THE EXCAVATION, CONSERVATION, STORAGE, AND DISPLAY OF RUBBER ARTIFACTS RECOVERED FROM THE USS *MONITOR* (1862)

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ABSTRACT—In joint research efforts between the National Oceanographic and Atmospheric Administration, the United States Navy, and the Mariners' Museum, more than 50 rubber artifacts have been recovered from the rotating gun turret and steam engine of the USS *Monitor*. These rubber items include a glass jar seal, a comb, uniform buttons, and pipe gaskets. Waterlogged rubber artifacts from a highly saline environment present a unique opportunity for examining current conservation issues such as handling, treatment, and storage of rubber objects manufactured during the Civil War. Research into conservation treatments, such as chemical cleaning and electrophoresis, was conducted to determine the efficacy of specific methods to remove chlorides and corrosion products. Oxygen-free storage, using the Mitsubishi RP System, was elected as a preventive conservation step. The opening of the USS *Monitor* Center, a state-of-the-art laboratory and exhibition gallery for objects from the *Monitor*, has afforded the opportunity to increase public awareness of conservation processes through interactive exhibits and laboratory viewing stations.

TITRE—La fouille, la conservation, la mise en réserve et l'exposition des artéfacts en caoutchouc provenant de l'USS MONITOR (1862). RÉSUMÉ—Un effort conjoint entre le *National Oceanographic and Atmospheric Administration—NOAA* (Administration national pour l'atmosphère et les océans), la *United States Navy—USN* (la marine américaine), et *The Mariners' Museum—TMM* (le musée des marins) a permis de récupérer plus de cinquante objets en caoutchouc provenant du canon de tourelle rotatif et du moteur à vapeur de l'USS Monitor. Ces objets en caoutchouc sont un seau de jarre en verre, un peigne, des boutons d'uniformes et des joints d'étanchéité de canalisation. La découverte d'artéfacts en caoutchouc gorgés d'eau, provenant d'un milieu marin riche en sels, constitue une occasion exceptionnelle pour examiner les grandes questions de l'heure en ce qui concerne la manipulation, le transport et la mise en réserve de ce type d'objets produits pendant la guerre civile. Une recherche sur les traitements de conservation, tels que le nettoyage chimique et l'électrophorèse, fut entreprise pour déterminer l'efficacité des méthodes pour l'élimination des chlorures et des produits de corrosion. Un stockage en milieu anoxique, à l'aide du système RP, a été choisi comme mesure de conservation préventive. L'ouverture du centre USS Monitor, doté d'un laboratoire à la fine pointe et d'une exposition dédiée aux objets découverts sur le Monitor, permet de sensibiliser le public à l'aide de présentations interactives et de postes permettant de voir le travail en cours dans les ateliers, ce qui augmente l'éveil du grand public aux processus de restauration.

TITULO—La excavación, conservación, almacenamiento y exhibición de artefactos de caucho de la nave USS Monitor (1862) RESUMEN—En un esfuerzo conjunto de investigación entre la National Oceanographic and Atmospheric Administration—NOAA (Administración Nacional Oceánica y Atmosférica), la United States Navy—USN (Armada de los Estados Unidos), y The Mariners' Museum—TMM (Museo de los Marineros), más de cincuenta artefactos de caucho han sido recuperados de la torre giratoria de tiro y de la máquina de vapor de la nave USS *Monitor*. Estos objetos de caucho incluyen el sello de un tarro de vidrio, un peine, botones de uniforme y juntas de cañería.

Los artefactos de caucho sumergidos en agua altamente salina presentan una oportunidad única para examinar cuestiones actuales de conservación tales como la manipulación, el tratamiento y el almacenamiento de objetos de caucho fabricados durante la Guerra Civil. Cuando se manipulan artefactos de caucho vulcanizado durante su tratamiento y almacenamiento, la salud y la seguridad deben ser muy tenidas en cuenta. Para determinar la eficacia de métodos específicos de remoción de cloruros y de productos de corrosión, investigamos tratamientos de conservación como limpieza química y electroforesis. El almacenamiento libre de oxígeno que utiliza el sistema RP fue elegido como un paso de conservación preventiva. La inauguración del Centro USS *Monitor*, un laboratorio y galería de exhibición con tecnología de punta para los objetos del *Monitor,* brindan la oportunidad de educar al público en general a través de exhibiciones interactivas y estaciones para observar el laboratorio, con lo que se aumenta la apreciación del público por los procesos de conservación.

TÍTULO—A escavação, conservação, armazenamento e exibição de artefatos de borracha recuperados do *USS Monitor* (1862) RESUMO—Num esforço conjunto entre a *National Oceanographic and Atmospheric Administration—NOAA* (Administração Oceanográfica e Atmosférica Nacional), a *United States Navy—USN* (Marinha dos Estados Unidos), e o *The Mariners' Museum—TMM* (Museu dos Marinheiros), mais de cinqüenta artefatos de borracha foram recuperados da torre do canhão giratório e da máquina a vapor do *USS Monitor*. Esses ítens de borracha incluem um selo de uma jarra de vidro, um pente, botões de uniforme e gaxetas de apito. Artefatos de borracha mergulhados em água de um ambiente altamente salino apresentam uma oportunidade única para exame de questões atuais de conservação, tais como manuseio, tratamento e armazenamento de objetos de borracha manufaturados durante a Guerra Civil. Foi realizada pesquisa em tratamentos de conservação, tais como limpeza química e eletroforese, a fim de determinar a eficácia de métodos específicos para remoção de cloretos e produtos corrosivos. O armazenamento livre de oxigênio, usando-se o Sistema RP foi escolhido como uma das etapas de conservação preventiva. A inauguração do *USS Monitor Center* (Centro do USS Monitor), um laboratório de última geração e uma galeria de exposição para os objetos do *Monitor*, oferece a oportunidade de educar o público em geral através de exposições interativas e de estações visíveis de laboratório que ampliam a consciência do público sobre o processo de conservação.

1. INTRODUCTION

In 1862, at a pivotal point during the Civil War, the USS *Monitor* was built to defend the wooden frigates from Confederate forces, namely the ironclad CSS *Virginia* (formerly the USS *Merrimac*). The ironclad sides of the *Monitor*, combined with her low draft and revolutionary rotating turret containing two 11-inch Dahlgren shell guns, changed the future of naval architecture and had a lasting international effect on shipbuilding. The epic Battle of Hampton Roads was fought on March 9, 1862, between the *Monitor* and the *Virginia*. Neither succeeded in sinking the other; however, neither vessel survived the year. The *Monitor* sank during a severe storm while under tow to North Carolina (fig. 1) and the *Virginia* was destroyed to prevent it from being recaptured by the Union fleet. Today, the *Monitor* rests in 250 ft. of seawater off the coast of Cape Hatteras, North Carolina. A sunken time capsule from 1862, the ship contains examples of military life and technology which survived the violent capsizing and deterioration processes during 144 years of burial.

Fig. 1. Lithograph from Harper's Weekly, 1863. Artists rendering of the sinking of the USS *Monitor* on December 31, 1862. Courtesy of The Mariners' Museum, LE3211.

The wreck site was located in 1973 by researchers from Duke University; in the late 1970s, smaller artifacts at risk of being swept away and lost were recovered. In 1998, the National Oceanic and Atmospheric Administration (NOAA) worked in conjunction with the United States Navy (USN) to recover large components of the vessel, mainly the propeller. The steam engine and condenser were recovered in 2001 and the gun turret was removed from the seabed in 2002. The Mariners' Museum (TMM) was designated as the official repository for artifacts from the USS *Monitor*, and conservation is currently being undertaken on both small finds and large objects such as the turret, engine, and condenser.

In addition to the innovative design of the *Monitor* by Swedish inventor John Ericsson, the materials used to build the vessel could be considered technologically advanced for its time. One example of a distinctive material found on the *Monitor* is rubber. The types of rubber artifacts excavated from the *Monitor* include a comb excavated from the interior of the turret, large buttons from a naval uniform, gaskets on the pipes and machinery of the engine, and a seal from one

Table 1. Table Illustrating the Rubber Objects Excavated from the USS *Monitor* and the Treatment that was Performed

Accession Number	Object	Original Condition	Treatment
MNMS.1990.001.019	Food Storage Jar Seal	Stable	Unknown
MNMS.2002.001.230	Comb	Iron Staining, Concretion	Mechanical Cleaning, 3% Hydrogen Peroxide,
MNMS.2002.001.187	Buttons	Iron Staining, Concretion	Mechanical Cleaning, 5% EDTA
Various	Pipe Gaskets	Iron and Copper Staining, Concretion	Mechanical Cleaning, 3% Ammonium Citrate

of the jars, the pickled contents of which remained preserved (table 1).

Factors considered in the treatment of these rubber objects included the removal of corrosion products, such as iron and copper staining, chlorides deposited from the surrounding seawater, and concretion, a mixture of minerals, including sand and shell, that are deposited to form a hard concrete-like layer on the surface of an object.

2. HISTORY OF RUBBER IN THE UNITED STATES

Natural rubber has been used for hundreds of years, with the first documented accounts of the Mesoamericans utilizing the unique material for *juego de pelotas* (ball games) around 1500 BC (Hosler et al. 1999). More than 3,000 years later, in 1832, the Roxbury India Rubber Company was established as the first commercial producer of rubber in the United States. The company failed soon after, due to problems with the uncured rubber (Goodyear 1855; Korman 2002). Charles Goodyear invented a method for curing the raw material by adding sulfur and other stabilizing compounds in the mid-1800s (Loadman 1993).

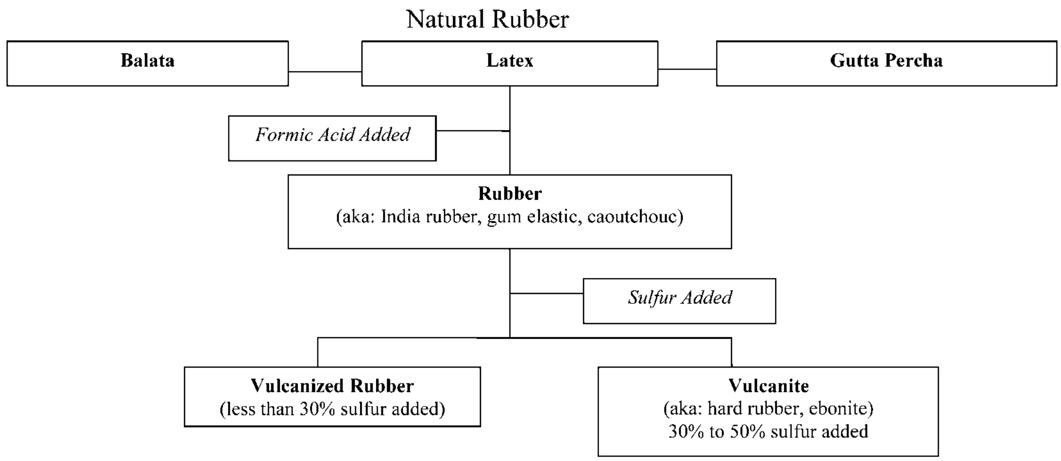
According to Goodyear's account (1855), there were several steps in producing a usable product. Firstly, the latex was cut, pounded and washed by an industrial machine. Secondly, in what is called the compounding stage, the latex was mixed with stabilizers and additives such as gums, oils, coal-tar carbon, earths and oxides, pulverized metal and ores, fibrous substances, lampblack, or ground cork. Sulfur was also added during the compounding stage by pouring it into the batch, by dusting it on the surface before placing the rubber into the heater, or by exposing the rubber to a sulfurous gas produced in the oven during the final heating stage. Which companies manufactured the rubber artifacts from the *Monitor* is not known, although there are Goodyear patent marks on the comb and buttons excavated from the turret.

Natural rubber is an elastomeric polymer produced from latex, a milky colloidal suspension obtained from the sap of some plants. The term vulcanization is derived from the name of the Roman god of fire and volcanoes, Vulcan, and indicates that sulfur has been added to the rubber to increase its strength and durability.

3. EXCAVATION

Several small items were recovered from the wreck site in 1979, including a food storage jar that was excavated from the area of the captain's cabin. The glass jar was fitted with a rubber gasket, a wax seal, and a glass lid (fig. 2). The lid of the jar is marked "Hartell's Glass-Air Tight Cover" and there is a patent date of 1858 on the top of the lid. The relish inside was analyzed and found to contain cloves, onions, pepper seeds, cucumbers, mustard seeds, peppercorns, and mushrooms. The remarkable preservation of the contents could be due in part to the sealing of the jar with the rubber flange that survived nearly 150 years, and in part due to its anaerobic burial environment.

In 2001, the steam engine and condenser were brought to TMM for conservation. The rubber objects associated with this machinery, such as rubber pipe gaskets, had served a more industrial purpose than the jar gasket (fig. 3), and they were more difficult to remove from their original context. The pipes used in the construction of the engine and the condenser were made from iron in some cases, and from



Latex: a milky substance obtained from specific plants that congeals when exposed to air
Rubber: a product of coagulating latex using formic acid, ammonia, or another chemical to stabilize it; used widely to describe materials that are elastic solids that do not conduct electricity nor absorb water.
Natural Rubber: usually referring to rubber made from latex as opposed to synthetic rubber.
India Rubber: same as rubber, possibly referring to the origin of rubber products from the Mesoamerican "Indians" or where rubber was imported from India.
Gum Elastic: same as rubber.
Caoutchouc: same meaning as rubber, most likely derived from a Spanish word used by the South Americans to describe a rubber tree.
Gutta Percha: common name for the plants that are specifically found in Asia, produces inelastic latex that softens when heated.
Vulcanite: hard, polished rubber that has been vulcanized (had sulfur added) using 30% to 50% of sulfur
Hard Rubber: same as vulcanite.
Ebonite: same as vulcanite.
Synthetic Rubber: artificial man-made material that resembles rubber (neoprene, IIR)

Fig. 2. Diagram of rubber terminology.

Fig. 3. A food storage jar excavated from the captain's cabin area. The rubber seal is on the lower right side. MNMS.1990.001.019.

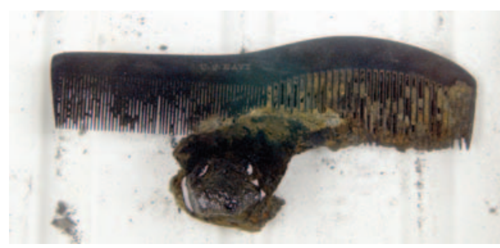


Fig. 4. A hard rubber comb excavated from the turret before treatment. Notice the concretion adhering to the teeth and the iron staining to the right. Length = 7 in. MNMS.2002.001.203.

a copper alloy in others. The rubber gaskets attached to each pipe displayed both iron and copper corrosion products, most likely due to the close proximity of the two types of pipes on the seabed. In most cases the rubber gaskets were well preserved, which may be due to the fact that they were sandwiched between the pipe flanges, preventing exposure and subsequent erosion and damage caused by organisms in the surrounding seawater. The gaskets were all constructed of alternate layers of rubber and cotton plain-weave textile (fig. 4). The number of layers varied on each gasket according to its deterioration. There were several gaskets that remained in situ on the pipes of the engine and condenser that are expected to be removed during the disassembly stage.

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Fig. 5. Comb after treatment. The impressions in the rubber are magnified. MNMS.2002.001.203.

Fig. 6. Two of the hard rubber buttons from Novelty Rubber Company. Notice the iron staining on the surface and the raised surface decorations. Length = 1 1/2 in. (Image courtesy of The Mariners' Museum. MNMS.2002.001.187.

In the following year, the turret was partially excavated by Navy divers, lifted from the seabed, and brought to TMM. Smaller personal items, such as the comb and buttons, were excavated from the sediment that filled the gun turret. Although the removal of sediment is ongoing, the excavation of the turret mainly took place over a three-month period in 2002.

During excavation, two sets of human remains were found next to the port hatch inside the turret. The hard rubber comb was located next to the leg bone of one of these two individuals. When removed from the sediment, the comb was heavily encrusted with marine deposits, and somewhat stained with iron on the surface (fig. 5). The comb is stamped with "U.S. Navy" on one side and "I R Comb Co. Goodyears Patent May 61" on the other side. The presence of the impressions reveal that the comb was a military-issue item produced in 1861 by the India Rubber Company.

Also found in proximity to the human remains were eight hard rubber buttons, 1–1/2 in. in diameter, from an overcoat belonging to the first individual recovered (fig. 6). Surface decorations include the letters "U.S.N." above the four center thread holes and three five-point stars across the middle; below the stars is a fouled anchor. On the reverse side the following is printed in raised lettering in a circular arrangement around the four thread holes: "Novelty Rubber Co. Goodyear's Patent 1851 New York." Four additional rubber buttons were found in the aft area of the turret on the port side; these buttons have the same surface decorations as those described above.

4. CONSERVATION

Although the conservation of rubber from a highly saline, waterlogged environment is complicated by the presence of corrosion products and marine concretions, in most cases staining due to metal corrosion products is superficial. Rubber does not appear to absorb water or chlorides as easily as do other organic materials, based on the rate of chloride extraction and the total air-drying time. Even so, it is necessary to remove chlorides from waterlogged material as they can accelerate the rate of deterioration through mechanical damage (North 1987; North and MacLeod 1987).

Chloride analysis was performed using two methods, comparing results to ensure accuracy. A Fisher Accumet AR25 unit equipped with an Orion Chloride Ion Selective Electrode was standardized with three chloride solutions before analysis: 10 ppm, 100 ppm, and 1000 ppm. A second technique used to analyze chloride extraction was the Jenway PCLM3 chloride titration unit. Desalination for all organic materials was accomplished in changing baths of deionized water at 1-week intervals. The water level varied according to the size of the storage container. There was no agitation, due to the fragile nature of the waterlogged organic materials. An object was considered to be chloride-free when a reading of 1 ppm or less was obtained at the end of the week of soaking.

Limited research has been performed into the conservation of rubber from a waterlogged environment, perhaps due to the lack of sample material. Singley (1988) discusses the conservation of rubber from freshwater environments, but it appears little is understood about the deterioration processes. Florian (1987) also discusses rubber, but in a limited context.

4.1 CONSERVATION OF THE JAR SEAL

The relish jar seal was originally treated in 1980, and retreatment is currently being considered due to crystal growth on the surface in recent months. The exact composition of the clear crystals is unknown; there are no conservation records for the previous treatment. Scanning electron microscopy (SEM) analysis thus far has produced inconclusive results. One suggestion is that the rubber was improperly desalinated and chlorides have migrated to the surface and crystallized. Additional analysis with x-ray diffraction (XRD) is being conducted to determine the source of the formations.

Fig. 7. Part of the collection of rubber gaskets from the *Monitor* steam engine. Notice the variety in size and condition.

4.2 CONSERVATION OF THE HARD RUBBER COMB AND BUTTONS

The hard rubber comb and buttons were initially disfigured by overall iron staining and concretion. Under microscopic reexamination, no pitting or surface damage is currently observed. Documentation of previous treatment is incomplete (Peterson 2003a), but does describe the previous treatment to remove chlorides. First, the objects were subjected to extensive soaking in 5 changing baths of deionized water over a 3-week period. The exception was for one set of buttons that was stored in 1% aqueous sodium hydroxide to assist in removing chlorides. Secondly, corrosion products were chemically removed by soaking in a single bath of a 5% (w/v) aqueous solution of ethylenediaminetetraacetic acid (EDTA) for 1 week. The objects were then rinsed in 3 changing baths of deionized water for 1-week intervals to remove any chemical residues. After any chemical treatment, the artifact was soaked in a rinsing bath, typically for the same amount of time as the duration of the chemical treatment, to ensure removal of all remnants of the chemical. The pH of the rinsing baths was monitored, and a pH of 7 was deemed to indicate that the EDTA had been removed.

As part of the 1980 treatment, concretions found on the comb were removed mechanically and chemically (fig. 7) (Peterson 2003a). On each object, the concretion varied in thickness and adhered firmly to the surface of the organic material. The 1980 report states that dental tools and a Chicago Pneumatic CP-9361 air scribe were successful in removing any staining and loosening concretions. Areas on the hard rubber buttons where concretions could not be removed mechanically were soaked for 24 hours in a 3% (v/v) aqueous solution of hydrogen peroxide. Hydrogen peroxide reacts with the carbonates of the concretion and dissolves them, producing carbon dioxide (Pearson 1987). The more stubborn concretions were subjected to a 5% (v/v) aqueous solution of oxalic acid or a 2% (v/v) aqueous solution of phosphoric acid bath for a 6-hour period (Hamilton 1999).

Current treatment was limited to soaking the hard rubber objects in deionized water to remove chemical residues, then allowing them to air-dry in environmentally controlled storage.

4.3 CONSERVATION OF THE RUBBER GASKETS

Iron and copper corrosion products were removed from the surface of some of the rubber gaskets from the steam engine and condenser. Approximately 15 of the 30 gaskets removed during the 2001 documentation and treatment of the engine were originally treated with glycerol (Peterson 2003b). It is uncertain why glycerol was used; it may have been suggested as a substitute for polyethylene glycol, which is used as a bulking agent for the conservation of waterlogged plant materials.

It was necessary to remove the glycerol because it had produced a tacky surface that attracted particulate matter in the storage environment. It should be noted that thus far, no bulking material has been required for rubber artifacts. With the previous treatment in mind,

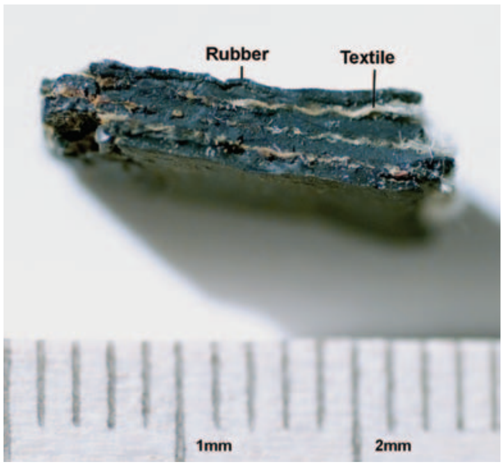

Fig. 8. Cross-section view of a fragment of rubber showing distinct layers of rubber and textile. MNMS.2001.003.069C.

four main objectives were identified for the treatment for the rubber gaskets, both the previously treated and the newly excavated ones: remove the previous treatment of glycerol (where necessary), eliminate iron and copper corrosion products, mechanically clean the adhering concretion, and extract chloride ions from the matrix of the rubber.

4.3.1 Physical Characteristics

As part of the documentation of the rubber gaskets, all of the gaskets were tested for chemical characteristics such as vulcanization and pH. A simple test outlined in Saunders (1966) was used to confirm that the gaskets were made of vulcanized rubber. For this test, a fragment of rubber gasket with no context (MNMS.2001.003.069C) was submerged in toluene. When latex is exposed to toluene, it will dissolve. Swelling rather than dissolving in response to toluene indicated that the rubber had been cross-linked with sulfur. A second sample was submerged in concentrated nitric acid and produced brown smoke, also indicating that the rubber had been vulcanized.

The surface pH of each gasket was measured using ColorpHast test strips, by applying a drop of deionized water to the strip and pressing it against the surface of the rubber (fig. 8). Generally, the gaskets measured between pH 4 and 7.

The presence of lead was suspected on the surface of the gaskets, possibly due to the use of a lead-containing pipe sealant during the original deployment of the gasket. Each gasket was surface-tested for the presence of lead using a Plumbtesmo lead test. A drop of deionized water was placed on the test strip and then applied to the suspected area. This produced 3 positive results out of the 30 gaskets tested. X-radiographs were then taken to determine if the lead could be located visually. Because of its density, lead was indicated by solid white areas on the radiographs (Grieve 2006). Those gaskets that contained lead were treated in separate deionized water baths to ensure preservation of the sealant and to prevent contamination of other gaskets.

4.3.2 Chemical Treatment

The engine and condenser contained several different types of pipes with flanges, some composed of iron and others of copper alloys. Rubber gaskets found attached to each flange were removed when possible. A suitable method was needed for removing the chlorides from the rubber gaskets taken from the engine, and an appropriate treatment was needed to ensure their long-term stability in storage and on display.

In some cases where iron staining was not present, it was necessary only to soak the rubber in frequently changed baths of deionized water. The gaskets that had been treated with glycerol were soaked in changing baths of deionized water over a 2-month period. This method was successful in removing the glycerol, but did not affect the iron and copper corrosion products. An additional experiment was conducted using 2% (w/v) aqueous dibasic ammonium citrate as a chelating agent; this method was very successful in removing the iron corrosion products.

Electrophoretic removal of concretion and extensive iron and copper staining was evaluated, with inconclusive results (Grieve 2006). In electrophoresis, the gasket is placed in an electrolytic solution between an anode and a cathode, which attract corrosion products away from the object depending on polarity (La Baume 1989; Pennec et al. 1989; Bergeron 2005).

5. RESULTS

The primary goal in the conservation of waterlogged materials recovered from saline environments is to remove any chlorides that have penetrated the surface. This was achieved by soaking the rubber objects in deionized water, refreshing the deionized water at 1-week intervals until the levels reached less than

1 ppm. The removal of staining, such as iron and copper corrosion products, was most efficient using a 2% (w/v) aqueous solution of dibasic ammonium citrate. Mechanical cleaning using an ultrasonic dental scaler was also helpful in loosening adhered surface material, but required great care not to damage or puncture the surface of the rubber. Concretion on organic materials from a waterlogged site can be integrally bound and cause mechanical tears during detachment. Some artifacts were cleaned mechanically with an air scribe, but more often a 3% (v/v) aqueous solution of hydrogen peroxide was satisfactory in loosening surface encrustations, followed by repeated rinses in deionized water to minimize oxidation of the rubber.

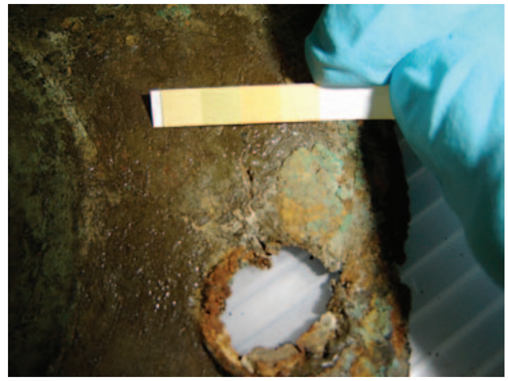

Fig. 9. Surface testing of the pH of the gaskets using a colorpHast pH strip. Notice the oily reflective surface of the glycerol and the flaking corrosion products.

6. HANDLING RUBBER ARTIFACTS

As with any archaeological object, correct handling of rubber artifacts will minimize potential damage to the material, whether mechanical or chemical. Additionally, handling vulcanized rubber may be potentially dangerous to staff, due to the deterioration of the original chemicals used during manufacture; recipes for rubber were closely guarded trade secrets and additives are often unknown and difficult to detect. To avoid absorption of harmful chemicals through contact with the skin, appropriate safety measures should be taken, including wearing non-porous nylon powder-free gloves.

In transport, the inherently soft rubber objects should be properly padded to prevent surface puncturing. Tissue paper should not be used in contact with the rubber surface, as it could adhere to any tacky areas. Mylar or silicone release paper can be used as an interface between the rubber surface and padding materials. A valuable tool for securing rubber items to a display support is Teflon tape, which will also not adhere to the surface of the rubber. Because the long-term stability of Teflon tape has not been thoroughly tested, it should not be used for storage.

7. STORAGE CONDITIONS

Appropriate storage conditions will inhibit deterioration of rubber artifacts. Deionized water should be used for wet storage of waterlogged rubber until treatment is commenced. It is not necessary to add chemicals to assist in the removal of chlorides. The decision to submerge the object in a chelating agent should be decided on a case-by-case basis, depending on the extent of iron staining. It has not been documented that metal corrosion products, namely iron and copper, penetrate the rubber. It may help to place the container in a refrigeration unit to reduce algae and bacteria growth, but a freezer should not be used if the object has retained water.

Storage conditions should be below 75°F (25°C) and at or below 50% RH. The UV radiation in direct sunlight can be harmful. While a completely dark environment prevents viewing the object, it inhibits deterioration from ultraviolet rays that break down polymer chains (Florian 1987; Baker 2001). Rubber objects are also subject to damage from mechanical stress, so should not be stored stacked or under continuous pressure from contact with storage materials (Singley 1988; Ward and Shashoua 1999; Ciesielski 2000).

The process of vulcanization uses sulfur to improve the working qualities of the rubber. As suggested in Florian (1987), sulfur may oxidize in the presence of water and corrosion products to form sulfuric acid. This could indicate a future problem for storage. Because one concern with the dry storage of rubber is harmful oxidation of the rubber, the Mariners' Museum currently stores rubber artifacts in an anoxic environment using the RP System, K Type from Mitsubishi, in conjunction with Escal enclosure systems (fig. 9). The Escal bags can be further sealed at joins with aluminum tape, available at most local hardware stores. Oxygen sensors can be included in the packaging of the object to determine if the oxygen has been completely removed or if the bag has a leak, but these are often unreliable and have a short shelf life.

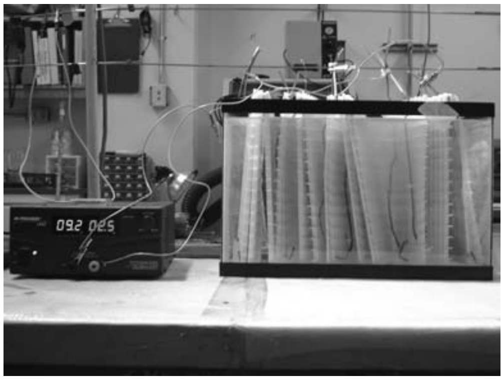

Fig. 10. The arrangement for the electrophoresis experiment. The power source is located to the left. The white crating system was designed to protect the rubber during treatment.

Fig. 11. The RP-K 20 system in use on a rubber gasket. The gasket is enclosed in an Escal bag and heat sealed. Aluminum type is then placed around the seal. The RP is in the center in a polyethylene bag. A coroplast board is placed under the gasket for support.

Indicator cards are used to monitor the relative humidity, and can be seen through the Escal bags.

8. DISPLAY

At the USS *Monitor* Center, designed to commemorate the Battle of Hampton Roads, some exhibition galleries are devoted to artifacts recovered from the USS *Monitor*. On display are numerous organic materials including leather shoes, wooden objects, and the rubber personal items.

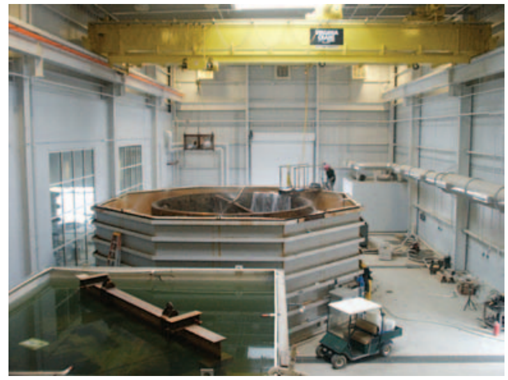

Fig. 12. The USS Monitor Center wet laboratory. The engine is in the foreground and the turret is in the background.

Display cases that were designed to contain organic material are located in areas without natural light. The glass windows have a coating to prevent UV rays from penetrating the exhibit area. When the rubber objects are displayed with other organic material in an enclosed space, the RP-K sachets are used to remove oxygen and corrosive gases; a reasonably safe 50%RH is maintained using conditioned silica gel and is measured with relative humidity indicator cards and digital dataloggers.

There is a potential for rubber to off-gas sulfur fumes when enclosed in a case or an Escal bag, which may cause deterioration of other materials in the case, possibly accelerating tarnishing of silver and copper alloys, and increasing sulfur-compound formation on leather and wood artifacts. Recent research in the conservation of waterlogged wood suggests that wood, and possibly other organic material, absorbs sulfur from the burial environment and over time produces sulfuric acid (Sandström et al. 2001). This process may be accelerated by sulfur off-gassing from rubber.

9. CONCLUSION

While it is not unknown to discover rubber artifacts on archaeological sites, techniques to conserve rubber are not well known. The best chance for the preservation of rubber begins as soon as the material is excavated, by using proper storage and transportation materials. Conservation of rubber can be as simple as controlling the relative humidity and temperature of the dry storage environment, and as complex as chemical extraction of corrosion products. The variety of rubber artifacts found on the *Monitor* wreck site allows conservators a chance to study and analyze several different types of rubber manufactured and used during the Civil War. The final storage of the rubber objects is perhaps the most crucial step in the conservation process. By removing the oxygen and maintaining a stable environment, the life of the object is prolonged. Rubber can be safely displayed if certain guidelines are followed. It is not always understood that rubber was in use as early as the Civil War in North America; its exhibition affords a unique opportunity to educate the public on material science and conservation processes.

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REFERENCES

Baker, M. T. 2001. Polymers in museums. In *Historic textiles, papers, and polymers in museums*, ed. J. Cardamone. Washington, D.C.: American Chemical Society.

Bergeron, A. 2005. Conservation treatments of the organic artifacts recovered from the Elizabeth and Mary. *Proceedings of the ICOM Conservation Working Groups on Wet Organic Archaeological Materials and Metals*. Copenhagen, Denmark. Bremerhaven: International Council of Museums.

Ciesielski, A. 2000. *An introduction to rubber technology*. Shropshire, England: Rapra Technology Limited.

Florian, M.-L. E. 1987. The underwater environment. In *Conservation of marine archaeological objects*, ed. C. Pearson. London: Butterworths.

Goodyear, C. [1855] 1939. Gum-elastic and its varieties, with a detailed account of its application and uses, and of the discovery of vulcanization. In *A centennial volume of the writings of Charles Goodyear and Thomas Hancock comprising "Gum-elastic and it's varieties..." by Charles Goodyear and the "Personal narrative of the origin and progress of the Caoutchouc or India-Rubber manufacture in England" by Thomas Hancock, 1939*. Boston: American Chemical Society.

Grieve, S. 2006. Archaeological conservation of modern materials: A case study of waterlogged rubber gaskets from the USS *Monitor*. *Journal of Middle Atlantic Archaeology* 22:79–90.

Hamilton, D. 1999. Methods of conserving archaeological materials from underwater sites. http://nautarch.tamu.edu/class/anth605/File0.htm (accessed 4/19/07).

Hosler, D., S. Burkett, and M. Tarkanian. 1999. Prehistoric polymers: Rubber processing in ancient Mesoamerica. *Science* 284:5422.

Korman, R. 2002. *The Goodyear story: An inventor's obsession and the struggle for a rubber monopoly*. San Francisco, Calif.: Encounter Books.

La Baume, S. D. 1989. Archaeological wood desalinating by electrophoresis. *Conservation of Wet Wood and Metal: Proceedings of the ICOM Conservation Working Groups on Wet Organic Archaeological Materials and Metals, Fremantle, 1987. Volume 1*, ed I. D. McLeod; international wood study ed. by D. W. Grattan. Perth, Western Australia: Western Australian Museum. 153–163.

Loadman, M. J. R. 1993. Rubber: Its history, composition and prospects for conservation. *Saving the Twentieth Century: The Conservation of Modern Materials, Proceedings of a Conference Symposium*. Ottawa, Canada. Ottawa: Canadian Conservation Institute.

North, N. A. 1987. Conservation of metals. In *Conservation of marine archaeological objects*, ed. C. Pearson. London: Butterworths.

North, N. A., and I. D. MacLeod 1987. Corrosion of metals. In *Conservation of marine archaeological objects*, ed. C. Pearson. London: Butterworths.

Pearson, C. 1987. Conservation of ceramics, glass, and stone. In *Conservation of marine archaeological objects*, ed. C. Pearson. London: Butterworths.

Pennec, S., N. Lacoudre, and J. Montluçon 1989. The conservation of Titanic artefacts. *Bulletin of the Australian Institute for Maritime Archaeology* 13(2):23–26.

Peterson, C. 2003a. Conservation report for the rubber comb and buttons. The Mariners' Museum, Newport News, Virginia.

Peterson, C. 2003b. Conservation report for the rubber gaskets. The Mariners' Museum, Newport News, Virginia.

Sandström, M., F. Jalilehvand, I. Persson, U. Gelius, and P. Frank. 2001. Acidity and salt precipitation on the Vasa; the sulfur problem. *Proceedings of the 8th ICOM-CC Wet Organic Archaeological Materials Conference*. Stockholm: ICOM.

Saunders, K. J. 1966. *The identification of plastics and rubbers*. London: Chapman and Hall Ltd.

Singley, K. 1988. *The conservation of archaeological artifacts from freshwater environments.* South Haven, Mich.: Lake Michigan Maritime Museum.

Ward, C., and Y. Shashoua. 1999. Interventive conservation treatments for plastics and rubber artefacts in the British Museum. *ICOM Committee for Conservation 12th triennial meeting*. Lyon, France. London: James & James.

SOURCE OF MATERIALS

ColorpHast pH Test Strips (Product #9590-3)
Potassium Nitrate (Product #BP368-500)
Product #9590-3
Fisher Scientific Inc.
2000 Park Ln.
Pittsburgh, PA 15275
(412) 490-8300
www.fishersci.com

Coroplast Support
Silicone Release Paper
Talas
20 West 20th St.
New York, NY 10011
(212) 219-0770
www.talasonline.com

Plumbtesmo Lead Test Paper
Macherey-Nagel Inc.
6 South Third St.
Suite 402
Easton, PA 18042
(610) 559-9848
www.macherey-nagel.com

Ammonium Citrate, Dibasic
Jost Chemical
8150 Lackland Road
St. Louis, MO 63114
(314) 428-4300
www.jostchemical.com

Ageless and the RP System
Mitsubishi Gas and Chemical
655 Third Ave.
24th Floor
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www.MGC-A.com

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