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Michigan State University
Cooperative Extension Service
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June 1972
4 pages

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COOPERATIVE EXTENSION SERVICE
MICHIGAN STATE UNIVERSITY

Extension Bulletin E-745
Marketing Series
June 1972

Warping of Furniture Panels

By Otto Suchsland, Department of Forestry

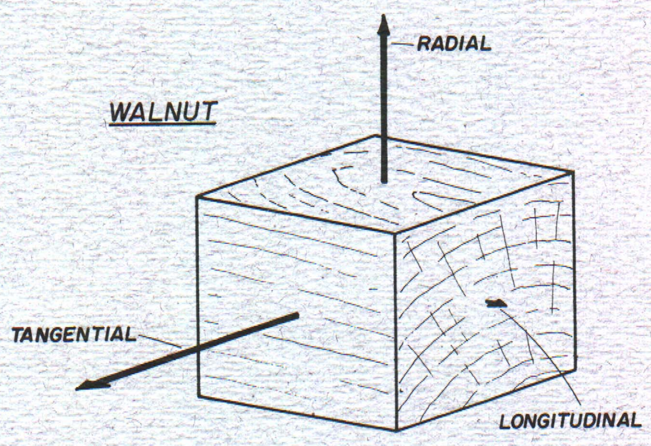
Solid wood and most wood based products respond to changes in the relative humidity of the air by swelling or shrinking. This characteristic is one of the most important properties of wood. While advantageous in some cases, as in the tightening of the seams of a planked boat hull, the swelling and shrinkage of wood is generally undesirable and requires proper allowances in the design and manufacture of furniture and other wood products.

Any restraint applied intentionally or unintentionally to swelling or shrinking wood generates considerable stresses which if not properly balanced could lead to the distortion, or even destruction, of the product. An appreciation of the magnitude of these swelling stresses and of their consequences is prerequisite to the design and manufacture of troublefree products. This bulletin explains the origin of swelling stresses and their contribution to the warping of unbalanced furniture panels.

Swelling and Swelling Stresses

Figure 1 illustrates the swelling of solid wood without any restraint. The swelling is minimal in the longitudinal direction (along the grain of the wood). Largest swelling occurs across the grain in the tangential direction (tangential to the annual rings). No swelling stresses are associated with this free swelling of solid wood.

In Figure 2, a piece of solid wood is placed in a condition of complete restraint, like in a rigid vice. If the piece would just fit into the vice snugly at 0 percent moisture content, any moisture content increase would result in swelling stresses. The stresses in the wood would be the same as those that would occur if the piece was first allowed to expand freely and then compressed to its initial length. The **stresses**, in this case compressive stresses, are indicated in pounds per square inch of cross-sectional area (psi). The total **force** applied to the vice is therefore equal to the stress multiplied by the cross-sectional area. The magnitude of the stress depends on the



Direction	Longit.	Radial	Tangential
Green to ovendry, %	0.5	5.4	7.5
Per 1% moisture content change, %	0.019	0.208	0.289
Per 1% moisture content change, in./in.	0.00019	0.00208	0.00289
Per 1% moisture content change, in./48 in.	0.0091	0.0998	0.1387

Figure 1. Dimensional changes of solid wood (Walnut) due to increasing moisture content.

moisture content change, the free expansion of the wood and the stiffness of the wood. The stiffness of the wood is an indicator of its resistance to deformation under stress. The stiffness is generally expressed in terms of the modulus of elasticity in psi. The higher the modulus of elasticity, the smaller the deformation under a given stress, or, the higher the modulus of elasticity, the larger the stress associated with or required to achieve a given deformation either in tension or compression. The stiffness of solid wood is strongly affected by the grain direction as is shown in Figure 2. Thus, although the expansion due to moisture content changes is small in the longitudinal direction, because of the large modulus of elasticity in this direction, the resulting swelling stresses are high.

Moisture Content Change, %	Longitudinal psi	Radial psi	Tangential psi
2	646	354	491
4	1292	707	983
6	1938	1061	1474
8	2584	1414	—
10	3230	—	—
Modulus of elasticity, psi	1,700,000	85,000	

Figure 2. Swelling stresses of completely restrained solid wood (Walnut), as a result of increasing moisture content.

Plywood

Figure 3 illustrates the expansion of three-ply plywood. The three veneers are crosslaminated so that the grain of the core veneer runs perpendicular to the grain of face and back. The piece of plywood is free to expand as a result of increasing moisture content. The individual veneers, however, are in a condition of mutual restraint. Figure 4 takes a closer look at one edge of the same piece of plywood. It shows the free expansion of each of the veneers as it would occur in response to a moisture content increase without the presence of the restraining glue line. The glue line, however, imposes the condition that all three veneers have to expand the same amount. This means that face and back will be held back by the core and that the core will be pulled out by face and back. Compressive stresses will therefore develop in face and back and tensile stresses in the core. At the line indicating the resultant expansion of the plywood, the compressive forces in face and back (stress times cross-sectional area) are equal to the tensile force in the core. Since the veneer has a much higher stiffness along the grain than across the grain, stresses grow much faster in the core as it is being stretched by face and back than in face and back as they are being pulled back by the core. The point of resultant expansion and force balance lies therefore much closer to the line indicating the small free expansion of the core than to the line indicating the large free expansion of face and back. The resultant expansion of plywood is, thus, very close to the normal free expansion of solid wood along

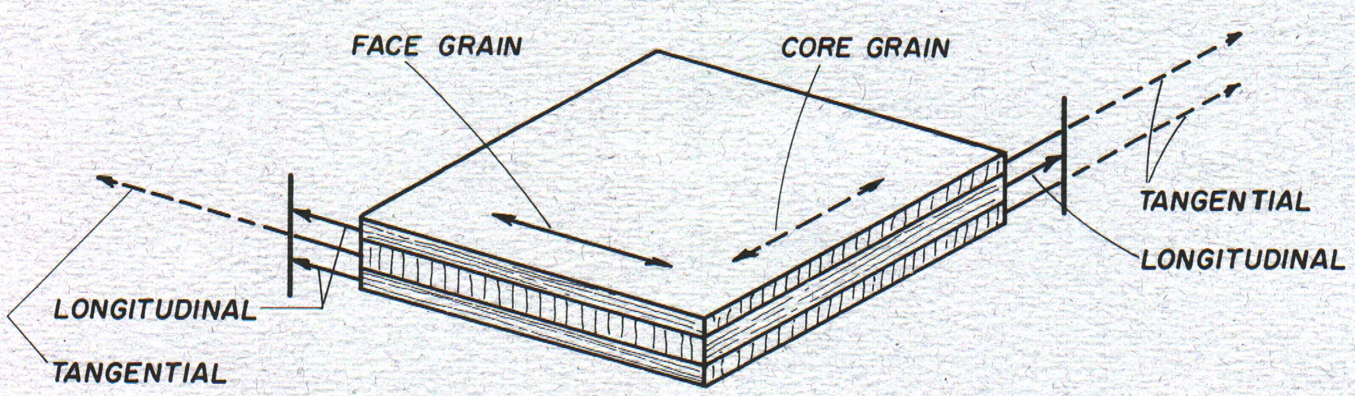


Figure 3. Mutual restraint of veneers in three-ply plywood.

the grain. This is a very important result of cross-lamination. It can be stated as follows:

> **Minimal linear expansion of solid wood and maximal stiffness in compression and tension occur in the same direction relative to the grain (longitudinal direction). This combination causes the minimal longitudinal expansion to dominate the expansion of cross-laminated products like plywood.**

The line indicating the resultant expansion and the point of force balance in Figure 4 would move to the right if face and back thickness would be increased relative to the core thickness, because the forces in face and back would increase. The dominance of the core would thus be diminished.

The Unbalanced Laminated Panel

A laminated panel like a plywood sheet or a veneered lumber core panel will warp because of either a temporary unbalance caused, for example, by exposing one side of the panel to a higher or lower relative humidity than the other, or by a built-in permanent structural unbalance like face and back being of different thickness or species. Warping caused by temporary unbalance is beyond the control of the manufacturer and will generally disappear when the moisture content of the entire panel equalizes at the higher or lower level. Built-in unbalance may not immediately result in a warped panel, but warping will occur as soon as the moisture content changes and will persist even after the panel has come to equilibrium and has a uniform moisture content throughout. We are more concerned with the latter type of unbalance, because it can generally be avoided or kept at a minimum by careful control of manufacturing conditions.

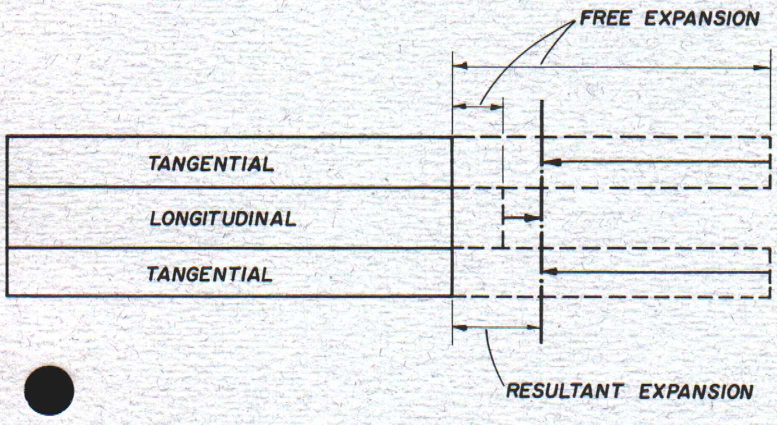


Figure 4. Resultant expansion of three-ply plywood.

Figure 5 shows the cross-section of an expanding panel in which the face veneer is thicker than the back veneer. The thickness ratios depicted are, of course, exaggerated. Assuming that face and back have the same expansion characteristics, it is obvious that the free expansion of face and back must be identical, as indicated. Thickness does not affect the free expansion of the veneer. Under the condition of restraint imposed by the glue line, however, the thicker face will exert a larger force (force = stress x cross-sectional area) than the back, which will result in the face being longer than the back as shown by the line indicating resultant expansion and force balance. The panel will warp as shown. The larger the moisture content change, the more severe the warping. Shrinkage of the veneers would also result in warping except that then the top would be concave. A common cause of the type of warping described above is the unequal sanding of veneered panels, which initially may have had a perfectly balanced construction. If a veneered panel has to be sanded, care should be taken to remove equal amounts from both faces.

A different type of unbalance is shown in Figure 6. Here, both face and back are of the same thickness but the face has a larger free expansion than the back. The restraining core will cause higher stresses to develop in the face because of

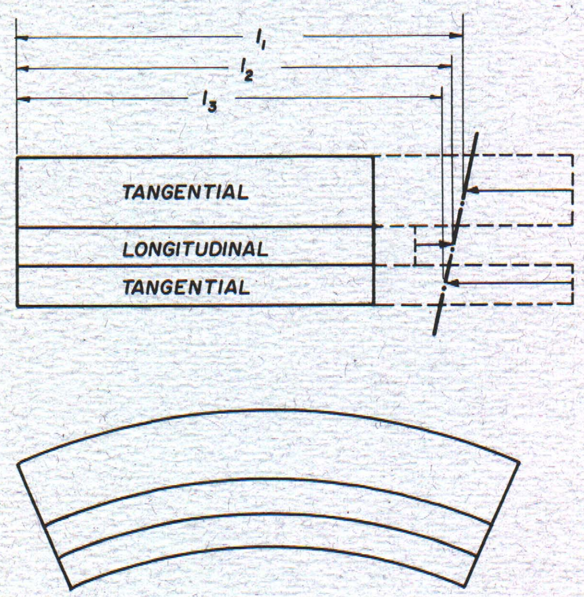


Figure 5. Warping of expanding three-ply panel due to unequal thickness of face and back veneers.

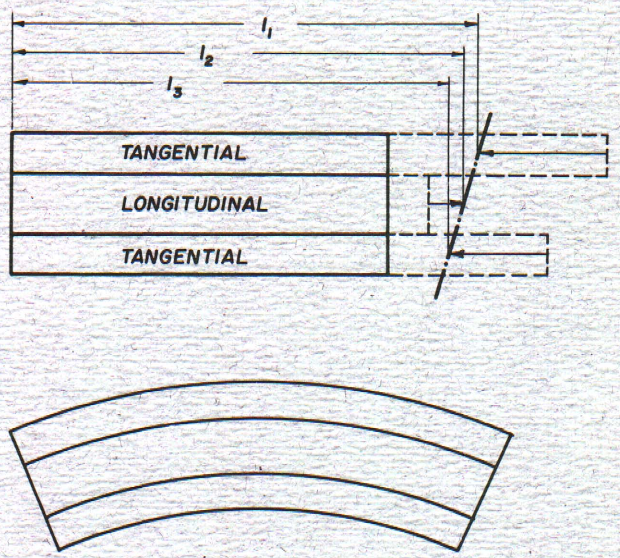


Figure 6. Warping of expanding three-ply panel due to unequal expansion of face and back veneers.

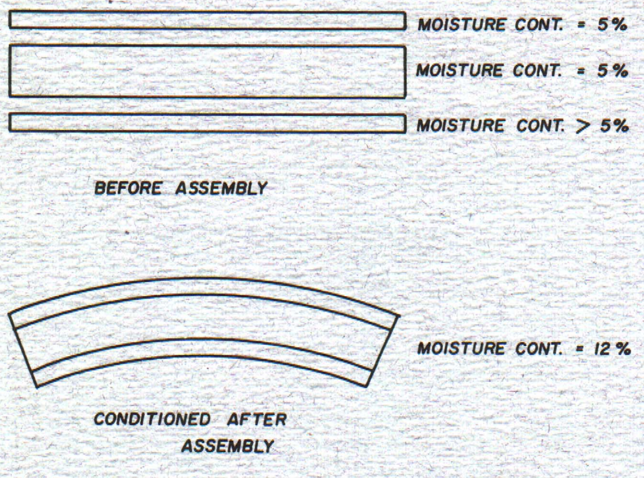


Figure 7. Warping of expanding three-ply panel due to unequal moisture content in face and back veneers prior to laminating.

the larger compression deformation in the face. The force in the face will therefore be larger than that in the back. Warping will occur as indicated. This type of unbalance could be caused by using different species with different expansion characteristics for face and back or by using veneers with different grain characteristics like burl or composite veneer for the face and straight grain for the back. This problem can sometimes be solved by varying the thickness of the back veneer in which case one unbalance would be compensated by another of opposite effect. Composite veneer faces could be balanced by composite back veneers. The pattern used for the back veneer could, of course, be much simpler than that used for the face.

Figure 7 shows how a permanent unbalance can be built into a panel although both face and back veneers are identical in terms of thickness, expansion characteristics and stiffness. In this case, the two veneers have unequal moisture contents before lamination. If the lamination process occurs in the hot press, the back veneer would lose more moisture than the face and would try to shrink more. This shrinkage, however, is being restrained by the rest of the panel, resulting in the development of tensile stresses in the back veneer. Upon removal from the press, the panel will warp immediately. The warping will remain constant regardless of the final moisture content of the panel. This condition may either be caused by different moisture contents in the veneers, by

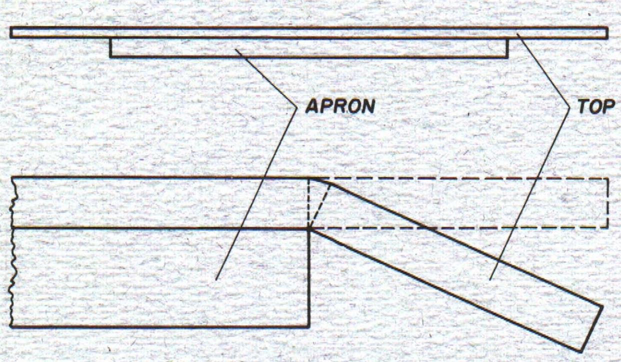


Figure 8. Illustration of table overhang deflection due to restraint of top panel expansion.

unequal glue spread, or by a number of other factors that would allow one of the veneers to have a higher moisture content than the other at the time of laminating.

There can be many reasons for the warping of large panels like table tops. Figure 8 illustrates one condition that contributes to the sagging of table tops with large overhang. The table top, which might be a veneered particleboard or lumber core panel is rigidly connected to the apron. Assuming that the apron swells less with increasing moisture content than the top panel, it will have a restraining effect on the panel. Along the joint between panel and apron both members swell the same amount. The top layers of the panel, however, are less restrained and swell more, causing the deflection of the overhang as indicated. A less rigid connection between top and apron would reduce restraint and warping.

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U. S. Department of Agriculture. George S. McIntyre, Director, Cooperative Extension Service, Michigan State University, E. Lansing, Mich. 1P-2.5M-6:72LB.