TECHNICAL BRIEF

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MOISTURE MANAGEMENT FOR THE CONTROL OF CHECKING AND WARPING IN HARDWOOD PLYWOOD PANELS

Introduction

All materials have properties that must be considered if the material, or the product made with the material, is to exhibit satisfactory field performance. Wood products are hygroscopic in nature: they will readily adsorb and desorb moisture in both exterior and protected, heated interior applications. As wood gains or loses moisture it will expand or contract. Thus, dimensional change in response to moisture is a factor to be considered in the use of wood.

Hardwood plywood and other wood products designed for interior use can change dimension as the material responds to changes in indoor relative humidity. Changes in humidity are reflected in changes in the equilibrium moisture content (EMC) of the wood product. For most wood products EMC changes little with daily swings in indoor humidity. Longer duration seasonal changes in indoor relative humidity are important, especially in temperate regions. In many areas of the Northern Hemisphere, such as North America and Europe, indoor relative humidity can drop to 30% or less in the winter with the lowest levels usually in January, and rise to 70% or more in the summer with the highest levels in July and August.

The Nature of Dimensional Change in Wood and Hardwood Plywood

Wood is anisotropic, having different properties in different directions. Thus, the tendency of wood to shrink and swell with changes in moisture content is different in the three dimensions. Solid wood has a relatively low coefficient of expansion/contraction in the *longitudinal* direction (along the grain), characteristically 0.1 to 0.2 % between oven dry and the fiber saturation point (the place above which dimensional change does not occur, at 27 to 30% moisture content for most species and as low or lower than 22% for certain species with high extractive content). In the *tangential* direction (across the grain such as in flat cut) the coefficient is typically 7 to 9%. In the *radial* direction (generally through the thickness of the wood), the coefficient is typically 4 to 5%. Depending on taper and other log related factors and the type of cut, the board or sheet of veneer may have a combination of directional expansion/contraction forces. For example, a flatcut board or plain sliced veneer sheet will exhibit primarily longitudinal forces along the length of the piece, but may also exhibit some radial forces.

Hardwood plywood is made using the cross-laminated construction principle. Components are glued together with the grain direction of each at about 90^o to the grain direction of the adjacent component. This tends to "equalize" the potential for dimensional change along the panel length and across the panel width. Typically the coefficient of expansion or contraction over the moisture content range of 0 to fiber saturation is about 0.45% along the grain (longitudinal) and about 0.67% across the grain (tangential) in plywood. By orienting the grain directions of successive layers at approximate right angles, the effect of hardwood plywood construction is to increase the longitudinal movement slightly, but significantly restrict the potential tangential movement to 1/20th or less that of solid wood. Even when hardwood plywood inner ply components are used that do not have a specific grain direction, such as particleboard and medium density fiberboard (MDF), there is still some equalization of the along the grain and across grain expansion/contraction coefficients as compared with solid wood. In thickness, there is little difference in shrinkage characteristics between hardwood plywood and solid wood. Since thickness is usually the smallest dimension in hardwood plywood, changes in this dimension are typically of little consequence in product service. Longitudinal shrinkage, being the smallest, is often ignored; however, it can be a factor in large expanses. A panel of moderate shrinkage characteristics, such as birch, theoretically could expand or contract over 2.5mm (1/10 inch) in the 2440mm (96 inch) dimension with a persistent change in EMC of 8%.

Moisture Conditions, a Key Factor in Product Dimensional Change

Factors related to the wood, the moisture content of the components, and to the glue spreading and hot pressing processes can all be important in subsequent dimensional change in wood products. Dimensional change can give rise to face checking and warping. Relative humidity drives gains and losses in wood moisture and the potential for changes of dimension in plywood components. This can lead to face checking and warping. Temperature is a factor that can also indirectly influence moisture related dimensional changes in wood. Temperature is relatively insignificant within the normal indoor comfort range of about 65 to 80^o F; outside temperature, however, can play an important role. The capacity for holding moisture is much lower at low temperatures which occur outside during the colder months of the year when the temperature is near freezing and below. When the inside and outside air are mixed through the use of mechanical heating systems and through leakage into the home or building, the incoming outside air with relatively low moisture is heated, substantially lowering the relative humidity of the indoor environment. Humidification can be important during the winter months in various geographical areas in order to prevent excessive drying of interior woodwork.

With respect to the secondary processor, distributor and final user of the wood article, moisture conditions may not always be ideal. Conditions in the dry Southwest are different than those in the humid Gulf states. Moisture conditions in the remainder of the U.S. are typically between these two extremes. Information developed by the Forest Products Laboratory of the U.S. Department of Agriculture in Table 1 lists the recommended EMCs of interior wood products in the three regions related to more typical conditions in those areas. Figure 1 further delineates actual areas in these three zones.

TABLE 1 RECOMMENDED MOISTURE CONTENT VALUES FOR VARIOUS WOOD ITEMS AT TIME OF INSTALLATION

USE OF WOOD PRODUCTS	MOISTURE CONTENT (PERCENTAGE OF WEIGHT OF OVENDRY WOOD) BY REGIONS AS SHOWN IN FIGURE 1					
	DRY SOUTHWESTERN STATES		DAMP SOUTHERN COASTAL STATES		REMAINDER OF THE UNITED STATES	
	Avg. %	INDIVIDUAL PIECE %	Avg. %	INDIVIDUAL PIECES %	Avg. %	INDIVIDUAL PIECES %
INTERIOR FINISH WOODWORK SOFTWOOD FLOORING	6	4 TO 9	11	8 TO 13	8	5 TO 10
HARDWOOD FLOORING	6	5 TO 8	10	9 TO 12	7	6 TO 9

NOTES:
1. In general, the moisture content averages have less significance than the range in moisture content of individual pieces. If the moisture content values of all the pieces in a lot fall within the prescribed range, the entire lot will be satisfactory as to moisture content, no matter what its average moisture content may be.

2. While the values above apply generally to lumber, the values would also be applicable to interior use veneer core hardwood plywood. For particleboard and MDF core hardwood plywood, the values may be slightly lower, particularly at the higher ranges.

Table 1 extracted from information appearing in Moisture Content of Wood in Use, Bulletin No 1655, as prepared by the Forest Products Laboratory of the U.S. Department of Agriculture.

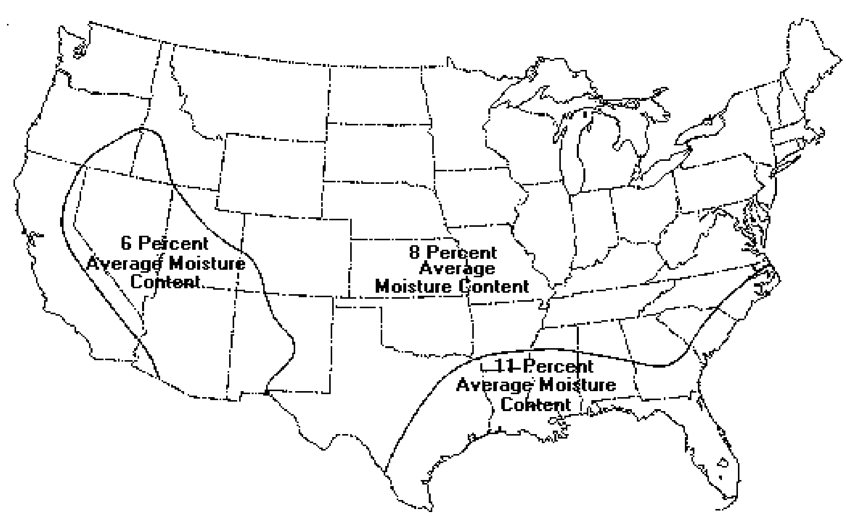

Figure 1
Recommended average moisture content for interior use of wood products in various areas of the United States.
Source: USDA Agriculture Handbook 72, 1987

Effects of Large Moisture Changes of Long Duration on Wood Products

Two effects can occur when decorative hardwood plywood panels are subjected to persistent and significant changes in relative humidity. These are warping and face checking.

Warping is a distortion of the intended shape of a panel and can take forms such as twisting or cupping. Warping is associated with plywood panels whose components on each side of the center ply or layer are not reasonably well balanced in thickness, moisture content, grain orientation, and dimensional change coefficients, or which have been exposed to extremes of low or high moisture.

Face checks are most prevalent as longitudinal openings along the grain on the surface of the panel. Wood is weakest in tension across the grain, thus when differential movement occurs, stresses are relieved across the grain in the thin face or back layer of the decorative plywood assembly. When the across the grain (tangential) movement is large in the face and back veneer, stress relief may be reflected in longitudinal checks that are visible to the naked eye.

Face checking can also be related to the use of surface finishes. These checks will appear on the finish, and are often associated with lathe or cutting checks in the face veneer or the cellular porosity of the wood, such as springwood (earlywood) in ring porous woods. In some cases where there is substantial finish build, the finish may not have sufficient elasticity to move with the underlying wood substrate.

Occasionally across grain face checking will occur, usually associated with compression wood, a characteristic sometimes seen in the growing tree. Typically when this occurs the cross checks are confined to relatively small areas on the surface of the panel.

While the determination of the precise cause or causes of checking is usually difficult, it is clear that the condition results because of the inability of one layer of the panel to effectively resist the stresses created when dimensional changes occur. Whatever can be associated with checking, the greater the moisture change in the plywood the more chance that checks will occur, and the more severe they will be if they do occur. Consider a well made flat panel that is used as a component in an article placed in an exceedingly dry indoor environment. Components in this panel or article are at approximately 8 to 9% EMC. The conditions in a dry environment are 70^{o} F and 15% RH which generally persist several months. In response, various components in the panel or article shrink as the theoretical EMC for that condition (less than 4% EMC) is approached. The face veneer may not be able to adequately resist the stresses caused by the persistently low indoor moisture level, and longitudinal checks may appear on the surface to relieve the stress.

Enhancing the Performance of Hardwood Plywood and Veneer by Minimizing the Effects of Moisture

Matching Panel Construction to the Application

Different hardwood plywood constructions are made to satisfy a number of end use applications: veneer core is recognized for its tendency for low linear expansion, relatively light weight and high screw holding power. Particleboard core has a tendency to lay flat in large widths and lengths and is the choice in certain applications because it is a cost effective solution. Because of the homogeneous appearance of the wood fibers used in manufacturing medium density fiberboard (MDF), hardwood plywood with an MDF core is preferred in circumstances where the furniture or cabinet component will be routed or otherwise machined.

Everything else being equal, 5-ply construction is better at equalizing with across grain stresses than 3-ply in 9.5 mm (3/8 inch) veneer core panels and in 12.7mm (1/2 inch) and thicker board core (particleboard and MDF) constructions. In general the greater the number of plies the greater the panel stability in veneer core constructions. Veneer core products in the most common 19 mm (3/4 inch) thickness are generally 7 or 9 ply. In board core panels, a high ratio of core (5/10ths to 7/10ths of the total panel thickness) helps to assure flatness.

Controlling the Service Environment

Persistent seasonal wide swings in relative humidity need to be controlled. Moisture content of components for hardwood plywood or for use in making furniture, cabinets, and similar items should be at levels that will result in a product with a moisture content at the EMC that is expected in the service environment. This will minimize changes in dimension and thus reduce the chance of problems in the field. Thin veneer can change EMC very quickly when the material is moved from the more normal mid-range environment (40 to 50% RH) to a very dry or very moist environment. Changes in daily relative humidity in indoor home living environments are typically of brief duration and affect dimensional change in wood very little. More important are the longer duration indoor RH levels related to the seasons in temperate regions, generally assumed to range from about 30% or less in the cold winter months to about 70% or more in the hot humid summer months. These longer duration periods suggest a theoretical change in EMC of wood from about 5 to 7% in the winter to about 10 to 12% in the summer for most areas of the U.S. Figure 2 shows the relationship between relative humidity levels and EMC at 70^{o}F.

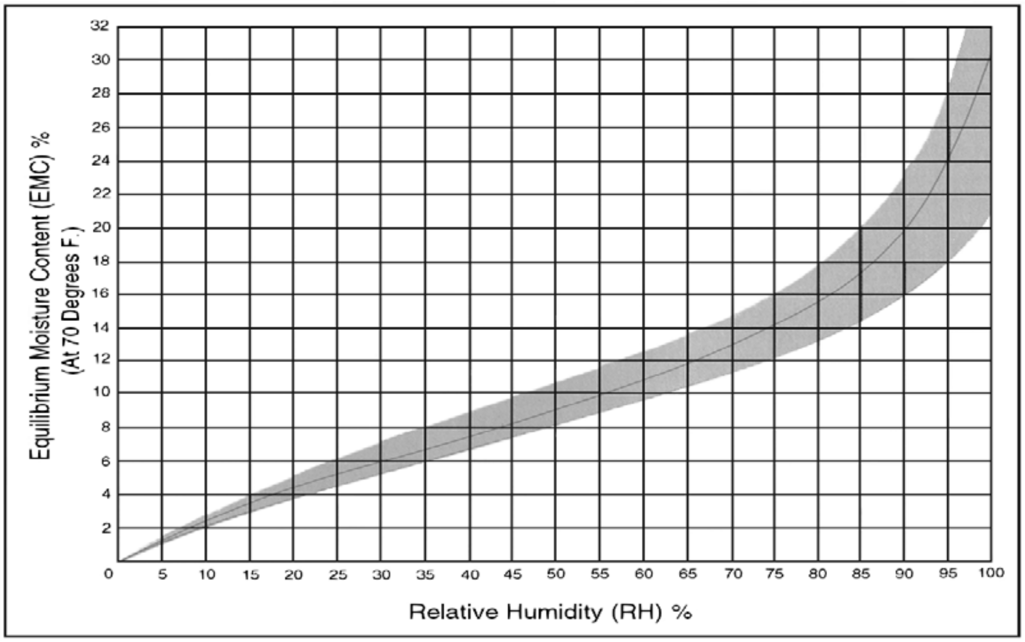

Figure 2 The solid line represents the curve for white spruce, a typical species with fiber saturation point (FSP) around 30% equilibrium moisture content (EMC). For species with a high extractive content, such as mahogany, FSP is around 24%, and for those with low extractive content, such as birch, FSP may be as high as 35%. Although a precise curve cannot be drawn for each species, most will fall within the color band.

Wood products are decoratively and protectively finished with lacquers, oil or synthetic finish systems. Most finishes will reduce the rate that moisture is either adsorbed or desorbed by wood products. Finishes that create a discernible film or "build" on the surface are usually more effective vapor retarders than in-the-wood oil type treatments. Finishes can also be a factor related to warp. For example if a highly impermeable finish is applied to the decorative and exposed side of the component and the back or unexposed side is left unfinished, the rate of moisture movement will be different and in some cases, the component will warp if not adequately restrained.

The key is to make sure that seasonal interior relative humidity conditions are not allowed to become too high or too low. Most modern indoor mechanical climate systems will remove some moisture when air conditioning is activated. Many buildings have humidification equipment that can be used during the colder months to increase indoor relative humidity levels. Indoor conditions and applications should be avoided that would cause shrinkage to occur on one side of the wood product and expansion on the other, or that would cause differential shrinkage or swelling on opposite sides of the panel.

Other Considerations

Mechanical restraint is important for some products. Some wood components are only partially restrained in application. For example wood cabinet doors are restrained on only one edge when they are fastened to the door framing. The thickness, species and grain orientation of components must be considered when selecting hardwood plywood for these applications. Moreover, the door may be exposed to slightly different conditions on one side than the other when the door is in the characteristic closed condition. In some cases a small door cut from a larger panel will become warped because the particular area of the panel from which the door was cut had face grain orientation at an angle to the back veneer, whereas the grain direction of the entire panel was relatively straight and parallel to the edge of the panel. In other circumstances, fastening a panel to a supporting member with significantly different shrinkage characteristics may contribute to panel warping.

Conclusions

Wood is a natural material that will change dimension with persistent changes in moisture content. The change in the across the grain (tangential) direction is the greatest and more often related to problems when they occur. Changes in wood product moisture content are primarily due to changes in relative humidity in environments to which these products or components of products are exposed, either in the factory or end-use setting. Long duration changes in relative humidity will be reflected in the change of a wood based product's equilibrium moisture content (EMC). When the EMC changes, one or both conditions can occur: checking or warping.

Cross-laminated components in hardwood plywood equalize the longitudinal (with the grain) and the tangential (across the grain) movement providing for relatively small dimensional changes. This permits the use of wide panels. While ideal balance is rarely achieved in actual practice, reasonable balance should be maintained. This is particularly true in certain applications where components of the product are only partially restrained. Care must be exercised by making sure that face and back veneers are tightly cut, grain direction deviations are kept to a minimum, and the moisture contents of the components result in a product that will be near that expected in use.

Whatever the multitude of factors that may be associated with or contribute to warping or checking, it is the process of adsorption or desorption of moisture that ultimately causes these defects to develop. In the factory, relatively short duration low or high humidity exposures can be important in processing thin veneers. In end-use settings, it is usually long duration seasonal low or high humidity conditions that are most important. In both settings, it may be necessary to remove moisture from the air during hot humid seasons and use humidification during dry seasons.

By giving attention to various factors and understanding the nature of wood, manufacturers of hardwood plywood and veneer, woodworking plants, and end-users can enhance the use of hardwood veneered panel products, and articles made with veneered panel components.

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This Technical Brief is published by HPVA as a service to those who manufacture, distribute and use hardwood plywood. HPVA is an international trade association representing manufacturers of hardwood plywood and veneer, laminated wood flooring, hardwood plywood prefinishers, distributors and suppliers to the industry. The Association offers numerous services including; industry representation and problem solving, education, market promotion and development of industry voluntary standards. HPVA also provides extensive technical and testing services to both member and non-member clients.

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