Candidate Materials Evaluated for a High-Temperature Stirling Convertor Heater Head

The Department of Energy and NASA have identified Stirling Radioisotope Generators (SRGs) as a candidate power system for use on long-duration, deep-space science missions and Mars rovers (ref. 1).

One of the developments planned for an upgraded version of the current SRG design is to achieve higher efficiency by increasing the overall operating temperature of the system. Currently, the SRG operates with a heater head temperature of 650 °C and is fabricated from the nickel-base superalloy 718. The current operating temperature is at the limit of alloy 718's capability, and any planned increase in temperature will be contingent on identifying a more capable material from which to fabricate the heater head. To this end, personnel at the NASA Glenn Research Center are evaluating advanced materials for a high-temperature heater head to allow a higher convertor temperature ratio and, thus, increase the system efficiency (ref. 2). A generic list of properties that were used to screen the candidate materials follows: (1) creep, (2) fabricability, (3) helium gas containment, (4) long-term stability and compatibility, (5) ability to form a hermetical closeout seal, and (6) ductility and toughness.

For the lower end of the advanced heater head operating temperature range, superalloys are an obvious choice. To identify potential candidates, Glenn researchers screened essentially all commercially available superalloys on the basis of their published properties to the criteria just listed. From this initial screening, five candidate superalloys were chosen for detailed testing: MarM-247, Udimet 720, IN738LC, IN939, and MA754. A 50-lb heat of each material was then obtained, and creep testing was performed at various stress/temperature combinations. After 1 year of creep testing and microstructural characterization, we decided that MarM-247 was the most promising candidate. Additional heats of MarM-247 were then obtained, with various grain sizes in order to determine the optimum grain size for maximizing creep resistance in the thin, 1-mm-thick heater heads.

Screening criteria similar to those used for the superalloys were used to screen the refractory alloys. ASTAR-811C (tantalum alloy) and rhenium were chosen for in-depth study. ASTAR-811C is promising for high-temperature applications because of its high melting temperature, high strength, and good weldability, fabricability, and ductility. Rhenium was included as a refractory metal candidate for high-temperature space power applications because of its excellent high-temperature strength, low-temperature ductility, good weldability, and good fabricability. Long-term creep testing of these alloys is currently underway.

Because of the high cost of rhenium, machining a heater head from a solid ingot would be extremely expensive since a large amount of material is wasted. It was, therefore, important to demonstrate near-net-shape (NNS) processing of a rhenium heater head. The figure shows the result of this development effort.

NNS forming of a rhenium heater head.
Long description of figure. A closeup photograph of 4-cm- (1.6-in.-) diameter by 15-cm- (6-in.-) long cylindrical shape made of rhenium. Although additional machining of this part would be required to form a heater head, the feasibility of near-net-shape (NNS) forming of this material has now been demonstrated.

With NNS feasibility now demonstrated, plans for future work focus on creep property optimization. Numerous vacuum creep frames have been refurbished, and we plan to use these extensively in determining the vacuum creep resistance of these alloys.

References

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