The Potential for Glycol Treatments to Counteract Warpage in Wooden Objects

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The potential for chemically bulking the concave surfaces of warped wooden objects is explored. Low molecular weight polyethylene glycol and dipropylene glycol are found to be particularly effective under mild treatment conditions. Concerns such as hygroscopicity, discoloration, dimensional stability, and permanence are addressed.

The difficulty of treating warped wooden objects has led many conservators to devote hours cultivating in their clients and curators a love and appreciation for the moral and aesthetic virtue of nicely warped wood.

It is certainly true that, in most instances, the best approach to take with a warped object is one of tolerance. Occasionally, however, one must treat objects which defy this conservative rationale. Sometimes the extent of warpage is so great that the appearance of an object is severely affected. Even worse, warpage may impede the function of an object, or may contribute to stresses which may ultimately cause further deterioration. In these instances, it may be the obligation of the conservator to devise some form of treatment.

There has been considerable success in treating warpage by inducing compression shrinkage in the convex side of an affected board. (This process was described by Wallace Gusler at the 1986 Annual Meeting of AIC/WAG in Chicago). Basically, the original warp is reversed by the application of moisture to the concave surface and heat to the other side. The board is then restrained nearly flat in cauls for a period of time, during which moisture is frequently applied to the formerly convex surface. This induces compression shrinkage equal and opposite to that on the formerly concave side - resulting in a flat board.

Though generally successful, this method usually necessitates the sacrifice of the surface finish, and is not advisable on objects retaining early transparent or painted finishes, or those which are veneered on one side.

Such objects are analogous to warped panel paintings, the: subject of considerable pioneering research some years ago by Richard Buck and colleagues. Buck, unlike many of his predecessors, did not view a warped wooden panel as an expendable commodity thus rejecting the drastic panel thinning,[1] sawkerf[2] or transfer methods used by many. Buck was one of the first conservators to develop a working understanding of the rheology of wood, and as a result he even began to question relatively conservative cradling techniques for warped panels, believing them to promote dangerous stresses which could result in irreversible damage.

Panel paintings tend to experience compression shrinkage on their reverse sides; hence, the convex warpage on their faces. Unlike Gusler's treatment, the fragile surface here precludes the induction of opposing compression shrinkage as a treatment. Buck did use similar principles of restraint and moisture retention, however, concentrating his efforts on the treatable concave side. He found that, if moisture levels in a temporarily flattened, restrained panel were kept sufficiently high over a period of time, the wood gradually underwent plastic deformation, relieving the warp and resulting in a stress free flat panel.

Buck's published treatments, though theoretically of interest, are problematic for furniture conservators. He made use of a variety of backings on panel paintings, which were designed to seal in moisture during treatment, serve as moisture barriers following treatment, and to provide gentle support. While acceptable on two dimensional objects, such supports are generally impractical on furniture. And if barriers are not employed as described in Buck's treatments, there is every reason to believe that a straightened warp would eventually return upon exposure to humidity cycles.

It is the purpose of this paper to explore another possibility for the treatment of warpage, particularly in objects where the face exists as a convex untreatable moisture barrier or restraint (paint, gesso, glue, veneer et cetera). In such cases the face has relative dimensional stability, the reverse has not. This sets up the situation for compression shrinkage. It seems only logical that a chemical treatment to simultaneously swell and stabilize the concave side of a warped panel could produce long lasting desirable results. This would involve neither inducing an opposing compression shrinkage, nor releasing an existing one, but would create a wood/chemical composite on the formerly shrunken surface which would approximate the dimensional stability of the face.

Chemical bulking of wood has long been the object of research by wood chemists searching for ways to improve various properties of wood - and one of the most sought-after goals is the achievement of dimensional stability. A wide variety of stabilizing treatments are discussed in the literature. Some are available commercially (Kopper's Impreg - water-borne phenol-formaldehyde resin)[3] while others remain subjects of research (acetylation)[4]. Most stabilizing treatments can be automatically rejected for use in conservation, by virtue of their toxicity, heat and pressure requirements, or negative physical and visual effects upon the wood surface. Others show promise, but are not within the scope of this paper (acetone-rosin).[5]

Polyethylene Glycol (PEG)[6] represented an obvious first choice for experimentation in warp reduction for a number of reasons. It is non-toxic (incorporated in food and cosmetics), water-soluble, can be used at room temperature; and importantly, it is inexpensive. It has been heavily researched for its commercial applications as a stabilizer for green wood, and after at least thirty years of use, it has remained the most widely employed consolidant by conservators of archaeological wood. The only draw-back to the choice was that nowhere was it recommended for use on sound, seasoned wood.

There are, however, a number of manufacturers who market products that are purported to have intriguing wood swelling properties. "Chair-loc"[7], "Bondex Wood Swell and Lock"[8], and Behlen's "Swell-lock"[9] are all sold as replacements for "messy adhesives" in retightening chair rungs, fastening loose tool handles and any other job requiring fastening two wooden members. Upon simple experimentation with "Bondex Wood Swell and Lock", it became obvious that, as the manufacturer claims in boldface, **"IT ACTUALLY SWELLS WOOD!"** The working properties seemed very similar to PEG and, though a Bondex technical representative declined to reveal the exact nature of his product, it seemed likely that the active bulking ingredient was a low molecular weight PEG.

Further experimentation with the Bondex product and a range of polyethylene glycols yielded the Bondex as the most effective treatment. That and the presence of other dissimilar properties led to the discovery that the principle ingredient of this product, other than water, was not PEG but dipropylene glycol.[10] This was found to be true of the Behlen's product as well, though the "Chair-loc" representative claimed other ingredients for his product, including rosin and propylene glycol.

Chemically, dipropylene glycol, $(CH_3CHOHCH_2)_2O$, and PEG, $HO\text{-}(CH_2CH_20)_n\text{-}H$, are very similar, both containing ether linkages and two hydroxyl groups. One of the chief differences is in molecular weight. Dipropylene glycol, a dimer, has a m.w. of 134.18, while PEG, a polymer, can have a m.w. ranging from fairly low to over 20,000. Molecular weight, as will be seen, plays a very important role in the effectiveness of glycol treatment on seasoned wood.

The theory of glycol stabilization of wood is simple. A glycol/water solution is introduced to wood (preferably wet wood). The non-volatile glycol has an affinity for the cellulose-rich secondary cell walls of the wood, (h-bonding probably occurs between hydroxyl groups) and as the water evaporates the glycol remains to bulk the cell walls, maintaining them in a swollen state at or near the fiber saturation point. It is important to note that the effectiveness of treatment is directly dependent on the amount of cell wall bulking - if the glycol only fills cell voids, shrinkage will recur, and there will be no improvement in dimensional stability.

There are several problems encountered in attempts to effectively treat one surface of a seasoned wood object with glycols. First, penetration must occur laterally rather than longitudinally. End-grain penetration can be up to 200 times more effective, but it cannot be used to advantage in this process. Lateral penetration is made even more difficult in dry seasoned woods for the following reasons: The lateral transmission of fluids in green wood is accomplished by valve-like bordered pits located mainly on the walls of tracheids. These pits control the flow of sap from one cell to another, but become shut off (aspirated) when wood is dried, leaving only much finer capillary action to transport liquids. In addition, the presence of air within dried wood greatly reduces fluid penetration.

The problems of impregnating dry wood are by no means easily surmounted, but certain steps were taken in the following experiments to minimize difficulties:

- For the purpose of increasing penetration, experiments were conducted with PEG of low molecular weights (300, 400, 600, 1000) as well as the even lower dipropylene glycol (m.w. 134.18).

- Most experiments were conducted after warps had already been reversed by swelling with water. In this way the glycol solution could diffuse into the swollen water/wood structure more readily than it could penetrate dry wood.

- Some experiments were conducted with moderate levels of heat, known to have a positive effect on the penetration of glycol into wood.

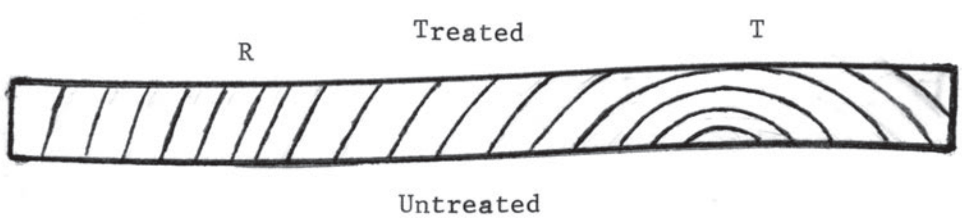
- Three means of impregnation were tested to determine their relative merits: Concave face down in a warmed tray of solution, concave side up using paraffin wax and modelling clay dams to retain the solution, and simple brush coats of solution. In all tests, end and side grain were coated to prevent absorption.

Because of the limited number of samples employed and the variety of woods tested, results can only be viewed in qualitative terms. In most instances, the intention was not to produce flat samples, but rather to determine how much the deflection of a given sample would change following treatment under a predetermined set of conditions. All tests were carried out at 70°F room temperature, 55% R. H.

Experiment One: Mahogany Strips - Comparative Effectiveness of Glycols
Shallow (1/4" deep) plexiglas trays were constructed to closely conform to warped mahogany samples resawn from a casehardened board, 3" long x 14-3/4" across the grain x 7/16" thick. Trays were placed over a constant heat source of 100°F. Concave surfaces were soaked in water for approximately three hours, producing considerable reverse warpage. Water was then replaced by a 25% glycol solution of a different molecular weight for each sample. Additional solution was added the second and third days, and water was added the fourth day to replace evaporation. At the end of the fifth day samples were removed, cleansed of excess solution, dried two weeks, and warps were measured.

Results (See Table 1): A consistent relationship between glycol molecular weight and effectiveness of treatment was established. Initial warps were 4.0-4.5 mm. PEG 1000, with a treated warp of 3.5mm, was only marginally effective, while PEG 300 reduced warpage to 1.0 mm and dipropylene glycol produced a reverse warp of 1.0 mm. Interestingly, the sample treated with water suffered increased compression shrinkage and warpage increased to 7.0 mm. Color of treated surfaces ranged from a leached appearance (dipropylene glycol) to very dark (PEG 1000).

Note: Several samples display a slight S-curve when viewed on end. This is likely to be related to variations between the tangential and radial nature of the samples as below:



The nearly tangential surface T swelled considerably more than the radial surface R.

Experiment 2: Tangential vs. Radial Swelling
To examine the differences between tangential and radial swelling, 2 mm. thick flat samples were cut from mahogany and tulip poplar, and sides and ends were sealed with paraffin. Samples were divided into four groups, each containing a tangential and radial sample of each species, and each group was brushed with solution until its surface appeared saturated. Warps were measured when samples were fully wet, and again after drying for ten days.

Table 1: The Effect of Low Molecular Weight Glycols on Warped Mahogany

Mahogany dimensions: 14 3:/4" across the grain, 3" longitudinally, 7/16" thick

Conditions of Treatment: Duration - five days
Method - concave face down
Temp. of Solution - 100˚F

Sample	**Treatment Solution**	**Initial Deflection Warp (mm)**	**Deflection After Treatment (mm)**
1	25-40% Dipropylene Glycol	4.0	-1.0 (reversed)
2	25-40% PEG 300	4.5	1.0
3	25-40% PEG 400	4.2	2.0
4	25-40% PEG 600	4.5	3.0
5	25-40% PEG 1000	4.5	3.5
6	Water	4.0	7.0

Results (See Table 2) - In all cases tangential samples were considerably more responsive to bulking, and tulip poplar more affected than mahogany. As above, the greater the molecular weight of the solution, the less effective the treatment. Note also the differences between deflections when saturated with solution versus the deflection after drying for ten days. Figures suggest that dipropylene glycol has a much greater antishrink efficiency than PEG under these conditions. (The tulip poplar samples treated with DPG showed no change in warpage after drying.) In addition all samples except for those treated with dipropylene glycol feel slightly damp. These differences may be accounted for by the more complete association of DPG with the cell walls, leaving little residual glycol.

Experiment Three: Ponderosa Pine - Brush Coat Test
Six samples of ponderosa Pine were coated on side and end grain with resorcinol resin adhesive, and placed concave side down in water until their original warps were reversed. They were then saturated by brush coating with varying m.w. glycol solutions. All but the one treated with water maintained fairly extreme reverse warps.

Results: Consistent with previous experiments, but the less dense ponderosa pine is far more responsive to treatment than other woods. The control sample treated with water experienced further compression set and an increase of its original warpage. Examination of the end grain of several samples shows stress cracks in the resorcinol resin, similar in appearance to casehardened (honeycombed) lumber, thus suggesting that in extreme cases treatment with glycols can result in tension failure below the swollen surface.

Experiment Four: Yellow Pine and Black Walnut: Concave Face Up
Four warped black walnut samples 5 ½" across the grain x 2 3/4" long x 11/32" thick and four warped yellow pine samples 12 1/8" across the grain x 2 15/16" long x 15/16" thick were coated sides and end grain with paraffin. Clay and/or paraffin dams were constructed around the perimeter of their concave

Table 2: Comparative Swelling of Flat Mahogany and Tulip Poplar Samples in Both Tangential and Radial Sections

Sample dimensions: Mahogany: 45mm across grain x 30mm long x 2 mm thick
Tulip Poplar: 40 mm across grain x 40 mm long x 2 mm thick

Conditions of Treatment: Method - Four brush coats applied in one day
Duration - Dried for ten days
Temperature - 70°F

	25% DPG		**25% PEG 300**		**25% REG 600**		**H2O**	
	wet[1]	**dry[2]**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**
Tulip Poplar, Tangential	4.75	4.75	2.5	2.0	2.5	1.0	4.0	-.5
Tulip Poplar, Radial	2.0	2.0	1.6	.75	1.6	.5	1.75	-.5
Mahogany, Tangential	1.5	.5	1.0	.1*	1.0	.05*	1.5	0
Mahogany, Radial	.8	.25*	.8	.2*	1.0	.05*	.75	0

[1]Wet = measurement in millimeters of maximum warp when saturated

[2]Dry = measurement in millimeters of warpage after drying for ten days

*Estimated - very slight deflection

faces. They were treated with PEG or DPG solutions at room temperature without presoaking in water, concave face up.

Results: Black walnut samples display very little change in warpage after treatment. Yellow pine samples did experience considerable correction of warpage (1.5 mm for a DPG-treated sample which had an initial deflection of 3.5 mm), but results point to the importance of presoaking for maximum effectiveness of treatment.

Experiment Five: Mahogany: Concave Face Up

A single mahogany strip from the same board used in Experiment 1 was treated by presoaking, with its concave face down in warm water to induce reverse warpage, followed by surface drying and the construction of a paraffin dam around its perimeter. It was then treated with its formerly concave face up at room temperature with a 25% dipropylene glycol solution for ten days, replenished at intervals to compensate for water evaporation.

Results: After drying, the sample maintained a 1.0 mm reverse warp, with only a slight S-curve such as described in Exp. 1. Color of the treated surface was acceptable.

Experiment Six: Bleaching and Finishing

Surfaces of dark woods (walnut and mahogany) display considerable darkening upon treatment with PEG, and extractives appear to be leached by dipropylene glycol (Black walnut resembles lighter European walnut after treatment). These effects are much more pronounced on samples treated with the heat. Light colored woods show very little color change. Oxalic acid treatment (2 teaspoons/1/2 cup water) was only moderately successful at lightening the darkened woods.

For finishing, the literature recommends cleaning surfaces with toluene, then coating with moisture-cure polyurethane, epoxy, or “Danish” oil-type finishes. In experiments with coatings more acceptable for conservation, shellac did not dry properly when applied to a glycol-treated surface, although coatings of Acryloid B-67 and B-72 appeared to adhere and dry with no ill effects.

Conclusions

Lower molecular weight PEG and dipropylene glycol treatments offer the potential for counteracting warpage in seasoned wood. They may be effective under very mild treatment conditions (room temperature, ambient pressure) though leaching of color is likely to occur. The success of treatment is dependent upon the depth of penetration as well as the amount of permeation into the cell walls. Depth of penetration can be increased by presoaking the surface to be treated in water, and cell permeation is encouraged by the use of lower molecular weight glycols.

Glycols cannot be recommended for treatment until several important questions have been answered. Permanence is one major concern. Thus far, samples have remained stable in an uncoated condition for over SIX months. They seem to be subject to neither appreciable evaporation (according to the MSDS for dipropylene glycol, evaporation is nil) nor diffusion throughout the wood structure.

Dimensional stability is also a matter for study. The closer a wood is swollen to its fiber saturation point, the more stable it becomes. But it is likely that in order to reach F.S.P., some warps may be swollen to the point of extreme reversal. Settling for penetration below the F.S.P. will necessarily result in less dimensional stability.

Methods for controlling the swelling must also be determined. To do this a study of the antishrink efficiencies of various concentrations of glycol should be undertaken. Of particular concern is the uneven swelling caused by the variations in tangential or radial character of the wood being treated, as discovered in Experiment 1. It is likely that physical restraint during drying (battens or cauls) may contribute to the success of the treatment.

The well-known hygroscopicity of glycols is another area of some concern. Generally, the lower the molecular weight of a glycol, the more moisture it attracts. For this reason, conservators of waterlogged archaeological wood initially avoided low m.w. PEG. In a study published in 1981,[11] however, David Grattan found that the hygroscopicity of wood treated with 25% PEG 400 was actually less than that of either wood or PEG 400 in their pure states, at R.H. levels of below 60%. Above 80% R.H., the hygroscopicity of the wood/PEG 400 composite increased dramatically. This suggests that, for treated objects stored or exhibited in a humidity-controlled environment, moisture attraction and associated problems may not represent any difficulties.

As for the potential for treatments using dipropylene glycol or low molecular weight PEG, a number of possibilities exist. Not only could glycols be used for single-sided treatments on objects with veneered, painted, or finished surfaces, but they may become a useful component of treatments employing induced compression set. In such treatments, the flattening of a warped board often causes tension in the concave face, and the impregnation of glycols at low concentrations may help to relieve such tension, reducing the likelihood of cracks. In addition, glycols may be used for localized swelling of deformed, twisted boards which may contain troublesome knots on reaction wood. While much remains to be learned, the prospect that low molecular weight glycols may become a useful aid to the practice of furniture conservation appears bright.

FOOTNOTES

[1]L. Tinton and A. Rothe, “Observations on the Straightening and Cradling of Warped Panel Paintings”, Conservation of Wood in Painting and the Decorative Arts. N.S. Brommelle, ed., London: International Institute for Conservation, 1978, p.179-80.

[2]S.N. Hlopoff, “On the Straightening of a Warped Mahogany Veneered Panel”, Ibid., p.33-36.

[3]Koppers Corporation, Pittsburgh, Pennsylvania.

[4]Roger M. Rowell, “Penetration and Reactivity of Cell Wall Components”, The Chemistry of Solid Wood. Washington, D.C.: American Chemical Society, 1984,p.175-209.

[5]T. Bryce and H. McKerrel, “The Acetone-Rosin Method for the Conservation of Waterlogged Wood”, Problems in the Conservation of Waterlogged Wood. W.A. Oddy, ed., Greenwich: National Maritime Museum, 1975, p. 35-43.

[6]Union Carbide Corp., Ind. Chemicals Division, 39 Old Ridgebury Rd., Danbury, Conn. 06817

[7]Chair-Loc Co., P.O. Box 45, Lakehurst, NJ 08733

[8]Bondex International, Inc., 3616 Scarlet Oak Blvd., St. Louis, Mo. 63122

[9]Mohawk Finishing Products, Inc., Amsterdam, NY 12010

[10]J.T. Baker, Inc., 222 Red School Lane, Philipsburg, NJ 08865

[11]David W. Grattan, "A Practical Comparative Study of Treatments for Waterlogged Wood. Part II. The Effect of Humidity on Treated Wood", Proceedings of the ICOM Waterloqged Wood Working Group Conference. Ottawa: Canadian Conservation Institute, 1981, p.243-251.

BIBLIOGRAPHY

Brommelle, N.S., Anne Moncrieff and Perry Smith, Conservation of Wood in Painting and The Decorative Arts. London: International Institute for Conservation, 1978.

Buck, Richard D., The Behavior of Wood and the Treatment of Panel Paintings. Minneapolis: The Upper Midwest Corporation Association, 1975.

Grattan, D.W., "A Practical Comparative Study of Several Treatments for Waterlogged Wood", Studies in Conservation, Vol. 27, 1982, p.124-136.

Grattan, D.W., ed., Proceedings of the ICOM Waterlogged Wood Working Group Conference. Ottawa: Canadian Conservation Institute, 1981.

Hoadley, R. Bruce, Understanding Wood. Newtown, Conn.: Taunton Press, 1984.

Hoffman, Per, "On the Stabilization of Waterlogged Oakwood with PEG," Studies in Conservation, Vol. 31, 1986, p.103-113.

Jane, F.W., The Structure of Wood. London: Adam and Charles Black, 1970.

Meylan, B.A. and B.G. Butterfield, Three-dimensional Structure of Wood. Syracuse: Syracuse University Press, 1972.

Oddy, W.A., Problems in the Conservation of Waterlogged Wood. Greenwich: Maritime Monographs and Reports, No. 16, 1975.

Rowell, Roger M. "Penetration and Reactivity of Cell Wall Components". The Chemistry of Solid Wood. Washington, D.C. American Chemical Society, 1984.

Spielman, Patrick, Working Green Wood with PEG. New York: Sterling Publishing Co., 1985.

Waterlogged Wood - Study and Conservation. Grenoble: CETBGE-CENG ORIS, 1984.

Wise, Louis E., Wood Chemistry. New York: Reinhold Publishing Corp., 1944.