The Effect of Moisture on the Physical Properties of Polyurethane Shape Memory Polymer Foams

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Statement of Purpose: Thermally actuated shape memory polymer (SMP) foams are materials that can be stored in a secondary geometry and then actuated to a primary geometry by heating. Polyurethane (PU) SMP foams are being investigated for numerous biomedical device applications because of their excellent biocompatibility and high volume expansion capabilities.[1] Because water absorption has been shown to significantly lower the glass transition temperature (T_g) and alter the thermo-mechanical properties of urethanes.[2] With our ultimate goal of engineering SMP PU foams for use in blood contacting environments, we have investigated the effects of moisture exposure on the physical properties of PU foams. To our best knowledge, this study is the first to investigate the effects of moisture absorption at varying humidity levels (non-immersion and immersion) on the physical properties of PU SMP foams. Water uptake, shifts in T_g, stress-strain behavior, and shape memory behavior of the foams were investigated for PU SMP foams that were exposed to 40%-100% humidity levels for varying lengths of time (and temperature at 100% humidity).

Methods: Polyurethane SMP foams were made from hexamethylene diisocyanate, N,N,N',N'-tetrakis(2-hydroxypropyl) ethylenediamine, and triethanolamine; however, the details of the synthesis are proprietary. Foam samples were placed in an environmental chamber at 25 °C, with controlled humidities of 40 %, 60 %, and 80% for time periods of 12 h, 24 h, 48h, and 96 h. For 100% humidity, the samples were immersed in a water bath at control temperatures of 25 °C and 37 °C. To measure the water uptake of the foams, TGA experiments were run on the foam samples, and mass decrease up to 150 °C was defined as water loss. To evaluate the effect of moisture absorption on T_g, DSC experiments were run. To determine the effects of moisture uptake on the stress-strain behavior and maximum recoverable strain of the samples, strain to failure and free strain recovery experiments were run.

Results: TGA results demonstrated that the foams exhibited a maximum water uptake of 8.0% (by mass) after exposure to 100% relative humidity for 96 h. For the lower humidities, distinct saturation levels were evident, and the effects of humidity level and moisture exposure time on water uptake are shown in Figure 1. DSC results, provided in Figure 2, demonstrated that water absorption significantly decreased the T_g of the foams, with maximum water uptake shifting the T_g from 67 °C to 5 °C. Tensile testing results demonstrated that water uptake caused significant plasticization in the foams: samples exposed to 100% humidity for 96 h exhibited 100% increases in failure strains and 500% decreases in failure stresses. Free strain recovery results, provided in Figure 3, demonstrated recovery ratios approaching 100% for samples strained to 25% or lower.

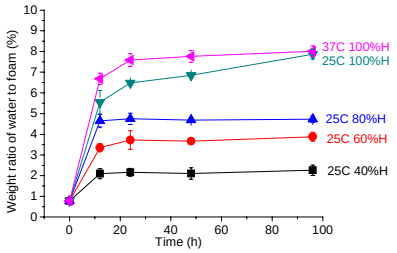

Figure 1. The effect of humidity exposure time up moisture absorption, measured by TGA

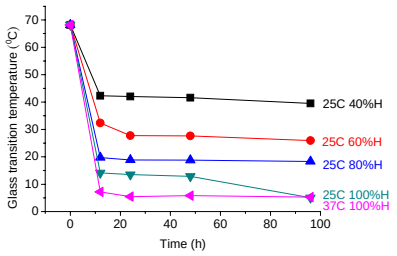

Figure 2. The effect of moisture absorption on T_g

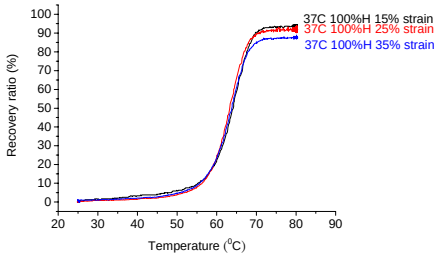

Figure 3. The effect of moisture absorption on recoverable strain

Conclusions: The results of this study have implications in both the storage and use of PU SMP foam devices. The water uptake of the polyurethane SMP foams increased with increased humidity exposure time, increased humidity, and increased temperature. The T_g of the PU foams decreased upon moisture absorption, and a maximum shift from 67 to 5 °C occurred after 8% water uptake. Even at maximum water saturation, recoverable strains approaching 100% were achievable. These PU SMP foams thus maintain good shape memory behavior after moisture exposure and consequently appear to be useful in biomedical device applications that will subject the foams to physiological conditions.

References:

1. Small, et al. J. Materials Chem., 2010; 20: 3356-3366.
2. Yang, et al. Polymer, 2006; 47: 1348-1356.