The Compound Bending of Douglas Fir Plywood

by

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INTRODUCTION

<u>Purpose</u>:

The purpose of this thesis is twofold, namely the investigation of the problems confronting operators in bending for waterproof plywood construction, and the testing of 1/8" 3 ply Douglas Fir to determine the methods and extent to which compound bends may be achieved.

The term compound bend as used in this thesis refers to the deflection produced in a cylindrical slice (abcd) when stress is applied (by force p) at right angles to the cylinder axis along the arc of a circle (xy) made by a bisecting plane.

<u>Importance of the Problem</u>:

In the sale and use of waterproof bond plywood much can be gained by providing instruction in the capacities of the material in use. In selecting a material for use in boats, consideration is given (6) to weight, cost, seaworthiness, ease of handling, speed, seams and portability. Waterproof plywood has proven itself advantageous in most of these factors. However, in considering speed and attractiveness of the individual craft, certain compound curves must be produced if the product is to be readily accepted on the competitive market.

The question of just how much and in what manner compound curves may be obtained has been asked of the Douglas Fir Plywood Association for sometime (1) by users and prospective users of the product.

Review of Related Previous Studies:

After considerable investigation it seems probable that little information is available on this subject. In this regard L. J. Markwardt (12) writes, "We have not experimented with the bending of plywood. It is doubtful if there has been much published on the subject." Considerable work has been accomplished, however, in an unscientific way, but as yet the extremes in the use of the product and the conditions which contribute to most successful workmanship have not yet been recorded.

Methods of Procedure and Sources of Data:

In conducting the survey of the problems confronting operators in waterproof plywood bending, retail distributors in the Portland area presented lists of the major producers to which such problems would be common. Prominent boat-building, trailer, and cabinet construction firms were contacted, both personally and by correspondence, in an effort to isolate the problems and determine the various methods being used in the field.

The experiments in compound bending were organized and carried through with a plan developed from original ideas and valuable suggestions from the Douglas Fir Plywood Association and the Wood Products Department.

RESULTS OF SURVEY

Bent Plywood Construction:

The survey of operators attempting to produce compound curvature in marine construction showed only the more progressive and large size operations carrying on this type of work. Most of this was found on special construction. Many of the operators were undoubtedly interested in more progressive construction which definitely showed greater market appeal (14). Problems of trailer and cabinet makers were confined primarily to simple bends, but showed that in streamlining and in customer appeal there was a definite place for compound bends.

Boats:

Among the boat-builders there were several phases of compound bending observed. Mr. E. A. Stephens (17) recently completed a racing shell of 1/8" 3 ply waterproof Douglas Fir plywood. The shell was constructed of six large plywood panels, and showed considerable compound bend through the central portions of the boat. In this construction the panels were laid from the gunnel to the keel. Wet cloth and a blow torch were used on the surface to obtain pliability during construction, and final equalized pressure was obtained by using wide strips of inner tube tightly stretched over the entire curved surface.

In the line of small motor boat and launch construction two companies have made considerable progress. C. R. Dillabaugh, a Portland boat builder, has handled some special orders (6) in which four piece hull construction has been used. The upper side panels contained slight compound bends, but in construction offered no great **problem.** However in the lower hull he achieved considerable compound bend with an increasing simple curve diameter progressing toward the stern of the boat. In actual construction he found a wet steam spray very useful in softening the outer ply which was in tension during the bending process. He also stated that he was unable to obtain a concave surface verging into a convex curve without undue and extensive rupture. Such curves are commonly found in planked construction. In a similar boat of larger size L. P. Burch, Aberdeen, Washington boatbuilder, (4) seems to have mastered many of the difficult problems of compound bending in two panel hull construction. However the information on this construction is not available, for he writes:

> "We are sorry we find it inadvisable to pass the information you desire on at this time. Our engineers have been for several years perfecting the method we employ in bending plywood...Through their efforts we find it possible to bend any and all of these materials in the thicknesses which you mention, (1/8" and 1/4") into any bends we desire, without encountering difficulty with checks, splits, or buldges. On the other hand, our method of bending, instead of weakening, increases the catenary strength of the materials thus treated."
>
> "These methods on all such materials are entirely protected by 'patents pending'. In fairness to the research work of our own engineers we do not feel at liberty to transfer this information until such time as they see fit to publish the patents."

As was stated by Mr. Burch, he has achieved some remarkable bends with an entire side of the boat hull

Figure I

HARBOARD PLYWOOD SPEEDBOAT

Standard hull construction with bent Harboard plywood.

Protecting bumper shown across one piece side of hull.

constructed from one panel (Figure I), and with a very sharp simple bend from the sides to the bottom of similar one piece construction at the stern of the boat.

Trailer Houses:

In trailer construction nothing as yet has been done with compound bends. The Brumpton Company in Portland (3) uses plywood only for interior simple curves, exterior panelling being entirely of Masonite. However it is entirely possible that they would change to a plywood exterior if sufficient compound curvature were possible to further streamline their trailers. The Road Home Company (15) uses exterior plywood but has also only worked with simple bends. Considerable extra rib members would have to be added to provide compound bends, and as yet they have not experienced any strong demand for greater streamlining.

Cabinet Work:

In this field almost any type of bend may prove of value; however, as most work is finished with hardwood veneers, only the basic forms offer any problem. (2) The plywood used for cabinet work is usually not of the waterproof type, and thus the possibility of steaming to increase pliability is eliminated. Any value to be derived by cabinet workers must come from primarily the bending capacity of dry material, unless waterproof bond plywood is used.

EXPERIMENTS IN COMPOUND BENDING

Application to Field Problems:

After considerable investigation in the field it seems important that the individual workman be provided with some basic data on the amount of compound bend that can be expected from a given simple bend. He is also interested in the width of stock which he can best use on any given project. Such a problem has a very vast scope as the amount of simple bend continually changes in the lines of a boat, but it is felt that the majority of the difficulty comes in the portions of the boat which are subjected to the most extreme compound bends.

To offer some information which should prove of value in the field the following compound tests were devised and run.

Objective:

To determine the methods of preparation and amount of deflection in compound bending (see definition page 1) obtainable in 1/8" 3 ply Douglas Fir for fixed simple curve diameters common in standard construction.

Procedure:

Organization of the experiment consisted of selecting representative simple curve dimensions and preparing methods and forms to test the plywood samples for deflection.

In selecting basic radii to be used in the simple curves of the test a 6" interval was used, hoping to arrive at a representative trend with the diameters of 60", 48", and 36".

The 22 samples available for the test were divided into two groups for testing. One group of samples was used to determine the compound bend obtainable in dry stock, and the other group was used to determine the compound bend in steamed stock. In arriving at a desirable method of softening the samples for the second group to obtain extreme bends several processes were considered including soaking in water, using wetting agents (Appendix 2), dry steaming, and wet steaming. After conference (3, 5, 6, 14) the wet steaming process was selected as best from the standpoint of field application and extreme pliability.

In examining the samples it was found that some showed heavier sanding on one face than on the other. In these cases dry tests were most successfully run with the scant face convex, while the steamed samples run more successfully with the thick face convex. (Appendix 3)

In regard to steamed samples, pretreatment was found to be of little value, as the layers of veneer being very thin dry almost instantaneously, and thus steam should be most aptly applied during the bending process.

The initial tests were run with the forms in a large hydraulic press, however, when it was found that relatively little pressure was required (300 lbs. maximum), pressure methods were confined to large wooden hand clamps similar to those probably used in the field.

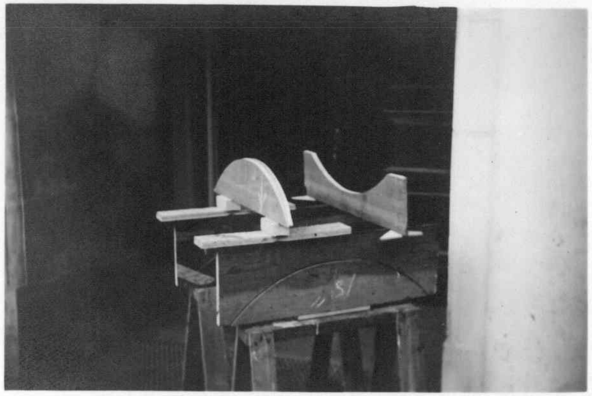
Forms:

The forms for carrying on the compound bending tests were constructed for standard 24" width 1/8" 3 ply samples, since this size was believed to be applicable to standard field construction. To test the diameters of 60", 48", and 36" three forms were constructed using a 1.5' span (Figure IIa) with male and female forms on each end fitted loosely together to allow give and take during the bending tests. The span of 1.5' between end members was found to be the most readily tested and should provide a standard for deflection computation for any length of span. Screw fasteners were used in construction to assure rigidity. The stress members were centered with the form and lined up (Figure IIb) to assure even stress over the entire bending surface.

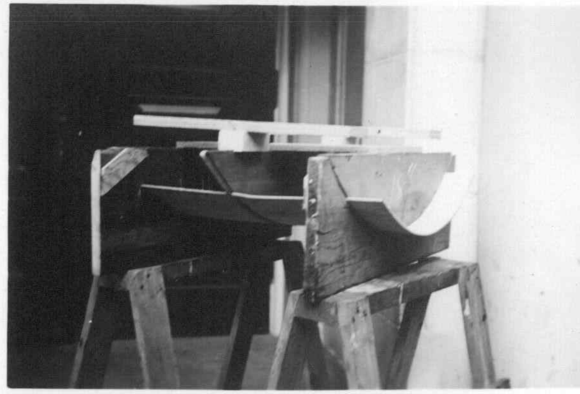
Direct Bend:

The term direct bend refers to those tests in which the stress member was placed within the concave portion of the simple curve and the force applied against the concave surface (Figure IIc). The first tests were run with dry material in this manner and the outer portions of the surface were found to buckle or curve away from the form. To prevent this tendency and to similate closely the field application of the problem a metal band was fastened over the convex surface of the sample opposite the stress member (Figure IId). In the dry samples tested rupture occurred from buckling at the outside edges of the sample, though

Figure II

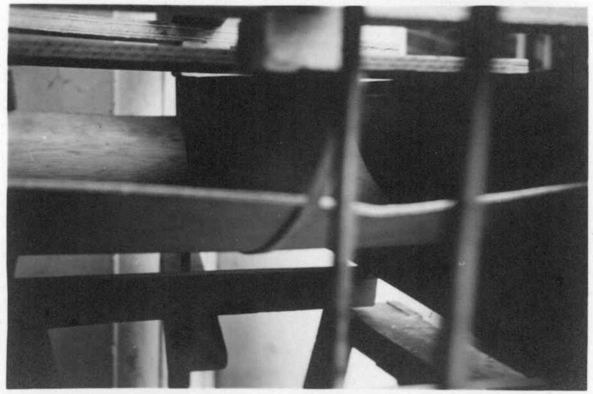


a. Forms



b. Stress member forms bisecting plane

c. Direct Bend



d. Sample under pressure using metal strap the inner 14" in the width of the pieces showed very little buckle and could have taken more deflection.

In testing the steamed samples, a steam spray was applied over the entire surface for one minute before stress was applied. In the process of bending buckle occurred as in the dry tests, but was usually found on alternate sides of the stress member.

Deflection measurement taken with rule graduated in hundredth of inches measuring from form to top of pressure member.

Reverse Bend:

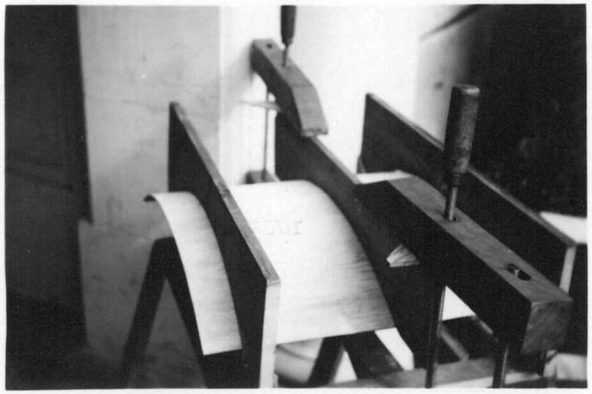
The term reverse bend refers to those tests in which the pressure member was placed on the convex portion of the simple curve and the force applied against the convex surface (Figure IIIb). In these tests buckle and deflection from the curve occurred along the center line (of the width) and rupture invariably occurred at this point. Considerably more pressure was required to bring maximum deflection and rupture in reverse bends particularly in the 36" diameter in which all pressure available using large wooden clamps was necessary. Deflection measurement in these tests was taken in hundredths inches with interior calipers, measuring the span from the center of the concave surface to the center of the form, and correcting for buckle in computing the final rupture deflections.

Figure III

a. Direct Bend

b. Compound Bend

c. Sample in form



d. Compound Bend

Evaluation of Data:

In organizing the experimental results of the tests (Table I, II) there are several noticeable discrepencies. In considering Table I the dry tests of 60" simple diameter showed less deflection attainable than with smaller simple diameters. Laboratory notes show that in the first two samples errors in testing procedure occurred. In the first no strap was used on the convex face and excessive buckling occurred prematurely. In the second a screw jack pressure device was used to apply force to compression member and uneven pressure was applied over the surface causing early rupture on one side of the sample. The third sample was a rerun of the test and is believed to be accurate. In other cases where supposed discrepency occurred no error in procedure could be found.

In evaluating the data and presenting results a table of results was considered to be most applicable (11). However since most related material is presented by straight line graphs, the material is plotted and a straight line fitted (Appendix 5) in Graphs I and II. Dotted lines were used since the results are not considered conclusive having a high standard of error due to light sampling.

Record of Experimental Results

Table I

Direct Bend:

Dry

Simple O Diameter	Deflection Obtained
*60"	.48"
*60"	.37"
60"	.65"
60"	.76"
48"	.54"
36"	.38"

Steamed

Simple O Diameter	Deflection Obtained
60"	.82"
60"	.93"
48"	.63"
48"	.74"
36"	.80"
36"	.82"

Table II

Reverse Bend:

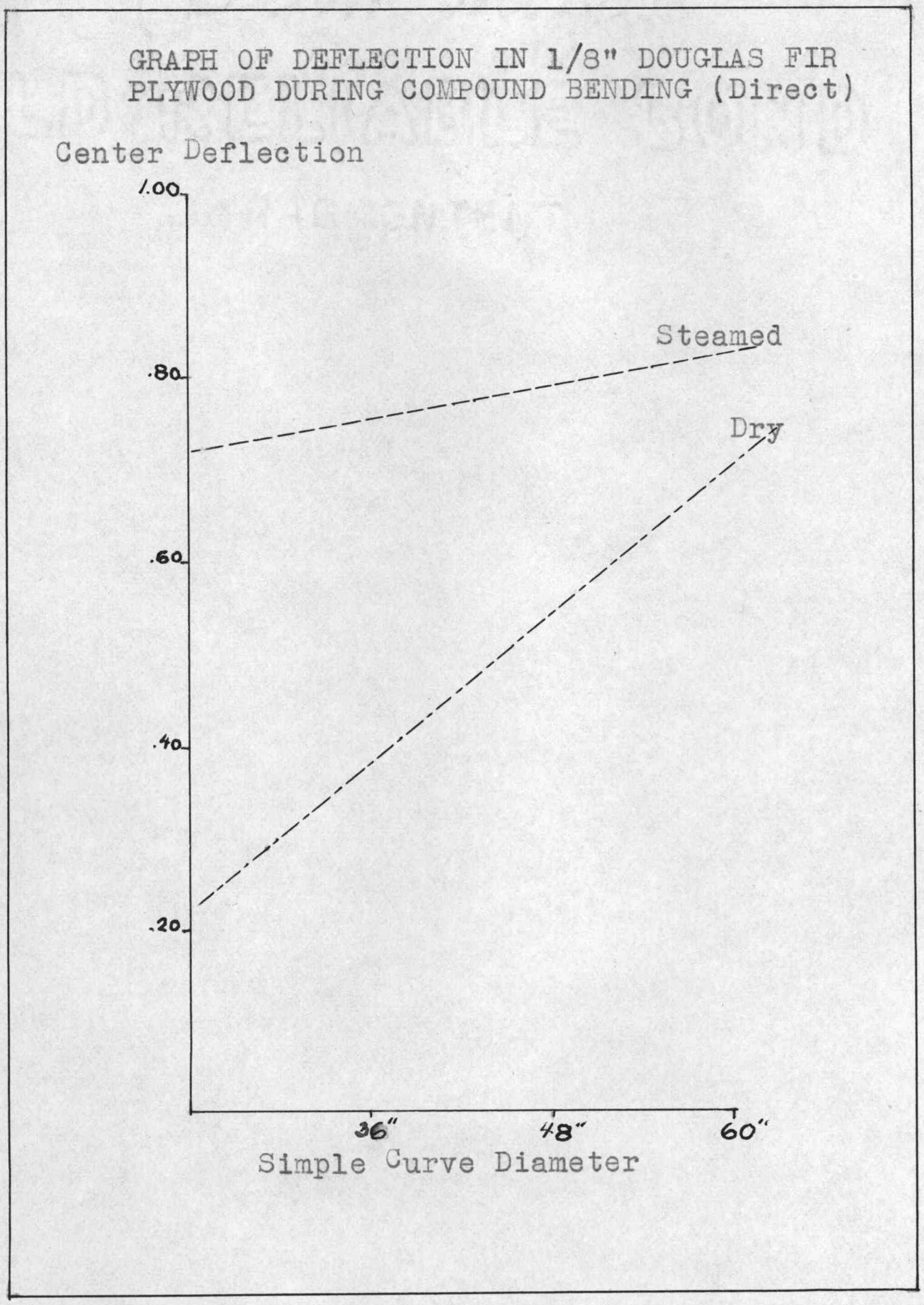
Dry

Simple O Diameter	Deflection Obtained
60"	.27"
48"	.14"
48"	.14"
36"	.18"
36"	.19"

Steamed

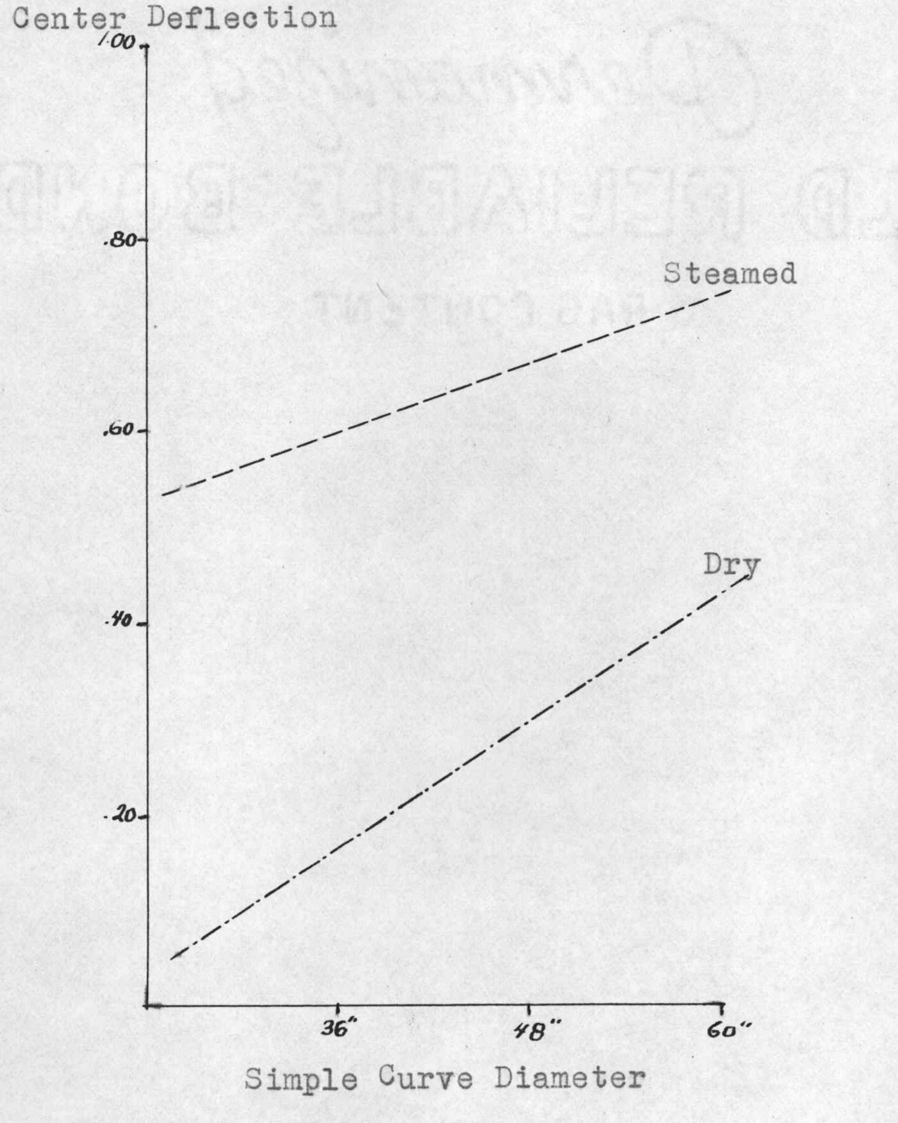
Simple O Diameter	Deflection Obtained
60"	.98"
60"	.58"
48"	.41"
48"	.81"
36"	.66"
36"	.59"

Graph IV


GRAPH OF DEFLECTION IN 1/8" DOUGLAS FIR
PLYWOOD DURING COMPOUND BENDING (Direct)
Center Deflection
1.00
.80
.60
.40
.20
Steamed
Dry
36"
48"
60"
Simple Curve Diameter

Graph II

GRAPH OF DEFLECTION IN 1/8" DOUGLAS FIR PLYWOOD DURING COMPOUND BENDING (Reverse)



CONCLUSIONS

Survey:

From the material collected in the field it seems important that the subject of waterproof plywood bending be investigated thoroughly and results be presented in readable pamphlet form for use by members of the customers in the field. Such a guide should contain methods as well as limits in the use of the material. Through this program a greatly enlarged market can be developed which may in time swing certain construction methods to exclusive use of waterproof plywood.

Compound Bending Tests:

The results presented (Tables I and II) show that compound bend can be obtained from plywood panels of 1/8" material, and that the bends can be greatly increased without rupture if a wet steam spray is applied. It is also evident from these tests that the problem of buckling along the edges of the stock occurs prior to any evidence of rupture, and it is felt from observations during the tests that if an individual bend in the field does not show any extreme tendency to buckle that no possibility of rupture will occur.

Having completed the initial study in plywood bending it is felt that an important step has been made in collecting data for practical application.

The most outstanding fallacy in this testing program lays in the inadequate sampling necessary to obtain conclusive results. However the forms and procedure are considered adequate to provide valuable information when material is available for complete sampling with (18) about 50 samples for each individual test.

Recommendations:

To supply adequate information on compound bending the experiments herein should be completed with adequate sampling and a simple pamphlet prepared for use in the field.

Observations during the course of this thesis show that extreme compound bending could be produced in 1/8" waterproof plywood if a chamber was built which would provide a humidified atmosphere during the entire bending process. By this method pretreatment could be achieved and pliability retained throughout the bending process.

In applying compound bends to field construction it is most important that the resultant buckle from this type of bending be considered since it is felt that this is a major problem in satisfactory construction.

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APPENDIX

1. In the field of simple bending the trailer companies have developed a simple and effective technique for curves applicable to cabinet and interior house construction. The individual bend to be made is measured on the line of curve desired and the plywood is cut to this width. Butt joints are constructed on either side of the curve, and one side of the member to be curved is set into one of these butt joints and nailed. The portion to be curved is then crowded evenly into the corner until it slides into place. By this method any normal bend down to a 16" radius can be obtained. Trailer builders report (3, 14) negligible split and defect from this method.

2. In the initial phases of this thesis some thought was given to emersing the samples in water and it was suggested that more rapid results could be obtained by using some type of wetting agent. The principle involved in a wetting agent (5) is a matter of reducing the surface tension or cohesion of the water molecules to allow more rapid penetration. Any basic or alcohol compound would accomplish this but the expense and the possibility of a portion of the applied substance remaining in the wood and causing undue softening prevented their use on small projects. However it is felt that emersion in a hot water bath for a long enough period will accomplish thorough saturation and may offer a solution in handling heavier stock. (Thicker than 1/8")

3. In describing the selection of faces to be used on the convex surface it was stated that the thin face was best in dry tests and the thick face was better in steamed tests. It has been stated (17) that the maximum stress occurs on the tension or convex surface during bending, and in some cases particularly if the projects reach a point of mass production, some type of strap may be used to take up the tension stress and bring the outer layers of wood to a point of equilibrium as found in the center line of any bent member. Such conditions may arise in boat building, however in this particular case the solution lay in selecting the surface which could best withstand the tension stresses. In dry samples the surface had a natural tendency to form a convex face on the thin side and by using the material in this form some of the tension was transferred to the core which by the nature of its grain could be easily bent to the problem requirements. In the steamed samples the thick face having a maximum of wood material outside the impenetrable glue line showed considerable swelling and thus was adapted to the tension stress. Some samples showed even sanding and offered none of the above adaptations.

4. In regard to the selection of stock for boats it must be remembered that wide variations occur in the growth of various peeler logs. In this regard the following items should be considered closely (17): selection of stock (no patches allowed unless waterproof glue is used), seasoning, softening and rendering stock pliable, bending, and fixing

in shape (being sure that the stock has even drying from the steamed to the final conditions).

5. The straight line applied to the data in Graph I and II was fitted by modified use of the statistical method of least squared in which the plus and minus deviations were equal and the numerical total of deviations was adjusted to give the smallest possible total.