Zero Thermal Expansion Polymer Lattice Structure
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Abstract
Zero Thermal Expansion (ZTE) Structures are a class of structure designed to control the effects of thermally-induced expansion. ZTE structures combine 2 materials with dissimilar Coefficients of Thermal Expansion (CTEs) to delay the expansion at certain nodal points. This allows precision structures, such as optical mounts and aerospace vehicle frames, to maintain their original shape over a wide range of temperatures. This design offers a unique combination of low thermal expansion and high stiffness.

Purpose
While research has been done with metal-based ZTE Structures, there has been little or no work done in the field of polymers. The purpose of the project was to design and fabricate a polymer ZTE Structure in order to evaluate the cyclical fatigue performance of the design and to validate its ZTE performance.

Design History
Our project is a continuation of a feasibility study conducted by Professor Evans into ZTE lattice structures. His team identified a relationship between the skewness angle, side lengths, material CTE ratio, and the resulting final lattice CTE for metallic, pin-jointed ZTE lattice structures (see figure 1). We took this a step further by verifying the feasibility of polymer, bonded-jointed ZTE lattice structures.

Design Concept
The operating principle behind this form of ZTE structure is that geometrical interactions between materials can be used to offset their dissimilar CTEs. As visualized below, the inner material expands quickly causing a deformation in the outer material that compensates for the outer piece’s thermal expansion at the three floating nodes. These nodes can be used as connection points to create a lattice with ZTE behavior.

Testing Results
- Exhibited no deterioration in ZTE due to stress fatigue
- Different behavior when being cooled vs. being heated
- Increased dwell times caused behavior to approach a linear relationship
- Conclusion: Differing cooling/heating behavior is due to difference in thermal diffusivities in materials. We observed up to 5ºC in lag between materials
- Design may not perform acceptably for rapid temperature changes
- For dynamic environments thermal diffusivity should be considered during material selection.

Testing Methodology
- Hyper Accelerated Life Test (HALT) Chamber
  - Uniform temperature control
  - Material temperature monitored directly with thermocouples
  - Wide Temperature Range: -70ºC to 150ºC
  - Rapid Thermal Cycling: 45ºC/min
- Laser Triangulation Sensor
  - Remote sensing capability that is compatible with the HALT Chamber.
  - Software was developed to track the laser dot on a webcam and to output coordinates of the dot’s centroid to 1/10th of a pixel
  - Calibration tests revealed a resolution of 2-3 thousandths of an inch

Recommendations
- Test materials with similar thermal diffusivities such as Makrolon and ABS in order to confirm that the difference in thermal diffusivities was the cause of the conflicting cooling/heating behavior observed in our earlier testing
- Modify angles between the pieces to improve the ZTE performance of the structure

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References