First Progress Report

TESTS ON WIREBOUND BOXES

In cooperation with the Wirebound Box Manufacturer's Association

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As generally understood, the wirebound box is a container having a greater number of metal bindings than the ordinary strapped box, and with the amount of lumber reduced to a minimum. The sides, top, and bottom are made of thin boards, rotary-cut, or from thicker boards resawn, to which are stitched several steel binding wires. The sides, top, and bottom are secured to cleats at each end by staples driven astride the end binding wires, and the ends are nailed or stapled to the inside of the same cleats. The box is closed by twisting together the two ends of each binding wire.

The wirebound box is light, strong, economical of material, and adaptable to a wide variety of uses. It is machine made and about seventy-five per cent assembled when it leaves the box factory, yet it is shipped flat and occupies little car or warehouse space. It is easily assembled, convenient to load and easily closed, and, when
properly closed, offers excellent protection against pilling.

Until recently, the makers of wirebound boxes have done most of their own research work. This work, however, has been principally for the purpose of developing packages for specific commodities rather than for the study of fundamentals. As the result of several years of practical experience the makers realized that there are many relations between factors which needed closer investigation. On August 18, 1924, through their association, they entered into a cooperative agreement with the Forest Products Laboratory for a comprehensive study of wirebound packing boxes, the object of which was to determine the proper relation between the various details of construction as a basis for formulating rules for design.

Under this cooperative agreement the Wirebound Box Manufacturer's Association furnishes all of the material required for the tests, a box blank machine for making the boxes, and one half of the money required for the work, the Forest Service furnishing the balance.

Object of the Investigation

The general aim of this investigation is to furnish detailed information on the following points, all in relation to the size and shape of box and weight and nature of contents:

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1. The number, size, nature of temper, and position of wires;
2. Number, size, and spacing of staples;
3. Kind and thickness of material;
4. Number of pieces in the ends, sides, top, and bottom;
5. Type of end construction, including size and arrangement of cleats and battens;
6. Methods of joining ends of cleats;
7. Condition of the wood at time of manufacture;
8. Method of packing the contents;
9. Storage and transportation conditions.

It has been impossible, in the time that has elapsed since the beginning of the investigation, to study in detail all of the points enumerated above, and the work is not to be considered complete in any particular. Nevertheless, some very sound progress has been made. The main emphasis has been laid on determining the proper thickness of material and number and size of wires for boxes of several shapes and sizes carrying various weights of contents. Incidentally, it has been necessary, in a number of cases, to study also the influence of the number of staples, the type of end construction, and methods of reinforcement, in order to balance their strength against the strength of the other parts of the box.

The purpose of this report is to present the information thus far obtained so that it may be put to practical use by manufacturers and users of wirebound boxes.
Description of Material

The material used consisted of two shipments of veneer and logs and two shipments of wire, all of about average commercial quality. The veneer in the first shipment was variable as to quality but was dry and in good condition when received. The logs of this shipment were sawed into lumber at the laboratory and the stock was kiln dried. Part of the lumber was cut 13/16 inch thick for cleats, battens, etc., and part of it was cut thinner and dressed to 5/16 and 3/8 inch for ends, sides, tops, and bottoms. In the second shipment the veneer was of uniformly good quality and well dried. The logs were all cut into lumber which would dress 13/16 inch and the stock was kiln dried.

The binding wire was 12 gauge, 13 gauge, 14 gauge, and 15 gauge; the stapling wire was 16 gauge and 18 gauge.

Marking and Matching

Each piece of veneer was marked with the log number, bolt number, and piece number as it was cut from the bolt, and each piece of sawed lumber was marked with the log number and a number to indicate its position in the log.

When each series of boxes was made up the material was selected so that, as nearly as possible, the corresponding pieces of veneer in the several boxes were
of the same quality, usually from the same log, and that the corresponding cleats and battens were from the same board.

**Boxes Tested**

The following sizes and shapes of wirebound boxes, loaded with the weights of contents indicated, have been tested:

- **Long flat boxes**, 24-1/8 by 12-1/8 by 8-1/8 inches inside measurements, capacity 1.38 cubic feet, loaded with 50, 80, 125, 135, 200, 300, or 420 pounds.

- **Cubical boxes**, 16-1/8 by 12-1/8 by 12-1/8 inches inside measurements, capacity 1.37 cubic feet, loaded with 50, 120, 125, 210, 300, or 420 pounds.

- **Long flat boxes**, 32-1/4 by 20-1/8 by 12-1/8 inches inside measurements, capacity 4.55 cubic feet, loaded with 80, 120, 170, 200, 300, 500, or 800 pounds.

- **Flat square boxes (export type)** 20-1/8 by 32-1/4 by 12-1/8 inches inside measurements, capacity 4.55 cubic feet, loaded with 170, 300, or 500 pounds.

- **Cubical boxes**, 20-1/8 by 20-1/8 by 20-1/8 inches inside measurements, capacity 4.7 cubic feet, loaded with 175, 300, 500, or 800 pounds.

- **Cubical boxes**, 33-1/2 by 33-1/2 by 33-1/2 inches inside measurements, capacity 21.8 cubic feet, loaded with 300 pounds.
For each of the sizes, shapes, and weights of contents shown above there were usually several variations of thickness of material, number or size of wires, number of staples, or end construction. As a rule only one factor was varied at a time.

**Loading**

The contents of each box consisted of sufficient small cylinders (4 inches in diameter and 4 inches long) to fill the box, and of such weight as to give the desired total load for the box. These cylinders were arranged so that the axis of any one of three adjacent cylinders in a row parallel to an edge of the box was at right angles to the axes of the other two. This arrangement allowed a rolling action between the cylinders in all directions and prevented as much as was practicable any self-supporting action of the contents.

**Tests**

The principal tests were made in the laboratory's large box testing drum, but the drop test was used to check certain deductions. Notes of each failure of the box and the number of the drop at which it occurred were recorded, and the test was continued until the contents were spilled.

A moisture sample was cut from each box immediately after the test and the moisture content determined.
Whenever it appeared that abnormally high or low specific gravity of the material was affecting the results of the tests, specific gravity determinations were made.

Tension tests were made on several samples taken from each roll of wire used in the manufacture of the boxes for the purpose of determining the quality of the wire, and on sample closure twists to determine the efficiency of the closure.

Method of Attack

From the laboratory's experience with nailed wooden boxes, both unstrapped and strapped, prior to beginning the investigation, it had been deduced that thicknesses of sheet material (thin boards) required for the sides, top, and bottom of wirebound boxes could probably be represented by the equation \( t = k \frac{\sqrt{w}}{b} \) in which "t" is thickness of sheet material, "w" is weight of contents, and "b" is the breadth of the narrowest face of the box. A value for constant "k" of 0.05 was thought to be about right for Group III woods in wirebound boxes carrying about an average commodity.

The general plan when the work was begun was to start with the thickness of material given by the above equation for each size and shape of box and weight of contents tested. The plan also included material 1/16 inch

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thicker and 1/16 inch thinner than required by the equation.

The number and size of wires were to be determined by means of the "curves for designing wirebound boxes," a modification of the laboratory's strapping chart adapted to wirebound boxes by the research department of the Chicago Mill and Lumber Company and formally adopted by the Wirebound Box Manufacturer's Association. The plan also provided for tests with both more and less wires than are called for in the wire chart -- this with the object of checking the wire requirements as set forth in the chart.

Results

Comparatively little difficulty has been experienced in designing a fairly well-balanced wirebound box for loads up to 250 or 300 pounds by adjusting the thickness of sheet material, number and size of wires, and the end construction. For the heavier loads, however, the ends and cleats, and the fastenings of the sides, top, and bottom to the cleats are weak and it is difficult to reinforce such boxes sufficiently by means usually employed; that is, by battens or heavy ends. In order to develop the full strength of the thicker sheet material (5/16 and 3/8 inch) in boxes carrying heavy loads, it has been found necessary to use reinforcing wires lengthwise around the
box at right angles to the regular binding wires.

**Thickness of Material**

It has been quite definitely brought out by the tests that once a balance has been established between thickness of sheet material, number and size of wires, staples, and end construction for a certain weight and nature of contents, increasing the thickness of material does not generally justify the use of fewer or smaller wires, nor can a decrease in thickness of material be compensated for by adding more wires.

The results of the tests show that the equation $t = 0.05 \sqrt[\frac{W}{b}]$ for thickness of material allows somewhat greater loads than the sheet material will carry without excessive breaking across grain and splitting, and that this form of equation does not apply throughout the complete ranges of widths of box face and weights of contents commonly encountered in wirebound boxes. It appears, however, that if the constant of this equation is changed to 0.06, thus making the equation $t = 0.06 \sqrt[\frac{W}{b}]$, the thickness of material will be about right for an average commodity, within the mid-ranges of box size and weight of contents. This equation is shown by the straight diagonal lines of the thickness of material chart which is included herewith as a part of this report.

In addition to the above relations there appears
to be an upper limit of the load allowable for each thickness of material. This is expressed by the equation 
\[ t = \frac{2}{5} \frac{w}{V} \] 
and is shown by the straight horizontal lines in the right-hand portion of the same chart.

For the relatively narrow box faces there is another limiting factor, -- a minimum cross section (thickness times breadth) of material for each weight of contents. This relation is expressed by the equation 
\[ t = \frac{0.1056}{\frac{3}{5}} \] 
and is shown by the curved lines in the lower left-hand portion of the chart.

**Size and Spacing of Wires**

Tests of boxes reinforced with flat metal straps or wire ties have shown that the required size and number of the straps or wires bears a direct relation to the weight of the box and contents. The laboratory strapping chart which is based on the results of tests of several thousand strapped boxes is derived from the equation

\[ a = \frac{w^{1/2}}{k} \]

in which "a" is the gross area of the cross section of the straps, "w" is the weight of the box and contents and "k" has a value of 990 for one strap and 594 for two or three straps. Tests of wirebound boxes have shown that the same general relations which were determined for metal straps on nailed wooden boxes hold with reference to the binding wires of wirebound boxes. The equation suggested for determining the gross area of the cross
section of binding wires is \( a = \frac{w^{1/2}}{460} \), which is the same equation as for strapping except that the constant is such as to give a slightly greater cross section of binding wires than is specified for two or more straps (flat metal). This is considered necessary for the reason that the binding wires on a wirebound box, in most instances, are used to fasten down the top in addition to serving as metal reinforcements to the container itself. The equation is shown in graphic form in the left portion of the chart previously referred to in connection with thickness of material.

End Construction and Reinforcement

While the end construction and reinforcements are admittedly of as much importance as other details of the design of wirebound boxes these points have not yet been given as much attention in this study as some of the other factors. Important observations have been made but the exact limits within which the various types of end construction should be used have not been determined definitely.

Battens perform several important functions. They may be employed to advantage where ends are made of several pieces, to reinforce relatively large ends made of thin material, or to reinforce the cleats and afford means for additional nailing. The subject of thick ends has not been
thoroughly investigated but it appears that thick ends are not generally of much advantage unless the sides, top, and bottom are nailed to them, and if the sides, top, and bottom are made of thin material, this nailing is not effective.

In boxes using very thin sheet material, such as 1/8 inch rotary-cut veneer, the ends and cleats, without battens, are stronger than necessary to balance the strength of the sides, top, and bottom. With 3/16 inch sheet material there is a good balance between the sides, top, and bottom and unreinforced ends. For the 1/8 inch, 1/6 inch, and 3/16 inch thin boards, therefore, it is not necessary to use battens except perhaps to break up long spans of the thin material or unless the ends are made of several pieces.

After passing the 3/16 inch material, however, the sides, top, and bottom are stronger than the ends and cleats. In general, the strength of the ends and cleats may be brought into good balance with the strength of the sides, top, and bottom by battens reinforcing the cleats and a few nails driven through the sides, top, and bottom and cleats into the battens. Boxes made of 7/32 inch or 1/4 inch thin boards may also be reinforced and the full strength of the sides, top, and bottom developed, without battens, by applying reinforcing wires or flat metal straps lengthwise, at right angles to the regular binding wires.
In boxes having 5/16 inch sides, top, and bottom the cleats are very much weaker than the sheet material, and while battens reinforcing the cleats result in greater resistance to rough handling, the battens do not afford sufficient reinforcement to develop the full strength of the sides, top, and bottom, and are not nearly as effective as reinforcing wires or straps lengthwise of the box.

The 3/8 inch sheet material is so much stronger than the cleats and the usual end construction that in order to gain the full advantage of this thickness all cleats must be reinforced with battens and in addition reinforcing wires or flat metal straps must be used.

**Number of Staples**

The standard spacing of staples adopted for these tests was 2 inches. In a number of boxes, however, for various conditions of size, shape, thickness of material and load, staples were spaced about 1 inch apart over the end binding wires.

Other details of construction being equal, boxes with the staples spaced 1 inch apart withstood, as a rule, more rough handling than the boxes with staples spaced 2 inches apart. Exceptions to this rule were boxes made of relatively thin material, perhaps too thin for the weight of contents carried, and in which the strength of the material was not equal to the strength of normal stapling;
and boxes, usually for the heavier loads, in which the cleats were the weakest parts of the box. Increasing the number of staples to this extent on boxes for the heavier loads appeared to cause a reduction in the resistance of the box to rough handling by increasing the tendency of the cleats to split at the staples.

**Number of Pieces**

The number of pieces in the several parts (or faces) of the wirebound box affects the box chiefly in one way -- its rigidity. The greater the number of pieces in the faces the more the box will weave. The principal disadvantage of such weaving is the danger which may come to its contents through rubbing, thereby defacing the surface of the commodity, i.e., lithographed wrappers to canned goods. Weaving of the box absorbs the shocks of falls with much lower stresses than are developed in the rigid box, and for some commodities (fire brick, for example) wirebound boxes whose faces are made of several pieces may perhaps be specified to advantage.

**Shape of Box**

The shape of the box is of much more importance than might at first be supposed. Tests have shown that the box which is nearly cubical in shape withstands a great many more drops in the drum than the long box having the same capacity and the same thickness of material, spacing
of staples, and number and size of wires, and carrying the same weight of contents. In the drop test the cubical boxes generally withstand only a slightly greater number of drops than the long boxes. The difference in the results of the two tests is accounted for by the fact that the long box is carried higher in the drum and falls harder than the cube. It is probably also true in service that the long box receives the harder falls but not quite to the extent represented by the drum test. The cube, on account of its shape, is easier to balance in design. The sides, top, and bottom have a shorter span and, therefore, spring less and the stapling edges are longer, giving room for more staples. All this suggests that the box should be designed as closely to the cubical form as may be practical.

Tests made on boxes approximately 32 by 20 by 12 inches inside measurements in which the 32 by 12 inch faces instead of the usual 20 by 12 inch faces were given the end construction (the so-called export type of wire-bound box) showed that the export type requires better end reinforcement than the domestic type in order to withstand as much tumbling and dropping. The export type of wire-bound box, no doubt, does excel in rigidity and in its ability to withstand outside pressure (as in slings or in stacking), and by means of sufficient end reinforcement (battens, etc.) it is possible also to make it equal, if
not superior to the domestic type in general resistance to rough handling.

Chart for Designing Wirebound Boxes

The accompanying "Tentative Chart Showing Minimum Thicknesses of Sheet Material and Number and Size of Binding Wires for Wirebound Boxes" has been prepared for the purpose of presenting graphically certain rules for designing wirebound boxes which have been prepared as a result of this investigation, especially with reference to the selection of the proper thickness of material, number, size, and spacing of wires, and end reinforcement.

How to Use the Chart

Thickness of Material

To determine the thickness of sheet material to be used find the weight of contents to be shipped. (The weights are given along both the right and left borders of the chart.) Follow the horizontal weight line to its intersection with the vertical line representing the narrowest face (side, top, or bottom) of the box. "Broadths of box face are given along the lower border of the chart.) At or above this intersection is the line representing the thickness of material required.
Number and Size of Wires

To determine the number and size of wires to be used, start with the weight of the contents to be shipped. (The weight scale along the left border of the chart is convenient.) Follow the horizontal weight line to its intersection with the curve representing the gauge of wire chosen. At or to the right of this intersection is the vertical line representing the number of wires required. (The scale indicating the number of wires is shown along the 400 pound weight line.)

For many weights there is a choice of the gauges and number of wires that may be used. The dimensions of the box must be kept in mind, however, and also the fact that the wires cannot be spaced closer than 4 inches to each other, and notes on the chart regarding maximum spacing of wires should be observed. These points may prove the determining factor in a given case where a greater range of selection is otherwise indicated by the chart.

End Reinforcement

Each notation regarding end reinforcement shown in the right portion of the chart is intended to apply to the entire area upon which it appears; that is, the notation shown below the 1/4 inch material line applies to all boxes requiring 1/4 inch thin boards, etc. The battens required, as indicated by the chart, are largely for the
purpose of reinforcing the cleats and, to be most effective, should be placed adjacent to the cleats (i.e. Type D, N, etc.). Battens also may be required for other reasons as on large ends made of thin material or on ends made of several pieces.

The reinforcing wires and straps referred to in this connection are in addition to the regular binding wires and are applied lengthwise of the box; that is, at right angles to the regular binding wires. The required cross-sectional area of these reinforcing wires in each direction around the box (ends and sides, or ends, top, and bottom) is about one-third that of the gross cross-sectional area of the regular binding wires.
TENTATIVE CHART SHOWING
MINIMUM THICKNESSES OF SHEET MATERIAL
AND NUMBER AND SIZE OF BINDING WIRES FOR WIREBOUND
BOXES

GROUP III WOODS

Boxes made of 1/8" material.—
Wires or straps required to reinforce cleats —
and ends. Maximum spacing of binding wires 5/8".

Boxes made of 1/4" material.—
Wires or straps required to reinforce cleats and ends. Battens also desired.
Maximum spacing of binding wires 1/2".

Boxes made of 1/2" or 11/4" material.—
Wires, straps, or battens required to reinforce cleats and ends. Maximum spacing of binding wires 1/2".

Boxes made of 1" material.—
Maximum spacing of binding wires 1/2".

Directions for Using Chart

Thickness of Material
Follow horizontal weight line from scale at right or left border to intersection with vertical line from scale at lower border representing narrowest face (side, top, or bottom) of box, at or above this intersection is the line representing the thickness of material required.

Number and Size of Wires
Follow horizontal weight line to intersection with curve representing gauge of wire chosen. At or to the right of this intersection is the vertical line indicating number of wires required.

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