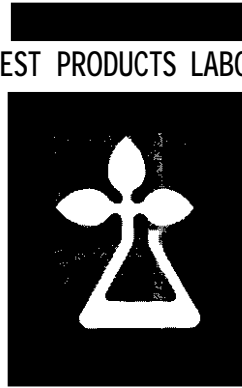


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SOME CAUSES OF WARPING IN PLYWOOD
AND VENEERED PRODUCTS¹

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Requests are frequently received by the Forest Products Laboratory to examine warped plywood, veneered table tops, or similar products, to explain the cause of the warping, and if possible to suggest measures to remedy the difficulty.

In examining samples of warped veneered products, it is very helpful to consider that a flat plywood panel or veneered top represents a construction in which swelling or shrinking stresses are balanced. The stresses were at a minimum at the time the glue set during the gluing operation; if, in service, the moisture content and the moisture distribution could again be the same as at the time the glue set, the stresses would again be reduced to a minimum. It is almost impossible to realize this condition, and for all practical purposes plywood construction may be considered as always stressed. If the stresses are balanced, the panel will remain flat. If the stresses acting on one side are not sufficiently well balanced by opposing stresses on the other side, warping will result.

¹Originally written by Don Brouse, former Forest Products Laboratory engineer, in 1940 as Report No. 1252 under the same title.

²Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The magnitude of the stresses will depend, in part, on how much the moisture content departs from that prevailing when the glue set. The greater the moisture changes, the greater will be the stresses developed and the greater will be the warping tendencies. The more nearly the average moisture content in service approaches the moisture content prevailing at the time the glue set, the lower will be the stresses developed and the less the warping tendencies.

If all points of the surface of a plywood panel lie in one plane or if all points touch when the panel is laid on a true and even surface, the panel is said to be "flat." If the surface of the panel is not in a single plane or if, when laid on a true and even surface, a portion of the panel does not touch the surface, the panel is said to be "warped."

When warped plywood or veneered products are examined, the warping should be classified as either twisting or cupping. For this discussion, twisting may be defined as that type of warping in which one corner is out of the plane of the other three. When laid on a flat surface, three corners of such a panel can be made to rest on the flat surface, but the fourth will be off the surface when the other three are touching. A panel is cupped or bowed, if, when laid on a flat surface, the four corners can be made to touch but the center portion of the panel is raised from the flat surface. These two types of warping in plywood result from somewhat different causes and should be considered separately although both may occur together.

Twisting

Ordinarily, the causes of twisting are more easily detected than the causes of cupping. AS a general rule, twisting in plywood is a matter of grain direction. While factors other than grain direction can cause twisting they are not so frequently encountered in practice, and if plywood or veneered tops unattached to supporting members are twisted, it is most likely that the grain direction is at fault.

In a five-ply veneered top with a comparatively thick core and thinner crossbands and faces, the crossbands are most essential in maintaining a flat panel free from twist. In this construction, the grain of the crossband on one side should be parallel to the grain of the opposing crossband on the other side of the core. Just how much variation from this condition of parallelism may be permitted will be affected by several factors, such as thickness of core, density of core, moisture content of core at the time of gluing, service conditions,

and the amount of twist that can be tolerated in the finished product. With thin panels, it has been demonstrated experimentally that a variation of 5° in the direction of the grain of opposing crossbands has caused noticeable twisting, and examination of commercial five-ply veneered tops has often disclosed pronounced twisting with a variation of 15° .

While the crossbands of five-ply construction are usually the critical elements, the faces are the critical elements in three-ply construction. If the crossbands of five-ply thick core construction are properly laid, minor variations in the direction of grain of the faces seldom cause objectionable twisting. In five-ply thin core construction, however, parallel grain is important in the faces as well as in the crossbands. In the so-called "hollow-core" and "floating-core" constructions used in flush doors, it seems likely that all plies of the facings may affect the tendency of the doors to distort, but the relative importance of the different plies has not been clearly established.

To avoid or reduce twisting that results from grain direction will usually require some changes in manufacturing procedure. One of the simplest and least costly methods for reducing twisting is to select for crossbands of five-ply panels those species, like basswood, aspen, and poplar, that generally produce reasonably straight-grained stock. Figured, interlocked, and irregularly grained stock should be reserved for uses where twisting is not a problem.

In addition, the clipping and trimming of the veneer should be done parallel and perpendicular to the grain rather than parallel and perpendicular to the axis of the veneer bolt. Trimming veneer parallel to grain will probably prove time consuming unless the clipper is equipped with a knife that can be shifted. Some waste of veneer will probably result from spirally grained bolts but where avoidance of twisting is important, the amount of waste should be more than compensated by the reduction of twisting.

Since adjacent pieces of sliced veneer would be very similar in grain formation, twisting could be avoided by using two adjacent pieces of sliced veneer for the two crossbands of one panel (laid, of course, with the grain parallel). By properly arranging and marking rotary cut veneer as it came from the lathe, the same principle could be applied to insure that adjacent sheets would be used for the two crossbands of a panel.

In some special products where very little twisting can be tolerated and where price may justify considerable care in manufacturing, the probability of twisting can be reduced still further by clipping crossband stock into narrow widths, reversing alternate strips end for end, and taping or edge gluing. This principle is often used in lumber core construction.

Where other considerations permit, it is also possible to reduce twisting by constructing a thick panel of many thin plies, each ply at right angles to the adjacent ply. If this method is to prove successful, the number of plies must be great enough that chance distribution would serve to average out the variations in grain direction.

While variation in grain direction is the major factor in the greater percentage of twisting problems, this form of warping may occasionally result from other causes, which are also associated with cupping. If a panel changes in moisture content to a marked degree at the ends while the center changes very little, the stresses developed may cause twisting. This condition could be detected, of course, by determination of the moisture content at the edges and at the center of the panel and much of the twisting would probably disappear when the panel was reconditioned to a uniform moisture content.

Twisting has also been observed when plywood panels were fastened rigidly to supporting members whose shrinkage characteristics differed from those of the plywood panel.

The presence of compression wood over a part of the veneer sheet used for crossbands or faces may also cause twisting, although the more common result of the use of veneer containing compression wood is a cupping of the panel.

Cupping

Ordinarily the exact cause of cupping of plywood panels or veneered tops is much more difficult to establish with certainty than the cause of twisting. When once established, however, cupping difficulties are often more easily eliminated in commercial operations than are the causes of twisting.

While twisting involves grain direction and, therefore, a consideration of the direction of the forces acting to restrain the core, it is sometimes helpful to think of cupping as resulting when the forces that restrain the core are of unequal magnitude on the two sides. If, for example, a crossband were glued to only one side of a core, the core would be greatly restrained on one side in its movements with moisture changes but not at all on the other side, and cupping would certainly result. Further, the direction of the cupping would depend on whether the core increased above or dried below the moisture content it had when the glue set.

It is not assumed that all the different causes or combinations of causes of cupped panels will be covered here, but a few of the more frequent ones will be listed and discussed briefly. The possible causes of cupping can be divided into two groups: those that are the result of defects within the panel itself; and those that are the result of mistakes in handling plywood that, in itself, was properly constructed.

A. Details of Construction That Will Cause Cupping

1. Thicker crossbands on one side than on the other. In this construction, when the core attempts to change dimension under changes in moisture content, the movement of the core will be restricted more strongly on the side with the thicker crossband than on the other side, and cupping will result. While this cause is comparatively rare in five-ply construction, it sometimes results apparently from a confusion of veneer thicknesses. It is much more common in three-ply construction when the face is sanded more than the back. It has been seen on panels that were originally made for three-ply, one face sanded more than the other and then a face and back of equal thickness laid to make a five-ply construction.

2. Cross-grained crossband on one side and a straight-grained crossband on the other. When the grain in a sheet of veneer dips abruptly through the sheet from one surface to the other, the veneer will have greater endwise shrinkage than a piece in which the grain is parallel to the plane of the sheet. If such a cross- or short-grained³ sheet is laid as one crossband and a straight-grained piece as the opposing crossband, the cross-grained piece will not offer the same resistance to the movement of the core as the straight-grained piece and cupping will result. In three-ply panels, the use of cross-grained or figured veneer for the face and of straight-grained veneer for the back will cause cupping. If figured veneer is required for the faces, it will probably be necessary either to use five-ply construction or to use reject figured veneer for the backs.

3. Partially rotten or doty crossband on one side and a sound crossband on the other. In this case the result is very similar to No. 2. When the core shrinks or swells under moisture changes, the doty crossband offers less resistance to the dimension change than the sound crossband.

³The term cross-grain has been used with two different meanings. In this paragraph the term implies that the grain dips abruptly through the sheet of veneer from one surface to the other, while in the discussion of twisting the term implies that the grain was parallel to the surface of the sheet, but not parallel to the edges.

4. Compression wood in one crossband and normal wood in the other. One of the characteristics of compression wood is a high degree of endwise shrinkage as compared to normal wood. If compression wood is laid as one crossband opposed by a crossband of normal wood, the compression wood band will shrink and swell much more with a given moisture change than the normal crossband, and distorting stresses will result. Furthermore, since dimension changes in the core are resisted to a much greater degree by the normal wood than by the compression wood, very marked cupping is favored. It is very possible for a crossband to be partly normal wood and partly compression wood. This would favor twisting rather than cupping. It is doubtful that compression wood can be used successfully in the commercial production of plywood, but it certainly cannot be used when veneer sheets of compression wood are mixed indiscriminately with veneer sheets of normal wood.

5. Species of widely different strength and shrinkage properties should not be used for the two crossbands of the same panel, at least not in the same thickness. Dissimilar combinations will produce cupping in thin three-ply panels but the effect is less noticeable when the core is thick. It is possible to use species of different densities providing the thickness is adjusted to conform with density. Computations are available showing methods of obtaining balanced panels when species of different densities are used. In ordinary commercial work, however, such combinations are seldom used since most manufacturers use the same thickness and the same species in crossbanding any one group of panels and cupping caused by dissimilar species is rare.

6. In thin three-ply panels it is possible to produce cupping by laying one face at a high moisture content and the other at a low moisture content. Ordinarily, the normal variations in moisture content of the veneers in commercial operations are not great enough to cause cupping. However, it would be extremely difficult to establish the reason for it by an examination of the finished panel. The practice of spreading two faces for the first panel in a bundle and withholding one to be laid on the last panel in the bundle may result in a considerable difference in the moisture content of the two faces of the last panel at the time the glue sets. When this procedure is followed, it is advisable to mark and observe the top panels from the bundles to make sure, as they pass through the factory, that no cupping results from the practice.

B. Some Errors in Handling That Cause Cupping of Well-Constructed Plywood

1. Drying more rapidly from one face than from the other. This case is best illustrated by the frequent cupping of the top panel of a pile of panels that has not been properly covered. So far as it is practical, plywood should be

handled so that the panels can absorb or give off moisture equally from both sides. When panels are piled solid, the top of the pile should be kept covered to prevent moisture loss through the top surface. If considerable changes in moisture content are expected, it is often desirable to protect the ends and edges of the panels from unusually rapid changes. As mentioned previously, unusual changes in moisture content at the ends may result in twisting that is not related to grain direction.

2. The use of a finish highly resistant to the movement of moisture on one side of the panel and not on the other. When a highly resistant finish is applied to one side of a panel and either no finish or one low in resistance to moisture movement is applied to the other, moisture will move in and out of one surface more rapidly than the other. In this case, cupping may result just as when panels are allowed to dry more rapidly from one surface than from the other.

3. Fastening the panels firmly to supporting members of different shrinkage characteristics. While plywood shrinks and swells much less than normal wood in either a tangential or radial direction, it shrinks and swells more than normal wood does in a longitudinal direction. A plywood panel fastened firmly to a longitudinal supporting member, therefore, will probably warp or pull loose from the fastenings under any considerable changes in moisture content. If the design requires a fastening between plywood and framing members, provision should be made to permit a slight movement of the plywood relative to the supporting member just as a solid table top is ordinarily fastened to the frame in such a way as to permit a slight swelling and shrinking of the top.

4. Use in installations where one side is exposed to air at a different relative humidity than the other. When exterior doors, for example, are of the hollow-core flush type, or when sandwich-type constructions are used for exterior walls, they may bow convexly outward during the heating season because the inside facings will then tend to reach a lower moisture content, and consequently shrink more, than the outside facings.

General

The major portion of this discussion has dealt with specific causes of either twisting or cupping but consideration should be given to those items that affect the general stability of the plywood or veneered construction.

A. Moisture Content. The moisture content of the different plies should be adjusted just prior to gluing so that the average moisture content when the glue sets is as nearly as possible equal to the average moisture content the stock may be expected to reach in service. As pointed out earlier, the stresses developed

vary with changes in moisture content from that prevailing when the glue set. The less the magnitude of these changes, the less the stresses and the less the warping tendency.

B. Density Numerous tests have shown that the warping of plywood panels, when subjected to varying moisture contents, is least for panels made of low-density species, such as basswood, poplar, and cedar, and generally increases with increasing density of the species used.

C. Ratio of Core to Total Plywood Thickness. A high percentage of core to total plywood thickness helps maintain a flat, unwarped surface. In general, the core should comprise 5/10ths to 7/10ths of the total thickness of the panel where flatness is an important consideration.

Summary

The following outline summarizes the different factors that may contribute to warping and is offered as an aid in determining the probable causes from an examination of warped plywood panels.

Twisting

- A. Grain direction
- B. End drying
- C. Method of fastening

Cupping

- A. Defects in construction
 1. Thicker crossbands on one side than on the other
 2. Cross-grained crossbands on one side and straight-grained on the other
 3. Doty crossband on one side and sound crossband on the other
 4. Compression wood in one crossband and normal wood in the other
 5. Species of widely different shrinkage characteristics
 6. Widely varying moisture contents at the time of gluing
- B. Improper handling
 1. Drying more rapidly from one side than the other
 2. Highly resistant finish on one side with a finish of lower resistance on the other
 3. Method of fastening

General

- A. Moisture content at the time of gluing
- B. Density of species
- C. Ratio of core thickness to total panel thickness