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THE GLUING PROPERTIES of CERTAIN TROPICAL AMERICAN WOODS

Technical Report No. 4

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THE GLUING PROPERTIES OF CERTAIN TROPICAL AMERICAN WOODS /1

Technical Report No. 4

Benjamin S. Troop and Frederick F. Wangaard

This study is one of a series undertaken as part of a continuing investigation of the properties of tropical woods. The investigation is being conducted at the Yale School of Forestry and is sponsored by the Office of Naval Research, Department of the Navy, under Contract N6ori-44, Task Order XV (Project Designation NR-033-020). The scope of the complete research program is indicated in <u>Properties and Uses of Tropical Woods, I</u>, published in TROPICAL WOODS 95 (June 1, 1949) (1).

This report presents the results of a preliminary survey of the gluing properties of a group of selected tropical woods which, on the basis of their mechanical and physical properties, appear to be adapted to a number of industrial or structural uses.

It is likely that imported woods will always be more costly than native species. Gluing of these woods is therefore important not only from the standpoint of assembly gluing as employed conventionally in fabricated wood products and structures but, in addition, from the standpoint of more complete utilization as may be made possible through laminated and edge-glued construction. The advantages afforded by a valuable wood of unusual properties may, under certain conditions of use, be obtained by laminating in combination with other less expensive woods and even by incorporating thin veneers with low-cost lumber cores.

Twenty-nine tropical American woods are included in this study in addition to Burma teak and domestic white oak. Two adhesives, one a resorcinol resin /2 and the other a phenol-resorcinol /3, were employed in these tests and

/1 This paper is condensed from a thesis by Benjamin S. Troop submitted to the Yale School of Forestry in partial fulfillment of the requirements for the degree of Master of Forestry (1949).

/2 Penacolite G-1124, Pennsylvania Coal Products Dept., Koppers Co., Inc., Pittsburgh, Pa.

/3 Perkins RP-18, Perkins Glue Co., Lansdale Pa.
Appreciation is expressed to these firms for their cooperation in furnishing the resins.

an evaluation of the gluing properties of each wood is based on joint strength and percentage of wood failure as developed in the standard block-shear test. With one exception gluing was limited to machine-planed surfaces, and special surface treatments such as sanding or chemical cleaning were not investigated. The results of this survey furnish a preliminary indication of the relative ease or difficulty of gluing these particular species. It is recognized that other types of adhesive and other gluing techniques may yield results considerably different than those reported here.

Test Materials and Their Preparation

The bulk of the material used in this study was obtained from 5/4-inch boards sawed radially or tangentially from log quadrants remaining after selection of specimens for standard mechanical tests of the wood (1). An attempt was made to obtain equal amounts of radially- and tangentially-cut stock to yield blocks 3/4 by 2 1/2 by 12 inches. With some species, however, it was found necessary to use material of only one type with respect to growth-ring placement.

All stock selected for gluing had been air seasoned to a moisture content below 18 percent and most of the material had reached 15 percent prior to preparatory conditioning in a kiln. Moisture content at the time of final machining and gluing was limited to the range of 10-15 percent.

Conditioned stock was ripped into strips 2 1/2 inches wide and planed on both wide surfaces with a thickness planer. A final light cut of 1/64 inch was made on surfaces selected for gluing. Planing preceded gluing by no more than one week, usually only a day or two, and any planed material which could not be glued immediately was bulk piled and stored under equilibrium moisture content conditions of about 12 percent to reduce the possibility of raised grain and distortion resulting from changes in moisture content.

Immediately prior to gluing the surfaced stock was cross-cut into 12-inch blocks which were assembled in pairs to assure combining pieces of similar growth-ring placement and specific gravity. A maximum differential in moisture content between paired blocks of 2 percent was allowed.

Gluing Procedure

Details of the gluing procedure were adapted in each case to comply with instructions furnished by the adhesive manufacturer. The adhesive was double spread at the rate of 60 pounds per 1000 square feet of joint area. With Penacolite G-1124 a 10-minute open assembly was followed by a 10-25 minute closed assembly. In the case of Perkins RP-18 a 5-minute open assembly was followed by 15-35 minutes of closed assembly. All gluing was done at a room temperature of approximately 75° F.

Gluing pressure was applied by means of rocker-head, screw clamps and pressure was correlated with the specific gravity of the wood as follows: 100-150 pounds per square inch for the specific gravity range of 0.36-0.45; 150-200 pounds for the range 0.46-0.55, and 200-250 pounds for specific gravities of 0.56 or more.

Curing of the adhesive was accomplished in a temperature-and humidity-controlled cabinet by maintaining a glue-line temperature of 155° F. ±5° F. for a period of 8 hours [1]. Equilibrium moisture content conditions were maintained equivalent to the moisture content of the stock at the time of gluing. About 6 hours were allowed for cooling which was aided by spraying water into the

[1] Selection of these particular curing conditions does not imply that cure of the resins was complete nor was an attempt made to compare results with those obtained under other conditions. Other tests made at the Forest Products Laboratory, Madison, Wisconsin, however, have indicated that curing at 140° F for 10 hours is desirable for obtaining highly durable bonds with relatively dense woods such as white oak (3).

chamber, following which the clamped assemblies were released from pressure and stored for conditioning. A conditioning period of at least 7 days preceded machining of test specimens for mechanical testing of the glue joints.

Test Procedure and Results

After conditioning, the 2-ply laminated blocks were sawed to a 2-inch by 10-inch size and,[1] from each of these, three standard block-shear specimens were cut immediately prior to testing.

The block-shear test was carried out in accordance with American Society for Testing Materials standard procedure (A. S. T. M. Designation D905-~~47T~~ 49), "Strength properties of adhesives in shear by compression loading." A minimum of six specimens from at least two different blocks was tested to failure, and maximum shear stress in pounds per square inch together with estimated percentage of wood failure was recorded. Average moisture content at test and average specific gravity (oven-dry weight and oven-dry volume basis) were also determined.

Results of shear tests for each of the 31 species tested, averaged for the two adhesives used, are given in Table 1. Only limited data are available with which to compare the results obtained in this study. Values for white oak and mahogany glued with a number of adhesives have been published by the Forest Products Laboratory (2, 6) and are shown in Table 2 together with the results obtained in this study with resorcinol and resorcinol-phenol resins.

[1] For a description of standard block-shear specimens, see U. S. Dept. Agr. Dept. Bulletin No. 1500 "The Gluing of Wood" (6).

Table 1. Average results of dry shear tests of tropical woods glued with resorcinol and resorcinol-phenol resin adhesives.

Species	Source	Specific Gravity	Moisture Content	Shear Strength	Wood Failure
		oven-dry vol. basis	percent	lb. per sq. in.	percent
Muira-juba (*Apuleia molaris*)	Brazil	0.86	10.3	2560	80
Goncalo Alves (*Astronium graveolens*)	Honduras	1.02	13.0	2350	39
Brazil Nut (*Bertholletia excelsa*)	Brazil	0.64	9.6	1720	86
Cedro Espino (*Bombacopsis quinata*)	Honduras	0.56	8.9	1760	69
Yellow Sanders (*Buchenavia capitata*)	Puerto Rico	0.71	10.8	2120	63
Andiroba (*Carapa guianensis*)	Brazil	0.66	11.2	2190	80
Cedro Granadino (*Cedrela Tonduzii*)	Panama	0.46	10.8	1730	92
Mora Amarilla (*Chlorophora tinctoria*)	Honduras	0.70	8.4	2290	70
Laurel Blanco (*Cordia alliodora*)	Nicaragua	0.40	8.7	1300	90
Cumaru (*Coumarouna odorata*)	Brazil	1.08	11.4	2150	28
Tauary (*Couratari pulchra*)	Brazil	0.60	9.0	1800	86
Angelique (*Dicorynia paraensis*)	Surinam	0.70	10.6	1960	80
Black Kakeralli (*Eschweilera Sagotiana*)	British Guiana	0.95	11.0	1910	58
Lignum Vitae (*Guaiacum officinale*)	/1	1.22	12.1	1180	8
Angelim dos Amarelos (*Hymenolobium excelsum*)	Brazil	0.68	9.3	2380	86
Kaneelhart (*Licaria cayennensis*)	Surinam	1.20	8.8	2100	32
Hububalli (*Loxopterygium Sagotii*)	British Guiana	0.67	10.0	1760	59
Vaco (*Magnolia sororum*)	Panama	0.60	9.7	2230	76
Bulletwood (*Manilkara bidentata*)	Puerto Rico, Surinam	0.98	10.0	2640	65
Determa (*Ocotea rubra*)	Surinam	0.58	11.6	1190	95
White Oak (*Quercus alba*)	United States /2	0.68	10.4	2330	96
Mahogany (plantation-grown) (*Swietenia macrophylla*)	Honduras	0.64	10.4	2190	60
Mahogany (*Swietenia macrophylla*)	Central /2 America	0.50	10.6	1680	90
Primavera (*Tabebuia Donnell-Smithii*)	Honduras	0.46	10.4	1610	82
Guayacan (*Tabebuia guayacan*)	Honduras	1.06	9.0	2370	29

Table 1. (cont'd)

Species	Source	Specific Gravity	Moisture Content	Shear Strength	Wood Failure
		oven-dry vol. basis	percent	lb. per sq. in.	percent
Roble Blanco (*Tabebuia pentaphylla*)	British Honduras, Honduras	0.55	10.0	1680	86
Teak (plantation-grown) (*Tectona grandis*)	Honduras	0.62	8.9	2030	74
Teak (*Tectona grandis*)	Burma /2	0.65	10.0	2040	92
Nargusta (*Terminalia amazonia*)	British Guiana	0.80	10.2	2410	67
Masa (*Tetragastris balsamifera*)	Puerto Rico	0.82	9.6	2750	68
Fiddlewood (*Vitex Gaumeri*)	British Honduras	0.71	9.4	2090	52

/1 Lignum Vitae was supplied in the form of 1-inch sawed blanks by the Lignum-Vitae Products Corp., Jersey City, New Jersey.

/2 Supplied in plank form from stock of the New York Naval Shipyard, Brooklyn, New York.

Table 2. Comparison of results of gluing white oak and mahogany with different adhesives.

Adhesive	White Oak Specific Gravity/1	White Oak Shear Strength/2	Mahogany Specific Gravity/1	Mahogany Shear Strength/2
Resorcinol-type resin	0.64	2330-96	0.48	1680-90
Urea resin/3	0.63	2670-94	0.47	1924-99
Animal/4	0.66	2375-78	0.46	1750-92
Vegetable/4	0.66	2300-53	0.46	1925-93
Casein/4	0.68	2050-45	0.45	1800-69

/1 Specific gravity based on oven-dry weight and volume at test.

/2 The value preceding the hyphen denotes strength in pounds per square inch, the following value is percentage of wood failure.

/3 Forest Products Laboratory Report 1342 (2).

/4 U. S. Dept. Agr. Dept. Bulletin 1500 (6).

From these results it would appear that all types of adhesive are not equally satisfactory for the gluing of these two species for which comparison is permitted. Particularly with reference to wood-failure values, casein and vegetable glues do not seem to permit as full a development of the strength of white oak as do the animal, urea, and resorcinol adhesives. Eickner (2) concluded that there was less difference between the gluing characteristics of woods of different densities when glued with urea resin than when glued with casein. Insofar as mahogany and white oak permit such a comparison, the non-resin adhesives show appreciably lower wood failure values in the case of white oak. Results for the resorcinol-type adhesives compare favorably with urea resin in this respect. Differences in shear-strength values undoubtedly reflect, at least in part, variation in the strength of the wood itself and are probably of no particular significance. The general influence of specific gravity upon the strength of glue joints made with resorcinol and resorcinol-phenol adhesives is shown in Fig. 1. In this figure the 31 species of this study are arranged in order of increasing specific

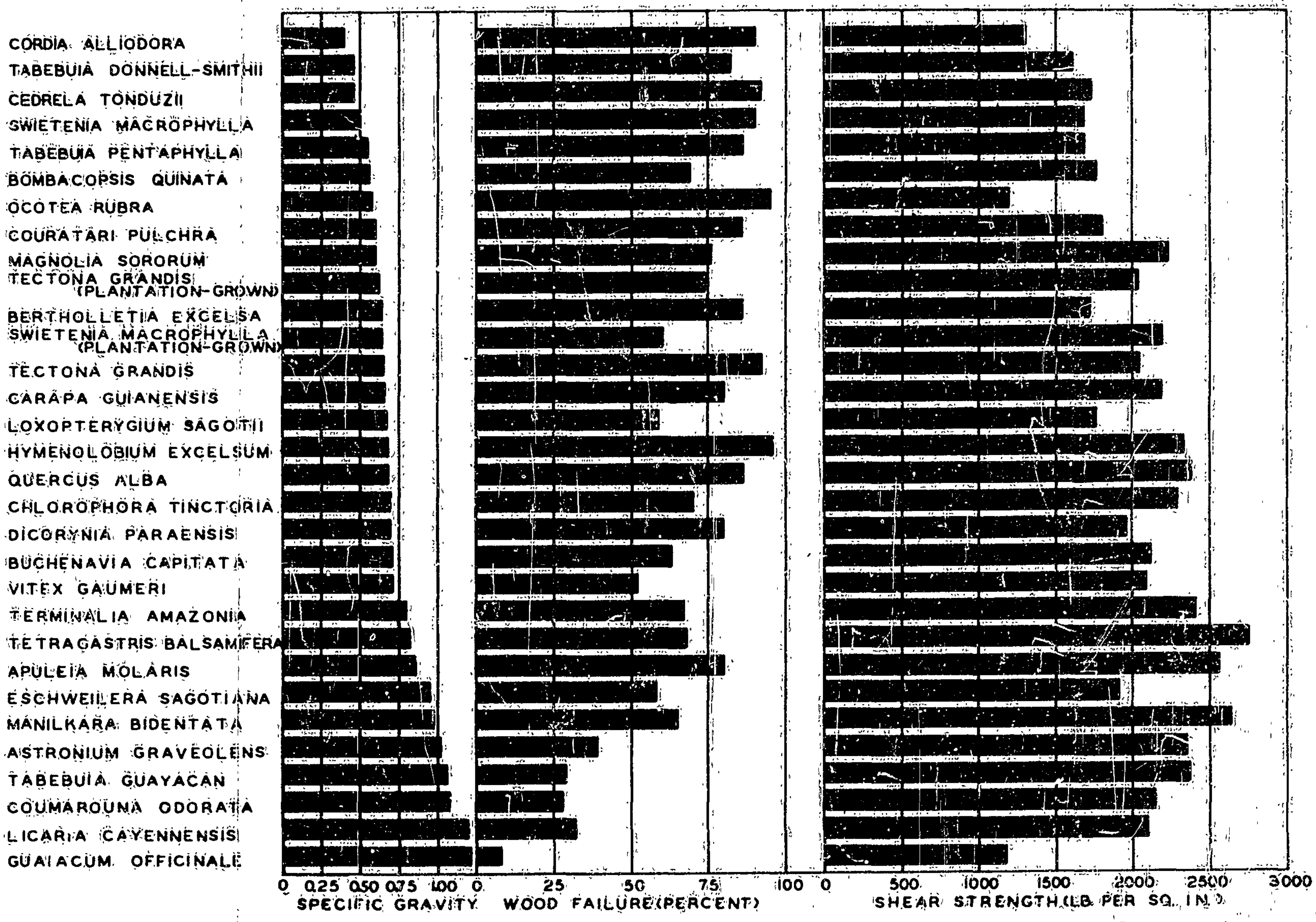

FIG 1 - AVERAGE RESULTS OF SHEAR TESTS ON JOINTS OF TROPICAL WOODS USING RESORCINOL AND RESORCINOL-PHENOL GLUES.

gravity and the general trend is that of increasing joint strength and decreasing wood failure with increase in specific gravity. In general, the trend toward decreasing percentage of wood failure is less marked than that previously noted for animal, vegetable, and especially casein glues and is more nearly comparable to that of urea resin for woods of similar density (2, 6). On the basis of the values indicated in Figure 1, these woods have been classified into four groups relative to their ease of gluing as shown in Table 3. Of the woods shown, only 5 species, all with a specific gravity above 1.00, developed less than 50 percent wood failure.

The uneven character of the trend of values for wood failure and shear strength in Figure 1 provides evidence of interference with the adhesive encountered in certain species. Such interference may be introduced as a result of defective surfacing or it may be related to the character of chemical components, such as gums, resins, oils, and waxes which occur in varying amounts as extractives in many woods. The effect of such interference is partly obscured in shear-strength data because of deviations of individual species from the strength values anticipated on the basis of specific gravity alone.

Among the species that appear to involve some type of incompatibility with the adhesive that interferes with the development of the full strength of the wood are the following: Loxopterygium Sagotii, Buchenavia capitata, Vitex Gaumeri, Astronium graveolens, Tabebuia guayacan, Coumarouna odorata, Licaria cayennensis, and Guaiacum officinale. Only in the last named, however, was this influence sufficient to reduce the strength of the joint to an extreme degree. Of these woods surfacing difficulties, primarily associated with the presence of interlocked grain, were encountered in all but Buchenavia capitata and Guaiacum

Table 3. Classification of tropical woods according to gluing characteristics with resorcinol-type adhesives.

Woods Easy to Glue

Muira-juba (Apuleia molaris)

Brazil Nut (Bertholletia excelsa)

Andiroba (Carapa guianensis)

Cedro Granadino (Cedrela Tonduzii)

Laurel Blanco (Cordia alliodora)

Tauary (Couratari pulchra)

Angelim dos Amarelos (Hymenolobium excelsum)

Vaco (Magnolia sororum)

Determa (Ocotea rubra)

White Oak (Quercus alba) (control)

Mahogany (Swietenia macrophylla)

Primavera (Tabebuia Donnell-Smithii)

Roble Blanco (Tabebuia pentaphylla)

Teak (Tectona grandis) (control)

Woods Moderately Easy to Glue

Cedro Espino (Bombacopsis quinata)

Mora Amarilla (Chlorophora tinctoria)

Angelique (Dicorynia paraensis)

Mahogany (Swietenia macrophylla) (plantation-grown)

Teak (Tectona grandis) (plantation-grown)

Nargusta (Terminalia amazonia)

Masa (Tetragastris balsamifera)

Table 3. (cont'd.)

<u>Woods Requiring Special Care in the Gluing Operation</u>

Goncalo Alves (*Astronium graveolens*)

Yellow Sanders (*Buchenavia capitata*)

Cumaru (*Coumarouna odorata*)

Black Kakeralli (*Eschweilera Sagotiana*)

Kaneelhart (*Licaria cayennensis*)

Hububalli (*Loxopterygium Sagotii*)

Bulletwood (*Manilkara bidentata*)

Guayacan (*Tabebuia guayacan*)

Fiddlewood (*Vitex Gaumeri*)

<u>Woods Requiring Special Preparatory Surface Treatment for Gluing</u>

Lignum Vitae (*Guaiacum officinale*)

officinale and may be assumed to be at least partially responsible for the interference noted.

Several of these woods including Loxopterygium Sagotii, Tabebuia guayacan, and particularly Guaiacum officinale are known to contain appreciable amounts of extractive materials which are believed to be primarily responsible for gluing difficulties. Teak (Tectona grandis) also contains an oily extractive which is reputed to interfere with its gluing characteristics. In this connection a previous experiment (4) with teak is of interest. In that study an attempt was made to improve the gluing characteristics of teak by washing the surface with acetone immediately prior to gluing with a resorcinol adhesive which was subsequently cured at 190° F. for 10 hours. By means of this technique joint shear-strength was increased from 1025 to 1262 pounds per square inch and wood failure from 63 to 83 percent in comparison with untreated control specimens. The results obtained in the present study with Burma teak without employing a special surface treatment—shear strength of 2040 pounds per square inch with 92 percent wood failure—indicate that teak does not necessarily require such preliminary treatment with resorcinol adhesives.

Lignum vitae (Guaiacum officinale) is clearly the most difficult to glue of the woods tested and evidently requires some type of special treatment to secure even moderately successful glue joints. Rapp (5) has investigated the possibility of various surface treatments to improve the gluing performance of lignum vitae by removal of at least part of the resinous extractive contained in this wood. Among the treatments applied to normal machine-planed surfaces were solvents such as carbon tetrachloride, benzene, acetone, and alcohol. None of these was as successful, however, as an application of 10 percent caustic soda solution, wiped on the surface, allowed to remain for 10 minutes, and removed by washing with water. After drying, the same resorcinol-type glues employed in the present study were applied in the normal way and the 2 1/2 by 12-inch standard glued blocks were retained in clamps for 10 hours at 160° F. to cure the resin.

Other blocks were first sanded with No. 2 flint sandpaper preceding the caustic soda wash treatment. Average results are shown below:

	Shear Strength lb. per sq. in.	Wood Failure percent
Control (untreated)	1185	22
Washed with NaOH	1770	30
Sanded; washed with NaOH	2000	37

In one series of tests the results obtained from the combination sanding-caustic soda treatment averaged 2760 lb. per sq. in. with 56 percent wood failure, shearing half of the specimens radially and half tangentially. It is not known at present whether such high values are attributable to the particular adhesive used or to some unrecognized difference in the technique employed.

The influence of surface interference with gluing is evident from these results. The improvement shown by preparatory washing with caustic soda alone indicates the extent to which removal of chemical extractives was beneficial to adhesion. The further improvement made possible by sanding before the application of caustic soda may result from its effect in permitting a more thorough cleaning of the surface.

Although the particular technique of surface treatment best adapted for the improvement of gluing characteristics of the woods tested in this study remains unsettled, the degree of improvement secured with lignum vitae leaves little doubt that, except for some of the woods with specific gravity in excess of 1.00, virtually the full strength of the wood can be developed with resorcinol-type adhesives if proper gluing techniques are employed. Even with these extremely dense woods, strengths in excess of 2000 pounds per square inch are obtained. With the great majority of the woods covered in this report, satisfactory joints can be attained without any special preparatory treatment.

Summary

Information relative to the gluing characteristics of 29 tropical American woods, together with teak and white oak, is given in this report based on

tests employing a resorcinol and a resorcinol-phenol resin adhesive. The species tested differed in specific gravity from 0.40 to 1.22 and thus present an unusually wide range in density for observation of its influence on gluing characteristics.

From the results of dry shear tests, these woods are classified as to their relative ease of gluing. Most of the woods below 1.00 in specific gravity were glued satisfactorily by normal gluing techniques yielding joints that were virtually as strong as the wood itself. With the single exception of lignum vitae, substantial joint strength was developed even with the heaviest woods.

Evidence is presented that insofar as resorcinol-type adhesives are concerned, the gluing characteristics of lignum vitae can be greatly improved through a preparatory caustic soda treatment of the surface, and it is concluded that if various modifications of this or similar surface treatments (details of which are not developed here) are employed, together with proper gluing technique, satisfactory gluing of all the woods included in this study is possible with adhesives of the resorcinol-resin type.

It is recognized that these results serve only as an indication of the gluing characteristics of these woods when other types of adhesive are used. Additional work is needed in this connection.

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