INFLUENCE OF AMINE AND EPOXIDE POSS ON THE FUNCTIONALITY OF SHAPE MEMORY POLYMERS AND THEIR DURABILITY TO THE LOW-EARTH ORBIT SPACE ENVIRONMENT

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ABSTRACT

Thermally activated shape memory polymers (SMPs) can memorize at low temperature a temporary shape and return at higher temperature to their permanent shape. Due to the higher strength-to-weight ratio of the SMPs compared to metallic materials, a potential application is to replace metallic components that are used in spacecraft. One of the main hazards for low-Earth orbit (LEO) organic materials is atomic oxygen (AO). Unprotected polymers will erode in LEO by AO at a rate of ~100 μm/year. A potential solution to this problem is to incorporate Polyhedral Oligomeric Silsesquioxane (POSS) molecules into the polymer backbone, forming a SiO₂ passivation layer upon interaction with AO.

In this work, we studied the influence of two types of POSS, having either amine or epoxide groups, on the SMPs’ properties. The shape memory effect (SME) was studied by bending samples with various compositions to a bow temporary shape, using a hot bath and an aluminium mandrel. After cooling the samples while in their temporary shape, they were re-heated, and the SME was studied in terms of deployment time.

Mechanical properties of the SMPs, such as storage modulus (elastic property), loss modulus (viscous property) as well as their glass transition temperature, T_g, were characterized using Q800 model dynamic mechanical analysis (DMA). The experiments were carried out at a constant amplitude of 0.1% using a single frequency of 1 Hz and a temperature ramp rate of 3°C/min, from 30°C to 130°C. The T_g was determined from the curve of change of storage modulus slope vs. temperature.

Durability to AO was studied by exposing the SMP samples to a ground simulated AO environment based on RF-oxygen plasma source. The samples were removed periodically from the system in order to weigh their mass loss and evaluate the effect of the two types of POSS on their erosion yield.

SMP samples with varying amounts of POSS were prepared, from 0 (pristine epoxy) to as high as 75 wt.% POSS while maintaining a 1:1 molar ratio between amine and epoxide groups. As POSS concentration was increased, T_g, and as a result – deployment time, decreased for both types of POSS. However, although both types of POSS present the same trends for T_g and deployment time vs. POSS concentration, the effect of the POSS type on the SMPs’ mechanical properties were quite different. While the maximum POSS loading that enabled substantial deformation was 50 wt.% in the case of amine POSS-based SMP, epoxide POSS-based SMP allowed a maximum loading of 75 wt.%

Furthermore, in the case of amine POSS-based SMP, increasing the POSS concentration led to an increase in storage modulus, meaning an increase in the material’s elasticity. On the other hand, in the case of epoxide POSS-based SMP, increasing the POSS concentration led to an opposite effect, i.e. a decrease in the storage modulus, meaning a decrease in the material’s elasticity. The POSS-containing SMPs exhibited also higher durability to AO compared to pristine epoxy. Under the stringent conditions of the RF-plasma source, 15 wt.% amine POSS-based SMP, for example, showed an erosion rate of 25% the erosion rate of pristine epoxy. The decreased erosion rate may be attributed to the formation of a passivation layer where the AO oxidized the SiO₂ POSS into SiO₂.

This work presents novel nanocomposite materials and the benefit of incorporating POSS into the backbone of epoxy-based SMPs for increasing their durability to the LEO environment. It also presents the effect of POSS type on the SME and offers means to tailor the SMPs’ mechanical properties to desired values.