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UNIVERSITY OF LOUISVILLE

- I THE SURFACE IMPREGNATION OF WOOD
/
- II USE CHARACTERISTICS OF IMPREGNATED WOOD
- III INVESTIGATIONS OF RESIN ADHESIVES

A. Thesis

Submitted To The Faculty
Of The Graduate School
Of The University Of Louisville
In Partial Fulfillment
Of The Requirements
For the Degree Of

MASTER OF CHEMICAL ENGINEERING

by

John V. Birkel

1946

- I THE SURFACE IMPREGNATION OF WOOD
- II USE CHARACTERISTICS OF IMPREGNATED WOOD
- III INVESTIGATIONS OF RESIN ADHESIVES

Approved by the Examining Committee

Director _____

December, 1946

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ABSTRACT

This thesis is divided into three parts: I. The Surface Impregnation of Wood; II. Use Characteristics of Impregnated Wood; and III. Investigations of Resin Adhesives.

The material presented in Part I is a continuation of previous experimentation that had established general methods for producing a hardened surface wood product. The methods involved parting of the wood fibers on the surface by a special serrating tool, followed by a surface impregnation and final curing. This section presents work carried on to determine the optimum conditions for serrating and subsequent impregnation. The effect of species on impregnation, and the impregnation of unfinished lumber were also investigated.

In Part II are presented the results of investigations of the commercially important properties of the surface impregnated wood products. These include surface hardness, sanding, moisture resistance, and gluing characteristics. Techniques for veneering this product are also given.

The investigations of resin adhesives described in Part III were of two types: (1) the effect of various conditions of precure and final cure upon the strength and bond characteristics obtained with wood; and (2) the degree of cure as indicated by per cent extractables. The former study was carried out to determine whether or not the temperature and time of precure are critical in their effect upon adhesive bonds, and also to find whether pressure is necessary for the final cure. The latter was made to obtain recommendations for curing conditions now used in commercial production.

The author wishes to acknowledge
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I N T R O D U C T I O N

For many years wood has found wide usage in both gross and fine applications. Building construction of numerous types, furniture manufacturing, ornament making, and many other industries utilize this material. However, certain inherent properties of wood such as low strength and susceptibility to dimensional change and decay, exclude its use in many cases and minimize its value in others. Protective coatings have been found useful in improving the weathering properties, but improvement is temporary in that continuity of the protecting film or coating is necessary.

For fine uses in the home, certain properties are necessary. These include pleasing appearance, scratch and burn resistance, resistance to the variety of liquids encountered in the home, and a certain amount of strength. Hard woods such as oak and maple have been found to meet most of these requirements satisfactorily, but the high cost of the woods and the difficulties encountered in working them minimize their usage. Plywoods with hard surfaces and soft cores have been shown to be satisfactory.

Impregnation of wood with synthetic resins has been found to improve its properties greatly. The hardness, dimensional stability, compressive strength, and resistance to decay are all increased. However, when total impregnation is used, the resultant product is characterized by brittleness, low resilience, and by the inability to be easily glued or fastened.

A plywood of compressed resin treated face plies with a soft, practically uncompressed core has been made, combining improved surface characteristics with high resilience. Research (1, 2) has shown that by impregnating the surface layers of a solid piece of wood, it is possible to produce the hardened surfaces as an integral part of the wood section. It has also been found (2) that by serrating or separating the wood

fibers so as to produce a squeezing action on the surface, resin penetration is materially aided.

The object of this research on wood impregnation was consequently two-fold: First, to determine the optimum conditions for producing a satisfactory, surface impregnated wood product, including prescarification and pre-impregnation treatment, and general size of serrations to be used; and second, to investigate the properties of the product to determine whether or not they are such as to permit ultimate commercialization for specialized uses.

In the course of research on surface impregnation it became apparent that further information on the properties of resin adhesives was necessary. Many methods of approach to this subject are possible, but it was found advisable for the purposes of this investigation to utilize liquid extraction of cured resin films. The newer resin adhesives include those of the phenol-formaldehyde, resorcinol and melamine types. Adhesives of this kind were chosen for this investigation.

HISTORICAL

The unstable dimension characteristics of wood constitute one of its most detrimental properties. Swelling and shrinking with the accompanying checking, warping, and honey-combing seriously limit the applications of this material. Consequently, many investigations have been carried on in an effort to minimize these dimension changes.

Studies of impregnation with hygroscopic salts to retain the green condition (3) were made by Stamm. However, this method proved unsuccessful because the salts tended to leach out upon exposure to moisture. Replacement of the water within the swelling structure of wood with non-volatile materials (4) proved more successful in minimizing shrinking and swelling. An intermediate solvent was used to displace the water, and such non-volatile materials as melted waxes, oils, and resins were diffused into the cell wall structure. Efficiencies as high as 80% were obtained based on plain wood controls. These efficiencies were achieved because of a great decrease in the rate of moisture absorption rather than a change in equilibrium moisture content. Hence, this stabilization was only temporary.

Later, Stamm and Seborg (5) changed this equilibrium by impregnation with synthetic resins, thereby effecting a permanent increase in dimensional stability. These same investigators have shown a method for producing a compregnated wood (6). This process involves impregnation of veneers with a phenol-formaldehyde resin, followed by a diffusion period of one day, and drying at 150 to 160 degrees F. A compressed wood is then made from the dry treated veneer plies under pressures of 250 to 1200 psi at temperatures of 300 to 320 degrees F. Pressing periods of 15 to 30 minutes per inch of original thickness of wood were used. A plywood of compressed and uncompressed wood has also been made by compress-

ing the resin treated face plies and assembling them with an untreated core in one operation. Possible uses of these materials in airplane construction, flooring, paneling, and furniture manufacture are suggested.

Using a method similar to that of Stamm and Seborg, the DuPont Company (7) has produced a dimensionally stable wood using dimethylolurea as the impregnating material.

By utilizing the resin properties of lignin, Stamm and associates (8) have succeeded in producing a heat stabilized compressed wood. Internal stresses are relieved by compressing so as to cause a sufficient flow of lignin. Although not so stable as compregnated wood, the product possesses several improved properties, including a greater impact resistance.

Luce (9) has reported a method for producing a delignified, impregnated wood. Veneers are subjected to controlled delignification without disintegration of the wood, that process being used which will allow greatest strength in the final product. The "Kraft" or sulfate process, the Mitscherlich or other processes of digestion are suggested. Digestion is followed by washing and drying. Since the delignified wood is much more pervious than untreated wood, it can be easily impregnated by soaking for a short period of time. Natural or synthetic resins of the phenol-formaldehyde type are suggested. A diffusion period is next allowed, followed by drying. Resultant characteristics of the uncured wood include excellent pliability and improved resistance to splitting on bending. The final products are hard, stable, infusible combinations possessing good strength and exceptional strength - weight ratios. Laminates containing up to 40% resin may be made without weight increase over the original wood.

Casselman (10) has reviewed the effects of impregnating resin upon wood properties. He lists the effects as follows:

- (1) The resin plasticizes or softens the wood so that it can be compressed to high densities with reasonable pressure and low moisture content.
- (2) It holds the plies of veneers together.
- (3) The resin bonds the fibers, fixes them in their compressed state, and fortifies them against the tendency to spring back to their original positions after release of platen pressure.
- (4) The resin present interferes with the rate of moisture absorption and penetration.
- (5) It should have a real effect on the ultimate properties of the wood.
- (6) The resin increases the hardness and to a certain extent the compressive strength of the wood.
- (7) Impregnation causes embrittlement of the wood resulting in a loss of 90% of the notched Izod value in extreme cases.
- (8) The resistance of the wood to decay and attack by termites is greatly improved.
- (9) In the case of phenol resins, the resistance of the wood to acids is increased.

Many attempts have been made to find a rapid accurate test for determining the degree of cure of resin adhesives. Although actual service is the only certain test, some information can be obtained by shortened procedure.

The protective coating industry has used a solvent extraction method in following the polymerization of resin films. R. F. Blomquist (11)

has investigated the use of a similar procedure for determination of the degree of cure of resin adhesives by acetone extraction. He obtained definite correlations between per cent extractables and relative degree of cure when the adhesive is cured on a chemically inert surface.

•
T H E O R E T I C A L

Wood is composed of micelles or microscopic crystallites linked together in the form of a hollow, spindle-shaped, closed end tubes to make cells. As a tree grows and increases in diameter, some of the cells toward the center partially cease to function. This core of affected tissue is called heartwood. Sapwood is that portion of a tree which contains tissues that still participate in the life activities of the organism.

As sapwood is transformed into heartwood various organic compounds are formed which infiltrate into the cell walls. If present in large enough amounts, they may accumulate in the cell cavities ordinarily as amorphous deposits, causing the wood to darken. The presence of these substances causes heartwood to have greater density, greater rot resistance, and less permeability than sapwood.

Based upon theories somewhat similar to those involved in the change of sapwood to heartwood, attempts have been made to increase the dimensional stability of wood by depositing water-resistant materials within the structure. Such materials do not affect the moisture equilibrium, but greatly reduce the rate of attainment of equilibrium. Their value lies only in shedding of water and in stabilizing the dimensions under humidity conditions of a relatively rapidly oscillating nature.

Deposition of water-insoluble waxes within the cell wall structure of wood by replacement rather than by simply depositing it within the cell cavities increases the dimension stability further. The moisture equilibrium is not, however, changed by this treatment, and although the waxes are highly water resistant, they do not bond to the wood. Water eventually works its way between the wax and the wood.

Treatment with a material for which wood has a greater affinity than it has for water, in such a way as to bind the entire structure, is

necessary. This has been accomplished by formation of synthetic resin polymers within the cell wall structure from practically unpolymerized resin forming materials, in a procedure of conversions to water-insoluble materials within the wood. Forming of a phenol-formaldehyde resin has been found the most successful because both phenol and formaldehyde are strongly positively absorbed. The moisture equilibrium is definitely changed, resulting in permanent improvement in dimension stability. The formation of a phenol-formaldehyde-cellulose and a phenol-formaldehyde-lignin resin on the inner surface within the cell wall seems very probable.

In order to produce a product with hardened surfaces and a soft core, it is necessary that the penetration be wholly from the surface. Serrating or separating the wood fibers by a squeezing action on the surface materially aids resin penetration, probably because of the resultant increased area of exposed fibers.

Impregnation can be effected in any of a number of ways. Probably one of the simplest is the cylinder method. The wood is placed in a treating solution in a closed cylinder, and a pressure of 30 to 60 psi applied for a length of time depending upon the resistance to penetration of the wood. The solution is carried only into the coarse capillary structure, and time must be allowed for diffusion into the cell wall structure where it is desired. One to two days under non-drying conditions has been found satisfactory for this diffusion process.

The wood is then slowly dried so that the resin forming constituents can diffuse from the fiber cavities into the cell walls as water is removed from the fiber cavities. Drying can be accomplished at a temperature of 150 to 160 degrees F. without premature setting of some resins.

Wood treated and dried in this manner is much more plastic at hot pressing temperatures of 300 to 350 degrees F. than untreated wood. Hence, upon application of pressure to a surface impregnated wood at this temperature the surface should be easily compressed and hardened as polymerization of the resin occurs. The untreated and cooler core should be only slightly compressed, and should therefore retain its former soft, resilient condition.

The curing of a resin adhesive of the phenolic-aldehyde type proceeds by the mechanism of condensation with the formation of three dimensional polymers of unknown size or completed structure. Acetone and other organic solvents have the characteristics of dissolving low and medium molecular weight polymers of this type. Since fewer low weight polymers remain as the curing continues, the percent extractables should decrease. In this way an indication of the completion of cure can be obtained from a simple extraction test, and if a correlation is established between extractables and weather resistance or other actual working conditions, an acceptable short time test is achieved.

I. THE SURFACE
IMPREGNATION OF WOOD.
EXPERIMENTAL

Previous experimentation has established both that serrations are necessary for uniform surface impregnation, and what general types of serration are satisfactory. Therefore, this work was carried on to determine the optimum conditions for serrating and subsequent impregnation, and whether a broad, deep serration is more desirable than a narrow, shallow type. The effect of species on impregnation, and the impregnation of unfinished lumber were also investigated.

A. OPTIMUM CONDITIONS FOR SERRATING AND SUBSEQUENT IMPREGNATION

APPARATUS:

The serrations were made in the fiber direction on both faces of the samples by passing them between two rollers, suitably mounted and geared, each having a series of circular knives. These knives were of hardened steel and were ground to a fine edge. On one roller, they were so placed as to produce serrations approximately one sixteenth inch wide and one thirty-second inch deep; on the other to produce serrations one-eighth inch wide and one-sixteenth inch deep.

In preparing the wood compression samples, a tin pan was used as a container for the wood and resin solution. A hydraulic press made by the Charles E. Francis Company was used to apply pressure, and flat steel bars of different lengths and widths were employed to transmit the pressure to various parts of the wood samples. The press was manually operated and was capable of exerting a total force of 50 tons. The platens were electrically heated and had thermostats for temperature control. Laboratory electric ovens were used as kiln driers.

In the preparation of the hydrostatic pressure samples, a steel pressure cylinder (six inches inside diameter and twenty-four and one-half inches high) with pressure gauge and necessary pneumatic pressure connections,

and a galvanized iron pan were used. The press and ovens described above were also used.

MATERIALS:

Samples of black gum, approximately 6" x 3-7/16" were used. Durez 6686 (a phenolic resin), made by Durez Plastics and Chemicals, Inc., to which aniline blue was added in the concentration of 1/2 gram per liter, was the impregnant. This is a water soluble resin containing 50% solids. Permatex No. 2 was used as an end sealer on the wood.

Preliminary Experiments

Procedure:

Each sample was selected to contain both heart and sap woods and was treated as indicated, end sealed, and then either horizontally immersed in the resin under a pressure of 40 psi for 10 minutes, or compressed from 0.9 - 0.75 inches in the resin, as indicated. The serrations were of two types - approximately 1/8 inch wide and 1/16 inch deep, or 1/16 inch wide and 1/32 inch deep. All impregnated samples were air dried 24 hours, oven dried at 140 degrees F. for 22 hours, and cut transversely. One-half of each specimen was then compressed from 0.9 to 0.75 inch, cured for one-half hour at 300 degrees F., allowed to cool to 200 degrees F. in the press, and removed.

Samples were prepared according to the following procedure, although all steps were not used for each specimen.

Step A - Water soak of wood before serration

Step B - Serration

Step C - Water soak of wood after serration

Step D - Resin soak

Series I

Sample	A	B	C	D
1	None	Yes	None	40 psi Hydrostatic Head for 10 min.
2	None	Yes	Surface Moistened	"
3	None	Yes	1-1/2 hours	"
4	None	Yes	2-1/2 hours	"
5	None	Yes	4 hours	"
6	None	Yes	5 hours	"

Series II

7	Surface Moistened	Yes	Surface Moistened	40 psi Hydrostatic Head for 10 min.
8	Surface Moistened	Yes	17 hours	"

Series III

9	2 hours	Yes	None	40 psi Hydrostatic Head for 10 min.
10	2 hours	Yes	1 hour	"
11	2 hours	Yes	Sample Dried	"
12	2 hours	Yes	3 hours	"

Series IV

13	None	Yes	None	Mechanical compression from 0.9 to 0.75 in.
14	Surface Moistened	Yes	Sample Dried	"
15	Surface Moistened	Yes	1-1/2 hours	"

Results:

Series I: With increasing times of soaking after serration the total amount of absorbed resin increased because of end penetration, whereas the minimum surface penetration remained essentially constant at about 0.1 inch. Penetration occurred in both the heart and sap wood, and was very irregular.

Series II: Penetration occurred in both the heart and sap wood. Sample 7 had a minimum surface penetration of about 0.06 inch. The results of surface penetration in sample 8 were badly obscured because of end penetration.

Series III: A minimum surface penetration of about 0.12 inch was obtained. The results were difficult to observe because of a great amount of end penetration. Surface penetration was obtained in both the heart and sap wood.

Series IV: Penetration occurred in the serrations only, and more uniformly in the 1/16 inch than the 1/8 inch serrations.

Extended ExperimentsProcedure:

From the preliminary results it was concluded that long periods of soaking before and after serration do not increase surface penetration to any marked extent, and it was decided to limit further investigation to the following conditions:

1. Serrated dry, dry into resin.
2. Serrated dry, surface moistened, and then into resin.
3. Surface moistened, serrated, dried, and then into resin.
4. Surface moistened, serrated, surface moistened, and then into resin.

It was also decided to use only the hydrostatic head method of impregnation, and to reduce the time from 10 to 5 minutes to eliminate excessive end penetration. Four sets of samples were prepared.

Results:

The following observations are indicative of the general results.

Sample 1: Surface penetration occurred in both the heart and sap wood. A minimum surface penetration of about 0.08 inch was obtained in the 1/16 inch serrations and one of about 0.12 inch in the 1/8 inch serrations. End penetration was present to a slight extent.

The surfaces of the cured specimen were very hard, but the resin filled the 1/16 inch serrations more uniformly and completely than the 1/8 inch serrations.

Sample 2: Penetration occurred on both the heart and sap wood. The minimum surface penetration in the 1/16 inch serrations was about 0.08 inch, and in the 1/8 inch serrations, approximately 0.13 inch.

The surfaces of the cured specimen were very hard. In each case the serrations appeared to be more completely filled than in the case of sample 1.

Sample 3: Surface penetration occurred in both the heart and sap wood. A minimum surface penetration of about 0.12 inch was obtained in the 1/16 inch serrations and one of about 0.14 inch in the 1/8 inch serrations. The cured surfaces were very hard and appeared uniformly filled with resin.

Sample 4: Surface penetration occurred in both the heart and sap wood and was generally comparable to that of sample 3.

Discussion:

Serration of a surface moistened board accelerates and evens out surface resin penetration better than serration of a dry surface, probably because separation of the fibers is effected more readily, resulting in less internal compression. Wetting of the serrated surface just prior to impregnation does not appear to be particularly advantageous. There is also indication that a wide, deep type of serration gives deeper surface penetration than a narrow, shallow type. In order to investigate this effect more fully, the study of the following section was carried out.

B. THE EFFECT OF TYPE OF SERRATION ON IMPREGNATION

MATERIALS:

The materials were the same as those used in the preceding section.

PROCEDURE:

Five samples of black gum ($6 \times 3\text{-}7/16 \times 7/8$ inch) were taken in order from one board containing both heart and sap wood and serrated as follows:

Fig. 1. Method Of Serrating To Determine Effect Of Serration Type On Impregnation.

Eight surfaces - a, b, c, d, a', b', c', d' - were thereby obtained for comparison of the depth of surface penetration for the different serrations.

The samples were all serrated moist, dried, end sealed, and horizontally immersed in the Durez resin for five minutes under a pressure of 40 psi. The samples were air dried, and then cut so as to remove only the end sealer.

RESULTS:

The surface penetration in the $1/8$ inch serrations was greater in all cases than that in the corresponding surfaces with $1/16$ inch serrations. The minimum surface penetration for the $1/8$ inch serrations varied from $1/8 - 1/16$ inch in depth, while that in the $1/16$ inch serrations varied from about $1/16 - 1/32$ inch in depth.

DISCUSSION:

From the viewpoint of maximum surface penetration, the $1/8$

inch serration is superior to the 1/16 inch serration. This is very marked in the more dense heart wood areas. Hence, although a uniform and satisfactory impregnation may be obtained with shallow, close serrations on easily impregnated wood, a deeper and possibly wider serration is to be recommended for difficultly treated woods or heart woods containing imperfections.

C. THE EFFECT OF SPECIES ON IMPREGNATION

MATERIALS:

Black gum, red gum, yellow poplar, and red oak samples (6" x 3-7/16" x 7/8") were used. Bakelite Br 15100, a phenolic type resin, diluted with water to give 30% resin solids, was the impregnating agent. Aniline blue in the concentration of 1/2 gram per liter was added to impart color to the wood where penetration occurred. Permatex No. 2 was used as an end sealer.

PROCEDURE:

A black gum sample serrated moist, and plain and moist serrated red gum, yellow poplar, and red oak samples were prepared. The samples were end sealed and horizontally immersed in the Bakelite solution for five minutes under a pressure of 40 psi. They were then air dried, oven dried at 140 degrees F. for 22 hours and cut. One half of each was then cured as previously described. This procedure will be referred to subsequently as the standardized procedure for surface impregnation.

RESULTS:

Penetration occurred in both the heart and sap wood of serrated black gum. A minimum surface penetration of 1/16 inch was obtained in the 1/16 inch serrations and one of approximately 1/8 inch in the 1/8 inch serrations. The penetration was very regular across the width of the specimen, although a slight decrease in depth occurred in the heart wood. The surfaces of the cured specimen were very hard, and both types of serrations appeared completely filled.

Serrated red gum gave complete penetration throughout the sap wood, but in the heart wood penetration for the most part occurred only

in the serrations. This heart wood is very dense. While the cured surfaces were hard, neither the 1/16 inch nor the 1/8 inch serrations were completely filled.

Complete penetration throughout the sap wood of the plain red gum sample was obtained, but penetration in the heart wood was negligible. The cured surfaces were hard, but the resin depth was superficial in the case of the heart wood.

The sapwood of serrated yellow poplar was virtually completely penetrated. In the heartwood a minimum penetration of about 1/16 inch in the 1/16 inch serrations was obtained, and one of about 1/8 inch in the 1/8 inch serrations. The penetration in the heart wood was regular in both cases. The surfaces of the cured specimen were hard, but in neither case were the serrations completely filled.

Plain yellow poplar gave practically complete penetration throughout the sap wood, while penetration in the heart wood was negligible. The cured surfaces were hard but the resin depth was superficial in the case of the heartwood.

Penetration occurred to a slight extent in the serrations of red oak, and completely in the pores of the spring wood, both heart and sap. While the cured surfaces were hard, the 1/16 inch serrations were incompletely filled, though to a greater extent than the 1/8 inch serrations.

In plain red oak penetration occurred only in the pores of the spring wood, both heart and sap, and was incomplete. The surfaces of the cured specimen were hard, but the resin depth was superficial.

DISCUSSION:

Of the species tested, black gum gives the best overall results.

The sapwood of poplar and red gum may be easily impregnated, but serration is necessary for satisfactory results with heart wood of poplar, and for production of a thin surface hardening of heart wood of red gum. Red oak takes resin penetration only in summer wood pores and serration cuts, and on curing the resin causes collapse of the pores with a filling and densifying action. Surface finishes in all cases are good and the oak looks especially promising.

D. IMPREGNATION OF UNFINISHED LUMBER

MATERIALS:

Unfinished black gum and yellow poplar with one surface rough sawn and the other resawn were used in conjunction with Bakelite Br 15100 resin solution containing 30% resin solids. As previously, aniline blue was used to color the wood, and Permatex No. 2 was used as an end sealer.

PROCEDURE:

The following samples (6" x 3-7/16" and 15/16") were prepared from each species:

1. Plain
2. Serrated moist, dry into resin, 1/8" serrations on rough sawn surface.
3. Serrated moist, dry into resin, 1/8" serrations on resawn surface.

The samples were impregnated and cured according to previously standardized procedures.

RESULTS:

Plain yellow poplar gave practically complete penetration throughout the sap wood, but only slight, uneven penetration in the heart wood. The cured surfaces were very hard and smooth, but all inherent defects in the wood surface appeared as light or dark marks. As in the following cases, these are removable by a light (1/64 inch) sanding.

Practically complete penetration throughout was obtained for the yellow poplar sample with 1/8 inch serrations on the rough sawn surface. Considerable end penetration occurred. Surface penetration from the 1/8 inch serration was about 1/4 inch in depth, while that from the 1/16 inch serrations was approximately 3/16 inch. The cured surfaces were hard and smooth, but inherent defects in the wood were plainly discernable.

Yellow poplar with $1/8$ inch serrations on the resawn surface gave very irregular penetration. Considerable end penetration was noted. Surface penetration from the $1/8$ inch serrations was about $3/16 - 1/4$ inch deep, and that from the $1/16$ inch serrations roughly the same. The cured surfaces were hard and smooth, but defects inherent in the wood surfaces were visible.

The surface penetration was very irregular and occurred only in the sap wood of plain black gum. Penetration appeared to be deeper from the rough sawn than the resawn surface. The surfaces of the cured specimen were hard and smooth, but inherent defects were discernable. The resin depth was superficial in the case of the heart wood.

Penetration from both surfaces of black gum with $1/8$ inch serrations on the rough sawn surface was uniform. The surface penetration from the $1/16$ inch serrations was about $1/8 - 3/16$ inch deep, while that from the $1/8$ inch serrations was $3/16 - 1/4$ inch in both heart and sap wood. The cured surfaces were hard and smooth, but all defects were visible.

For black gum with $1/8$ inch serrations on the resawn surface, penetration was more uniform from the $1/8$ inch than the $1/16$ inch serrations. The minimum surface penetration from the $1/8$ inch serrations was about $1/8$ inch, while that from the $1/16$ inch serrations was $1/16 - 1/8$ inch. The surfaces of the cured specimen were hard and smooth. All defects of the surfaces were discernable.

DISCUSSION:

Deeper penetration is obtained in both heart and sap wood using rough sawn lumber and the $1/8$ inch serrations than any other combination. The results are equal if not slightly superior to those

obtained using surfaced lumber. After sanding, no detectable difference exists between impregnated finished and unfinished lumber.

S U M M A R Y A N D C O N C L U S I O N S

Serration of a surface moistened board accelerates and evens out surface resin penetration, probably because less internal compression is caused by separation of the fibers of a wetted surface. From the viewpoint of maximum surface penetration a wide, deep type serration is superior to a shallow, close type. Hence, although a satisfactory surface impregnation may be obtained with the latter on easily impregnated wood, the former type is to be recommended for difficultly treated woods or heart woods containing imperfections.

Serration is necessary for satisfactory impregnation of black gum and the heartwood of poplar, and for production of a thin surface hardening of heart wood of red gum. Red oak takes penetration only in summer wood pores and serration cuts. Surface finishes in all cases are good, especially that of oak.

Unfinished lumber can be satisfactorily impregnated with results equal if not superior to those obtained using finished lumber. After a slight sanding, no detectable difference exists between impregnated finished and unfinished lumber.

II. USE CHARACTERISTICS
OF IMPREGNATED WOOD
EXPERIMENTAL

Since it was demonstrated that a satisfactory surface impregnated product could be made, it was decided to investigate its properties to determine general commercial applicability. The product was known to have excellent surface hardness, and was considered a possible substitute for cross-bonded plywood as a core material. Therefore, its sanding, moisture resistance properties, and gluing characteristics, as well as relative surface hardness, were investigated.

A. SANDING AND MOISTURE RESISTANCE OF IMPREGNATED SURFACES

MATERIALS:

Samples were of yellow poplar approximately 6" x 3-7/16" x 7/8" before impregnation; Bakelite Br 15100, diluted to 30% resin solids, was the impregnant; and a fine sand paper (3/0 - 100) was used.

PROCEDURE:

Five samples of the yellow poplar were impregnated with the Bakelite resin and cured according to previously standardized procedures. These were sanded to the depths indicated, on a small belt sander, and together with an untreated, unserrated piece of poplar were subjected to moisture tests by allowing water to drop slowly and continuously from burettes onto the surfaces. The samples were placed at approximately 45 degrees with the horizontal to provide for drainage.

The following samples were tested, using the 1/16 inch serrated surfaces for sanding:

1. Unsanded
2. Sanded 0.03 cm. (0.012 inch)
3. Sanded 0.07 cm. (0.027 inch)
4. Sanded 0.13 cm. (0.051 inch)
5. Sanded to unimpregnated wood

6. Untreated, unserrated sample

After 31 hours these tests were discontinued, and the 1/8 inch serrated surfaces sanded as follows:

7. Unsanded
8. Sanded 0.04 cm. (0.016 inch)
9. Sanded 0.07 cm. (0.027 inch)
10. Sanded 0.11 cm. (0.043 inch)

The tests were then continued for 96 hours using these surfaces.

RESULTS:

All sanded surfaces were smooth, indicating that impregnated species lend themselves readily to sanding.

The following observations of the wetted 1/16 inch serrated surfaces were made:

After Seven Hours

1. Surface unaffected.
2. Surface wetted slightly, probably no soaking
3. Surface wetted to greater extent than sample 2; probably slight soaking.
4. Surface wetted to greater extent than sample 3; probably greater amount of soaking occurred.
5. Surface wetted badly; great amount of soaking occurred.
6. Surface wetted badly, but less than sample 5; probably less soaking.

After 24 Hours

1. Surface virtually unaffected.
2. Surface virtually unaffected.
3. Grain raised to a very slight extent.

4. Grain raised to a greater extent than sample 3.
5. Grain raised to a considerable extent.
6. Grain raised to a considerable extent, but less than sample 5.

After 31 Hours

1. Surface unaffected.
2. Grain raised to a very slight extent.
3. Grain raised to slightly greater extent than sample 2.
4. Grain raised considerably.
5. Grain raised very badly, worse than sample 4.
6. Grain raised badly, but less than sample 5.

The following observation of the 1/8 inch serrated surfaces were made:

After 5-1/2 Hours

All surfaces were virtually unaffected.

After 24 Hours

7. Surface unaffected.
8. Surface unaffected.
9. Surface unaffected.
10. Grain raised to a very slight extent.

After 72 Hours

7. Surface unaffected.
8. Surface unaffected.
9. Surface unaffected.
10. Grain raised to a slight extent.

After 96 Hours

7. Surface unaffected.

8. Surface unaffected.
9. Grain raised to a very slight extent.
10. Grain raised to a greater extent than sample 9, but not excessively.

DISCUSSION:

Yellow poplar, and probably all wood species, can be sanded after surface impregnation with resultant surfaces being fine and smooth. Original cured surfaces and sanded surfaces are reasonably resistant to water penetration unless depth of full resin penetration of fiber is exceeded. Adequate protection to a depth of between 0.03 - 0.07 cm (0.012 - 0.027 inch) is obtained in the case of the 1/16 inch serrated surfaces, and to a depth of between 0.07 - 0.11 cm (0.027 - 0.043 inch) in the case of the 1/8 inch serrated surfaces.

B. SURFACE HARDNESS TESTS OF IMPREGNATED AND PLAIN WOOD

MATERIALS:

Finished and unfinished yellow poplar and black gum were used in conjunction with Bakelite Br 15100 diluted to 30% resin solids. All treated samples were impregnated according to previously standardized procedure. To determine the effect of curing pressure on surface hardness, some of these samples were cured to different thicknesses, while keeping the temperature and time of cure the same. Samples of red oak, white oak and maple were also run for comparison.

PROCEDURE:

The relative surface hardness was determined using a standard Rockwell hardness tester with a major load of 60 kg., and a 1/2 inch hardened steel ball penetrator. Since some of the surfaces were softer than permitted by normal Rockwell test procedure, results were obtained and reported on an arbitrary basis. The test was as follows:

1. Indent specimen with 1/2 inch standard steel ball under minor load of 10 kg.; set zero indentation scale.
2. Apply major load of additional 50 kg. (total 60 kg) and allow to reach equilibrium.
3. Release load to original 10 kg. minor load.
4. Read indentation produced by major load application from position of indicator on indentation scale.

In most cases four readings from each of three different samples were taken. This was done for both heart and sap wood and, in addition, for both the 1/8" and the 1/16" serrations in the case of the impregnated samples.

RESULTS:

TABLE I. THE RELATIVE SURFACE HARDNESS OF IMPREGNATED AND UNTREATED SPECIES.

Sample	Species	Treatment	No. of Readings	Average (1) Indentation (mm.)
1	Poplar Heart	Plain	15	0.32
2	Poplar Sap	Plain	13	0.30
3	Poplar Heart	Impreg. - 1/8" ser.	14	0.12
4	Poplar Sap	Impreg. - 1/8" ser.	12	0.16
5	Poplar Heart	Impreg. - 1/16" ser.	13	0.12
6	Poplar Sap	Impreg. - 1/16" ser.	14	0.14
7	Poplar Heart	*R.S. " - 1/8" ser.	15	0.12
8	Poplar Sap	R.S. " - 1/8" ser.	15	0.16
9	Black Gum	Plain	12	0.32
10	Black Gum Sap	Plain	12	0.32
11	Black Gum Heart	Impreg. - 1/8" ser.	15	0.08
12	Black Gum Sap	Impreg. - 1/8" ser.	18	0.08
13	Black Gum Heart	Impreg. - 1/16" ser.	18	0.06
14	Black Gum Sap	Impreg. - 1/16" ser.	17	0.07
15	Black Gum Heart	R.S. " - 1/8" ser.	16	0.06
16	Black Gum Sap	R.S. " - 1/8" ser.	18	0.06
17	Maple	Plain	12	.28
18	Red Oak	Plain	12	.28
19	White Oak	Plain	12	.27

* R.S. - Rough Sawn

(1) - With 10 Kg. load and 1/2" steel ball.

RESULTS:

TABLE II. THE EFFECT OF CURING PRESSURE ON THE HARDNESS OF IMPREGNATED
SURFACES

1 - Compressed 0.9 to 0.8 inch

2 - Compressed 0.9 to 0.85 inch

3 - Compressed 0.9 to 0.875 inch

Sample	Species	Treatment	No. of Readings	Average Reading	Average (1) Indentation
1.a	Poplar-Heart	Imp. - 1/8" ser.	12	0.60	0.12
2.a	" "	Imp. - 1/8" ser.	12	1.01	0.20
3.a	" "	Imp. - 1/8" ser.	10	1.25	0.25
1.b	Poplar Sap	Imp. - 1/8" ser.	12	0.69	0.14
2.b	" "	Imp. - 1/8" ser.	10	1.01	0.20
3.b	" "	Imp. - 1/8" ser.	10	1.23	0.25
1.c	Poplar Heart	Imp. - 1/16" ser.	9	0.50	0.10
2.c	" "	Imp. - 1/16" ser.	5	0.74	0.15
3.c	" "	Imp. - 1/16" ser.	5	1.0	0.20
2.d	Poplar Sap	Imp. - 1/16" ser.	4	0.84	0.17
3.d	" "	Imp. - 1/16" ser.	5	0.95	0.19

(1) - With 10 Kg. load and 1/2" steel ball.

DISCUSSION:

The indentation of impregnated surfaces of a given species is relatively constant for both finished and unfinished lumber, for both heart and sap wood, and for both the 1/8 inch and 1/16 inch serrations. The indentation of impregnated poplar is roughly half as much as that of the untreated wood, while that of impregnated black gum is 1/3 to 1/4 as much as the corresponding untreated wood. The difference between the indentation of the impregnated species is attributed to the fact that black gum is surface compressed to a greater extent than poplar, giving a harder surface in the former case. This differential compression was indicated by the ends of the rays of black gum being bent to a greater degree than those of poplar, and by less external deformation in the former case.

In comparison to untreated red oak, white oak and maple, the impregnated samples are much more resistant to penetration.

From the samples compressed to different thicknesses, it appears that as the curing pressure is decreased, the indentation increases. However, the indentation of impregnated wood compressed only enough to restore it to its original thickness is still much less than that of untreated wood.

C. GLUING CHARACTERISTICS OF IMPREGNATED WOOD

MATERIALS:

Impregnated yellow poplar and black gum samples were prepared from finished and unfinished lumber using Bakelite Br 15100 (30% resin solids). Edge joints made with animal glue and resin adhesives Penacolite 1124, Plaskon 250-2, and Cascophen L.T. 67 were tested, as well as face-joints made with the resin adhesives.

PROCEDURE:

Edge-Joints

Strips approximately 1 inch wide were sawn from the cured stock of both species and the requisite number of edges finished on a planer. Adhesive was spread on both edges of the joint being prepared, and pressure applied by means of screw clamps placed at the center and ends of the sample. The adhesive was then cured as recommended. In this way the following samples were prepared from each species:

<u>No.</u>	<u>Preparation</u>	<u>Adhesive</u>	<u>Recommended Cure</u>
1	Finished	Penacolite 1124	190° F. - 6 Hours
2	Sawn	Penacolite 1124	190° F. - 6 Hours
3	Finished	Plaskon 250-2	190° F. - 6 Hours
4	Finished	Animal	Room Temp. - 24 Hours
5	Finished	Cascophen LT 67	190° F. - 10 Hours

From each resultant sample (approximately 8 x 2 x 3/4 inch) four shear blocks were cut as indicated, giving a glued area of 1-1/8 square inches for each specimen.

* - See Appendix for descriptions of the various types of resin adhesives.

Fig. 2. Standard Shear Block For Testing Of Edge Joints.

Four controls of each species were also prepared in the same manner from uncut stock. The samples were then placed individually in a hand-operated hydraulic press having one movable and one fixed (self-centering) head. (The shear fixture was a standard A.S.T.M. design). Pressure was slowly applied until failure occurred, the gauge reading noted, and converted into pressure on the glued area.

Face Joints

The following samples were prepared from each species:

<u>No.</u>	<u>Preparation</u>	<u>Adhesive</u>
1	Unsanded	Penacolite 1124
2	Sanded coarse	Penacolite 1124
3	Sanded coarse	Plaskon 250-2
4	Unfinished lumber Sanded coarse	Penacolite 1124
5	Sanded coarse Cross-banded	Penacolite 1124

(Samples 1-4 were of parallel grain glued surfaces.)

In all cases except number 1, $\frac{1}{64}$ inch was sanded from each face using coarse (No. 1) paper. Adhesive was spread on both faces of the joint being prepared, pressure applied by means of a clamp, and the adhesive cured as recommended. Shear blocks were cut from the resultant samples (approximately $8 \times 3\frac{1}{2} \times \frac{1}{2}$ inch) as follows:

Fig. 3. Standard Shear Block For Testing Of Face Joints.

The glued area was therefore 3 square inches. The samples were then tested as above.

RESULTS:

TABLE III. THE SHEAR STRENGTH OF GLUED, IMPREGNATED WOOD.

Samples 1-10 edge-joined; 11-20 face-joined.

Sample	Species	Preparation	Adhesive	Shear Strength (psi)	Per Cent Wood Failure
1 (a)	Poplar	Finished	Penacolite	1020	85
1 (b)	"	"	"	1100	80
1 (c)	"	"	"	1570	90
1 (d)	"	"	"	1260	90
		Average		1240	85
2 (a)	Poplar	Sawn	Penacolite	1570	100
2 (b)	"	"	"	1100	100
2 (c)	"	"	"	1180	100
2 (d)	"	"	"	1410	100
		Average		1320	100
3 (a)	Poplar	Finished	Plaskon	1180	100
3 (b)	"	"	"	1410	100
3 (c)	"	"	"	1570	90
3 (d)	"	"	"	1480	100
		Average		1410	97
4 (a)	Poplar	Finished	Animal	1100	40
4 (b)	"	"	"	780	60
4 (c)	"	"	"	700	50
4 (d)	"	"	"	790	50
		Average		840	50
5 (a)	Poplar	Finished	Cascophen	1250	100
5 (b)	"	"	"	1570	100
5 (c)	"	"	"	1570	100
5 (d)	"	"	"	1100	100
		Average		1370	100
Control	Poplar			2360	
"	"			1260	
"	"			1410	
"	"			1650	
		Average		1670	
6 (a)	Black Gum	Finished	Penacolite	1570	50
6 (b)	" "	"	"	1650	40
6 (c)	" "	"	"	1410	10
6 (d)	" "	"	"	1410	70
		Average		1510	40

TABLE III. (Continued) The Shear Strength of Glued, Impregnated Wood.

Sample	Species	Preparation	Adhesive	Shear Strength (psi)	Per Cent Wood Failure
7 (a)	Black Gum	Sawn	Penacolite	1570	100
7 (b)	" "	" "	"	1570	75
7 (c)	" "	" "	"	1800	95
7 (d)	" "	" "	"	1410	70
Average				1590	85
8 (a)	Black Gum	Finished	Plaskon	1340	70
8 (b)	" "	" "	"	1650	90
8 (c)	" "	" "	"	2200	80
8 (d)	" "	" "	"	780	40
Average				1490	70
*9 (a)	Black Gum	Finished	Animal	940	5
*9 (b)	" "	" "	"	0	0
*9 (c)	" "	" "	"	0	0
*9 (d)	" "	" "	"	0	0
Average				230	1
10 (a)	Black Gum	Finished	Cascophen	2080	100
10 (b)	" "	" "	"	2080	90
10 (c)	" "	" "	"	1570	100
10 (d)	" "	" "	"	1880	90
Average				1900	95
Control	Black Gum			1410	
"	" "			2200	
"	" "			2820	
"	" "			2900	
Average				2340	
11 (a)	Poplar	Unsanded	Penacolite	0	0
11 (b)	" "	" "	"	120	0
11 (c)	" "	" "	"	260	0
11 (d)	" "	" "	"	0	0
Average				95	0
12 (a)	Poplar	Sanded Coarse	Penacolite	1470	95
12 (b)	" "	" "	"	1830	98
12 (c)	" "	" "	"	1530	95
12 (d)	" "	" "	"	1590	100
Average				1600	97
13 (a)	Poplar	Sanded Coarse	Plaskon	1120	100
13 (b)	" "	" "	"	1000	100
13 (c)	" "	" "	"	1650	100
13 (d)	" "	" "	"	1470	100
Average				1310	100

* Considered unrepresentative

TABLE III. (Continued) The Shear Strength of Glued, Impregnated Wood.

Sample	Species	Preparation	Adhesive	Shear Strength (psi)	Per Cent Wood Failure
14 (a)	Poplar	Unfinished lumber Sanded Coarse	Penacolite	1770	95
14 (b)	"	"	"	1410	100
14 (c)	"	"	"	1000	100
14 (d)	"	"	"	920	100
		Average		1275	99
15	Poplar	Sanded Coarse Cross bonded	Penacolite	825	100
16 (a)	Black Gum	Unsanded	Penacolite	0	0
16 (b)	" "	" "	"	120	0
16 (c)	" "	" "	"	120	0
16 (d)	" "	" "	"	0	0
		Average		60	0
17 (a)	Black Gum	Sanded Coarse	Penacolite	2120	100
17 (b)	" "	" "	"	2650	100
17 (c)	" "	" "	"	1880	90
17 (d)	" "	" "	"	2520	95
		Average		2290	96
18 (a)	Black Gum	Sanded Coarse	Plaskon	2590	100
18 (b)	" "	" "	"	2300	100
18 (c)	" "	" "	"	2180	100
18 (d)	" "	" "	"	1240	100
		Average		2080	100
19 (a)	Black Gum	Unfinished lumber Sanded Coarse	Penacolite	1710	100
19 (b)	" "	" "	"	2120	100
19 (c)	" "	" "	"	2300	100
19 (d)	" "	" "	"	2030	98
		Average		2040	99
20	Black Gum	Sanded Coarse Cross Bonded	Penacolite	1120	60

DISCUSSION:Edge-Glued Samples

Good bonds were obtained in all cases for both poplar and black gum, except the animal glued samples. The average shear strengths of the various black gum samples were higher than those of the poplar in all cases

except the animal-glued samples, and observations indicate that this exception was caused by faulty gluing. The tests of controls of the two species indicate that the shear strength of black gum is definitely higher than that of poplar. From the results it also appears that the samples of Penacolite with sawn wood give about the same shear strength, but that the bonds obtained in the last two cases are superior to that obtained in the first. Cascophen gives about the same shear strength as the other resin adhesives in the case of poplar, but the strength is apparently greater than the others in the case of the black gum. The bonds obtained in this case are excellent. Hence, it appears that best edge-gluing results are to be obtained using sawn impregnated lumber and a resin adhesive. The developed shear on glue faces is from 65-80% of unglued stock.

Face-Joined Samples

The results indicate that sanding is necessary to obtain good bonding for face-joining. The shear strengths and bonds obtained using Penacolite and Plaskon in conjunction with finished lumber, and Penacolite in conjunction with unfinished lumber are approximately the same, the black gum samples giving the higher strengths in all cases. The bonds in these cases are excellent. Hence, since unfinished lumber can be successfully impregnated, its use in conjunction with resin adhesives is recommended.

It also appears from the results that while cross-bonding gives satisfactory strength, the strength is definitely less than for parallel grain. The parallel grain, developed shear on glue faces is about 60-80% of unglued stock.

The shear strength of samples joined with resin adhesives, although only a fraction of the strength of unjoined wood, still is considerably above that of the untreated, uncut wood.

D. IMPREGNATED WOOD AS A VENEER BACKING

Since surface impregnated wood was found to have satisfactory characteristics for a backing material, it was decided to investigate the techniques to be used in producing veneered woods using it as the core.

MATERIALS:

Samples of yellow poplar and black gum were impregnated with Bakelite Br 15100 solution (30% solids) according to previously standardized procedure, and veneered in the following ways, using various thicknesses of walnut and mahogany:

I. Separate curing and gluing with Plaskon 250-2 cold set urea formaldehyde adhesive.

II. Simultaneous curing and gluing with Amberlite PR-14 hot press phenolic resin.

III. Simultaneous curing and veneering - no additional adhesive.

Samples were also prepared using impregnated paper of the Kimberly-Clark Corporation as a surfacing material. Hardness tests were performed on all samples except those surfaced with paper. All the samples were parallel grain except where noted.

PROCEDURE:

Group I - The requisite number of pieces of impregnated wood of both species were cured at 300 degrees F. for 1/2 hour, compressed 0.9 - 0.75 inch. These were then sanded using coarse (No. 1) paper so as to remove 1/64 inch from each face. Plaskon adhesive mixed in the proportions recommended by the company was spread thinly on the sanded faces, and the veneering applied. After all samples had been prepared, they were placed in a clamp and subjected to a pressure of approximately 150 psi.

for 24 hours at room temperature.

The following samples (approximately 5 x 3-1/2 x 0.75 inch) were prepared:

Sample No.	Backing	Type of Veneering
I - 1	Poplar	1/12" Walnut
I - 2	Poplar	1/28" Walnut
I - 3	Poplar	1/48" Walnut
I - 4	Black Gum	1/12" Walnut
I - 5	Black Gum	1/28" Walnut
I - 6	Black Gum	1/48" Walnut
I - 7	Poplar	1/16" Mahogany
I - 8	Black Gum	1/16" Mahogany

Group II - In all cases Amberlite PR-14 mixed in the proportions recommended by the company was spread on both faces of the veneered stock, and on one side of each piece of veneer. The veneer was applied and the samples placed in a heated press. Pressure was then applied so that the core in each case was compressed 0.9 - 0.75 inch. A curing period of 1/2 hour at 300 degrees F. followed.

The same series of samples (approximately 5 x 3-1/2 x 0.75 inch) as Group I was prepared, except 1/12" Walnut on poplar and 1/16" Mahogany on black gum.

Group III - The veneer was placed on the surfaces of the uncured stock, and the assembly put in a heated press. Pressure sufficient to compress the core from 0.9 - 0.75 inch was applied in each case, after which a curing period of 1/2 hour at 300 degrees F. was allowed. The same series of samples (approximately 5 x 3-1/2 x 0.75 inch) was prepared as Group I, except 1/12" Walnut on black gum, and 1/16" Mahogany on poplar. Various samples with the veneer cross-bonded to the cores were prepared in the same manner.

Impregnated paper was bonded to uncured impregnated stock in the same way, except the temperature was reduced to 275 degrees F.

RESULTS: (For hardness data see Table IV)

Group I - Excellent bonds were obtained in all cases without strike through, and all surfaces were pleasing in appearance. The surface hardness decreases in rough proportion to the increase in veneer thickness and is approximately the same for both species and both types of serrations. The hardness of the 1/48" veneered surfaces is excellent and is comparable to that of cured impregnated surfaces. While the hardness of the 1/28" veneered surfaces is definitely less than that of the latter, it is much superior to that of untreated wood. Surface hardness approximating that of untreated wood is obtained using 1/16" mahogany and 1/12" walnut veneer.

Group II - The bonds obtained in all cases were excellent but all surfaces (except 1/12" walnut) were badly marred by strike through of the adhesive. As above, the surface hardness varies roughly inversely as the veneer thickness, except the 1/16" mahogany and the 1/12" walnut. These exceptions are probably caused by compression of the veneer and some resin penetration into it. This method of veneering is unsatisfactory because of the excessive strike through encountered except in the case of a very thick veneer (1-1/2" walnut).

Group III - The surfaces of all specimens were pleasing in appearance. The bonds were more satisfactory in the case of the 1/8" serrations than the 1/16" serrations because of the greater resin penetration into the stock in the former case. The bond obtained between sapwood and veneer is more satisfactory than between heart wood and veneer probably because of the same reason. Hence, since the bond is dependent upon the amount of resin in the stock, this method of veneering is of questionable value.

TABLE IV. THE RELATIVE SURFACE HARDNESS OF VENEERED, IMPREGNATED WOOD.

Sample	Veneer	Description	Backing	No. Trials	Average Reading	Average Penetration (m.m.)
I-1	1/12" walnut		1/8" serrated poplar	5	1.39	0.28
"	" "		1/16" " "	5	1.34	0.27
I-2	1/28" "		1/8" " "	15	1.20	0.24
"	" "		1/16" " "	15	1.16	0.23
I-3	1/48" "		1/8" " "	15	0.83	0.17
"	" "		1/16" " "	15	0.78	0.16
I-4	1/12" "		1/8" " black gum	5	1.46	0.29
"	1/12" "		1/16" " "	5	1.47	0.29
I-5	1/28" "		1/8" " "	15	1.23	0.25
"	" "		1/16" " "	15	1.20	0.24
I-6	1/48" "		1/8" " "	15	0.73	0.15
"	" "		1/16" " "	15	0.75	0.15
I-7	1/16" Mahogany		1/8" " poplar	5	1.72	0.34
"	" "		1/16" " "	5	1.72	0.34
I-8	" "		1/8" " black gum	5	1.84	0.37
"	" "		1/16" " "	5	1.79	0.36
II-2	1/28" walnut		1/8" serrated poplar	7	0.65	0.13
"	" "		1/16" " "	9	0.96	0.19
II-3	1/48" "		1/8" " "	5	0.64	0.13
"	" "		1/16" " "	8	0.50	0.10
II-4	1/12" walnut		1/8" " black gum	5	0.67	0.13
"	" "		1/16" " "	5	0.66	0.13
II-5	1/28" "		1/8" " "	8	0.65	0.13
"	" "		1/16" " "	8	0.62	0.12
II-6	1/48" "		1/8" " "	5	0.41	0.08
"	" "		1/16" " "	5	0.34	0.07

TABLE IV. (Continued) The Relative Surface Hardness Of Veneered, Impregnated Wood.

Sample	Veneer	<u>Descriptions</u>	Backing	No. Trials	Average Reading	Average Penetration (mm.)
II-7	1/16" mahogany		1/8" serrated poplar	8	1.50	0.30
"	" "		1/16" " "	5	1.12	0.22
III-1	1/12" walnut		1/8" serrated poplar	9	0.78	0.16
"	" "		1/16" " "	9	1.13	0.23
III-2	1/28" "		1/8" " "	10	1.13	0.23
"	" "		1/16" " "	9	1.18	0.24
III-3	1/48" "		1/8" " "	10	0.79	0.16
"	" "		1/16" " "	10	0.83	0.17
III-5	1/28" "		1/8" " black gum	10	0.79	0.16
"	" "		1/16" " "	10	1.11	0.22
III-6	1/48" "		1/8" " "	10	0.75	0.15
"	" "		1/16" " "	8	0.50	0.10
III-8	1/16" mahogany		1/8" " "	10	0.78	0.16
"	" "		1/16" " "	10	1.02	0.20

Description	Average Reading	Average Penetration
Untreated poplar	1.55	0.31
" black gum	1.60	0.32
Cured Impreg. poplar	0.67	0.13
" " black gum	0.34	0.07

The surface hardness decreases in rough proportion to the increase in veneer thickness, except the 1/16" mahogany and 1/12" walnut. The irregularity here is attributed to excessive strike through.

IV. Cross bonding of Veneer (no glue) - All surfaces were pleasing in appearance, but the bonds were not as good as those in Group III, and as before were dependent upon the resin penetration and distribution of heart and sap wood. Cross-bonding without additional adhesive is unsatisfactory.

V. Impregnated Paper as a Surfacing Material - Excellent bonds were obtained between the impregnated wood and phenol-formaldehyde impregnated paper. However, this material is unsatisfactory because ridges are left where the paper was pressed into the serrations.

S U M M A R Y A N D C O N C L U S I O N S

Yellow poplar, and probably all wood species, can be satisfactorily sanded after surface impregnation. Original cured surfaces and sanded surfaces are reasonably resistant to water penetration unless depth of full resin penetration of fiber is exceeded. This is about 0.04 inch in the case of the standard 1/8 inch serrations.

The indentation of impregnated yellow poplar obtained by modified Rockwell procedure is roughly half as much as that of the untreated wood, while that of impregnated black gum is 1/3 to 1/4 as much as that of the corresponding untreated wood. In comparison to untreated red oak, white oak, and maple, the impregnated species are much more resistant to penetration (i.e. harder).

As the curing pressure is decreased at constant temperature and time of cure, the indentation increases. However, the indentation of impregnated wood compressed only to its original thickness is much less than that of untreated wood.

Using resin adhesives, impregnated species can be satisfactorily edge-joined after sawing, and with slight sanding face-joined in both parallel and cross-bonded fiber directions. The shear strength in each case, although only a fraction of the unjoined wood, is considerably above that of the untreated, uncut wood.

After slight sanding, cured impregnated wood makes a very satisfactory backing material for veneers. A cold set urea-formaldehyde adhesive is recommended. The resultant surfaces are unmarred by adhesive strike-through, and have excellent hardness characteristics when thin and medium thickness veneers are used.

III. INVESTIGATIONS OF
RESIN ADHESIVES
EXPERIMENTAL

The investigation of resin adhesives were of two types: (1) the effect of various conditions of precure and final cure upon the strength and bond characteristics obtained with wood; and (2) the degree of cure as indicated by per cent extractables. The former study was carried out to determine whether or not the temperature and time of precure are critical in their effect upon adhesive bonds, and also to find whether pressure is necessary for the final cure. The latter was made to obtain recommendations for curing conditions now used in commercial production.

A. THE EFFECT OF VARIOUS PRECURE AND FINAL CURE CONDITIONS UPON ADHESIVE BONDS

APPARATUS:

Clamps with pressure equalizing heads and a calibrated torque wrench were used to apply pressure. A large electric oven served as the curing chamber. The samples were tested in block shear in a machine having A.S.T.M. shear fixtures, with pressure applied to the movable head by means of a hydraulic jack.

MATERIALS:

Straight grained white oak of average density was used in conjunction with Penacolite G-1124 resin adhesive (a resorcinol type).

PROCEDURE:

Panels 2-1/2 x 11 x 3/4 inch were taken from six different boards, each board being cut according to the following diagram.

a	b	c	d	e	f	g	h	5"
a	b	c	d	e	f	g	h	

Fig. 4. Method Of Obtaining Side-Matched Samples From A Given Board.

The letters refer to the following tests:

Test	Pressure	Precure Temp.	Time	Pressure	Final Cure Temp.	Time
a	-	-	-	150 psi.	140°F.	10 hrs.
b	150 psi.	40°F.	14 days	150 psi.	140°F.	10 hrs.
c	150 psi.	40°F.	14 days	None	140°F.	10 hrs.
d	150 psi.	40°F.	14 days	None	None	None
e	150 psi.	40°F.	21 hrs.	150 psi.	140°F.	10 hrs.
f	150 psi.	40°F.	21 hrs.	None	140°F.	10 hrs.
g	150 psi.	70°F.	21 hrs.	150 psi.	140°F.	10 hrs.
h	150 psi.	70°F.	21 hrs.	None	140°F.	10 hrs.

With panels at room temperature, an adhesive spread equivalent to 50 lbs. per 1000 square feet of glue line was applied to the 2-1/2 x 11" surfaces, and the panels placed together. After all samples of a given test were prepared, they were placed in clamps and a pressure of 150 psi. applied by means of a previously calibrated torque wrench. The samples were then cured as above. Standard test blocks (five from each sample) were then cut and tested in block shear.

DATA AND RESULTS:

Samples are designated by code. (board number)(test letter)
(block number), as 1-a-3, means board No. 1, test group a, block No. 3.

Tabular results are as follows:

TABLE V. THE EFFECT OF CURING CONDITIONS UPON ADHESIVE BONDS.

Sample	Shear Strength psi.	Per Cent Wood Failure	Sample	Shear Strength psi.	Per Cent Wood Failure
1-a-1	2830	100	4-a-1	2180	100
1-a-2	2560	100	4-a-2	2210	100
1-a-3	2720	100	4-a-3	2180	100
1-a-4	2780	100	4-a-4	2240	100
1-a-5	2950	100	4-a-5	2480	100
Average	2770	100	Average	2260	100
2-a-1	2480	100	5-a-1	2390	100
2-a-2	2480	100	5-a-2	1770	50
2-a-3	2600	100	5-a-3	2000	100
2-a-4	2600	100	5-a-4	1650	70
2-a-5	2420	100	5-a-5	2360	95
Average	2515	100	Average	2030	83

TABLE V. (Continued) The Effect Of Curing Conditions Upon Adhesive Bonds.

Sample	Shear Strength psi.	Per Cent Wood Failure	Sample	Shear Strength psi.	Per Cent Wood Failure
3-a-1	2150	100	6-a-1	1770	100
3-a-2	2540	100	6-a-2	1975	100
3-a-3	2300	100	6-a-3	2000	100
3-a-4	2420	100	6-a-4	1415	100
3-a-5	2480	100	6-a-5	1650	100
Average	2380	100	Average	1760	100
1-b-1	2770	100	4-b-1	2620	100
1-b-2	2770	100	4-b-2	2560	100
1-b-3	2740	100	4-b-3	2540	100
1-b-4	2740	100	4-b-4	2450	100
1-b-5	2420	100	4-b-5	2800	100
Average	2690	100	Average	2600	100
2-b-1	2480	100	5-b-1	2270	85
2-b-2	2390	100	5-b-2	2600	100
2-b-3	2480	100	5-b-3	2390	100
2-b-4	2240	100	5-b-4	2450	95
2-b-5	2680	100	5-b-5	1625	100
Average	2455	100	Average	2270	96
3-b-1	2390	100	6-b-1	1860	100
3-b-2	2330	95	6-b-2	1890	100
3-b-3	1770	85	6-b-3	1890	100
3-b-4	1800	85	6-b-4	1890	100
3-b-5	2300	85	6-b-5	1830	100
Average	2120	90	Average	1870	100
1-c-1	2540	95	4-c-1	2540	100
1-c-2	2660	95	4-c-2	2450	100
1-c-3	2450	80	4-c-3	2390	100
1-c-4	2950	85	4-c-4	2420	100
1-c-5	2270	25	4-c-5	2540	100
Average	2575	76	Average	2470	100
2-c-1	2240	95	5-c-1	1830	100
2-c-2	2330	90	5-c-2	1920	100
2-c-3	2390	90	5-c-3	2330	85
2-c-4	2420	65	5-c-4	2060	95
2-c-5	1860	95	5-c-5	2120	60
Average	2250	87	Average	2050	88
3-c-1	1360	100	6-c-1	1860	100
3-c-2	1950	100	6-c-2	1890	100
3-c-3	2120	100	6-c-3	1590	100
3-c-4	1830	95	6-c-4	1830	100
3-c-5	2300	100	6-c-5	1740	100
Average	1910	99	Average	1780	100

TABLE V. (Continued) The Effect Of Curing Conditions Upon Adhesive Bonds.

Sample	Shear Strength psi.	Per Cent Wood Failure	Sample	Shear Strength psi.	Per Cent Wood Failure
1-d-1	1090	0	4-d-1	1650	0
1-d-2	1535	0	4-d-2	2210	0
1-d-3	2330	0	4-d-3	2030	0
1-d-4	1590	0	4-d-4	2150	0
1-d-5	2240	0	4-d-5	2000	0
Average	1760	0	Average	2010	0
2-d-1	1920	0	5-d-1	1890	0
2-d-2	1240	0	5-d-2	1210	0
2-d-3	1535	0	5-d-3	1380	0
2-d-4	2330	0	5-d-4	740	0
2-d-5	1830	0	5-d-5	770	0
Average	1775	0	Average	1200	0
3-d-1	940	0	6-d-1	1710	15
3-d-2	1770	0	6-d-2	1830	10
3-d-3	1830	0	6-d-3	1830	15
3-d-4	1770	0	6-d-4	1860	15
3-d-5	1800	0	6-d-5	1530	15
Average	1620	0	Average	1750	14
1-e-1	2300	100	4-e-1	2035	85
1-e-2	2620	95	4-e-2	2300	100
1-e-3	2560	100	4-e-3	2300	90
1-e-4	1770	100	4-e-4	2420	100
1-e-5	2600	100	4-e-5	2360	100
Average	2370	99	Average	2290	95
2-e-1	2390	100	5-e-1	1860	95
2-e-2	2420	100	5-e-2	1975	95
2-e-3	2540	95	5-e-3	1650	70
2-e-4	2510	100	5-e-4	1360	75
2-e-5	2300	100	5-e-5	2035	95
Average	2435	99	Average	1775	86
3-e-1	2330	100	6-e-1	1420	100
3-e-2	2390	100	6-e-2	1590	100
3-e-3	2300	100	6-e-3	1625	100
3-e-4	1920	100	6-e-4	1770	100
3-e-5	2120	100	6-e-5	1625	100
Average	2215	100	Average	1605	100
4-f-1	1975	15	6-f-1	295	0
4-f-2	1770	5	6-f-2	1210	40
4-f-3	2035	10	6-f-3	440	0
4-f-4	1360	0	6-f-4	295	0
4-f-5	1950	10	6-f-5	1060	0
Average	1820	10	Average	660	8

TABLE V. (Continued) The Effect Of Curing Conditions Upon Adhesive Bonds.

Sample	Shear Strength psi.	Per Cent Wood Failure	Sample	Shear Strength psi.	Per Cent Wood Failure
5-f-1	1920	75			
5-f-2	1500	0			
5-f-3	1360	0			
5-f-4	1590	5			
5-f-5	1420	5			
Average	1560	17			
1-g-1	1920	100	3-g-1	2210	100
1-g-2	2540	100	3-g-2	2120	100
1-g-3	2330	100	3-g-3	2035	100
1-g-4	2920	100	3-g-4	2035	100
1-g-5	2920	100	3-g-5	2360	100
Average	2530	100	Average	2135	100
2-g-1	2360	100	4-g-1	2740	90
2-g-2	2720	100	4-g-2	2390	85
2-g-3	2480	100	4-g-3	2300	100
2-g-4	2480	100	4-g-4	2920	95
2-g-5	2600	100	4-g-5	2620	95
Average	2530	100	4-g-5	2595	93
5-g-1	2065	60	6-g-1	1535	100
5-g-2	2095	100	6-g-2	1590	100
5-g-3	2035	100	6-g-3	1770	100
5-g-4	2180	80	6-g-4	1950	100
5-g-5	1590	95	6-g-5	1300	100
Average	1995	87	Average	1630	100
4-h-1	1770	100	6-h-1	1535	100
4-h-2	2620	100	6-h-2	1565	100
4-h-3	2330	100	6-h-3	1680	100
4-h-4	2560	100	6-h-4	1680	100
4-h-5	2210	100	6-h-5	1535	100
Average	2300	100	Average	1600	100
5-h-1	2035	50			
5-h-2	1890	100			
5-h-3	1950	50			
5-h-4	1360	80			
5-h-5	1680	50			
Average	1780	66			

SUMMARY DATA

Group	Average Shear Strength psi.	Average Estimated Per Cent Wood Failure	Group	Average Shear Strength psi.	Average Estimated Per Cent Wood Failure
1-a	2770	100	1-b	2690	100
2-a	2515	100	2-b	2455	100
3-a	2380	100	3-b	2120	90
4-a	2260	100	4-b	2600	100
5-a	2030	83	5-b	2270	96
6-a	1760	100	6-b	1870	100
Average	2290	97	Average	2330	98
1-c	2575	76	1-d	1760	0
2-c	2250	87	2-d	1775	0
3-c	1910	99	3-d	1620	0
4-c	2470	100	4-d	2010	0
5-c	2050	88	5-d	1200	0
6-c	1780	100	6-d	1750	14
Average	2170	92	Average	1680	2
1-e	2370	99			
2-e	2435	99			
3-e	2215	100			
4-e	2290	95	4-f	1820	8
5-e	1775	86	5-f	1560	17
6-e	1605	100	6-f	660	8
Average	2110	96	Average	1350	11
1-g	2530	100			
2-g	2530	100			
3-g	2135	100			
4-g	2595	93	4-h	2300	100
5-g	1995	87	5-h	1780	66
6-g	1630	100	6-h	1600	100
Average	2240	97	Average	1890	89

DISCUSSION:

The results indicate the following:

1. Long or short periods of precure under pressure at 40° F. give approximately the same strength and bond characteristics, provided the final cure is also made without release of pressure. The characteristics are comparable to those of the controls.

2. A long period (14 days) of precure under pressure at 40° F. with final cure effected without pressure gives strength and bond characteristics much superior to a short period (21 hours) of precure at the same temperature, with final cure effected similarly. The former gives strength and bonds of approximately 90% of the controls, and the results are less consistent.

3. A long period (14 days) of precure under pressure at 40° F. with no subsequent curing gives wholly unsatisfactory strength and bond characteristics.

4. A short period (21 hours) of precure under pressure at 70° F. with subsequent curing effected under pressure, gives strength and bond characteristics comparable though slightly inferior to those of the controls. The same precure with final curing effected without pressure gives satisfactory characteristics, although more erratic results are obtained.

B. EXTRACTION OF RESIN ADHESIVES

Acetone extraction tests of Penacolite G-1124 were made to determine what time of dielectric heating is required to give a cure comparable to that of a control known to be satisfactorily cured. Dielectric or radio frequency heating is based upon the fact that a large amount of heat is generated by the excitation of the molecules of a given substance when they are placed in a rapidly oscillating or high frequency electric field.

Extraction tests with green whiskey were also made on various resin adhesives cured at different time-temperature cycles to determine what adhesive is satisfactory for the production of whiskey barrels, and the curing conditions required.

I - Acetone Extraction Tests

APPARATUS:

The main apparatus used was a battery of soxhlet extraction units. Each unit consisted of a 40 ml. extraction flask, a syphon cup, Whatman extraction thimble, and a condenser cap. The syphon cut condenser cap which rested on the neck of the flask. The battery was in the form of a rectangular wooden box lined with asbestos, and fitted with a removable lid in which holes were cut to receive the extraction flasks. The flasks were placed in cylindrical metal reflectors which directed the heat to them from 60 watt incandescent light bulbs located at the bottom of the battery. Cooling water for the condensers was supplied through an iron pipe manifold; the cooling system of the battery was connected in parallel.

The glue films were powdered to pass a 48 mesh Tyler Standard Screen by means of a mortar and pestle.

PROCEDURE:

Tests were made on samples furnished by Gamble Brothers and reported to be as follows:

1. Series A and B Control - 3 hours heating at 210° F. in an electric oven.
2. Series C Control - 3 hours heating at 210° F. in an electric oven.
3. Series A - Radio frequency heat - Curing time 30 seconds; temperature range 227-200° F.
4. Series B - Radio frequency heat - Curing time 90 seconds; temperature range 236-204° F.
5. Series C - Radio frequency heat - Curing time 180 seconds; temperature range 248-200° F.

The controls were reportedly obtained by mixing according to the proportions and methods recommended by the company, spreading thinly on glass plates, and curing as specified. The radio frequency heat samples were reportedly obtained by preparing suitable wooden forms, spreading the glue in the forms, placing a wooden top on each form, and curing as specified. After curing, the tops were removed by machining and the glue hand scraped from the forms. The samples were not refrigerated because of the high curing temperature employed.

A piece of Whatman filter paper was placed inside each of the extraction thimbles and extracted with acetone in the extraction battery for 24 hours. The thimbles were then dried for 1 hour at 110 degrees Centigrade in an electric oven, placed successively in a weighing bottle and weighed.

The controls were hand powdered by mortar and pestle to pass

a 48 mesh Tyler Standard Screen. The other samples were sufficiently fine as obtained. When all samples were prepared, the powders were weighed into the prepared extraction thimbles and acetone extracted for 24 hours. The extracted glues and thimbles were freed of acetone by heating in a drying oven at 110° C. for one hour, the losses recorded and calculated as per cent acetone extractables on an initial weight basis. This is the standard procedure for extraction tests of resin glues.

RESULTS:

The controls were hard and brittle enough to pulverize. As received, the radio frequency cured samples were for the most part finer than 48 mesh, and contained to a slight extent what appeared to be wood fiber.

TABLE VI. ACETONE EXTRACTABLES OF PENACOLITE G-1124

Sample	Curing Time	Curing Temperature	Per Cent Extractable
A and B Control	3 hrs.	210° F.	2.36
			-0.16
C Control	3 hrs	210° F.	1.97
A..Radio frequency heat	30 seconds	$227-200^{\circ}$ F.	5.45
			9.83
			1.32
B - Radio frequency heat	90 seconds	$236-204^{\circ}$ F.	5.77
			4.97
			5.57
C - Radio frequency heat	180 seconds	$248-200^{\circ}$ F.	2.28
			-4.68
			0.78

From the results it appears that while 90 seconds radio frequency heating will not give a value of extractables comparable to that of the control, adequate curing may be obtained using a time of 180 seconds.

II. WHISKEY EXTRACTION TESTS.

APPARATUS:

The extraction battery previously described was modified to eliminate vapor losses. Standard glass water-cooled condensers with a condenser cap in the top of each were placed in the extraction flasks. The syphon cups were eliminated because the time required to fill them was found excessive. Fine wire was used to suspend the extraction thimbles from the stoppers containing the water condensers. Laboratory electric ovens were used to cure the adhesive films.

PROCEDURE:

The adhesives were mixed according to the proportions recommended by the respective companies, spread thinly on glass plates, and cured according to a prearranged schedule. After curing, each plate was placed in a desiccator in a refrigerator which was held at 40° F. These glue flakes were hand powdered by mortar and pestle to pass a 48 mesh Tyler Standard Screen and immediately replaced in the refrigerator. When all flakes were prepared, the powders were weighed into prepared Whatman extraction thimbles and extracted for 24 hours with 109 proof White Bourbon whiskey. The extracted glues and thimbles were freed of the whiskey by heating at 110° C. in a drying oven to constant weight, the losses recorded and calculated as percent extractables on an initial weight basis.

RESULTS:

All cured films were hard and brittle except the Penacolite sample cured for 24 hours at room temperature. Upon extraction, this sample gave a sticky mass and the result reported is considered unreliable.

TABLE VII. WHISKEY EXTRACTABLES OF CURED RESIN ADHESIVES FILMS.

PER CENT EXTRACTABLES					
Time of Cure Hours	1/4	2	6	10	24
Penacolite					
Room					10.77
120° F.		13.60	10.11		(poor-sticky)
150° F.		10.90	9.81		
190° F.	13.49	10.54	7.74		
Cascophen					
120° F.		39.0		30.4	
150° F.		32.4		28.3	
190° F.		26.8		14.63	
Melmac					
190° F.		28.0		17.4	

DISCUSSION:

All adhesives tested show considerable solubility, although this effect is somewhat minimized by higher curing temperatures and longer curing times. Penacolite cured for 6 hours at 190° F. appears the best of those samples tested.

III. INVESTIGATION OF CURING TECHNIQUES FOR WHISKEY BARREL PRODUCTION.

Since Penacolite cured at 180° F. for 6 hours was found satisfactory by actual experience, it was decided to investigate the cures obtained using various plant curing techniques.

APPARATUS:

The extraction apparatus used was the same as that in the preceding section.

PROCEDURE:

The following curing techniques were investigated:

1. Heating for 6 hours at 180° F. in a curing chamber (screw clamped), and allowing to cool slowly.
2. Steam plate heating under pressure for 8 minutes (final midplane temperature of 240° F.) plus subsequent curing as in case 1.
3. Steam plate heating under pressure for 8 minutes (final midplane temperature of 240° F.), plus slow cooling in screw clamps.
4. Seventy seconds radio frequency heating, plus slow cooling.

Samples 1-3 were taken from the center of a 13/16 inch oak bundle with the adhesive between aluminum cauls. It was originally planned to take sample 4 from the same type bundle with the adhesive between Plastyle cauls. However, when it was found that the amount of adhesive obtained in this way was insufficient, samples were prepared from adhesive that had been pressed out of the cauls into the wood area of the center lamination of the bundle. All samples were extracted as described in the preceding section.

RESULTS:

All samples were hard and brittle enough to pulverize. The film in case 1 was very thick because the pressure exerted by the screw

clamps was insufficient.

TABLE VIII. WHISKEY EXTRACTABLES OF RESIN ADHESIVE

Penacolite 1124

Sample	Curing Conditions	Per Cent Extractables
1	6 hours 180° F. in curing chamber	12.73 12.60
2	Steam plate 8 min. plus cure as in case 1.	9.05 8.85
3	Steam plate 8 min.	7.98 8.16
4	Radio Frequency heating for 70 sec.	9.01) 7.91) outside cauls 9.80
5	6 hours - 190° F. on a glass plate	7.74

DISCUSSION:

Samples 2, 3, and 4 all give satisfactory cures as compared with 6 hours heating at 190° F. on a glass plate. Since the thick film in case 1 was probably incompletely cured, sample 5 should be used for comparison even though the value of extractables is probably low because of escape of volatile matter.

SUMMARY AND CONCLUSIONS

The length and temperature of pre-cure are not critical in their effect upon strength and bond characteristics obtained with wood using Penacolite 1124, provided pressure is retained during the final cure. Pre-cures with clamp removed prior to final cure are not satisfactory, although the effect is somewhat alleviated by long pre-cure periods or pre-cures at higher temperatures.

Radio frequency heating for 180 seconds gives a cure based on acetone extractables, equal or superior to that obtained by 3 hours heating at 210° F. in an electric oven. Penacolite 1124 cured for 6 hours at 190° F. was found satisfactory for whiskey barrel production by extraction tests, and 6 hours at 180° F. by actual experience. Steam plate heating for 8 minutes and radio frequency heating for 70 seconds give comparable cures.

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APPENDIX

A C K N O W L E D G E M E N T S

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Descriptions of Resin Adhesives

The following adhesives were used in various tests described in this thesis:

(1) Penacolate G-1124, a liquid resorcin resin (100 parts) plus Penacolate G-1125 liquid hardener (25 parts), manufactured by the Pennsylvania Coal Products Company.

(2) Cascophen LT-67, a liquid phenolic resin (100 parts) plus M-18 (a powdered paraformaldehyde base catalyst) (8 parts), manufactured by the Casein Company of America.

(3) Plaskon 250-2, a powdered urea formaldehyde resin (2 parts) plus water (1 part).

(4) Melmac 400, a melamine base resin (100 parts) plus water (65 parts).

VITA

John V. Birkel was born on November 29, 1924, in Louisville, Kentucky, the son of Louis F. Birkel and Anna Fante Birkel. He received his primary education at St. Columba Parochial School, and his secondary education at St. Xavier High School.

Mr. Birkel entered the Speed Scientific School of the University of Louisville in June, 1942, and received the degree of Bachelor of Chemical Engineering in June, 1945.

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