FEATURE

Reliability study of an emerging fire suppression system

Self-contained fire extinguishers are a robust, reliable and minimally invasive means of fire suppression for gloveboxes. Plutonium gloveboxes are known to present harsh environmental conditions for polymer materials, these include radiation damage and chemical exposure, both of which tend to degrade the lifetime of engineered polymer components. The primary component of interest in self-contained fire extinguishers is the nylon 6-6 machined tube that comprises the main body of the system.

Thermo-mechanical modeling and characterization of nylon 6-6 for use in plutonium glovebox applications has been carried out. Data has been generated regarding property degradation leading to poor, or reduced, engineering performance of nylon 6-6 components. In this study, nylon 6-6 tensile specimens conforming to the casing of self-contained fire extinguisher systems have been exposed to hydrochloric, nitric, and sulfuric acids. This information was used to predict the performance of a load bearing engineering component comprised of nylon 6-6 and designed to operate in a consistent manner over a specified time period. This study provides a fundamental understanding of the engineering performance of the fire suppression system and the effects of environmental degradation due to acid exposure on engineering performance. Data generated help identify the limitations of self-contained fire extinguishers. No critical areas of concern for plutonium glovebox applications of nylon 6-6 have been identified when considering exposure to mineral acid.

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INTRODUCTION

The most effective protection from radioactive materials is engineered barriers and has been incorporated through architectural and structural design.[1] Potential engineering controls include differential ventilation pressure zones, High-Efficiency Particulate Air filtration, radiation shielding, and gloveboxes. Gloveboxes used for radioactive materials are maintained at a lower pressure than the surrounding room atmosphere so that relatively small leaks result in air inflow rather than radioactive material release. In addition, they are constructed of stainless steel to provide structural stability.

However, seismic events present unresolved issues in designing gloveboxes. One of the most challenging accident scenarios is the post-seismic fire event. History has shown that glovebox fires can be extremely dangerous and may pose significant health hazards when the products of combustion include radioactive and toxic materials.[2]

As previously reported in this journal, self-contained fire extinguishers were demonstrated to be a robust, reliable and minimally invasive means of fire suppression for gloveboxes.[3] They can be mounted to the interior of the glovebox. One example of such a system is the Fire Foe^{TM} system. This self-contained fire extinguisher employs a nylon tube that contains a jelled fire suppression media. The nylon tube is pressurized to 0.7 MPa at room temperature conditions, and the combination of thermally induced weakening of the nylon material associated with heat from the fire and expansion of the jelled fire suppression media causes the rupture and release of the fire suppressant.

The overall system reliability depends on the tube failing predictably for any given fire scenario. There will be variability in the time of release associated with variations in the fire signature. As previously reported in this journal, methodology has been developed to predict fire induced wall failure in small scale compartments such as gloveboxes.[4] A small scale test apparatus has been developed to characterize tube wall temperature and breakage properties. In this experimental campaign, the thermal environment that causes a tube wall failure has been determined. The study shows that

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Figure 1. Self-contained fire extinguisher tube.

the heat release rate and heat flux has been accurately modeled since forward predicted temperatures closely matched the experimentally measured values.

Plutonium gloveboxes are known to be a harsh environment for polymer materials. Radiation, chemical exposure, inert atmosphere, and dry (low humidity) atmosphere have high potential to degrade the lifetime of engineered components.[5–7] In the Fire Foe™ system, the primary component of interest is the nylon 6-6 machined tube that comprises the main body of the system, as seen in Figure 1.

The investigation of the remaining engineered components of the fire suppression system is beyond the scope of this study.

The reliability of nylon 6-6 due to exposure alpha radiation was recently studied.[8] The environment of a plutonium glovebox is such that the expected dose rate from radiological sources ranges to very high levels of over several Mrad per year in the worst case. In the worst case glovebox scenario, the plutonium radiation sources exist as a thick plutonium oxide (PuO_2) dust which layers onto every surface within the glovebox. Methodology has been developed to predict radiation induced wall failure in small scale compartments such as gloveboxes. The data showed evidence of slight degradation in the nylon 6-6 material with increasing levels of alpha particle dose. Variations in the level of alpha particle dose applied to the nylon material show discolorations which may prove useful as a quick reference to age of self-contained fire extinguisher systems within gloveboxes. There appears to be a much higher level of degradation in the specimens under neutron irradiation. Data generated from radiation induced degradation studies help identify the limitations of self-contained fire extinguishers.

Besides high levels of radiation, plutonium gloveboxes are also exposed to high levels of mineral acids. The goal of this report is to create a model by which the effects of mineral acids on nylon 6-6 could be quantified and from which conclusions on the shelf life and reliability of the self-contained fire extinguisher systems could be drawn. The effect of mineral acid induced mechanical property changes on failure mode and lifetime are also characterized.

In the following study, a literature review of material properties of nylon 6-6 was conducted to provide a fundamental understanding of the engineering performance of the fire suppression system and the effects of environmental degradation. Engineering analysis and material testing in nylon 6-6 were conducted that measures the performance of the material under acid induced degradation. This information will be used to aid in the assessment of the performance of a load bearing engineering component comprised of nylon 6-6 and designed to operate in a consistent manner over a designated time period.

DEFINITIONS

- *Creep* (sometimes called cold flow): The time dependent tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses, despite stresses being below the yield stress of the material.
- *Hardness*: The measure of the materials resistance to deformation and is related to the yield stress and fracture toughness of the material.

LITERATURE REVIEW

An article by Thanki and Singh provided an excellent review of nylon 6-6 degradation from photooxidative, thermal, radiative and sensitized degradation.[9] Degradation of properties is identified as an irreversible process stemming from small structural changes within the polymer induced by the environment. A second review article, by Fairgrieve, provided insight into the background of nylon 6-6 properties and degradation.[10] This article summarized the history, the degradation properties, stabilization, and recycling of nylon 6-6. The chemistry behind the material is described as well as the reactions that take place during the degradation process. Early stages of research showed that nylon 6-6 was susceptible to heat and light. This observation is consistent with observations with glovebox glove polymers reported in this journal.[11] The degenerative process was characterized as a discoloration followed by loss in physical properties. Photooxidative degradation is also apparent in nylon 6-6.

Brown et al. studied the effect of sulfuric acid on nylon 6-6.[12] In this study the diffusion rate of sulfuric acid was studied in nylon 6-6 at various concentrations and temperatures. The pH concentrations ranged from distilled water to 1.0 M sulfuric acid. The temperatures tested ranged from 20 to 90 °C. The degradation of the material was based upon yield stress, flexural modulus, and inherent viscosity.

The yield stress of the material was then compared with the saturation temperature at different concentrations. Water and 0.1 M sulfuric acid were shown to slightly increase the yield strength of the material with increasing saturation temperature. Although at higher temperature, the acid present showed signs of degradation. Higher concentrations showed a significant decrease in the yield strength of the material as the saturation temperature was increased. A similar trend was found for the flexural