Thermal Expansion of Three Closed Cell Polymeric Foams at Cryogenic Temperatures

The Space Shuttle External Tank (ET) contains the liquid H2 fuel and liquid oxygen oxidizer and supplies them under pressure to the three space shuttle main engines (SSME) in the orbiter during lift-off and ascent. The ET thermal protection system consists of sprayed-on foam insulation and pre-molded ablator materials. The closed-cell foams are the external coating on the ET and are responsible for minimizing the amount of moisture that condenses out and freezes on the tank from the humid air in Florida while it is on the pad with cryogenic propellant awaiting launch.

This effort was part of the overall drive to understand the behavior of these materials under use-conditions. There are four specially-engineered closed-cell foams used on the tank. The thermal expansion (contraction) of three of the polyurethane and polyisocyanurate foams were measured from -423°F (the temperature of liquid hydrogen) to 125°F under atmospheric conditions and under vacuum. One of them, NCFI 24-124, is a mechanically-applied material and covers the main acreage of the tank, accounting for 77 percent of the total foam used. Another, BX-265, is also a mechanically-applied and hand-sprayed material used on the tank's "closeout" areas. PDL 1034 is a hand-poured foam used for filling odd-shaped cavities in the tank.

Measurements were made in triplicate in the three primary material directions in the case of the first two materials and the two primary material directions in the case of the last. Task 1 was developing the techniques for getting a uniform heating rate and minimizing axial and radial thermal gradients in the specimens. Temperature measurements were made at four locations in the specimens during this initial development phase of testing. Major challenges that were overcome include developing techniques for transferring the coolant, liquid helium (-452°F), from its storage container to the test facility with a minimal transfer of heat to the coolant and control of the heating rate at the lowest temperatures.

Significant differences have been found in thermal expansion as a function of material direction for the three foams which can largely be accounted for by the shape of each foam's closed cells. The three foams are exhibiting in all cases except the BX-265 33 direction under one atmosphere a tri-phasic response to temperature. From the lowest temperature measured, ~-440, to ~-375°F the materials have essentially a zero thermal expansion coefficient. From approximately -375 to -50°F the materials expand at a constant but intermediate rate. Then from -50 to 125°F they expand at a constant higher rate. Under vacuum the response is nearly linear from -375° to 100°F. The application of vacuum at either the lowest temperatures or at room temperature causes the BX and NCFI materials to expand in-plane (22, 33) and contract perpendicular to knitlines (33). The PDL material was less affected by ambient pressure particularly in the rise direction. The higher density of the PDL material suggests that there is more cell wall material to resist internal pressure. The BX material exhibited a permanent expansive set in the material in the 11 and 22 directions and contractive set in the 33 direction after going to 125°F under vacuum, whereas, the NCFI and PDL materials returned to there original length. Again, density indicates the BX material had the smallest amount of cell wall material resisting internal pressure driven loads.

This data can be explained by the columnar shape of the closed cells found in these materials. With reduced ambient pressure (increased internal cell pressure relative to external ambient pressure) the cells want to expand to a more spherical configuration (similar to the more thermodynamically stable shape of a soap bubble). In doing so, the axis of the column (33 direction) is reduced in length and the diameter of the column is increased (11 and 22 directions). The PDL material, either due to its higher cell wall content (thicker cell wall and/or smaller cells) and/or more spherical cells resists deformation due to changes in internal pressure.