Investigation of Novel Nickel-Based Alloys for Molten Chloride Fast Reactor Structural Applications

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Program: RC-1

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ABSTRACT:

The objective of this project is to design and develop promising Ni-Mo-W-Cr-Al-X alloys with superior thermomechanical, corrosion, and irradiation properties for high temperature structural applications in molten chloride salt fast reactors (MCFR). The project couples critical experiments with a high-value integrated computational materials engineering (ICME) approach. Modern MCFR designs require alloys that are superior to current alloys in thermal, radiation, intergranular corrosion and creep resistance to 900-950°C. We propose to investigate and develop novel Ni-Mo-W-Cr-Al-X alloys with suitable micro-alloying additions (Zr, Ti,Y) to getter chalcogens (O,S) and meet these needs. This choice is based on positive effects of Mo, W and Al and a design strategy to enhance both solid solution and precipitation strengthening and induce a hierarchical microstructure for superior resistance to long-term high temperature creep, radiation, He and Te embrittlement and molten chloride salt corrosion.

This project couples ICME with critical experiments, thermo-mechanical testing, simulations and processing, characterization, property evaluation and performance testing to develop novel Ni-Mo-W-Cr-Al-X alloys. Their behavior will be compared with the traditional Hastelloy N (Ni-16Mo-7Cr-4Fe) and Haynes 244, an advanced commercial Ni-22.5Mo-6W-8Cr-2Fe alloy, that are being evaluated for MSR applications. **Thermodynamic modeling** will be utilized to ascertain phase equilibria and help select suitable compositions, followed by **processing** using casting and forging/rolling to produce bulk materials with optimized microstructure for testing and characterization. The **micro-structure** of the alloys will be characterized using powerful electron microscopy and diffraction tools and the mechanical **properties,** including yield/tensile strength, ductility, creep strength, fatigue, creep-fatigue and fracture behavior will be evaluated over a range of temperatures up to 1000°C. The **performance** of the baseline Hastelloy N, Haynes 244 and selected Ni-Mo-W-Cr-Al alloys will be evaluated for their response to the other important challenges facing MCFR structural alloys: (a) irradiation, (b) He embrittlement, and (c) corrosion in the chloride salt under appropriate conditions of salt chemistry and temperature. Post-test samples will be characterized to ascertain damage modes and failure mechanisms.

The proposed project directly addresses the RC-1 workscope on innovative alloys for MCFR structural applications. It not only builds on the knowledge base from previous work on this class of novel alloys, but will also grow that knowledge base with the provision of a lot of new data and thereby help expand the alloy design space for new alloys. The results will lead to an ICME-guided, high-performance Ni-W-Cr-X alloy, and elucidate on a fundamental level both quantitative processing-structure-property relationships and a mechanistic understanding of the alloy's mechanical properties, irradiation tolerance and corrosion resistance. These results are expected to chart a new course for advanced nickel alloys for structural applications in MCFR and could also have crosscutting impact across all DOE-NE programs (VHTR, AR, etc.) and the MSR/MCFR industry in their development of advanced structural materials. Lastly, this project will help mentor early-career faculty and scientists and train students in cutting-edge methods to take their place in tomorrow's skilled technological workforce for the benefit of the nuclear energy industry, the nation and mankind.