Consolidant Application for Polyurethane Ester Foam: The Treatment of a Headset from NASA's Skylab Missions.

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Motivation for Consolidation Study of PUR foam:

Headsets from the Skylab Missions in the NASM collection possess badly deteriorated foam on the ear-cushions of these composite objects. The collection of 42 Skylab headsets all have foam deterioration issues, which served as the impetus to develop a treatment methodology to preserve these technical heritage objects.

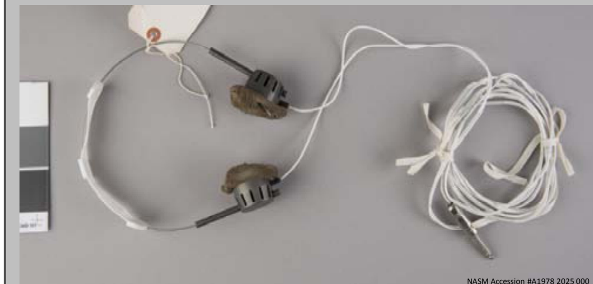

Figure 1: Skylab headset overall, before treatment.

Before Treatment Condition

Figure 2 and 3: Details of the headset and the foam ear-cushions before treatment condition: The most significant area of deterioration on the headset is the polyurethane (PUR) ester foam ear-cushions which are stiff, brittle, and actively crumbling to powder. There are deformations, indentations, and cracks. Additionally, the foam has no characteristic spring-back.

Treatment Objectives: The goal of the treatment is to stabilize the deteriorating foam ear-cushions to preserve the material structure overall, and return the foam's flexibility with minimal alteration to the surface (i.e color shift, or change in shape). If left untreated the foam will continue to shed material and become completely detached.

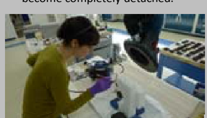

Figure 4: Consolidating the foam ear-cushions with Impranil applied via an airbrush with the compressor set at 30 psi.

Figure 5: Plastic component wrapped with Teflon tape before treating the foam.

Treatment Methodology:

The PUR ester foam ear-cushions were consolidated in a multi-step process.

1) The foam was pre-treated with isopropanol misted onto the surface with a Dahlia sprayer. The components adjacent to the foam were protected with Teflon tape.

2) Immediately following the isopropanol application, a v/v solution of (1:6) Impranil DLV/1: distilled water with 10% Isopropanol was applied using an airbrush with a pressure of 30 psi. The airbrush was held a few inches away from the surface of the foam during application. To ensure an even coating the airbrush was moved in circular motions over the surface which prevented overlapping lines of consolidant.

3) The airbrush was then used to distribute a flow of air at 30 psi over the treated foam to work the Impranil solution deeper through the foam matrix.

4) One more coating of Impranil solution was applied once the first application dried overnight.

After Treatment:

Figure 6 and 7:(Left) overall, (right) detail of PL ear-cushion :The ear-cushions are now structurally stabilized as evidenced by the lack of shedding foam. The hardness of the foam is still present, however, the brittleness has subsided and slight spring-back is observed. The color appears as a deep brown tone, which is different from its before treatment gray-brown color.

Introduction

Polyurethane (PUR) foam is found as a component of many composite artifacts in the National Air and Space Museum (NASM) collection. PUR foam is highly susceptible to degradation, and when it begins to deteriorate can transform into a fragile crumbly powder. This type of deterioration causes severe material loss and disrupts the interpretation of the artifacts' intended use. This research project was aimed at developing a treatment methodology for deteriorating polyurethane foam found on composite technological objects. A brief survey of 1970's communication devices with PUR foam in NASM's collection revealed a grouping of headsets from NASA's Skylab era that served as a collection for our case study. Our objectives were to 1) conclusively characterize the foam as either ester or ether based PUR foam using Fourier Transform Infrared spectroscopy (FTIR) (2) develop a treatment methodology to stabilize the foam so that the treatment could be implemented on all Skylab headsets in collection (3) evaluate our methods to determine the success of the treatment methodology.

Polyurethane Foam Characterization

PUR foam is fabricated by the reaction of a polyether or polyester polyol (an alcohol with at least two reactive hydroxyl groups) with a di-isocyanate compound and water (Van Oosten 2011: 21). The addition of water produces carbon dioxide gas within the solution mixture, causing it to rise and expand into flexible, cushioning foam.

Characterization of PUR Foam with FTIR

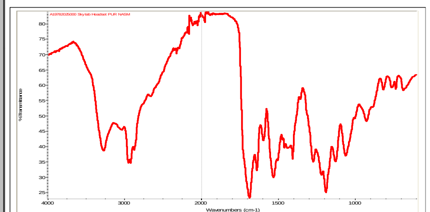

Figure 8: FTIR spectrum from the ear cushion on the Skylab headset. The analysis identified the foam to be polyurethane foam ester, due to the presence of the ester carbonyl absorption peak located at the 1725 cm^{-1} and the ester linkage (O=C-C-O-C) absorption peaks at 1218, 1170, 1124, and 1078 cm^{-1} (Van Oosten 2011: 63).

Structural Qualities of PUR Foam:

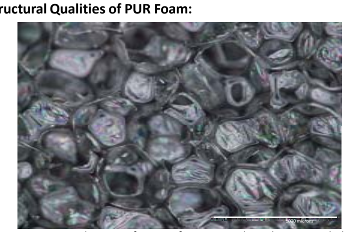

Figure 9: Under magnification foam in good condition revealed an ordered, open-cell structure comprised of many narrow struts that branch together.

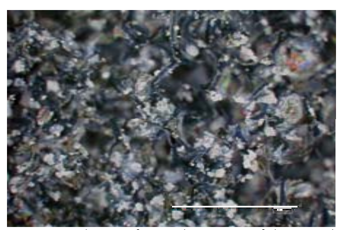

Figure 10: Under magnification the structure of deteriorated foam shows a collapsed of the open-cell structure.

Experimental Methodology

Mock-up samples were prepared using packing foam used to house an object from c. 1970s. Imprantil DLV/1 (an anionic aliphatic polycarbonate-polyether polyurethane dispersion in water) was selected as a consolidant after conducting a literature search on past treatments of PUR foam. Impranil DLV/1 was selected due to its extensive testing by Van Oosten (2004, 2011).

Figure 11: Foam squares cut to 3x 3 x3 inches approximately were prepared for consolidation experiments and were photographed in visible and UV light before and after consolidation experiments.

Experimental Methodology Continued

Fluorescent trackers:

Impranil DLV/1 gives no fluorescence as a dried film or when applied to foam. In order to track the depth of penetration of the consolidant we added a small amount of a fluorescent tracker into the Impranil DLV/1. Initial experiments were carried out with fluorescent water soluble Nano Dots. Due to the amount of Nano Dots required to fluoresce within the Impranil DLV/1 in solution (plus their cost), Rhodamine-B was ultimately selected as the tracking agent of choice.

Figure 12: UV image of fluorescent water soluble Nano Dots in Impranil DLV/1.

Figure 13: UV image of Fluorescent Rhodamine- B in Impranil DLV/1.

Application Techniques:

Initial application experiments included using the following (1) nebulizer, (2) commercial spray mister called "Misty Mate", (3) an airbrush attached to a compressor. The ideal goal was to achieve an even distribution of the Impranil DLV/1 solution across the surface of the foam and to deliver the consolidant with a depth of 6 mm, which related to the depth of the foam on the Skylab headsets. The florescent tracker was utilized to evaluate the depth of penetration by examining the samples under ultraviolet (UV) light.

Results of Application Techniques

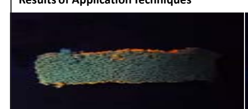

Figure 14: UV image of mock-up foam consolidant applied by nebulizer.

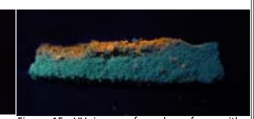

Figure 15: UV image of mock-up foam with consolidant applied with the Misty Mate.

Undesirable results where obtained from both the nebulizer and the Misty Mate. The UV images show that the consolidant traveled less then 2mm into the foam and was either barely visible on the surface (figure 14) or was thick and uneven across the surface (figure 15).

Figures 16: UV image of mock-up foam pre-treated with isopropanol via Dahlia sprayer, followed by applying the consolidant solution with an airbrush at 30 psi. Forced air at 30 psi was then applied over the surface to work the consolidant into the foam matrix.

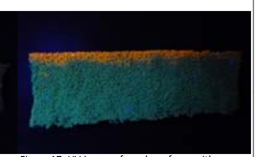

Figure 17: UV image of mock-up foam with consolidant solution applied by airbrush at 30 psi without isopropanol pre-treatment.

Samples in figures 16 and 17 illustrate desirable results due to the depth of 6 mm penetration, along with an even surface distribution.

Conclusions for the Application Technique: The mock-up sample in which the foam was pre-treated with isopropanol prior to applying the consolidant solution with the airbrush at 30 psi, followed by pushing a stream of air at 30 psi over the surface was the most successful and was ultimately chosen as the treatment technique for the foam ear-cushions on the Skylab headset. Using the airbrush to push air through the foam after the initial application of Impranil seemed to be the critical factor in achieving the desired depth of consolidant penetration.

Exploratory Evaluation of the Treated and Untreated PUR Foam

The scanning electron microscope (SEM) was used in a preliminary study to observe the consolidated and unconsolidated areas of foam while comparing the different application techniques. The samples were prepared by cutting 3mm squares from the treated mock-up foam samples seen in figures (14-17). Each mock-up foam sample was cut to incorporate the intersection of treated and untreated areas. Images were taken of these regions for visual comparison.

Results of Exploratory Evaluation with SEM:

Figures 18 and 19 show consolidant solution applied to the foam with the Misty Mate application technique (macro sample seen in figure 15). Foam consolidated with this technique shows little difference between treated and untreated foam.

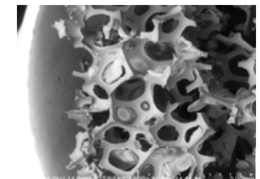

Figure 18: Area consolidated foam showing disjointed structures, many gagged, broken, frayed and torn edges.

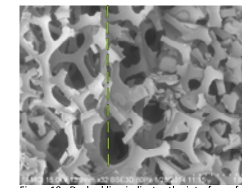

Figure 19 : Dashed line indicates the interface of consolidated (Right) and unconsolidated(Left) showing very little difference overall between the two areas.

Figures 20 and 21 show results of the application technique where the foam was pre-treated with isopropanol followed by consolidant solution applied by air brush at 30 psi followed by forced air at 30 psi (macro sample seen in figure 16). These images suggest that the forced air pushes the small disjointed bits of foam away from the structurally sound areas which results in the ordered structures that we see in the treated areas of these images.

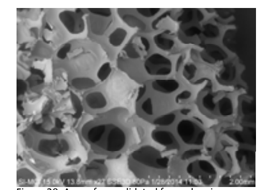

Figure 20: Area of consolidated foam showing an ordered structure open-cell structure with the struts having few breaks or tears, and minimal fraying and tearing along the edges.

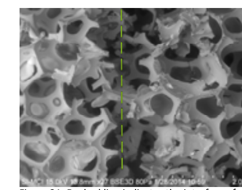

Figure 21: Dashed line indicates the interface of consolidated (Left) and unconsolidated(Right) foam showing many more broken and dislodged pieces of foam on the right side. The interface shows a disturbing break at the interface, which may be a result of sample preparation.

Figures 22 and 23 show results of the application technique where the consolidant solution was applied by air brush at 30 psi without isopropanol pre-treatment (macro sample seen in figure 17). Small breaks can be seen at the top left of the foam in figure 22 where the edges appear minimally frayed, possibly due to lack of pre-treatment which appears to lower the surface tension of the foam allowing the consolidant greater penetration.

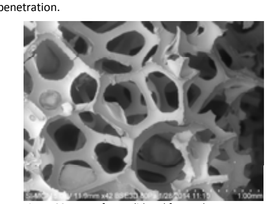

Figure 22: Area of consolidated foam where we see an ordered open-cell structure to the foam, with minimal breaks or small dislodged bits of foam within the struts.

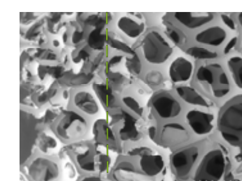

Figure 23: Dashed line indicates the interface of consolidated (Right) and unconsolidated(Left) foam. The area of jumbled foam with collapsed cells at left most likely illustrating the affects of the airbrush pushing dislodged foam to the left.

Conclusions for the Exploratory SEM Evaluation : The SEM images of the different application techniques suggest that the action of the airbrush at 30 psi to deliver the consolidant solution has a desirable affect on the foam, resulting in a return to the foam's open cell structure. The air pressure could be pushing small, dislodged foam bits from structurally intact areas thereby allowing the consolidant to travel further into the matrix. The first experiments with techniques lacking sufficient air pressure show disjointed and collapsed cell structures of the foam that were then consolidated in this damaged state. The experiments on the mock-up foam were instrumental in helping us determine desired results before attempting treatment on the Skylab headsets. While this study is very preliminary we believe that these initial results represent a good starting point for future studies of the issues with composite objects containing PUR foam.

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