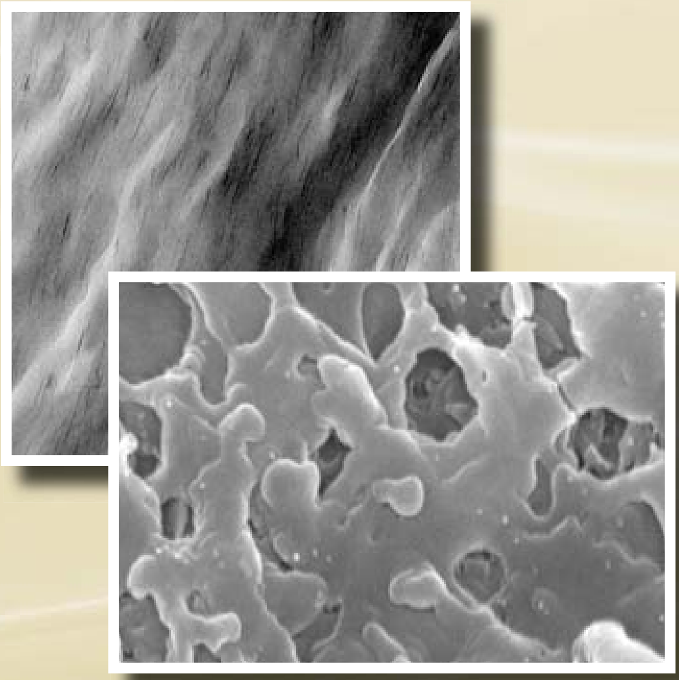
Self-Protection and Self-Healing of Polymer Nano-Composites

Accomplishment: Self-protecting and self-healing polymer nano-composites were conceived, produced and tested. Up to an order of magnitude improvement in durability was established in simulated launch and orbital space environments.



Impact: This accomplishment demonstrates a fundamentally new class of self-protecting and self-healing organic polymers that has a strong potential to improve access to space. An order of magnitude improvement in the durability of solid rocket motor insulation can reduce launch weight and increase the volume available for propellant, significantly increasing range and payload. Improved processiblity can eliminate the leading source of failure in current solid rockets. An order of magnitude increase in durability of organic polymers in orbital environments can decrease satellite weight and significantly increase mission lifetime and reliability.

Motivation and Approach: Organic polymers are essential materials due to their useful properties, light weight and exceptional processibility, but they are seriously damaged by aggressive space environments. Very high temperature gases burn organic polymer insulation used to protect solid rocket motor cases to a non-protective char. Up to 50% by volume of fillers are added to reduce the erosion rate, adding significant cost and weight, reducing the volume available for propellant, and requiring complex hand-processing that produces bondlines that are the leading cause of rocket motor failures. Satellites are exposed to strong ultraviolet radiation, atomic oxygen, and sub-atomic particles that rapidly degrade and remove organic polymers. Protection is currently achieved with ceramic coatings, by blending with inorganic polymers and micron-scale fillers, or copolymerization. Coatings provide only nominal protection in space, where coating damage cannot be detected or repaired. The other approaches decrease the polymer properties. All of these approaches add weight and considerable cost.

Polymer nano-composites consisting of nanometer-thick silicate or alumino-silicate clay platelets dispersed in an organic polymer matrix were conceived and produced at AFRL. Testing in simulated launch and orbital environments preferentially removed the organic polymer, leaving the clay platelets that form a protective ceramic-like surface layer. In ablation tests, the layered clay nanoparticles melt to form a self-healing, high viscosity liquid that reduces damage by filling holes. Less than 1% by volume of layered nano-particles gives protection equivalent to state-of-the-art organic polymers with 15-30% by volume of filler, and an order of magnitude reduction in damage rate was achieved with 8% by volume of clay nano-platelets. The lower volume fraction of this approach reduces weight, increases reliability via processing that eliminates bondlines, and drastically reduces cost. Since protective layer formation is an inherent property of the bulk polymer nano-composite, these materials are self-protective and self-healing, providing a fundamentally new concept and capability for durable space materials.

Team: This research was conducted at the Materials and Manufacturing Directorate by Dr. Rich Vaia, Maj. Derek Lincoln, Shane Juhl, Dr. Hao Fong (now at the South Dakota School of Mines and Technology) and Dr. Jeff Sanders, and at the Propulsion Directorate by Dr. Shawn Phillips and Dr. Joe Lichtenhan (now at Hybrid Plastics).