Lead Corrosion In Exhibition Ship Models

BY DANA WEGNER

Introduction

LEAD HAS BEEN A POPULAR METAL for fabricating fittings for exhibition ship models. It has been attractive because it is easy to obtain, it is soft and easy to fashion, and it melts at a relatively low temperature. However, lead fittings frequently corrode.[1] Corrosion may be so severe as to completely consume the piece, leaving behind a white or gray residue popularly, and aptly, called "lead disease," "lead rot," "lead cancer," or "lead bloom."

In the ship modeling community, there has been considerable speculation about what causes lead to severely corrode, how to arrest the process in pieces already installed, and how to prevent corrosion in the future. This report compiles some of the technical literature on the subject and relates that literature, in practical terms, to ship modelers and to museum staff who are unable to obtain the advice and services of objects conservators. (Figure 1)

The Problem

Lead parts or solder might be found in models made at any time. However, in quantity, ship models made by twentieth century artisans dominate many collections and these models are the focus of attention here. Solder, commercially produced fittings, home-made castings, parts fashioned from old toothpaste tubes, and even air gun pellets, all made from lead, are commonly found on ship models. By about 1922, commercial exhibition ship model kit and parts manufacturers used lead for their castings.[2] Many of these early castings, seen on a number of models in the Navy's collection, are today three-quarters of a century old and we observe the lead corrosion phenomenon frequently.

In addition to many full models, within the Navy Department's ship model collection are hundreds of 1:500- and 1:1200-scale ship identification models made commercially between 1942 and about 1960.[3] Some of these, especially those stored in contemporary wooden carrying cases, today show signs of lead deterioration or have completely decomposed to powder. (Figure 2)

Cause of Lead Corrosion in Ship Models

Lead is an ancient material and has been used by man for many centuries. Many examples of antiquarian coins, underground pipes, lead roofs on medieval churches, lead coffins, and lead bullets from

* Notes will be found at the article's end.

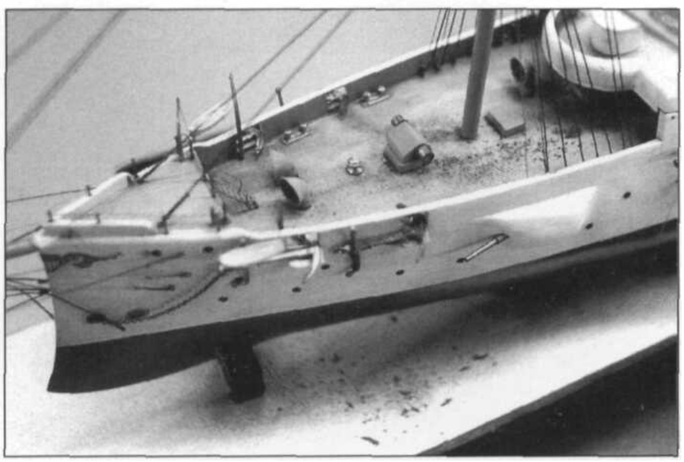

Figure 1. USS CHICAGO (Protected Cruiser). Department of the Navy model catalog number 181. Scale 1:96. Built by the Boucher Company, 1922. Photograph taken February 1996 showing advanced state of lead corrosion accrued since 1974. Here, some, but not all, of the lead bitts and ventilators have corroded and littered the forward deck with a gray corrosion byproduct. Portions of the port-side anchor have also corroded despite a coating of black paint. Between 1934 and 1994, this model was displayed in a large plywood and plexiglass display case containing a number of other models. Some of the other models showed similar signs of deterioration. NSWCCD Curator's Office photograph, Michael Condon.

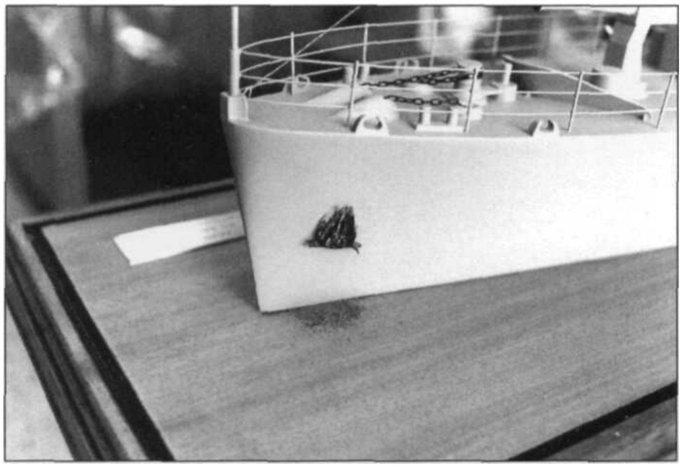

Figure 2. USS PC-461. Navy Department Ship model catalog number 587. Scale 1:48. Upgraded drawing room model by the Bureau of Ships, United States Navy, about 1940. Photograph taken March 1997. The anchors, the only lead fittings on this model, have been a recurring source of corrosion problems since 1963 when the model was mounted in a glass display case with a mahogany base finished with Fabulon clear coat. The anchor previously had been cleaned and repainted in September 1978. NSWCCD Curator's Office photograph, Michael Condon.

American Civil War battlefields attest that lead can be nearly eternal.[4] But why does lead sometimes turn to formless powder on our ship models?

The chief category of substances acting harshly upon lead are organic compounds and acetic acid is among the most destructive of these carbon compounds. Acetic acid acts upon lead and transforms it into lead carbonate. Lead carbonate is the white, granular, powder we frequently see on lead ship model fittings. The museum objects conservation community has been aware of the phenomenon for several decades and the chemical process that causes it is well-understood.[5]

The chemical process is this: Acetic and some other acids, in the presence of carbon dioxide, catalyze with lead to produce lead acetate and lead hydroxide. Lead acetate and lead hydroxide together react with carbon dioxide and form lead carbonate. Lead carbonate then releases acetic acid and the process becomes self-sustaining.[6] It is important to recognize that the formed lead carbonate is not just a substance clinging to the surface of a casting, it *is* the surface of the casting transformed to powder. For practical purposes, a portion of the lead is gone and lead carbonate is left in its place. The lead carbonate releases acetic acid which can continue the process until the lead part is progressively consumed from the outside, inward. Acetic acid attacks not only lead, but to a lesser degree, zinc, aluminum, magnesium, brass, copper, nickel, and even steel.[7]

During the nineteenth century, the artificial production of lead carbonate by using the "Dutch method" was a thriving commercial enterprise in the United States and England. In order to create lead carbonate, known as *white lead*, a valuable pigment used in high-quality opaque paint, earthen pots were filled with vinegar and covered with sheet lead or with cast lead waffles. The pots were stacked and then covered with a mound of *tan* — the bark from oak trees. The tan decomposed and heated the pots to about 180 degrees Fahrenheit. In about three months, the pots were recovered along with the dense white powder (lead carbonate) into which the lead had been transformed. In this process, carbon dioxide was in the air and was also formed as the tan decomposed. Acetic acid came from the vinegar (usually about 3 to 5 percent acetic acid and about 95 to 97 percent water) and from the oak bark. Heat generated by the decomposing bark accelerated the process.[8]

Micro-Environment of the Ship Model

Exhibit cases provide an artistic framework to visually enhance the appearance of models and to provide protection against physical damage and dust. Even though most display cases are not air-tight, they do provide some buffering against abrupt changes in temperature and humidity and tend to limit the model's exposure to common airborne pollutants. Even relatively loose-fitted showcases can support an internal atmosphere one hundred times more stagnant than the surrounding room.[9] (Figure 3)

Lead fittings can be exposed to acids through the atmosphere within a ship model display case and by direct contact with wood. To a lesser extent, many commonly used paints and glues may also contribute to an acidic environment. Certainly, for many ship models, wood is the major contributor of acetic acid. Concentrations of this acid as little as half a part per million can cause damage to lead components.[10]

The interior surfaces of an exhibit case may have a significant effect upon the micro-environment surrounding what is inside. The materials exposed within the confines of the display case consist of the

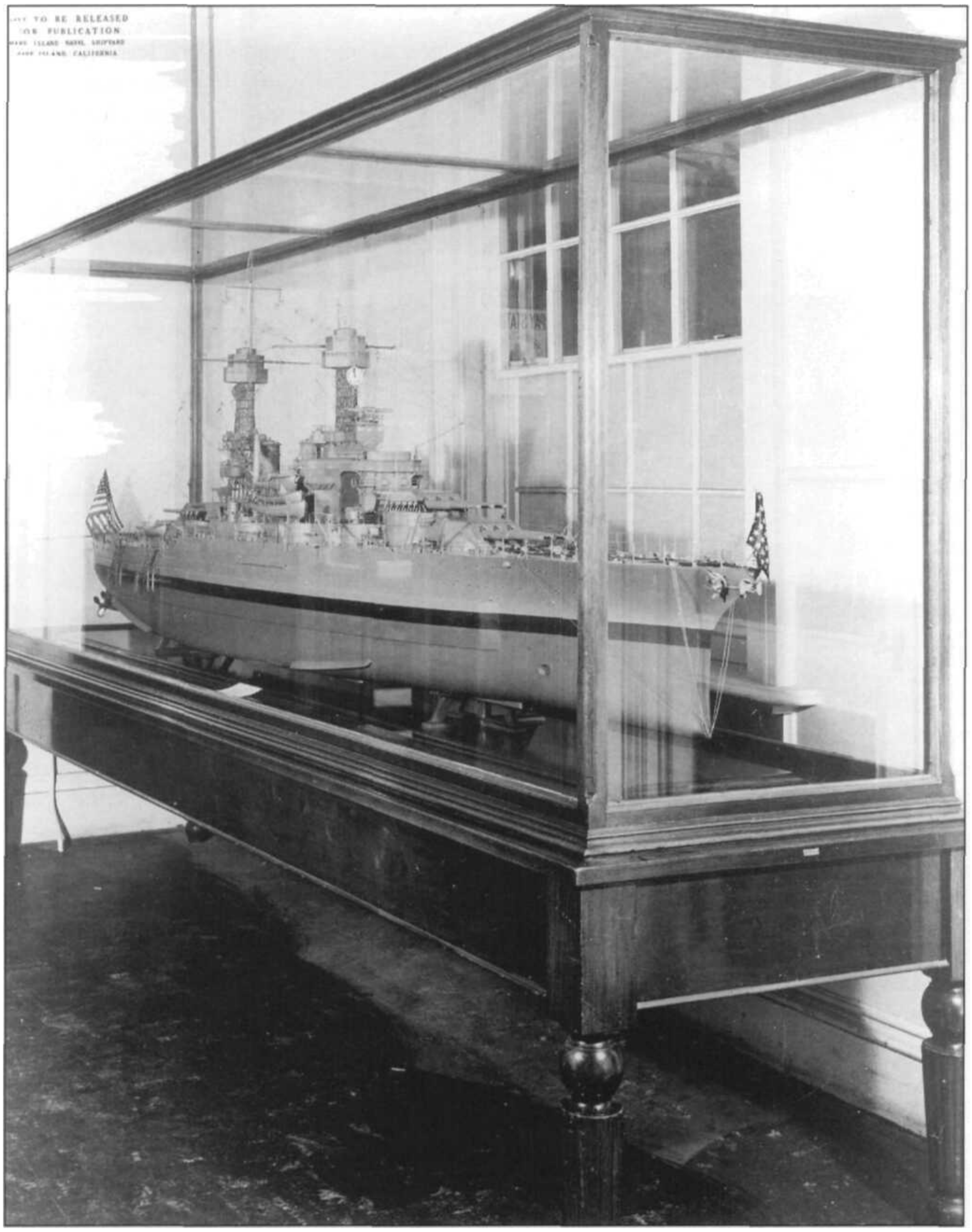

Figure 3. USS CALIFORNIA (BB-44). Navy Department Ship model catalog number 151. Scale 1:48. "Builder's model" by the Mare Island Naval Shipyard, about 1918. Resplendent in its beautiful contemporary mahogany and glass exhibit case, models such as these did not employ much lead in their construction. They present modern conservators with few lead-related problems. Perhaps the greatest lead-related conservation problem to be expected here is lead-bearing solder which might have been used for attaching parts together. The large glass plates of the exhibit case are set in a rabbet and simply are held in place with slim mahogany strip moldings. This relatively loose-fitted construction doubtless allows the air within the exhibit case to exchange at least once or twice a day, while still protecting the model from most dust and buffering the model from abrupt changes in temperature and humidity. NSWCCD Curator's Office photograph.

Table 1.
Woods Harmful to Lead.

Sources: Blackshaw and Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," mahoganies; Padfield, Erhardt, and Hopwood, "Trouble in Store," mahoganies; Miles, "Wood Coatings," unseasoned oak, basswood, teak, larch, ash, birch, beech, seasoned oak; S.M. Blackshaw and V.D. Daniels, "Testing of Materials for Use in Storage and Display in Museums," unseasoned oak, chestnut, seasoned oak; Rance and Cole, *Corrosion of Metals By Vapours from Organic Materials: A Survey*, plywood, chipboard, red cedar, mahoganies; Oddy, *Corrosion of Metals On Display*, fire- and rot-proofed woods; and Clarke and Longhurst, "Corrosion of Metals By Acid Vapours from Wood," rot-proofed woods.

Harmfulness	Woods
Very Harmful	Unseasoned Oak (white and red), Plywood and Chipboard, Teak, Basswood, Sweet Chestnut, Fire-proofed Woods, Rot-proofed Woods
Moderately Harmful	Seasoned Oak, Larch , Ash, Birch, Beech, Red Cedar
Less Harmful	Sitka Spruce, Douglas Fir, Pine, Honduras and African mahogany, Elm, Ramin, Obeche

interior surfaces of the case itself, the model and all of the materials used in it, and any other objects placed within the case — like simulated water, figures, sails, background fabrics, cradles, name plates, and more. Other than glazing materials, probably the most prevalent material within many exhibit case interior environments is wood.

Sources of Acid in the Ship Model Micro-Environment

Wood

By the 1890s, museum staff members were noticing that some objects became corroded when stored for long periods of time in wooden drawers. In the 1960s, concerted scientific tests were conducted by museum professionals who specialize in the preservation of historic artifacts." They found that all types of wood release acetic acid and that certain woods emit more than others. End grain releases more than edge grain. Some of the acid is naturally released by the wood and some is released as a function of age as the wood decomposes. In a few cases, seasoned or kiln-dried woods emit more acid than the same wood unseasoned. A secondary lead-corroding product, formic acid, is also produced by wood, but in quantities only about one-tenth as great as acetic acid.[12]

Wood exposed inside display cases with relatively stagnant atmospheres will create an acetic acid-laden micro-environment where lead artifacts will corrode even without being in physical contact with the wood. In addition to materials forming the surrounding exhibit case, the model itself may be made primarily from wood.

All woods will emit acetic acid to some measurable amount, but woods sometimes used by modelers that known to be harmful to lead are shown in Table 1. The woods listed have been tested by scientists primarily because they are occasionally used in the construction of museum display cases, shipping crates, or storage units. Ship model builders employ many more types of woods than those tested. Nevertheless, a general rule of thumb can be applied: Hardwoods emit more acetic acid than soft woods. But any wood will fall into at least the minimally harmful category.[13]

Paints, Glues, and Miscellaneous Materials

Although wood is by far the major culprit, recent investigations have identified a large number of materials which also add to the acetic and formic acid exposure of lead fittings. Potentially destructive materials used by ship model builders include those in Table 2.[14] The materials listed in the table are not in any particular order. They are general in nature and do not classify into groupings of high, medium, or low risk for lead corrosion. Some brands of the same material may be more or less harmful than other brands. As manufacturers change their formulas from time to time, items may fall into or out of the potentially harmful list. The creation of acetic and formic acids by these materials is a more complicated process than the emission of acids from woods and there is some disagreement among scientists whether some products, latex paint for example, release acid or not. Types of plastics found not to produce acids include polycarbonates, Mylar, and Nylon.[15]

Paint Vapors

Vapors from drying solvent-based paints like enamels and lacquers, as well as paints containing common drying oils have been found to produce acids also. After drying several weeks, the vapor levels are usually low enough to be considered not harmful to lead.[16] However, tests also show that the dried surfaces of these paints can also create acids.

Empirical Evidence

Our Experiences

The staff of the Curator of Ship Models at the Naval Surface Warfare Center [NSWC] has long experience in observing and treating the deterioration of exhibition ship models. We maintain the United States Department of the Navy's ship model collection containing over 1,900 models built between 1813 and today.

Museum professionals call the self-deterioration of objects *inherent vice* and some amount of decomposition is expected to be seen in all things.[17] General observation has shown that older ship models made using a limited variety of materials are less susceptible to inherent vice than newer models which employ a mix of many types of commercially available products. For new models, it appears that if deterioration has not been observed within the first five to ten years, and if the climate is not altered, the model probably will be relatively stable for many future decades.

We have found that even a low level of acetic acid inside an exhibit case can be detected by the human nose. When the display case is opened, the inside smells like vinegar. The human nose can detect the vinegar smell with a concentration perhaps as low as half a part per million. This amount also seems to be the lower concentration threshold for acetic acid to damage lead. The coincidence suggests that if an exhibit case interior carries even a slight vinegary smell, then acid is present in a harmful amount.[18]

Table 2.
Other Materials Harmful to Lead.

Sources: Materials listed have been compiled from the following sources: Miles, "Wood Coatings for Display and Storage Cases," latex varnish, alkyd paints, tung oil, polyurethane paints; Kathryn Hnatiuk, "Effects of Display Materials on Metal Artifacts," *Gazette of the Canadian Museums Association* (summer-fall 1981), PVA glue, contact cement, varnish, enamel paints, oil-based stains, wool, Styrofoam, oil-based paints, vinyl, wallpapers, velvet, burlap; and Rance and Cole, *Corrosion of Metals By Vapours from Organic Materials: A Survey*, alkyd paints, tung oil, PVA glue, rust inhibitors, polyesters, linseed oil varnish, plastic wood.

Material	Comment
Polyvinylacetate (PVA) or "white" glue	some brands
Contact cement	
Plastic wood	
Latex varnish	
Natural varnish	
Polyurethane varnish	
Tung oil varnish	
Linseed oil varnish	
Enamel paint	
Oil-based paint	
Alkyd paint	
Lacquer paint	
Varathane paint	
Oil-based stain	
Wool	some kinds
Styrofoam	
Vinyl	
Wallpaper	some types
Velvet	
Burlap	
Rust inhibitors	
Polyesters	some types
Plastics	some types
Dyes used in fabrics	some types
Jute	
"Flame-proofed" fabrics and wood	
Products treated for rot and/or insect resistance	
Products containing ammonia	
Products that smell like vinegar	
Low quality paper and cardboard	
Vermiculite	
Pebbles and sand	unwashed
Cast acrylic plastic or "plexiglass"	suspected
Silicon room-temperature-vulcanizing (RTV) adhesive: tub and tile caulks	some types

We have noted that thin pieces of lead, such as moldings made from toothpaste tubes cut into strips, corrode faster than more solid shapes. For example, model anchor flukes tend to show the effects of corrosion before the arms or shank. In general, lead corrosion is first observed along the thin edges of parts. This is probably because of the large ratio between the surface area of sheet stock, and thin edges, to the total volume of the piece.

When we started our investigation we had long stopped using lead parts in new models and repairs. We now use parts made from lead-free britannia metal. Britannia looks and behaves similarly to lead. It is commonly called *pewter* today and originated in the nineteenth century as a popular pewter substitute when the ill-health effects of genuine pewter (much of which contains lead) was discovered.[19]

Simple Experiment

We decided to artificially create a corrosive microenvironment for lead parts so that we could watch the process occur. We employed a surplus ship model dust cover 20 inches long, 12 inches wide, and 8 inches high made from 3/16-inch-thick plexiglass and set it on an unpainted plywood sheet. Inside we placed two cereal bowls each filled with a few ounces of household white vinegar, labeled "5% acetic acid," and a paper towel wick. From our tackle box of old and reclaimed fittings, we selected about a dozen old lead items, none of which then showed any signs of corrosion. The fittings were unpainted, from unknown sources, and at least twenty years old, probably older. We arrayed them in various locations within the case and the entire setup was placed near a window facing south.

All of the fittings were observed to tarnish darkly first, then eventually form a light surface coating of white powder. The powder increased in thickness and then showed small surface eruptions (blooming) as more of the metal was consumed. Some parts corroded faster than others. The first white corrosion was seen on two parts after only seventy-two hours. Parts positioned in areas of the case occasionally struck by direct sunlight corroded faster than parts in other areas probably because the sun's warmth accelerated the chemical process.[20] The parts continued to corrode when the bowls of vinegar had been removed from within the display case.

Impurities in Lead

We originally started our investigation of lead corrosion on the wrong track. A casual discussion in 1980 with one of the Model Shipways Company employees suggested that their lead castings were made using "type metal." We thought what he meant was most likely expended metal type from printing presses. An examination of literature showed that type metal should contain mostly lead and some measurable amounts of antimony, tin, and perhaps copper.[21]

Based on our experience and bolstered by observations made during the simple experiment described in the previous section, we knew that under seemingly identical conditions, some lead parts corroded faster than others. We surmised that perhaps lead corrosion was triggered by "impurities" like antimony or tin in the lead used in the castings.[22] We were wrong.

Recent tests done for us by the NSWC Materials Laboratory indeed confirm that there are minute amounts of antimony and tin and other metals in some lead ship model castings which have corroded, but the amount of lead corrosion created appears in positive proportion to the purity of the lead used in the fitting. In other words, the purer the lead, the more readily the part was affected by acetic acid.[23] Contrary to our first thoughts, antimony, copper, and tin in lead castings apparently tend to retard or reduce the formation of lead carbonate.

Empirical Mystery

Finally, our general experience over a two-decade period is that lead fittings on models displayed in plexiglass (cast sheet acrylic) exhibit cases corrode more rapidly than those displayed in glass cases. Oddly, our office seems to be the only museum group actually experiencing accelerated deterioration of lead objects under acrylic. While polycarbonates have been rated as non-producers of acetic acid, there are some current conservational concerns about acrylic sheet. We cannot yet explain what causes what we surely see, and more study needs to be done.

Solving the Problem

Treatment of Corroding Lead Parts

The fact that lead carbonate combines with carbon dioxide to form acetic acid demands that lead carbonate powder frequently be removed from the surfaces of affected castings and from inside the exhibit case or storage crate environment. We have found that brushing off the corrosive byproducts and repainting the affected fittings only serve as a temporary and cosmetic repair. The parts will begin to bloom again if they remain within the same acid-laden micro-environment. A variety of paints, clear coatings, cyanoacrylate glues, and even automobile battery terminal paint have been tried with no appreciable abatement found.[24] Indeed, many of these coatings may actually contribute to the problem.

One treatment that was suggested on the Internet to modelers was to wash parts in vinegar to neutralize the lead carbonate. While this treatment may facilitate cleaning the affected parts, obviously the vinegar wash itself may attack the lead until it is neutralized by liberally rinsing it in water. Thorough removal of lead carbonate from within the model's micro-environment is recommended, but we would suggest simply brushing it away.[25] Although basic lead carbonate does not dissolve in water, mechanically rinsing corroded parts in running water would be preferable to applying more acetic acid to the piece. Wear a respirator when disturbing dry lead carbonate dust and be sure to wash your hands after handling lead fittings or lead corrosion byproducts.

The Gibbs & Cox Company ship model builders (1939 - about 1962) employed some lead castings and lead-based solder in their exquisite models. They chose to electroplate those fittings with a thin layer of copper, thereby effectively sealing the casting surface from the atmosphere. Time has confirmed that electroplating is a good way to prevent lead corrosion. There are two drawbacks to electroplating. Some superfine relief detail may be lost, and the process is somewhat complicated and fraught with safety, health, and environmental hazards.

Many model builders simply do not use lead fittings in new models and replace lead fittings on old models with duplicates made from a more durable metal. While brass, bronze, or copper is suitable, britannia metal, which is usually composed of 89 percent tin, 7.5 percent antimony, and 3.5 percent copper, is frequently used to replace lead because it is easy to cast. Replacement is a way around the problem for hobbyists. However, for museums the wholesale substitution of new fittings for old would, or should, present a dilemma in conservational ethics.

There appears to be no known product currently available which can be applied to lead fittings to

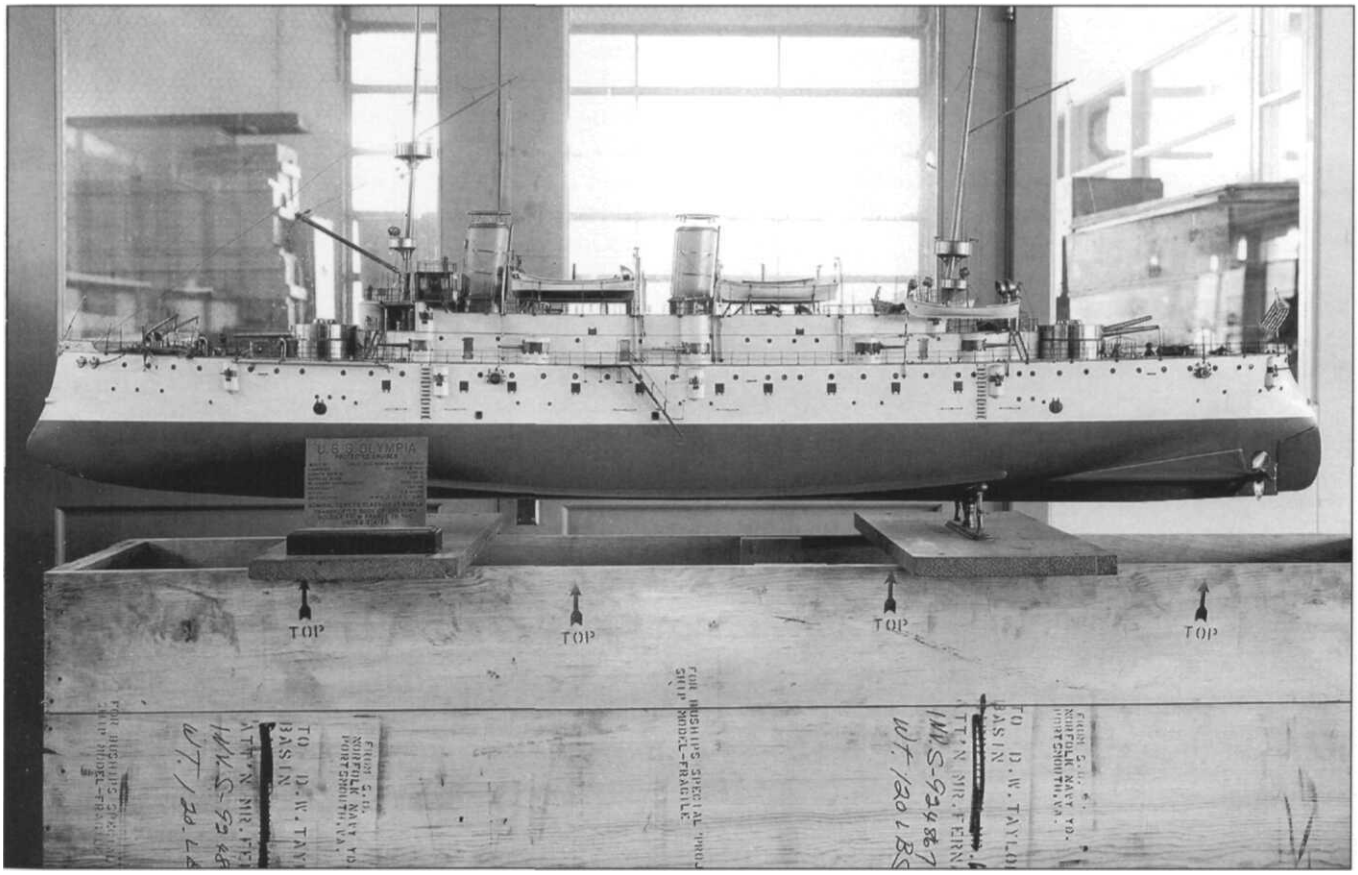

Figure 4. USS OLYMPIA (Cruiser #6). Navy Department Model catalog number 188. Scale 1:48. "Builder's model" by the Bureau of Construction and Repair, United States Navy, about 1891. Museums frequently store large artifacts like ship models in wooden crates for extended periods. Today we know that storage crates must be constructed from materials which will not adversely affect the contents. This photograph probably was taken in 1946 and shows the pine crate in which the model resided between 1945 and 1952. United States Navy models of this vintage usually were made from a limited list of materials which did not include lead. They have tended to be relatively stable. Here, some features of the model are bright brass, nickel, and copper. NSWCCD Curator's Office photograph.

render them fully impervious to acetic acid.[26] Other than electroplating fittings or replacing them with more durable castings, probably the best way to prevent lead corrosion is to isolate ship models from sources of acids.

Improving the Ship Model Micro-Environment

Solutions Which Don't Help

One unrealistic way to prevent lead corrosion would be to hermetically seal exhibit cases and replace the interior atmosphere with one containing no carbon dioxide. In an environment without carbon dioxide, one key ingredient necessary to create lead carbonate would be missing and the process could not occur. Even for museums, the costs of creating a large-scale controlled-gas environment would be technically and financially daunting.

Another imperfect solution would be to forego putting ship models in display cases. The free movement of air surrounding them would minimize their exposure to concentrated airborne acetic and formic acids. However, the potential for mechanical damage, exposure to dust, abrupt changes in temperature and humidity, not to mention aesthetic concerns and tradition make this a generally unpalatable response to the problem.[27]

A simple way to prevent woods from off-gassing acetic acid would seem to be to seal the wood using an acid-impervious coating. But most kinds of wood sealers, paints, and clear finishes are not impervious to the passage of acetic acid from woods, and indeed, the coatings might further contribute to the micro-environment problem. To date, researchers have found no product which can be applied as a liquid and which *fully* seals wood to suppress the emission of acids. Two-part epoxy and some urethane paints appear to offer a limited degree of barrier. Shellac, while not an acid producer, does not offer any protection. Sheet Melamine does not release acids and might be used for cladding, but the adhesive used to affix the sheet material to the underlay may, indeed, be undesirable.[28]

A Partial Solution

In practice, the lead corrosion problem can be mitigated by introducing a relatively small amount of free air into exhibit cases. Generally, the air should change inside the case about once or twice a day. One rule of thumb suggests that a one-inch diameter hole in an exhibit case is enough to exchange the air in a case with a volume of about one cubic yard. Keeping the exhibit case interior and the model cool by avoiding direct sunlight, heat-generating lights, or other sources of warmth will retard the corrosion process, too. Air pollutant absorbers *(sorbents)* like activated carbon will sop acetic acid from the air but these materials, placed in shallow trays to reveal a large surface area, become saturated and must be replaced periodically. Large-volume display cases would require substantial areas of sorbent surface to be effective.[29] (Figure 4)

Lead is a Health Hazard

Lead is a toxic substance which may enter the body by breathing or swallowing lead dusts, fumes, or mists. If food, cigarettes, or your hands have lead on them, lead may be swallowed while eating, drinking, or smoking. Once in the body, lead enters the bloodstream and may be carried to all parts of your body. Your body can absorb some of this lead, but if there is continued lead exposure, your body absorbs and stores more lead than it can eliminate. This stored lead may cause irreversible damage to cells, organs, and whole body systems. After exposure stops, it takes months or even years for all the lead to be removed from your body. One of the easiest ways to control lead exposure is by following good hygiene practices. Always wash your hands and face after being exposed to lead dust.[30]

Conclusions

The implications from our experience and our investigation of relevant literature about the corrosion of lead and its prevention suggests that lead parts cannot yet be treated with a coating which conveniently will render them impervious to acids. However, models with lead fittings could benefit by the reduction and perhaps elimination of exposure to materials known to be highly destructive to lead. Considering that the model itself may be made of some acid-producing materials, perhaps not every acid source can be eliminated. But at least major sources, especially those sources not inherent in the model itself and which affect the model's micro-environment, should be avoided.

- Models with lead parts should not be displayed or stored in cases made from oak or made from other woods on the highly destructive list. Woods not on the list in this report, and there are many, may range from minimally to highly harmful.
- Lead carbonate which has accumulated should be removed from affected parts and from inside the exhibit case interior as frequently as possible.
- For models with lead parts, exhibit case interiors should be kept as cool as may be practical.
- Exhibit cases should exchange interior air about twice a day.
- World War Two-vintage waterline identification models should not be stored closed within their original wooden carrying cases.
- Do not use lead fittings when constructing new models or refitting old models
- Wash your hands after handling lead

Next, in declining order of risk, would be to reduce or eliminate the model's exposure to less harmful woods, then reduce its exposure to large amounts of destructive materials other than wood, and finally limiting its exposure to even low-risk materials. Lead corrosion on ship models can be prevented or significantly reduced by eliminating or reducing the acidic environment within their exhibit cases or storage units.

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Notes

1 For simplicity, the practice of attaching chemical symbols to the names of materials has been declined in this report.

2 Until recently, lead was commonly used to package a variety of consumer products. Extruded lead "collapsible tubes" contained toothpaste, shoe polish, grease, artist's paints, and

model glue. Lead foil could be found enveloping cigarette packs and cigars as well as adorning Christmas trees as tinsel. As a point of reference, one pound of pure cast lead occupies 2.44 cubic inches. It will melt at 621 degrees Fahrenheit and boil at 2,777 degrees Fahrenheit. *Useful Information About Lead* (New York: Lead Industries Association, 1933), pp. 14, 22, 31, 101-103. Colan and Grace Ratliff, "History of Ship Model Kits," *Ships in Scale* (November-December 1987), pp. 14-16.

3 Edward P. Von der Porten, "Ship Models Go to War," *NRJ* 4:1 (March 1996), pp. 32-44.

4 Intact and nearly air-tight lead coffins, probably dating from the year 1680, have been found in St. Mary's City, Maryland. See: Henry M. Miller, "Mystery of the Lead Coffins," *American History*, September-October 1995, pp. 46-48, 62-65. George Washington was buried in a lead coffin in 1799. In 1905, John Paul Jones's corpse was found well-preserved by alcohol in a lead coffin buried in Paris in 1792. The coffin still surrounds his remains in the sarcophagus at the Naval Academy. See: Charles W. Stewart, comp., *John Paul Jones. Commemoration at Annapolis, April 24, 1906* (Washington: Government Printing Office, 1907), pp. 61-68, 71.

5 W.A. Oddy, *Corrosion of Metals On Display* (London: British Museum Research Laboratory, n.d.). Lead is resistant to most other acids including sulphuric and hydrochloric. *Useful Information About Lead*, p. 32.

6 S.M. Blackshaw and V.D. Daniels, "Testing of Materials for Use in Storage and Display in Museums," *The Conservator* 3 (1979), p. 18 and David Erhardt, conversation with author, 30 May 1997.

7 S.G. Clarke and E.E. Longhurst, "Corrosion of Metals By Acid Vapours from Wood," *Journal of Applied Chemistry* 11 (November 1961).

8 Ralph K. Strong, ed., *Kingzett's Chemical Encyclopedia* (New York: D. Van Nostrand, 1946), p. 570; Horace Greeley, et al., *Great Industries of the United States* (Hartford, Connecticut: J.B. Burr & Hyde, 1872), pp. 496-500; and Henry C. Pearson, *Crude Rubber and Compounding Ingredients* (New York: India Rubber Co., 1899), pp. 83-84. Techniques were later developed which greatly speeded up the corrosion process. White lead, until recently, was the preferred ingredient in most high-quality paints. Former United States government specifications required that commercial paints have a minimum content of 60 percent white lead pigment. In 1931, the three greatest uses for lead in the United States were in storage batteries, cable shielding, and for the production of white lead pigment. *Useful Information About Lead*, pp. 10, 37.

9 Vera E. Rance and H.G. Cole, *Corrosion of Metals By Vapours from Organic Materials: A Survey* (London: Admiralty Supply, 1958), p. 1; Tim Padfield, David Erhardt, and Walter Hopwood, "Trouble in Store," in N.S. Brommelle and Garry Thomson, eds., *Preprints of the Contributions to the Washington Congress, 3-9 September 1982: Science and Technology in the Service of Conservation* (London: International Institute for Conservation of Historic and artistic Works, n.d.), p. 25.

10 S.M. Blackshaw and V.D. Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," *Conference Proceedings*, ICOM Committee for Conservation, 5th Triennial Meeting, Zagreb, pp. 3, 8; and Clarke and Longhurst, "Corrosion of Metals By Acid Vapours from Wood," p. 438.

11 On the long-standing utilization of wooden display cases in museums, see: Margaret Talbot Jackson, *The Museum. A Manual of the Housing and Care of Art Collections* (New York: Longman's & Green, 1917), pp. 146-154. On the early discovery of museum storage problems, see: Elisabeth West Fitzhugh and Rutherford J. Gettens, "Calclacite and Other Efflorescent Salts On Objects Stored in Wooden Museum Cases," in Robert J. Brill, ed., *Science and Archaeology* (Cambridge, Massachusetts: MIT Press, 1971), pp. 91-102. Early investigations on the effects of organic acids upon metals include: Rance and Cole, *Corrosion of Metals By Vapours From Organic Materials* and P.C. Arni, G.C. Cochrane, and J.D. Gray, "Emission of Corrosive Vapors By Wood. II. The Analysis of the Vapours Emitted By Certain Freshly Felled Hardwoods and Softwoods By Gas Chromatography and Spectrophotometry," *Journal of Applied Chemistry* 15 (October 1965).

12 Oddy, *Corrosion of Metals On Display*; S.M. Blackshaw and V.D. Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," p. 3; Catherine E. Miles, "Wood Coatings for Display and Storage Cases," *Studies in Conservation* 31 (1986), p. 122.

13 The hardwoods-softwoods rule of thumb is from Miles, "Wood Coatings," p. 122; and Blackshaw and Daniels, "Testing of Materials for Use in Storage and Display in Museums," pp. 3-4.

14 Blackshaw and Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," p. 7.

15 Blackshaw and Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," p. 6.

16 Oddy, *Corrosion of Metals On Display*; Blackshaw and Daniels, "Selecting Safe Materials for Use in the Display and Storage of Antiquities," p. 7; P.D. Donovan and T.M. Moynehan, "Corrosion of Metals from Air-Drying Paints," *Corrosion Science* 5 (1965).

17 Blackshaw and Daniels, "Testing of Materials for Use in Storage and Display in Museums, p. 1.

18 On the odor threshold, see: Clarke and Longhurst, "Corrosion of Metals By Acid Vapours from Wood," p. 438. Miles, "Wood Coatings," uses 132 parts per million as the odor threshold. Padfield, Erhardt, and Hopwood, "Trouble in Store," p. 25.

19 Greeley, *Great Industries*, pp. 852-854; R.E. Peterson, ed., *Familiar Science* (Philadelphia: Sower Potts & Co., 1832), p.139; Edwin O. Jordan, *Food Poisoning* (Chicago: University of Chicago Press, 1917), pp. 27-29. Apparently a few variations of britannia do contain measurable amounts of lead. On the other hand, some variations of pewter do not contain any lead at all. This would suggest that the terms "pewter" and "britannia" sometimes overlap. See George S. Brady, *Materials Handbook* (New York: McGraw-Hill, 1971), pp. 595-596. Regarding using britannia made with lead, electron microscopic tests done at the Naval Surface Warfare Center suggest that alloys with less lead content are less likely to corrode from acetic acid. A rule of thumb for britannia might be, "Less lead is better, but no lead is best."

20 On heat accelerating the corrosion process, see: Blackshaw and Daniels, "Testing of Materials for Use in Storage and Display in Museums," p. 1.

21 John R. Rogers, *Linotype Instruction Book* (New York: Mergenthaler Linotype Co., 1925), pp. 104-107. Fresh Linotype metal is 85 percent lead, 11 percent antimony, and 4 percent tin. Other printing type metals might include electrotype, monotype, and stereotype alloys. Each has a different ratio of ingredients. The ratios change as the type metal is repeatedly remelted for reuse. *Useful Information About Lead*, p. 27. Of course, other sources for scrap lead might include old storage battery plates, automobile tire balancing weights, and firing range sweepings.

22 Strong, *Kingzett's Chemical Encyclopedia*, p. 569.

23 Confirming our findings, we belatedly learned that common virgin "pure lead" (99.7265+ percent to 99.931+ percent) is permitted to have minute amounts of impurities like silver, copper, tin, and arsenic. The purest form of lead (99.9330+ percent) was called "corroding lead" and was used in several modern processes to manufacture white lead. *Useful Information About Lead*, p. 11.

24 Miles, "Wood Coatings," p. 121.

25 *Useful Information About Lead*, p. 43. To avoid airborne contamination, it would not be advisable to vacuum up lead carbonate dust using an ordinary vacuum cleaner.

26 Miles, "Wood Coatings," pp. 118, 121, 123.

27 Forced ventilation of exhibit cases is not recommended. See: Padfield, Erhardt, and Hopwood, "Trouble in Store," p. 119.

28 Miles, "Wood Coatings": 118, 121, 123. Conservators sometimes apply on objects a relatively benign and reversible clear coating called Acryloid B-72. However, it appears that even B-72 is not impervious to acid. See, Miles, "Wood Coatings," p. 119.

29 Padfield, Erhardt, and Hopwood, "Trouble in Store," p. 25; Sucha S. Parmar and Daniel Grosjean, "Removal of Air Pollutants from Museum Display Cases," Getty Conservation Institute, August 1989. Granulated activated carbon is available from scientific supply houses like Fisher Scientific.

30 The text for this section on health considerations when handling lead is courtesy K. Patrick McKinney, Naval Surface Warfare Center, Carderock Division, Safety Office.