Moisture Content at Time of Assembly (percent)		Moisture Content at Time of Assembly (percent)		Specific Gravity
	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$
Pallet Corner Joints	77.4	6.1	66.1	9.1	.655
deckboards			61.5	6.2	.674
stringers			75.2	7.1	.617
Joint Rotation	77.4	6.1	64.7	10.1	.643
deckboards			56.6	5.6	.666
stringers			72.9	6.1	.619

TABLE 3

Maximum Load Means for Static Load on Corner Test

Treatment	Mean (pounds)	Standard Deviation
Nail	1560	180
Glue	2140	570
Nail/Glued	3850	370

the glued, nailed, and nail/glued specimens were all significantly different from each other. The glued joints had on average 1.68 times the initial load carrying capacity of the nailed only joint. The nail/glued joint had on average 2.45 times the initial load carrying capacity of the nailed joint. The addition of Marpoxy C2-31 significantly increased the initial load bearing capacity of the pallet joints.

To better understand the behavior of the three joints types under load, the charted load verses deflection curves which were closest to the mean joint strengths were superimposed and can be seen in Figure 7. From this it can be seen that the initial load carrying capacity is greatest in the nail/glued joint followed by the glue and finally the nailed joint. Both the nail/glued and glued only joints had a high initial load carrying capacity until the glueline failed. In the nail/glued joint, the initial load is resisted mainly by the adhesive bonded to the wood, though some of this initial load is shared by the nails. Once the glueline fails the total load is immediately supported by the fasteners. The failure of the gluebond is similar to an increased rate of loading on the joint which increases its load carrying capacity. Since the glued and nail/glued joints are quite rigid, the initial deformation of the joint

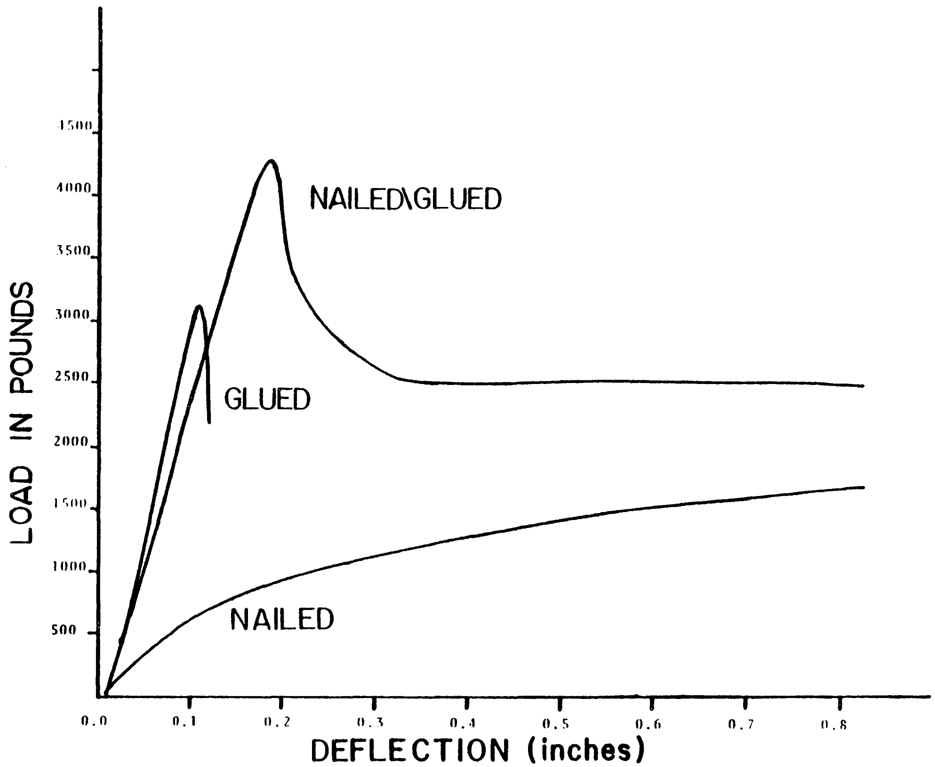

FIGURE 7. Typical Curves of Load vs. Deflection for the Three Treatments from Static Load on Corner Test

may be attributed to compression perpendicular to the grain. Once the glueline fails there is no difference in strength between that of the nailed joint or the nail/glued joint.

The static test of pallet corner joint also requires that the deflection at maximum load be measured. Table 4 shows the mean values for the deflection at maximum load. The result of the ANOVA procedure found that there was a significant difference in deflection at maximum load between treatments at a 0.05 alpha level. From the Duncan's procedure the nailed joint was found to be significanty different from the other two treatments. The deflection was determined to be at the point of maximum load from the first part of this discussion. Since the nailed/glued joint retains the ability to sustain loads after the gluebond fails, the deflection values reflect the stiffness of the joints. The ANOVA, Duncan's procedure and data on the static load on corner test can be found in Appendix F.

TABLE 4

Deflection at Maximum Load Means for Static Load on Corner Test

Treatment	Mean (inches)	Standard Deviation
Nail	0.744	0.091
Glue	0.107	0.019
Nail/Glued	0.186	0.026

Impact load on corner test

Table 5 is a summary of the average cumulative absorbed energy to failure. As can be seen the combination of the glue and nail increase the resistance to impact loading. Figure 8 shows a plot of the cumulative absorbed energy verses angular displacement typical of the three treatments tested. The addition of the adhesive increases the resistance to impact loading especially if used in conjuction with a fastener. In the nail/glued joint the fasteners help distribute the energy over the whole joint until a maximum load is applied and the glue bond fails. Then nail withdrawal and hence deformation begins. Data for the impact load on corner test can be found in Appendix H.

TABLE 5

Absorbed Energy Means from Impact Load on Corner Test

Treatment	Mean (foot-pounds)	Standard Deviation
Nail	470	105
Glue	90	52
Nail/Glued	790	184

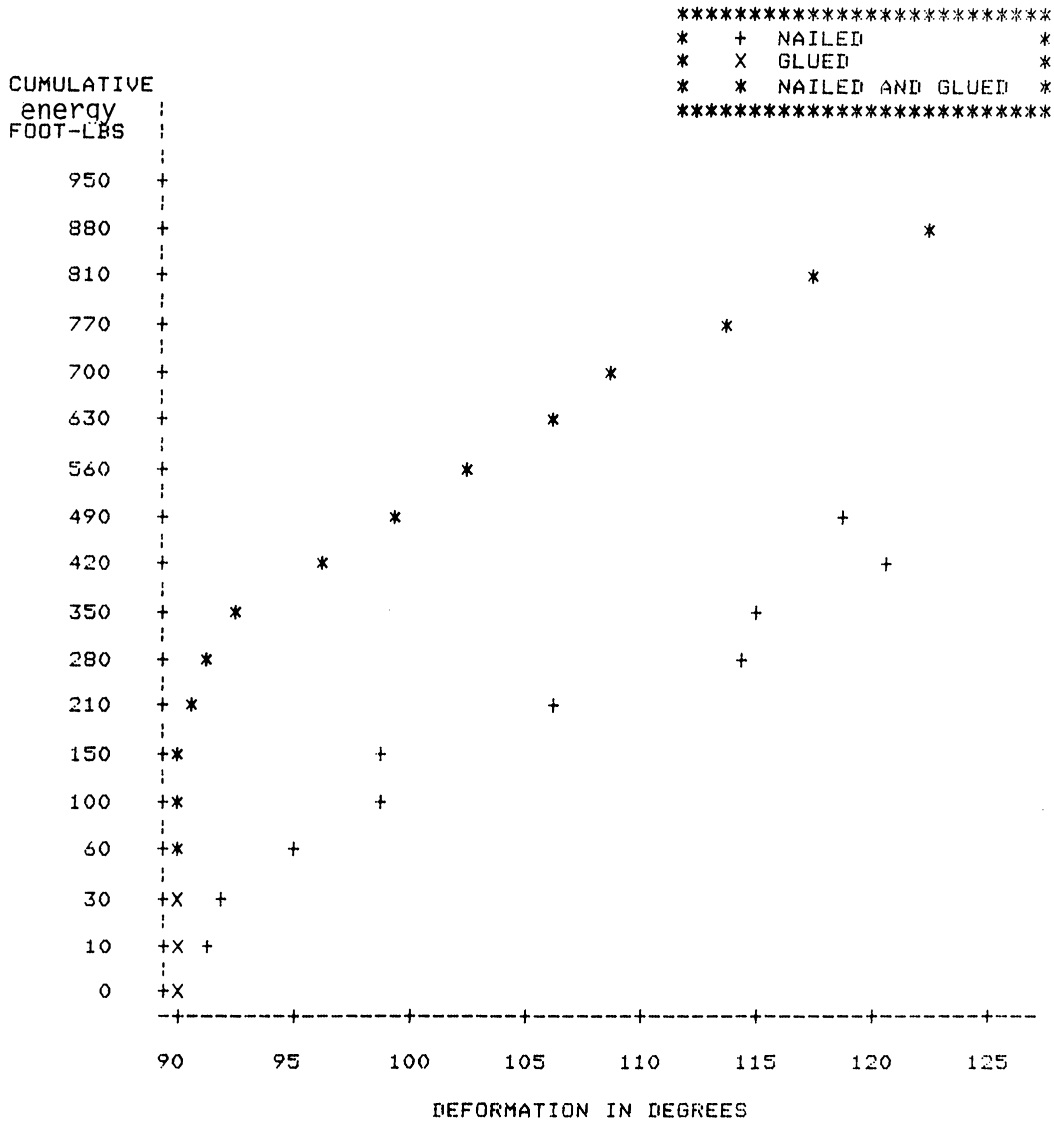

FIGURE 8. Typical Curves of Cumulative Absorbed Energy vs. Angular Deformation for the Three Treatments from the Impact Load on Corner Test

Joint Rotation Test

Table 6 shows the mean values for the joint moduli. The ANOVA found that there was a significant difference between the mean treatment values at an 0.05 alpha level. From the Duncan's procedure, it was shown that the glued and nail/glued joints were not significanly different. The nailed only joint was found to be significantly different from the other two treatments. The ANOVA and Duncan's procedure as well as data of individual specimens can be found in Appendix G.

Figure 9 is a superposition of three charted load verses deflection curves closest to the average values obtained in each treatment. It can be seen that similar behavior of the joint during loading occurred as in the static testing of pallet joints. The initial load carrying capacity is greatest in the nail/glued joint followed by the glue and finally the nailed joint. Both the nail/glued and glued only joints had a high initial load carrying capacity until the glueline failed. In the nail/glued joint, the initial load is resisted mainly by the adhesive bonded to the wood, though some of this initial load is shared by the nails. Once the glueline fails the total load is immediately supported by the fasteners. The failure of the

TABLE 6

Joint Rotation Modulus Means

Treatment	Mean (inch-pounds/radian)	Standard Deviation
Nail	15330	6050
Glue	60990	11830
Nail/Glued	69360	12070

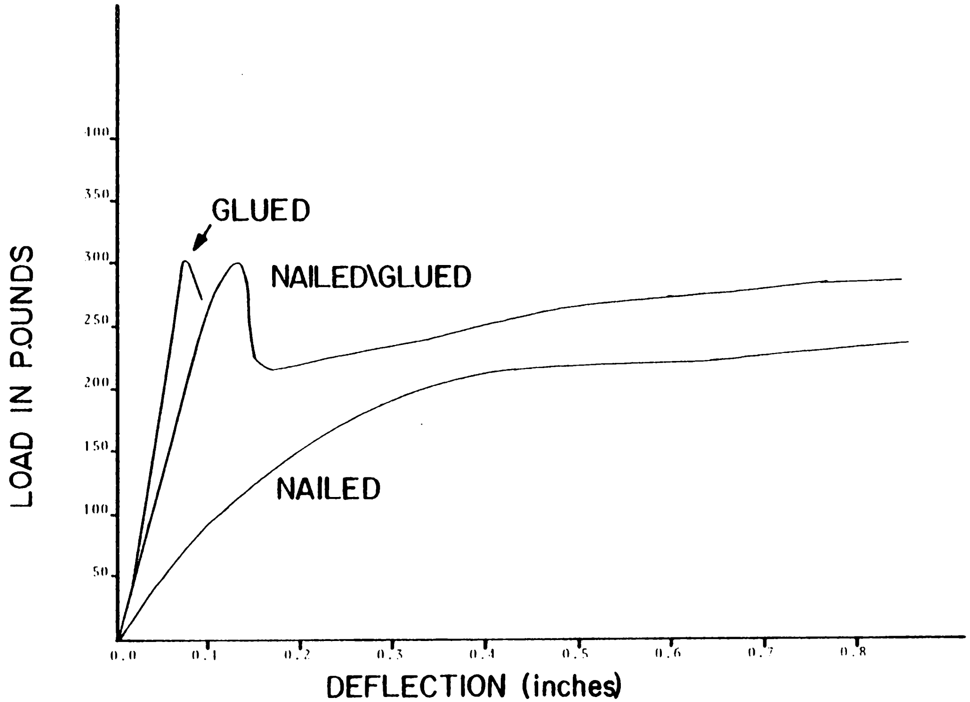

FIGURE 9. Typical Curves of Load vs. Deflection for the Three Treatments from the Joint Rotation Test

gluebond is similar to an increased rate of loading on the joint which increases the load carrying capacity of the joint. Since the glued and nail/glued joints are quite rigid, the initial deformation of the joint may be attributed to compression perpendicular to the grain. Once the glueline fails there is no difference in strength between that of the nailed joint or the nail/glued joint. The initial higher sustained load and higher stiffness by the glued and nail/glued joint is a result of the adhesive, and no nail withdrawal occuring until the gluebond fails.

Finally, to delevop a realistic understanding of how the high stiffness of a glued or nail/glued pallet joint would affect deflection in a full sized pallet, a computer simulation was performed. Using a program developed by Mulheren (1982), acronymed SPACEPAL which stands for SPACE FRAME ANALYSIS OF WOOD PALLETS, two pallet designs were analyzed. This program is based on the matrix displacement method and considers a pallet to be a three dimensional (space) frame. From the analysis the deflection as well as internal forces on any joint or member can be determined for a given pallet. The first analysis was with a fully reversable 42 x 48 inch pallet with eight 3/4 inch deckboards on the top (100 percent coverage) and bottom (100 percent coverage). The joint dimensions were the same as those tested in this experiment. Average joint moduli values for the nailed and nail/glued treatments were used in the analysis. Since the glued and nail/glued joint moduli were statistically the same, the average nail/glued modulus was used. Simulating a 2000 pound distributed load in a racked across the deckboards condition it was found that the nailed only pallet sections deflected .177 inches where as the nail/glued deflected .121 inches.

Decreasing the number of top deckboards to six (75 percent coverage), and the bottom deckboards to four (50 percent), a second set of analyses were performed using the same joint stiffnesses. For discussion purposes this pallet will be called a modified pallet. Simulating the same 2000 pound distributed load in a racked across the deckboards condition it was found that the nailed only pallet deflected .436 inches whereas the nail/glued deflected .311 inches.

It is of further interest in such an analysis to determine if the glue bond can maintain itself under an applied static load. Since the individual moment at failure of the gluebond is known as determined from actual testing, comparison can be made to the moment calculated by SPACEPAL. Using a joint located in the center of the fully reversable pallet the moment was found to be 324 inch-lbs for the nail/glued treatment. From actual experimental testing it was found that the failure of the gluebond in the nail/glued joint occured at an average of 910 inch-lbs. This 910 inch-lbs force is equivalent to a 5600 pound distributed load on the nail/glued fully reversable pallet. In the modified nail/glued pallet, the moment at the center joint was calculated by SPACEPAL to be 661 inch-lbs. This moment is equivalent to a distributed load of 2750 pounds. Since there are fewer members in the modified pallet to distribute and support the applied load a larger moment is applied to the individual joints.

Since the glued joint increases the stiffness of the pallet under load it seems reasonable that the bending stresses would increase especially in the deckboards. From analysis of SPACEPAL it was found that the increased rigidity of the pallet by using glue did not increase the bending stresses beyond the strength of the stringers or deckboards.

From the analysis by SPACEPAL it would be reasonable to conclude that a fully covered pallet could sustain substantial loads without experiencing failure in the glueline. The modified pallet may experience gluebond failure at a load well below that of the fully covered pallet.

Since the effects of drying stresses on the glueline are of importance the same number of specimens as in this study have been assembled green and will be tested in the air dry condition at a future date. This information will be made available at that time.

CONCLUSION

From testing of pallet corner joints the following information was found;

----In the Static Load on Corner Test the average maximum loads were 4346.3, 2980, and 1776 pounds respectively for the nail/glued, glued, and nailed joints.

----The average deflections at maximum load were .747, .107, and .136 inches respectively for the nailed, glued, and nail/glued joints.

----The joint rotaion moduli were found to be 60990, 69364, and 15332 in-lbs/rad, respectively for the glued, nail/glued, and nailed specimens.

This investigation has shown that some degree of strength and stiffness can be incorporated in red oak pallet joints assembled at an average moisture content of 77.4 using an specialized epoxy. The stiffness of the joint caused a sudden failure in the glued only and nail/glued joints which could have severe consequences because there is no warning before the failure occurs. Some modification of the epoxy to increase joint flexibility without reducing joint strength should be investigated. Field testing is recommended on full sized pallets since this study was conducted only on pallet joints and not full sized pallets.

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APPENDIX A

List of Donating Companies

List of Contributing Companies

Company	Adhesive
AMICON Lexington, MA	TU-902
BACON INDUSTRIES, INC. Watertown, MA	Kwick Plug - BA-77
DIAMOND SHAMROCK CORPORATION Morristown, NJ	Capcure 3-800, EH-30 Hardener 48, Der-331
EPOXYLITE CORPORATION Anahein, CA	Epoxylite #3351
GENESCO Nashville, TN	88 x 1630-1 88 x 1632
GOODYEAR Ashland, OH	Plionail
HARDMAN INCORPORATED Belleville, NJ	Epoweld 3673
HB FULLER St. Paul, MN	HM 964
KEY POLYMER CORPORATION Lawrence, MA	Marpoxy C2-30 Marpoxy C2-31
LEPOXY PLASTICS, INC. Fort Wayne, IN	Leebond 23-205
NATIONAL CASEIN Chicago, IL	R-14, WP-2200 LE-1200
PERKINS INDUSTRY Overland Park, KS	RP 20
SHELL CHEMICAL COMPANY Houston, TX	Epon 828/v40
SIKA CORPORATION Lyndhurst, NJ	Sikadur 31 Sikadur 33
3M Bristol, PA	Scotch Grip 5230 Scotch Weld 2216

WEYERHAEUSER COMPANY Tacoma, WA	WCO 87-507 HL 4

The following adhesives could not be used since they needed external heat for curing:

ASHLAND CHEMICAL COMPANY Columbus, OH	Isoset WD3-A320 CX-11
UNION CARBIDE Boundbrook, NJ	BIS 2700 Poly vinyl Buterate

APPENDIX B

ANOVA Procedure for Shear Strength (in psi) for Shearblock Test

Duncan's Multiple Range Test for Shear Strength (in psi)

ANOVA Procedure for Moisture Content at Time of Assembly - Shearblock

Statistics from Shearblock Tests

Grand Mean Statistics for Shearblock Tests

ANOVA PROCEDURE for SHEAR STRENGTH
(in psi) for SHEARBLOCK TEST

CLASS	LEVELS	VALUES
BRAND	23	AMCN902 BACON DER331 DI3-800 EPON282 EPOXYLT GEN1631 GEN1632 HARDMAN HM964 LEPOXY L1200 MARC230 MARC231 PLIONAL RP20 R14 SIKA31 SIKA33 WP2200 W87B 3M2216 3M5230

NUMBER OF OBSERVATIONS IN DATA SET = 230

DEPENDENT VARIABLE: PSI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	22	3427335.36400000	155787.97109091	40.93
ERROR	207	787927.36300000	3806.41238164	PR > F
CORRECTED TOTAL	229	4215262.72700000		0.0001

R-SQUARE	C.V.	ROOT MSE	PSI MEAN
0.813078	38.2232	61.69612939	161.41000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BRAND	22	3427335.36400000	40.93	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
BRAND	22	3427335.36400000	40.93	0.0001

DUNCAN'S MULTIPLE RANGE TEST RESULTS for
SHEAR STRENGTH (in psi)--SHEARBLOCK TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING				PERCENT WOOD FAILURE	MEAN strength (psi)	ADHESIVE
		A		27.0	439.96	Marpoxy C2-31
		A				
B		A		4.5	392.80	Epoxylite 3351
B						
B				6.8	360.40	Sikadur-31
		C		13.0	286.80	W87B
		C				
D		C		7.0	252.41	88 x 1632
D		C				
D		C		10.6	242.05	88 x 1630-1
D						
D		E		4.4	220.20	TU-902
D		E				
D		E		21.0	203.40	DER-331
D		E				
D		E		0.4	201.64	R-14
D		E				
D		E		0.9	201.40	LE-1200
		E				
F		E		11.1	161.33	Marpoxy C2-30
F						
F		G		6.0	122.45	Leebond 23-205
		G				
H		G		4.8	96.35	Epoweld 3673
H		G				
H		G		0.0	92.80	Epon 282/V40
H		G				
H		G	I	0.0	89.80	RP-20
H		G	I			
H		G	I	11.5	88.81	Scotch Grip 5230
H		G	I			
H	J	G	I	0.0	71.70	Capcure 3-800
H	J	G	I			
H	J	G	I	5.8	64.53	HM 964
H	J		I			
H	J	K	I	0.0	51.10	Scotch Weld 2216
	J	K	I			
	J	K	I	0.0	27.90	Kwik-Plus/BA-77
	J	K				
	J	K		0.0	26.10	Plionail
	J	K				
	J	K		0.0	18.30	Sikadur 33
		K				
		K		0.0	0.20	WP-2200

ANOVA PROCEDURE for MOISTURE CONTENT
AT TIME OF ASSEMBLY--SHEARBLOCKS

CLASS	LEVELS	VALUES
BRAND	23	AMCN902 BACON DER331 DI3-800 EPON282 EPOXYLT GEN1631 GEN1632 HARDMAN HM964 LEPOXY L1200 MARC230 MARC231 PLIONAL RP20 R14 SIKA31 SIKA33 WP2200 W87B 3M2216 3M5230

NUMBER OF OBSERVATIONS IN DATA SET = 230

DEPENDENT VARIABLE: MOISTURE CONTENT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	22	278.98000000	12.68090909	1.08
ERROR	23	269.75500000	11.72847826	PR > F
CORRECTED TOTAL	45	548.73500000		0.4261

R-SQUARE	C.V.	ROOT MSE	MOISTURE CONTENT MEAN
0.508406	4.2098	3.42468659	81.35000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BRAND	22	278.98000000	1.08	0.4261

SOURCE	DF	TYPE III SS	F VALUE	PR > F
BRAND	22	278.98000000	1.08	0.4261

STATISTICS from SHEARBLOCK TESTS

VARIABLE	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	C.V.
BRAND=TU-902					
PSI	220.2	156.0	270.0	33.2	15.1
PERWF	4.4	1.0	10.0	2.5	55.9
MC	80.9	80.7	81.1	0.3	0.3
BRAND=Kwik Plug/BA-77					
PSI	27.9	10.0	65.0	17.8	63.7
PERWF	0.0	0.0	0.0	0.0	.
MC	82.5	81.2	83.9	1.9	2.3
BRAND=DER-331					
PSI	203.4	144.0	254.0	43.3	21.3
PERWF	21.0	10.0	40.0	9.7	46.0
MC	77.8	74.3	81.4	5.0	6.4
BRAND=Capcure 3-800					
PSI	71.7	40.0	103.0	20.5	28.6
PERWF	0.0	0.0	0.0	0.0	.
MC	79.4	77.8	81.1	2.3	2.9
BRAND=Epon 282/V40					
PSI	92.8	58.0	124.0	19.8	21.4
PERWF	0.0	0.0	0.0	0.0	.
MC	79.1	78.6	79.7	0.8	1.0
BRAND=Epoxylite 3351					
PSI	392.8	308.0	459.0	48.0	12.2
PERWF	4.5	2.0	10.0	2.8	62.2
MC	82.8	81.5	84.2	1.9	2.3
BRAND=88 x 1630-1					
PSI	242.0	158.3	323.3	55.3	22.8
PERWF	10.6	5.0	20.0	5.9	55.9
MC	86.5	84.3	88.8	3.2	3.7

BRAND=88 x 1632					
PSI	252.4	133.3	439.2	97.2	38.5
PERWF	7.0	0.0	20.0	5.4	76.8
MC	82.2	81.4	83.1	1.2	1.5
BRAND=Epoweld 3673					
PSI	96.3	0.0	182.6	53.4	55.4
PERWF	3.8	0.0	10.0	2.9	75.3
MC	82.5	79.7	85.3	4.0	4.8
BRAND=HM 964					
PSI	64.5	50.0	75.8	8.0	12.4
PERWF	5.8	5.0	10.0	1.8	30.2
MC	82.8	80.7	85.0	3.0	3.7
BRAND=Leebond 23-205					
PSI	122.4	54.3	208.3	56.6	46.2
PERWF	6.0	5.0	10.0	2.1	35.1
MC	82.0	81.1	82.9	1.3	1.6
BRAND=LE-1200					
PSI	201.4	161.0	217.0	18.4	9.2
PERWF	0.9	0.0	5.0	1.7	192.1
MC	85.0	84.0	86.0	1.4	1.7
BRAND=Marpoxy C2-30					
PSI	161.3	91.7	257.3	53.3	33.0
PERWF	11.1	8.0	20.0	3.3	30.2
MC	81.2	81.1	81.3	0.1	0.2
BRAND=Marpoxy C2-31					
PSI	440.0	263.2	675.6	137.4	31.2
PERWF	27.0	20.0	40.0	6.3	23.4
MC	81.5	79.8	83.3	2.5	3.0
BRAND=Plionail					
PSI	26.1	5.0	58.0	14.6	55.9
PERWF	0.0	0.0	0.0	0.0	.
MC	78.3	77.2	79.5	1.6	2.1

BRAND=RP-20

PSI	89.8	0.0	183.0	77.2	86.0
PERWF	0.0	0.0	0.0	0.0	.
MC	83.5	83.4	83.7	0.2	0.3

BRAND=R-14

PSI	201.6	0.0	546.0	144.8	71.8
PERWF	0.5	0.0	5.0	1.6	316.2
MC	84.0	83.7	84.4	0.5	0.6

BRAND=Sikadur 31

PSI	360.4	267.0	557.0	81.5	22.6
PERWF	6.8	0.0	15.0	5.1	75.2
MC	81.5	78.1	84.9	4.8	5.9

BRAND=Sikadur 33

PSI	18.3	0.0	58.0	22.4	122.5
PERWF	0.0	0.0	0.0	0.0	.
MC	83.1	81.9	84.4	1.8	2.1

BRAND=WP-2200

PSI	0.2	0.0	2.0	0.6	316.2
PERWF	0.0	0.0	0.0	0.0	.
MC	78.3	77.2	79.5	1.6	2.1

BRAND=W87B

PSI	286.8	175.0	420.0	76.3	26.6
PERWF	13.0	7.0	25.0	5.9	45.6
MC	79.8	75.7	84.0	5.9	7.4

BRAND=Scotch Weld 2216

PSI	51.1	31.0	72.0	13.3	26.0
PERWF	0.0	0.0	0.0	0.0	.
MC	75.7	68.0	83.4	10.9	14.4

BRAND=Scotch Grip 5230

PSI	88.8	70.0	112.0	13.9	15.6
PERWF	11.5	5.0	20.0	4.7	40.6
MC	79.9	79.8	80.0	0.1	0.2

GRAND MEAN STATISTICS for SHEARBLOCK TEST

VARIABLE	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	C.V.
PSI	161.4	0.0	675.6	135.7	84.1
PERWF	5.8	0.0	40.0	7.9	136.3
MC	81.3	68.0	88.8	3.5	4.3

APPENDIX C

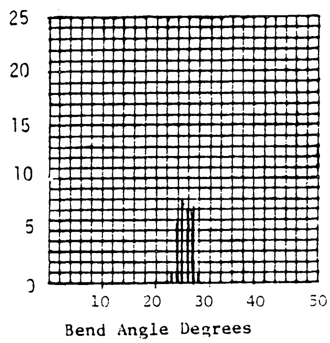
Fastener Quality Index

FASTENER QUALITY ANALYSIS

1. VPI Nail No.: 1875
2. Nails Submitted By: Philstone Nail Corporation
Canton, Massachusetts
3. Nail identification:
4. Nail Size (length x wire diameter in inches): 2.25 x 0.113
5. Nail Type: A. Stiff-stock ___ B. Hardened X
6. Shank Deformation:
A. Annularly Threaded
B. Helically Threaded X
C. Fluted
D. Twisted
7. Thread Characteristics:
A. Length (inches)
B. No. of Flutes 4
C. Helixes/Inch
D. Thread Angle (deg.) 60
8. Date of Receipt at VPI: January 27, 1976
9. Date of Test: January 28, 1976
10. Lab Report By: J.W. Akers
11. General Appearance:

Nail	MIBANT Angle (degrees)
1	27
2	26
3	25
4	26
5	25
6	28
7	26
8	26
9	28
10	27
11	26
12	25
13	25
14	26
15	28
16	24
17	27
18	27
19	28
20	28
21	28
22	26
23	25
24	27
25	27
Avg.	26
Min.	25
Max.	28

MIBANT Angle Frequency Distribution



APPENDIX D

Marpoxy Technical Service Bulletin

TECHNICAL SERVICE BULLETIN

PRODUCT • MAHPOXY C2-31A/B *(Typical Properties)*

SUGGESTED USE	Two Component Adhesive for Green Lumber
OUTSTANDING FEATURES *(Typical)*	Room temperature curing system (as low as 40° F) Good adhesion to wet surfaces.
PHYSICAL PROPERTIES *(Typical)*	Description: thick, beige, non-sagging material Solids: — Wt./Gal.: 7.61b/ga. Ph: — Viscosity: 5.73×10^5 cps Catalyst Required: C2-31B Flash Point: < 200° F
APPLICATION PROCEDURE *(Typical)*	How to Apply: Apply with a stiff brush, spatula, or spreader. How Much: Drying Time / Temp: Curing Time / Temp: 24 hours @ room temperature Other Instructions: Working life of 150 g mass is approximately 1-1/4 hours at room temperature.
HANDLING & STORAGE *(Typical)*	Diluent: — Degree: Cleaner – Wet: Alcohol Cleaner – Dry: Stability: Packaging: Package in metal cans or glass jars. Storage: Store at room temperature. Shelf life: 6 months.
PRECAUTIONS	Do not get in eyes. Avoid prolonged or repeated contact with skin. In case of contact, immediately flush skin or eyes with plenty of water for at least 15 minutes.
MIX RATIO	Mix 26 pbw C2-31B to 100 pbw C2-31A.
MISC. DATA	Average lap shear strength: 537 psi.

COATINGS & ADHESIVES

key polymer corp.

DS #379

Date: June 17, 1983

APPENDIX E

Statistics for Moisture Content at Time of Assembly - Pallet Joints

Moisture Content Data at Time of Assembly

ANOVA Procedure for Variable Moisture Content - Pallet Corner Joints

ANOVA Procedure for Variable Specific Gravity - Pallet Corner Joints

ANOVA Procedure for Variable Moisture Content - Joint Rotation Specimens

ANOVA Procedure for Variable Specific Gravity - Joint Rotation Specimens

Mean Statistics for Moisture Content and Specific Gravity at Time of Test - Joint Rotation

Mean Statistics for Moisture Content and Specific Gravity at Time of Test - Pallet Corner Joints

Raw Data for Moisture Content and Specific Gravity - Pallet Corner Joints

Raw Data for Moisture Content and Specific Gravity - Joint Rotation Specimens

PALLET JOINTS
STATISTICS FOR MOISTURE CONTENT AT TIME OF ASSEMBLY

VARIABLE	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	C.V.
GREENWT	141.4	36.0	243.6	63.9	45.2
OVENDWT	80.0	19.2	147.0	36.5	45.6

MOISTURE CONTENT DATA AT TIME OF ASSEMBLY
for ALL PALLET JOINT SPECIMENS

OBS	GREENWT	OVENDWT	MC
1	193.78	108.72	78.2377
2	201.24	112.42	79.0073
3	243.60	147.05	65.6579
4	206.38	114.14	80.8130
5	228.51	123.70	84.7292
6	230.73	122.64	88.1360
7	171.68	94.84	81.0207
8	201.35	117.41	71.4931
9	198.29	115.14	72.2164
10	196.81	114.19	72.3531
11	141.98	77.01	84.3657
12	145.98	81.20	79.7783
13	172.69	97.95	76.3042
14	156.39	91.26	71.3675
15	92.39	52.75	75.1469
16	187.89	109.53	71.5420
17	157.85	93.97	67.9791
18	36.05	19.17	88.0543
19	38.51	21.31	80.7133
20	41.46	23.53	76.2006
21	115.75	69.18	67.3171
22	95.71	51.13	87.1895
23	43.61	24.16	80.5050
24	102.24	56.05	82.4086
25	84.74	49.72	70.4344
26	36.33	20.69	75.5921
27	98.49	54.71	80.0219
28	93.08	52.92	75.8881
29	170.99	96.57	77.0633
30	157.19	86.85	80.9902

ANOVA PROCEDURE for VARIABLE MOISTURE CONTENT
for ALL PALLET CORNER JOINTS

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 60

DEPENDENT VARIABLE: MOISTURE CONTENT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	248.92686262	124.46343131	1.50
ERROR	57	4734.23192045	83.05670036	PR > F
CORRECTED TOTAL	59	4983.15878307		0.2321

R-SQUARE	C.V.	ROOT MSE	MOISTURE CONTENT MEAN
0.049954	13.7874	9.11354488	66.10071565

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	248.92686262	1.50	0.2321

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	248.92686262	1.50	0.2321

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MOISTURE CONTENT
ALPHA=0.05 DF=57 MSE=83.0567
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	67.608	24	GLUE
A			
A	67.191	18	NAIL
A			
A	63.001	18	NAILGLU

ANOVA PROCEDURE for VARIABLE SPECIFIC GRAVITY
for ALL PALLET CORNER JOINTS

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 60

DEPENDENT VARIABLE: SPECIFIC GRAVITY

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	0.00168474	0.00084237	0.44
ERROR	57	0.10974674	0.00192538	PR > F
CORRECTED TOTAL	59	0.11143148		0.6478

R-SQUARE	C.V.	ROOT MSE	SPECIFIC GRAVITY MEAN
0.015119	6.6977	0.04387917	0.65514186

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	0.00168474	0.44	0.6478

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	0.00168474	0.44	0.6478

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: SPECIFIC GRAVITY
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.05 DF=57 MSE=.0019254
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	0.66189	18	NAILGLU
A			
A	0.65629	18	NAIL
A			
A	0.64922	24	GLUE

ANOVA PROCEDURE for VARIABLE MOISTURE CONTENT
for ALL JOINT ROTATION SPECIMENS

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 48

DEPENDENT VARIABLE: MOISTURE CONTENT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	276.41683479	138.20841740	1.37
ERROR	45	4534.01673958	100.75592755	PR > F
CORRECTED TOTAL	47	4810.43357437		0.2641

R-SQUARE	C.V.	ROOT MSE	MOISTURE CONTENT MEAN
0.057462	15.4979	10.03772522	64.76840917

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	276.41683479	1.37	0.2641

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	276.41683479	1.37	0.2641

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MOISTURE CONTENT
ALPHA=0.05 DF=45 MSE=100.756
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	67.627	16	GLUE
A			
A	64.922	16	NAIL
A			
A	61.755	16	NAILGLU

ANOVA PROCEDURE for VARIABLE MOISTURE CONTENT
for ALL JOINT ROTATION SPECIMENS

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 48

DEPENDENT VARIABLE: MOISTURE CONTENT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	276.41683479	138.20841740	1.37
ERROR	45	4534.01673958	100.75592755	PR > F
CORRECTED TOTAL	47	4810.43357437		0.2641

R-SQUARE	C.V.	ROOT MSE	MOISTURE CONTENT MEAN
0.057462	15.4979	10.03772522	64.76840917

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	276.41683479	1.37	0.2641

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	276.41683479	1.37	0.2641

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MOISTURE CONTENT
ALPHA=0.05 DF=45 MSE=100.756
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	67.627	16	GLUE
A			
A	64.922	16	NAIL
A			
A	61.755	16	NAILGLU

ANOVA PROCEDURE for VARIABLE SPECIFIC GRAVITY
for ALL JOINT ROTATION SPECIMENS

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 48

DEPENDENT VARIABLE: SPECIFIC GRAVITY

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	0.00386901	0.00193451	0.77
ERROR	45	0.11286036	0.00250801	PR > F
CORRECTED TOTAL	47	0.11672937		0.4684

R-SQUARE	C.V.	ROOT MSE	SPECIFIC GRAVITY MEAN
0.033145	7.7916	0.05008002	0.64274533

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	0.00386901	0.77	0.4684

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	0.00386901	0.77	0.4684

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: SPECIFIC GRAVITY
ALPHA=0.05 DF=45 MSE=0.002508
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	0.65427	16	NAILGLU
A			
A	0.64161	16	GLUE
A			
A	0.63236	16	NAIL

ROTATION MODULUS
MEAN STATISTICS for MOISTURE CONTENT AND SPECIFIC GRAVITY
AT TIME OF TESTING

VARIABLE	MEAN	MAXIMUM VALUE	MINIMUM VALUE	STANDARD DEVIATION	C.V.
SECTION=DECKBOARD					
MC	56.599	65.986	45.628	5.649	9.981
SPGRAV	0.666	0.868	0.616	0.054	8.150
SECTION=STRINGER					
MC	72.938	81.594	57.824	6.160	8.446
SPGRAV	0.619	0.692	0.570	0.031	5.029

MOISTURE CONTENT AND SPECIFIC GRAVITY GRAND MEAN
ROTATION MODULUS SPECIMENS

VARIABLE	MEAN	MAXIMUM VALUE	MINIMUM VALUE	STANDARD DEVIATION	C.V.
MC	64.768	81.594	45.628	10.117	15.620
SPGRAV	0.643	0.868	0.570	0.050	7.754

PALLET CORNER JOINTS AT TIME OF TESTING
MEAN STATISTICS for MOISTURE CONTENT AND SPECIFIC GRAVITY

VARIABLE	MEAN	MAXIMUM VALUE	MINIMUM VALUE	STANDARD DEVIATION	C.V.
SECTION=DECKBOARD					
MC	61.539	78.194	48.446	6.263	10.177
SPGRAV	0.674	0.748	0.610	0.035	5.142
SECTION=STRINGER					
MC	75.223	83.765	52.441	7.096	9.433
SPGRAV	0.617	0.710	0.581	0.033	5.278

GRAND MEAN STATISTICS MOISTURE CONTENT AND SPECIFIC GRAVITY
OF PALLET CORNER JOINTS AT TIME OF TESTING

VARIABLE	MEAN	MAXIMUM VALUE	MINIMUM VALUE	STANDARD DEVIATION	C.V.
MC	66.101	83.765	48.446	9.190	13.903
SPGRAV	0.655	0.748	0.581	0.043	6.633

MOISTURE CONTENT AND SPECIFIC GRAVITY-PALLET CORNER JOINTS
AT TIME of TESTING

OBS	SPECNUM	SECTION	TREATMNT	GREENWT	OVENDWT	OVENWT	DISP	MC	SPGRAV
1	3	S	NAIL	119.98	69.54	69.54	119.7	72.5338	0.580952
2	3	D	NAIL	68.03	42.38	42.38	64.5	60.5238	0.657054
3	3	D	NAIL	50.91	32.43	32.43	48.5	56.9843	0.668660
4	4	S	NAIL	68.43	38.87	38.87	65.8	76.0484	0.590729
5	4	D	NAIL	65.59	41.58	41.58	58.1	57.7441	0.715663
6	4	D	NAIL	75.37	47.62	47.62	66.1	58.2738	0.720424
7	5	S	NAIL	145.89	83.33	83.33	141.8	75.0750	0.587659
8	5	D	NAIL	78.78	47.49	47.49	71.0	65.8876	0.668873
9	5	D	NAIL	63.33	38.91	38.91	56.5	62.7602	0.688673
10	6	S	NAIL	109.62	60.54	60.54	100.5	81.0704	0.602388
11	6	D	NAIL	56.08	32.60	32.60	48.7	72.0245	0.669405
12	6	D	NAIL	53.95	32.15	15.34	22.3	67.8072	0.687892
13	7	S	NAIL	91.89	52.92	52.92	89.9	73.6395	0.588654
14	7	D	NAIL	71.81	44.50	44.50	64.3	61.3708	0.692068
15	7	D	NAIL	93.12	57.03	57.03	78.4	63.2825	0.727423
16	8	S	NAIL	96.06	56.17	56.17	95.5	71.0166	0.588168
17	8	D	NAIL	63.19	38.27	38.27	54.7	65.1163	0.699634
18	8	D	NAIL	65.46	38.90	38.90	57.3	68.2776	0.678883
19	3	S	NAILGLU	109.56	60.66	66.66	104.3	80.6133	0.639118
20	3	D	NAILGLU	77.33	49.18	49.18	68.2	57.2387	0.721114
21	3	D	NAILGLU	64.30	41.16	19.54	26.7	56.2196	0.731835
22	4	S	NAILGLU	61.52	36.02	36.02	57.5	70.7940	0.626435
23	4	D	NAILGLU	48.15	31.90	31.90	49.1	50.9404	0.649695
24	4	D	NAILGLU	46.33	31.21	31.21	46.8	48.4460	0.666880
25	5	S	NAILGLU	137.07	74.59	74.59	127.9	83.7646	0.583190
26	5	D	NAILGLU	81.83	51.40	25.36	35.4	59.2023	0.716384
27	5	D	NAILGLU	88.94	55.96	55.96	74.8	58.9350	0.748128
28	6	S	NAILGLU	105.02	59.38	59.38	100.2	76.8609	0.592615
29	6	D	NAILGLU	52.88	33.21	33.21	48.1	59.2291	0.690437
30	6	D	NAILGLU	58.67	37.84	37.84	50.9	55.0476	0.743418
31	7	S	NAILGLU	123.87	73.00	73.00	117.7	69.6849	0.620221
32	7	D	NAILGLU	77.48	48.39	48.39	72.6	60.1157	0.666529
33	7	D	NAILGLU	53.45	34.19	34.19	52.0	56.3323	0.657500
34	8	S	NAILGLU	77.24	42.40	42.40	71.1	82.1698	0.596343
35	8	D	NAILGLU	53.50	34.18	34.18	53.4	56.5243	0.640075
36	8	D	NAILGLU	39.34	25.90	25.90	41.5	51.8919	0.624096
37	1	S	GLUE	49.90	29.68	29.68	46.3	68.1267	0.641037
38	1	D	GLUE	53.35	31.62	31.62	48.6	68.7223	0.650617
39	1	D	GLUE	34.91	22.25	22.25	34.6	56.8989	0.643064
40	2	S	GLUE	53.49	29.51	29.51	45.6	81.2606	0.647149
41	2	D	GLUE	75.77	46.20	46.20	72.2	64.0043	0.639889
42	2	D	GLUE	43.22	26.40	26.40	39.8	63.7121	0.663317
43	3	S	GLUE	60.13	34.41	34.41	52.7	74.7457	0.652941
44	3	D	GLUE	53.28	29.90	29.90	45.1	78.1940	0.662971
45	3	D	GLUE	43.76	27.01	27.01	40.1	62.0141	0.673566
46	4	S	GLUE	63.16	34.48	34.48	58.2	83.1787	0.592440
47	4	D	GLUE	40.88	23.99	23.99	39.2	70.4043	0.61990
48	4	D	GLUE	34.74	21.90	21.90	35.4	58.6301	0.68644
49	5	S	GLUE	63.55	35.59	35.59	56.5	78.5614	0.69912
50	5	D	GLUE	57.73	34.65	34.65	51.3	66.6089	0.65439
51	5	D	GLUE	68.14	41.83	41.83	61.8	62.8974	0.66861
52	6	S	GLUE	81.67	45.78	45.78	72.2	78.3967	0.64072
53	6	D	GLUE	47.33	27.51	27.51	45.1	72.0465	0.69978
54	6	D	GLUE	48.33	30.82	30.82	45.2	56.8138	0.61858
55	7	S	GLUE	45.58	29.90	29.90	42.1	52.4415	0.70214
56	7	D	GLUE	37.71	22.92	22.92	34.2	64.5288	0.60175
57	7	D	GLUE	47.81	29.98	29.98	47.4	59.4730	0.62489
58	8	S	GLUE	86.51	49.58	49.58	78.8	74.4857	0.69188
59	8	D	GLUE	76.94	45.31	45.31	68.1	69.8080	0.65345
60	8	D	GLUE	56.83	36.28	36.28	54.3	56.6428	0.68140

ROTATION MODULUS
RAW DATA for MOISTURE CONTENT AND SPECIFIC GRAVITY

OBS	SPECNUM	SECTION	TREATMNT	GREENWT	OVENDWT	OVENWT	DISP	MC	SPGRAV
1	1	S	GLUE	48.30	27.03	27.03	41.7	78.6903	0.648201
2	1	D	GLUE	28.59	17.80	8.94	12.6	60.6180	0.709524
3	2	S	GLUE	49.52	28.58	28.58	41.3	73.2680	0.692010
4	2	D	GLUE	38.99	23.49	23.49	37.1	65.9855	0.633154
5	3	S	GLUE	40.60	23.33	23.33	35.6	74.0249	0.655337
6	3	D	GLUE	24.90	15.26	15.26	24.4	63.1717	0.625410
7	4	S	GLUE	82.11	47.25	47.25	71.3	73.7778	0.662693
8	4	D	GLUE	40.01	26.40	26.40	35.1	51.5530	0.752137
9	5	S	GLUE	27.51	15.43	15.43	25.2	78.2890	0.612302
10	5	D	GLUE	31.96	20.53	20.53	32.0	55.6746	0.641562
11	6	S	GLUE	48.54	26.73	26.73	46.3	81.5937	0.577322
12	6	D	GLUE	30.73	19.50	19.50	30.6	57.5897	0.637255
13	7	S	GLUE	85.07	47.17	47.17	81.7	80.3477	0.577356
14	7	D	GLUE	40.04	26.45	13.23	21.2	51.3800	0.624057
15	8	S	GLUE	61.69	34.80	34.80	61.0	77.2701	0.570492
16	8	D	GLUE	36.16	22.77	22.77	35.2	58.8054	0.646875
17	1	S	NAIL	76.09	42.16	39.23	64.0	80.4791	0.612969
18	1	D	NAIL	17.34	10.46	34.80	55.6	65.7744	0.625899
19	2	S	NAIL	98.05	56.05	43.91	73.3	74.9331	0.599045
20	2	D	NAIL	18.89	11.56	34.94	54.5	63.4083	0.641101
21	3	S	NAIL	76.51	44.32	35.35	54.9	72.6309	0.643898
22	3	D	NAIL	33.83	20.60	32.13	48.5	64.2233	0.662474
23	4	S	NAIL	162.52	91.27	42.08	69.9	78.0651	0.602003
24	4	D	NAIL	32.20	20.26	30.61	49.4	58.9339	0.619636
25	5	S	NAIL	111.63	66.06	55.85	91.2	68.9827	0.612390
26	5	D	NAIL	46.13	30.42	21.05	30.3	51.6437	0.694719
27	6	S	NAIL	78.69	44.15	37.69	65.8	78.2333	0.572796
28	6	D	NAIL	54.83	35.97	36.81	52.7	52.4326	0.698482
29	7	S	NAIL	106.00	65.36	36.43	57.9	62.1787	0.629188
30	7	D	NAIL	42.53	27.94	29.61	43.7	52.2190	0.677574
31	8	S	NAIL	57.03	35.01	45.42	74.5	62.8963	0.609664
32	8	D	NAIL	47.99	31.63	30.06	48.8	51.7230	0.615984
33	1	S	NAILGLU	47.61	28.54	28.54	48.6	66.8185	0.587243
34	1	D	NAILGLU	29.90	18.83	18.83	21.7	58.7892	0.867742
35	2	S	NAILGLU	109.29	63.36	63.36	105.8	72.4905	0.598866
36	2	D	NAILGLU	42.92	26.78	13.54	20.2	60.2689	0.670297
37	3	S	NAILGLU	66.32	39.85	39.85	62.8	66.4241	0.634554
38	3	D	NAILGLU	23.01	14.43	14.43	21.3	59.4595	0.677465
39	4	S	NAILGLU	47.00	29.78	29.78	45.8	57.8240	0.650218
40	4	D	NAILGLU	50.30	34.54	34.54	53.7	45.6283	0.643203
41	5	S	NAILGLU	124.99	71.60	71.60	115.8	74.5670	0.618307
42	5	D	NAILGLU	43.10	28.73	28.73	45.2	50.0174	0.635619
43	6	S	NAILGLU	109.76	63.69	63.69	101.4	72.3347	0.628107
44	6	D	NAILGLU	47.12	31.51	31.51	46.1	49.5398	0.683514
45	7	S	NAILGLU	114.06	66.09	66.09	106.1	72.5828	0.622903
46	7	D	NAILGLU	39.14	25.43	25.43	39.8	53.9127	0.638945
47	8	S	NAILGLU	116.78	67.97	67.97	105.7	71.8111	0.643046
48	8	D	NAILGLU	58.03	37.29	38.29	57.3	55.6181	0.668237

APPENDIX F

ANOVA Procedure for Variable Maximum Load from Static Load on Corner Test

ANOVA Procedure for Variable Deflection at Maximum Load from Static Load or Corner Test

Statistics for Static Load on Corner Test

Raw Data for Static Load on Corner Test

ANOVA PROCEDURE for VARIABLE MAXIMUM LOAD
from STATIC LOAD ON PALLET CORNER TEST

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLUE

NUMBER OF OBSERVATIONS IN DATA SET = 12

DEPENDENT VARIABLE: MAXIMUM LOAD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	13229920.16666666	6614960.08333333	39.88
ERROR	9	1492810.75000001	165867.86111111	PR > F
CORRECTED TOTAL	11	14722730.91666667		0.0001

R-SQUARE	C.V.	ROOT MSE	MAXIMUM LOAD MEAN
0.898605	13.4231	407.26878239	3034.08333333

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	13229920.16666666	39.88	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	13229920.16666666	39.88	0.0001

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MAXIMUM LOAD
ALPHA=.05
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN (pounds)	N	TREATMNT
A	4346.3	4	NAILGLUE
B	2980.0	4	GLUE
C	1776.0	4	NAIL

ANOVA PROCEDURE for VARIABLE DEFLECTION AT MAXIMUM LOAD
from STATIC LOAD ON CORNER TEST

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLUE

NUMBER OF OBSERVATIONS IN DATA SET = 12

DEPENDENT VARIABLE: DEFLECTION AT MAXIMUM LOAD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	0.96274850	0.48137425	156.64
ERROR	9	0.02765850	0.00307317	PR > F
CORRECTED TOTAL	11	0.99040700		0.0001

R-SQUARE	C.V.	ROOT MSE	DEFLECTION at MAXIMUM LOAD MEAN
0.972074	16.0452	0.05543615	0.34550000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	0.96274850	156.64	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	0.96274850	156.64	0.0001

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DEFLECTION AT MAXIMUM LOAD
ALPHA=0.05
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN (inches)	N	TREATMNT
A	0.74350	4	NAIL
B	0.18575	4	NAILGLUE
B			
B	0.10725	4	GLUE

STATISTICS for STATIC LOAD ON PALLET CORNER TEST

VARIABLE	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	C.V.
TREATMNT=GLUE					
MAXLOAD	2980.0	2140.0	3430.0	574.2	19.3
DEFMAXLD	0.1	0.1	0.1	0.0	17.8
TREATMNT=NAIL					
MAXLOAD	1776.0	1564.0	2000.0	179.8	10.1
DEFMAXLD	0.7	0.6	0.8	0.1	12.2
TREATMNT=NAILGLUE					
MAXLOAD	4346.3	3850.0	4650.0	368.2	8.5
DEFMAXLD	0.2	0.2	0.2	0.0	14.1

RAW DATA for STATIC LOAD ON PALLET CORNER TEST

OBS	JOINTNUM	TREATMNT	MAXLOAD	DEFMAXLD	SUSLOAD	SUSDEF	QUASIMOD
1	2	NAIL	1800	0.707	1800	0.707	10100
2	4	NAIL	1740	0.850	1740	0.850	7300
3	6	NAIL	2000	0.640	2000	0.640	5680
4	8	NAIL	1564	0.777	1564	0.777	11630
5	2	GLUE	3225	0.110	3225	0.110	28500
6	4	GLUE	3430	0.133	3430	0.133	25000
7	6	GLUE	3125	0.096	3125	0.096	34500
8	8	GLUE	2140	0.090	2140	0.090	20600
9	2	NAILGLUE	4650	0.185	2835	0.358	36400
10	4	NAILGLUE	4600	0.217	2850	0.456	27800
11	6	NAILGLUE	4285	0.188	2500	0.358	21300
12	8	NAILGLUE	3850	0.153	2760	0.443	27800

APPENDIX G

ANOVA Procedure for Rotation Modulus

Mean Statistics Rotation Modulus Adjusted Stringer Width

Raw Data - Rotation Modulus

ANOVA PROCEDURE for ROTATION MODULUS

CLASS	LEVELS	VALUES
TREATMNT	3	GLUE NAIL NAILGLU

NUMBER OF OBSERVATIONS IN DATA SET = 24

DEPENDENT VARIABLE: ROTATION MODULUS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	2	13531207096.333329	6765603548.166664	62.96
ERROR	21	2256610742.625006	107457654.410715	PR > F
CORRECTED TOTAL	23	15787817838.958334		0.0001

R-SQUARE	C.V.	ROOT MSE	ROTATION MODULUS MEAN
0.857066	21.3461	10366.178390	48562.29166667

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TREATMNT	2	13531207096.333329	62.96	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
TREATMNT	2	13531207096.333329	62.96	0.0001

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: ROTATION MODULUS
ALPHA=0.05
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	TREATMNT
A	69364	8	NAILGLU
A			
A	60990	8	GLUE
B	15332	8	NAIL

ROTATION MODULUS MEAN STATISTICS ADJUSTED STRINGER WIDTH

VARIABLE	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	C.V.
----- TREATMNT=GLUE -----					
ROTATION MODULUS	60990.4	48006.0	78706.0	11834.4	19.4
----- TREATMNT=NAIL -----					
ROTATION MODULUS	15332.4	9535.0	27924.0	6052.4	39.5
----- TREATMNT=NAILGLU -----					
ROTATION MODULUS	69364.1	55500.0	89742.0	12070.2	17.4

ROTATION MODULUS RAW DATA ADJUSTED STRINGER WIDTH

OBS	JOINT NUMBER	TREATMENT	ROTATION MODULUS	MAXIMUM LOAD	DEFLECTION AT MAX LOAD	SUSTAINED LOAD	SUSTAINED
1	1NN	NAIL	27924	.	.	342	0.5
2	2NN	NAIL	19093	.	.	219	0.5
3	3NN	NAIL	13582	.	.	185	0.5
4	4NN	NAIL	10076	.	.	182	0.5
5	5NN	NAIL	11284	.	.	196	0.5
6	6NN	NAIL	9535	.	.	210	0.5
7	7NN	NAIL	14376	.	.	198	0.5
8	8NN	NAIL	16789	.	.	205	0.5
9	1GG	GLUE	75016	145	0.064	.	.
10	2GG	GLUE	78706	213	0.070	.	.
11	3GG	GLUE	55500	325	0.206	.	.
12	4GG	GLUE	51071	345	0.175	.	.
13	5GG	GLUE	68585	291	0.130	.	.
14	6GG	GLUE	50269	210	0.124	.	.
15	7GG	GLUE	48006	229	0.122	.	.
16	8GG	GLUE	60770	262	0.121	.	.
17	1NG	NAILGLU	84976	375	0.140	175	0.5
18	2NG	NAILGLU	65766	238	0.116	188	0.5
19	3NG	NAILGLU	55500	206	0.095	138	0.5
20	4NG	NAILGLU	57494	398	0.185	263	0.5
21	5NG	NAILGLU	67145	375	0.154	263	0.5
22	6NG	NAILGLU	67145	355	0.157	269	0.5
23	7NG	NAILGLU	89742	296	0.148	263	0.5
24	8NG	NAILGLU	67145	300	0.138	265	0.5

APPENDIX H

Data from Impact Load Test

Raw Data for Impact Load on Corner Test

OBS	GROUP	JOINTNUM	TREATMNT	DROP0	DROP1	DROP2	DROP3	DROP4	DROP5	DROP6
1	1	1	NAIL	0	10	20	30	40	50	60
2	1	3	NAIL	0	10	20	30	40	50	60
3	1	5	NAIL	0	10	20	30	40	50	60
4	1	7	NAIL	0	10	20	30	40	50	60
5	2	1	NAILGL	0	10	20	30	40	50	60
6	2	3	NAILGL	0	10	20	30	40	50	60
7	2	5	NAILGL	0	10	20	30	40	50	60
8	2	7	NAILGL	0	10	20	30	40	50	60
9	3	1	GLUE	0	10	20	30	0	0	0
10	3	3	GLUE	0	10	20	30	40	50	0
11	3	5	GLUE	0	10	20	30	40	0	0
12	3	7	GLUE	0	10	20	0	0	0	0

OBS	DROP7	DROP8	DROP9	DROP10	DROP11	DROP12	DROP13	DROP14	DROP15	DROP16	DROP17
1	70	70	0	0	0	0	0	0	0	0	0
2	70	70	70	70	70	0	0	0	0	0	0
3	70	70	70	0	0	0	0	0	0	0	0
4	70	70	70	70	70	0	0	0	0	0	0
5	70	70	70	70	70	70	70	70	70	70	70
6	70	70	70	70	70	70	0	0	0	0	0
7	70	70	70	70	70	70	0	0	0	0	0
8	70	70	70	70	70	70	70	70	70	70	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0

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