Figure 1. Spheroid, 1988, Figured Tulipwood, The Museum of Fine Arts, Houston, 89.106.

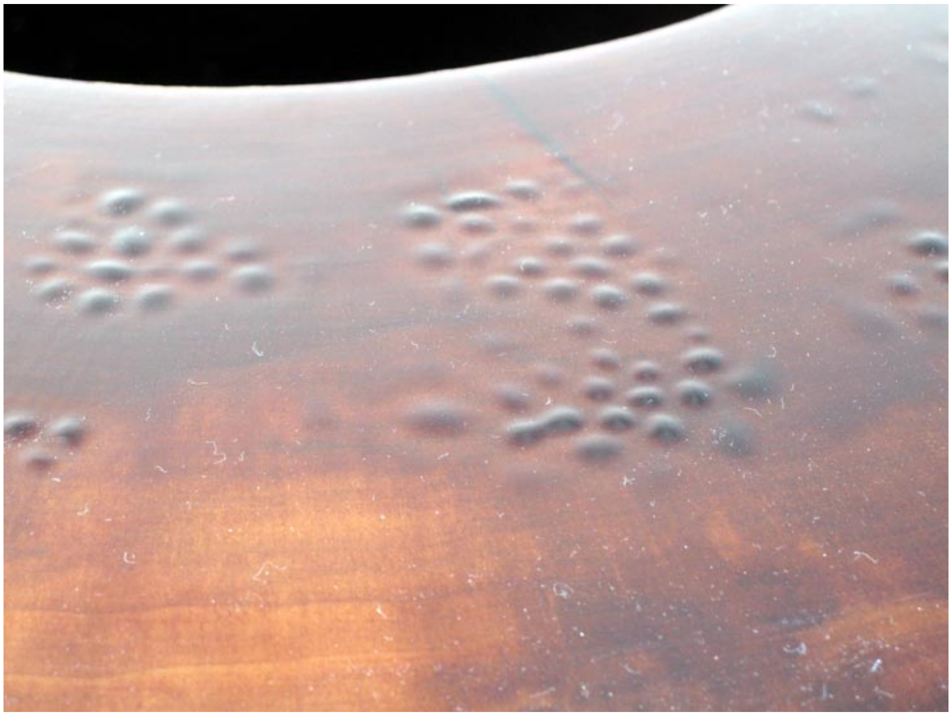

Figure 2. Blisters developed in the epoxy finish 14 years after the bowl entered the collection.

Adhesion Problems and Degradation of Epoxy Finishes on Peg Treated Wood

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ABSTRACT

In the 1950s Ed Moulthrop pioneered the green wood turning of native hardwoods into thin walled bowls as large as 36 inches in diameter. His innovative work was responsible for a generation of adventurous turning in the American craft community. His work is represented in most surveys and public collections of twentieth century decorative arts. Unfortunately, his use of diverse commercial materials produced for other applications has caused some of his work to be inherently unstable. This paper examines the materials and dynamics that resulted in the finish degradation of a Moulthrop bowl in the collections of the Museum of Fine Arts Houston (fig. 1).

Introduction

The general problems encountered with this bowl are not new to wooden artifacts conservation. The specific dynamics involved, however, are unique to the work of Moulthrop and those turners that have modeled their work on his. The artist kept few records and was known to be modifying his materials and technique throughout his career.[1] Those materials used were themselves prone to modification over time due to inherent vice and through interaction with each other.

In an effort to find a more proactive means to care for other works by this artist, this project attempted to collect data regarding Ed Moulthrop's working methods by interviewing his son Phillip Moulthrop and from published contemporary interviews with the artist.[2 3] Philip Moulthrop learned turning from his father and continues to turn along with his son Matt using primarily the same methods.[4]

In early January, 2005 a large turned wood bowl by Ed Moulthrop was being deinstalled from the Millennium Gallery in the Beck Building at the Museum of Fine Arts, Houston. The bowl had been placed on exhibit in November as part of a small exhibition of the museum's permanent collection of Modern and Contemporary Decorative Arts. The bowl was found to have developed blisters in the finish while on exhibit (fig. 2). On installation three months earlier the bowl was observed to be free of major surface blemishes but had developed several small patches of crazing and separating finish along the shoulder of the bowl (fig. 3).

The bowl was acquired in 1989 from a gallery in Scottsdale Arizona, the same year the bowl was made. An inscription on the bottom of the foot reads, "Ed Moulthrop/Figured Tulipwood/Liridendron Tulipifera/ 109891." The number represented the finish date in code that stands for 01/19/89 (10=01, 98=1989, and 91=19) with the numbers in reverse order and the year in the middle (fig. 4).

Materials

Lireodendron tulipifera (tulip poplar, yellow poplar, tulip wood) is known to be among the more stable hardwoods, easy to cut, and dimensionally less prone to shrinkage, with a specific gravity of 0.42. This is a diffuse porous wood common to nearly the entire east coast of the US. The sap wood is cream colored or grayish white. The heartwood is commonly greenish brown but can be shaded with purple, blue, black or yellow or with streaks of various colors.

Moulthrop was known to encourage spalting and blue stain in order to enhance the visual contrast between sapwood and heartwood. The discoloration may appear as pie-shaped wedges, spots or streaks. It is the result of a fungal infection of the sapwood which uses the simple sugars and starches as food. Spalting is a coloration associated with white rot fungus stains at the boundary between competing species of fungi and is seen as colored lines. The white rot causes more loss of mass in the wood elements than does blue stain.[5] One illuminating note on spalting is found in a US Forest Products Lab Techline publication (MO-1, Issued 03/04) with this entry:

> Rob makes a "spalting sauce" by mixing a can of beer, 1 ½ tablespoons of ammonia, 1 cup of a nitrogen-rich fertilizer (mixed double strength), and oak leaves mixed with grass clippings. He chops the ingredients in a food processor to create a paste like mixture, then covers the surface of a rough-turned vessel with the mixture. He places the turning in a plastic bag, and leaves the bag in a warm place for several weeks. When he is satisfied with the spalting, he finishes turning the vessel.

PEG 1000 is solid at room temperature with a melting point of between 100–104 degrees F, white, waxy in texture, and soluble in both water and isopropanol. Exploration of its use as a consolidant for wood began in the 1950s.

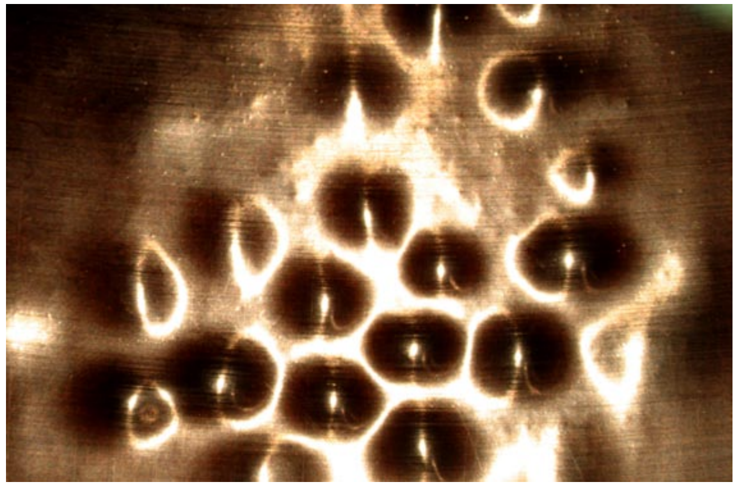

Figure 3. Blisters were specific to end grain on top facing surfaces and associated with fungus rich zones.

Figure 4. Moulthrop's signature, stamp and labeling.

Epoxy is formed from the mixing of intermediate resin and curing agent in an exothermic reaction. During curing, cross-linking results typically in a glassy resin with a high glass transition temperature (Tg) where the material transforms from a hard glassy state to a more fluid and flexible plastic state.[6] For clear films, the US Forest Products Labs has determined that it is one of the materials resistant to diffusion of water vapor.[7] Low temperatures can slow its curing. Excessive moisture during curing can cause the resin to include the water in its matrix as a plasticizer.[8] Epoxies can yellow and chalk on exposure to UV energy.[9] Although epoxies harden in minutes or hours, performance is dependent on several factors. Unknown factors of concern to us include the precision of the resin-to-catalyst ratio, temperature and humidity during cure, and moisture content of the bowl at time of application.

Working Methods and Materials

Ed Moulthrop was an architect working in the Atlanta area for 30 years before turning his interest in wood turning into his vocation and primary means of support. He is recognized as a pioneer in large scale wood turning in America. Moulthrop's eagerness to work on a large scale resulted in his working green wood. According to his son Philip, Ed began experimenting with PEG in the late 1950s or early 1960s.[10] By 1959, in Sweden, the project to raise Vasa was under way, while in Denmark, Christensen had begun to develop methods for treating the Viking ships. Both projects had the effect of giving great impetus to the field of waterlogged wood conservation and many new ideas and techniques emerged. Gratten and Clark record that the first two articles in conservation literature describing the actual procedures with PEG appeared at this time.[11] By 1962 conservators working in Sweden on the Vasa began perhaps the most popular application of PEG being used in this way. Whether Moulthrop found his inspiration through collaboration with industry or through conservation resources is not known. But we do know that by the early 1960s he began using PEG 1000 in an effort to prevent checking and extensive warping of his green-turned bowls on drying. [12]

Though refining his methods over the years he followed this basic procedure. He used only southeastern woods readily available in the Atlanta area. Yellow poplar, wild cherry, sweet gum, white pine, black walnut, orangewood, magnolia, and persimmon are his preference. He is known for turning simple forms such as globes, donut shapes, and lotus thus allowing the figure of the wood to assume a dominant role in the design.

He was constantly adding to his stock of bolts which he kept stored on plastic around his yard. Sometimes the bolts were covered by plastic. He preferred to encourage fungal infection of his stock with the hope of allowing mild staining due to spalting and blue stain to enhance the decorative appearance of the final product. It is not known if he used supplemental materials to enhance fungal growth as is common among wood turners.

He developed a series of specially designed lathes that allowed him to work large outboard turnings. His annual output in the 1980s was said to be nearly 250 pieces per year. Although the majority of that work was of a modest scale he created bowls up to 40 inches in diameter from bolts weighing as much as 1500 lbs.

Moulthrop first cut the ends and any pulpy wood away from the blank until he could assess the firmness, figure and fitness of the wood to be turned. Then he'd mark off the center and affix a faceplate (sometimes made from a modified salvaged iron sprocket gear). He then began roughing out the exterior of the bowl with the lance (his tool of choice for all exterior work). The interior hole was started by driving an auger into the spinning bowl. This void was expanded by using a specially designed loop. In some interviews he acknowledged also using a large flexible shaft grinding bit as well.

Once the rough shape was complete the bowl was immersed in a vat of PEG 1000. The vats were usually made of plastic but Ed's son Philip reports that aluminum vats were also used.[13] The PEG was mixed with water to create a 30% concentration (based on a specific gravity measurement target of 1.05 at 60 degrees F). Small turning bolts were sometimes immersed prior to turning while large bowls were immersed after shaping. The bowls remained immersed for 1–3 months depending on the size of the bowl and time of year (related to exterior temperature). When the bowl was removed it was placed on a drying rack in the sun in order to have free water and PEG drain from the saturated wood. Final drying took from 1–3 weeks in a small drying room using a residential dehumidifier.

Finish work on the lathe consisted of minor refinement of both exterior and interior surfaces using the lance and loop. Then sanding commenced with metal-working disc papers as coarse as 16 or 24 grit and increasing in fineness as the process progressed. Holes, checks, and tear out were filled with a mixture of sawdust from the bowl mixed with epoxy in preparation for application of the finish.

Moulthrop experimented with various finishes for years in an attempt to improve the stability and appearance of his finishes. Reports from several sources acknowledge that his finishes often failed in the early years and each year turnings were returned for repair.[14] Experimenting with finishes in woodturning circles is common as with other forms of wood working. One of the more surprising practices common among turners today is the use of cyanoacrylate as a finish.[15] In a 1983 article in *Fine Woodworking,* Ed recommended that those new to the process would find polyurethane a more forgiving varnish. Most of his work however used a two part commercial epoxy.[16]

According to his son Philip, Ed's preferred finish process was as follows. First, in order to avoid fish eye and in an attempt to improve adhesion of the finish the first coat was a wash of epoxy thinned with lacquer thinner (proportions unknown). This is not unusual as epoxy manufacturers routinely dilute their cheaper grades of epoxy with denatured alcohol, xylene and other solvents. After 24–48 hours a thicker, undiluted, layer of epoxy was applied. After 24–48 hours that layer was sanded in order to level the finish and provide tooth for the third and final layer of epoxy. After another period of setting the bowl was then sanded a final time. Sanding was carried out on the lathe and perfectly concentric sanding marks are evident on the final product. Philip reported that both he and his son Matt (who carry on in the same tradition and techniques) often use finer grits and polish than did Ed to eliminate the sanding marks on their work.

Discussion

The blisters were only found in the dark zones and primarily in the top facing transverse section of the wood. Some blisters are directly related to the blue stain (fig. 5).

Philip Moulthrop recalls blistering being a problem nearly exclusively to tulip poplar, also confined to the black zones, and has been found on the interior surface only perhaps 1% of the time on affected pieces. There are patches of lifting finish across the body of the bowl. At these areas the finish is sound but de-lamination has occurred. On close inspection one can observe a loss of finish contact and saturation shadowing the growth rings in passages (fig. 6).

The blisters are firm to the touch but not hard. When depressed they are somewhat plastic. One blister was pierced by a syringe needle in order to extract some of the matter in the blister for analysis. Once the matter was removed air filled the void and fluid fingers of the brown matter could be seen radiating from the blister at the wood surface. The now vacant blister did not return flat but retained its shape. Plastic deformation had occurred (fig. 7). FTIR spectra on that sample revealed that the

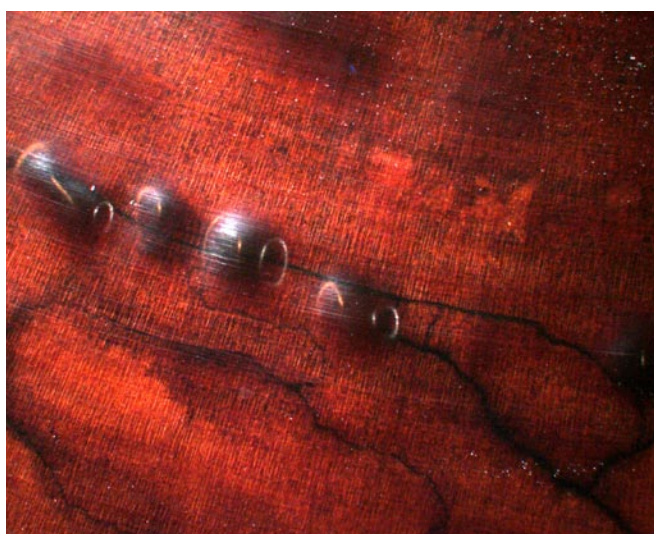

Figure 5. Some blisters followed lines of spalted figure.

Figure 6. Fractured finish was primarily related to growth rings.

blisters were filled with polyethylene glycols with traces of epoxy resins.[17]

Possible Dynamics

White rot hyphae penetrate and digest the wood and provide an unusually porous substrate capable of holding much greater volume of PEG solution that can fuel blistering.

The PEG vats used by Moulthrop were used for years by replenishing PEG as required to maintain an approximate 30% concentration.Water was added as a solvent in order to keep the PEG fluid at ambient temperatures. The drying process was imprecise and the eventual moisture content (MC) prior to finishing can not be determined. The MFAH piece was finished in January so PEG viscosity and degree of penetration may not have been optimal.

Thinning the first layer of epoxy is a strategy associated with poor adhesion of the finish and an attempt to avoid "fish eye." Getting any varnish to adhere to a waxy surface would be technically challenging.

Temperature and RH in the Millennium Gallery at MFAH are monitored continuously, recorded three times each day and the record reviewed daily by an engineer. Examination of the computer records of the HVAC for the duration of the exhibition showed that the temperature ranged from 69.5–71.5 degrees F and the RH from 47.3–53.7%. The bowl was lit by three spot light canisters at 25 fc during exhibition. Recent temperature readings at the same position the bowl occupied in the gallery revealed slight but potentially significant variations in temperature. The lighting in the gallery was programmed to turn on at 7am and turn off at 11:59pm each day. Local temperature at the bowl location with lights off was 67.5 degrees F and with lights on it increased to a maximum of 73.8 degrees F for a difference of 6.3 degrees. HVAC sensors are located in the returns to the room, collect an average reading and can not recognize discrete zones of variance in temperature and RH. Also noted was that local differences between the temperature for a white surface and black surface under the same conditions can be measurable and may have contributed to the problem.

The Potential Contribution of Osmosis

The potentially incomplete saturation of the wood in this first layer of epoxy finish or the network of trapped air bubbles in the epoxy could account for a semi–permeable film necessary for osmotic

Figure 7. Sampled blister retained distorted conformation after removal of PEG. Plastic deformation of the epoxy film was confirmed.

pressures to build up when trapped beneath the thicker upper layers of epoxy. The dynamic known as osmosis is what occurs when a porous substrate has a high fluid content beneath a semi-permeable membrane beneath an impermeable film. Osmosis is the passage of fluid from a region of high water concentration through a semi-permeable membrane to a region of low fluid concentration. As fluid passes through the osmotic membrane it is trapped between the substrate and film as the fluid pressure attempts to equilibrate across the membrane. The hydraulic pressures of increased mass between these two layers cause deformation of the film above and blistering results. The blisters on the bowl appear to follow this model.

Degradation of the PEG 1000 to a lower MW would contribute to an increased mobility and a depressed melting point. This degradation could occur due to the potential presence of metal salts in the vats or months of accumulated tannins in the solution causing a depressed average molecular weight. An increase in hydraulic pressure and development of the osmotic cell could result. These osmotic dynamics are known to be able to exert hundreds of pounds of pressure quite easily. Blisters of this type are familiar to boat builders and those who apply epoxy to concrete floors.

Several factors contributed to the osmosis dynamic and development of blisters. Breaches in the epoxy film (fig.6) allowed the previously static system to be upset. PEG 1000 was degraded and a lower melting point resulted. Although revered for its stability PEG is very hygroscopic and sensitive to temperature changes near its melting point.[18] As early as 1981 at the Ottawa ICOM conference, Dr. Allen Bronstein, a senior research chemist at Union Carbide, discussed the many factors related to the degradation of PEG. Of particular note is the concern of the effects of metal salts on its degradation, associated reduction of MW and depression of melting point.[19] It was noted by Philip Moulthrop that both plastic and aluminum drums were used as vats for PEG.[20] Water may have been incorporated into the epoxy matrix during curing. Moulthrop's reliance on a subjective drying evaluation and an unknown equilibrium moisture content (EMC) of the wood during finishing may have created a reserve of trapped water in the wood. If present in sufficient amounts that water could act as a plasticizer and thus decrease the Tg of the epoxy. A more elastic epoxy would be less resistant to the osmotic pressure of a migrating PEG solution.

Treatment recommendations

It was determined that the blisters were under dynamic hydraulic pressure from the PEG below the finish and that mending current blisters and avoiding future distortions to the epoxy could not be effective without accounting for that pressure. Other museums and private collections have chosen to refinish similar problem pieces in their collections over the years. Philip Moulthrop and other sources have reported that refinishing to correct such problems had been the resolution preferred by the artist throughout his career. Philip continues to undertake such repairs for his father's work.

The finish will be thoroughly documented and then removed. The original finish on the interior and the foot with the inscription applied by the artist will be preserved. The epoxy finish will be removed by solvent. Migrating PEG will be cleared by solvent prior to application of new finish. Two options for refinishing have been proposed and are currently being evaluated. First, the artist's methods can be duplicated. Another epoxy finish can be applied using an epoxy finish with the existing technical evaluation as a guide. Alternatively, a blend of wax and polymer that can mimic the physical appearance of the older film can be applied that can be both durable and easily retreated if necessary in the future. Both options are being considered and may be the subject of a future presentation on their relative merits and ethics.

Notes

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