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SPACE ENVIRONMENTAL EFFECTS ON POLYMERS AND COMPOSITES

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INTRODUCTION

The response of polymers and polymer-based composites to the space environment is being investigated. A wide range of materials are covered in this study, including elastomer seals for Space Station Freedom, polymer films for thermal control, and composites for space structural elements. Space environmental agents of concern include atomic oxygen, thermal cycling, space debris impacts, UV, charged particles and other forms of high-energy radiation. This ambitious project is potentially a multi-year research effort and the success of such a project could be expected to have a profound impact on the design of future space-based structures. The research goal of this first Summer is to identify the priority areas of research and to carry out the initial phase task so that a collaborative research can proceed smoothly and fruitfully in the near future.

PROJECT 1: SERVICE LIFE PREDICTIONS FOR SEAL ELASTOMERS

Accomplishments:

1. The most commonly used technique for studying the long-term performance of an elastomer seal--the compression set test--has been critically reviewed. A model has been developed to predict the compression set of an elastomer as a function of time and to provide insight into the molecular origins of compression set.

2. A simple standard linear solid model was utilized to derive constitutive equations that relate the compression set data to the corresponding stress relaxation and creep data for a given elastomer.

3. Effective techniques for studying elastomer degradation kinetics and mechanisms have been identified and the corresponding theoretical foundation has been established.

4. It is recommended that an extensive stress relaxation (or creep) test program be planned and carried out to cover a wide range of temperatures and radiation dose rates so that a master curve may be constructed to predict the service lifetime of an elastomer for space applications.

5. It is further recommended that an in-depth study be performed to understand the ageing mechanisms, at the molecular level, of select elastomers (e.g., S383 silicone and V747 fluorocompound rubber) over a wide range of temperatures. Proper thermal shift factors cannot be evaluated and the master curves cannot be constructed without the knowledge of degradation mechanisms for each elastomer. It is of particular significance to differentiate between physical and chemical stress relaxation, so that correct equations can be used to estimate the thermal shift factors.

For simulations of short-term deterioration of polymers, real-time measurements can be used by duplicating the expected real time space environment. For polymers exposed for many years to the space environment, the generation of real-time data is practically impossible. Predictions must be based on accelerated aging experiments completed in a shorter time-frame in a ground-based laboratory. Such lab work invariably involves increasing the environmental stress levels above those appropriate to the real exposures. This would likely mean higher than ambient UV dose rates, atomic oxygen fluence, higher temperatures, and higher mechanical stresses. Thus, developing predictive methods based on ground experiments necessitates understanding and modeling of space environment dose-rate effects.

The dose rate effects of polymers exposed to high energy radiation, such as in a nuclear environment, have been studied extensively [1-7]. A common assumption in these studies is that the total dose alone determines the damage under inert atmosphere situations and that long-term predictions for low dose-rate conditions can be made by using an equal dose, equal damage basis. It is now well known that, in the presence of air (oxygen), dose rate effects are frequently observed and can be very significant [8,9]. This observation could be extended to predict that, in the presence of atomic oxygen which is even more reactive than molecular oxygen, dose rate effects may be significant in the space environment. This has yet to be verified experimentally.

Temperature is an important factor to consider when discussing the space environmental effects on polymers. Stress relaxation of elastomers can occur as a result of chemical reactions inducing the breakdown of the network structure. Several network degradation theories have been developed and chemical stress relaxation studies have been carried out on a wide range of elastomers in order to study their thermal degradation mechanisms. During this Summer, these theories were critically reviewed, along with the chemical stress relaxation technique and other methods for investigating cross-linking and chain scission of polymers.

PROJECT 2: THERMAL CYCLING OF POLYMER COMPOSITES

Accomplishments:

1. Thermal cycle induced micro-cracking phenomena were observed on carbon fiber reinforced polymer matrix composites. One or two minute intraply cracks were observed on thermoplastic matrix composites after a single thermal cycle between -45°C and +85°. Microcracks appear to initiate at the fiber-matrix interface, preferentially in fiber-rich (or resin-deficient) zones. Microcracking appears more severe in

PPS than in PEEK composites. Microcracking was not observed in epoxy composites for the first twenty cycles. Judging from the fact that thermoplastic composites tend to have weak fiber-matrix interfacial bonding, these observations appear to suggest that interfacial bond plays a critical role in initiating microcracks in carbon fiber reinforced polymer composites. Intraply cracks are known to be the precursors to the delamination cracks, the most serious life-limiting failure mode in laminated composites.

2. Thermal cycle cracks obviously are caused by the hygrothermal stresses present in a laminate. The residual thermal stresses in a fibrous composite may be analyzed at different levels of complexity. First, the differential thermal stresses established between a single fiber and the matrix may be estimated either analytically or numerically. Second, the residual stress fields developed within a group of regularly arrayed fibers may also be determined either theoretically or experimentally. Third, the thermal stresses that occur between laminae with different effective thermal expansion coefficients (e.g., due to different fiber orientations) may also be calculated using, for example, the classical lamination theory. In each level of study certain assumptions have to be made to render the problem more tractable.

As a first approach (levels 1 and 2), a "thick cylinder model" was developed to simulate the thermo-mechanical behavior near a fiber in a group of fibers with a given fiber volume fraction. In this model, the stress and the strain fields in a thick cylinder under uniform pressure were derived based on the classical elasticity theory. Using such a thick cylinder model, the residual stresses established in a model single fiber-matrix system representing various polymer composites were calculated.

In practically all cases the matrix has a greater CTE than the fiber, which subjects the fiber to compressive stress. For most practical volume fractions of fibers, the matrix will generally be subjected to a radial compression at the fiber-matrix interface and a tangential tensile stress. Even in the absence of a good chemical bond, this radial compression against the interface provides friction forces to assist in the load transfer process between the fiber and the matrix. The magnitudes of such residual thermal stresses at the microscopic level have been calculated for the composite systems being considered for space applications.

A change in temperature (ΔT) or moisture content of a composite structure causes a variation in its dimensions proportional to the change in temperature (ΔT) or moisture content (ΔC) and its initial dimensions. This leads to the

development of a thermal strain (ϵ^T) or hygroscopic strain (ϵ^H). However, thermal deformation of a lamina is constrained by its neighboring laminae, leading to the development of residual stresses. The magnitudes of these macroscopic residual stresses in each layer of a composite for several composite systems have been estimated using the classical lamination theory. These data, in combination with the interface thermal stress data mentioned earlier, may be used to explain the thermal cycle induced micro-cracking phenomena in composites.

PROJECT 3: RESIDUAL STRENGTH PREDICTION OF ATOMIC OXYGEN ERODED MATERIALS

A statistical fracture mechanics approach is being developed for predicting the residual strength of engineering polymers and composites as a function of surface morphology, which varies with atomic oxygen exposure conditions. This project is just now getting started. Literature review on the subject *Surface Cracks* has been conducted. Theoretical equations are being derived while the mechanical test samples are being prepared.

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