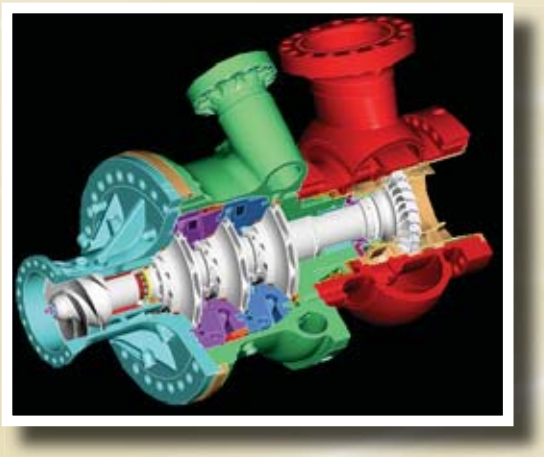
Nano-Aluminum Alloy to Replace Titanium in Liquid Rocket Engines

Accomplishment: A nanoparticle strengthened cast and wrought aluminum alloy with a strength-to-weight ratio up to 30% higher than high purity Ti-5Al-2.5Sn has been developed. A full scale impeller of this alloy surpassed the properties required for a revolutionary two stage liquid hydrogen turbopump.



Impact: This alloy enables a revolutionary two stage liquid hydrogen turbopump that achieves major objectives of the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Initiative for dramatic increases in thrust-to-weight, reliability and affordability of liquid rocket engines for improved access to space. Additional applications are being pursued with industrial partners, including turbopump housings and large pipes in liquid rocket engines, aircraft wheels and automotive parts.

Motivation and Approach: Increasing the strength-to-weight of liquid hydrogen turbopump impeller alloys offers the most significant opportunity to improve thrust-to-weight, reliability and affordability of liquid rocket engines. This allows increased impeller speed, giving higher compression and reducing the number of impeller stages from three to two, giving dramatic decrease in weight, volume and cost. The titanium alloys currently used are expensive and have little potential for higher strength-to-weight ratio. Almost all other metal alloys are embrittled in liquid hydrogen, are heavy, or have poor ductility at the operating temperature of -425 degrees Fahrenheit. Current commercial aluminum alloys satisfy all impeller requirements except strength-to-weight ratio.

Existing aluminum alloys were modified with up to 0.8% by weight of elements that combine with aluminum during controlled heat treatment to form nanometer-sized strengthening particles. Strengthening becomes increasingly potent as the size and spacing between the particles approaches nanometer dimensions. About 0.5-0.9% by volume of strengthening particles that are 5-30 nanometers in diameter and 50-150 nanometers apart give a strength-to-weight ratio in these new aluminum alloys that is up to 30% higher than the high purity Ti-5Al-2.5Sn titanium alloy currently used for liquid hydrogen impellers. Processing and manufacturing of billets up to 20 inches in diameter was established. A full-scale impeller was designed, manufactured and successfully spin-tested, exceeding the rotation speed needed for a revolutionary two-stage turbopump.

Team: This research was led by Dr. Oleg Senkov at UES, Inc., with contributors in the Materials and Manufacturing Directorate and the Propulsion Directorate. The program was managed by Dr. Kevin Kendig at the Materials and Manufacturing Directorate. Funding was provided by a Small Business Innovation Research program, from IHPRPT, from the Air Force Office of Scientific Research (Dr. Brett Connor, Program Manager) and from the Materials and Manufacturing Directorate. Industrial partners included Pratt and Whitney Rocketdyne (formerly Boeing Rocketdyne), Wagstaff Engineering, Wyman-Gordon and Universal Alloy Corporation.