Advanced Alloy Innovations for Structural Components of Molten Salt Reactors

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ABSTRACT:

The goal of the proposed research is to develop and evaluate specific advanced metallic alloys for structural components in fluoride salt-cooled molten salt reactors (MSRs) for the following qualities: (i) excellent corrosion resistance in molten fluoride (with and without UF_4 and impurity additions) salt, (ii) ASME Section III Division 5 code certifiable for mechanical properties at 700^{o}C and higher, (iii) good radiation damage tolerance, and (iv) good weldability. The primary basis for alloy compositional design and selection will be resistance to corrosion in molten fluoride salts which is recognized as a major challenge for the fruition of MSRs, and good high temperature strength for future ASME codification.

Four categories of metallic alloys will be investigated, namely, advanced Ni-based alloys, radiation damage tolerant high entropy alloys (HEA), refractory Mo-based alloys, and a compositionally-graded alloy designed for high surface corrosion resistance and good bulk strength. The Ni-based alloys are solid solution strengthened alloys with M_6C and MC carbide precipitate strengthening for high temperature strength. The alloys developed and patented by Oak Ridge National Laboratory are designed for corrosion resistance in molten fluoride salt environments, but with much higher creep rupture strength than Hastelloy-N. The HEA alloys have been selected for compositions for radiation damage resistance based on phonon scattering theory and for corrosion resistance based on free energy of formation of elemental. Mo has outstanding corrosion resistance in molten fluoride salts and therefore Mo-Hf-C and Mo-W-Hf-C alloys will be investigated – both these alloys have very high creep rupture strength. Compositionally graded materials will be developed by additive laser manufacturing to produce a Ni-rich surface on 316 stainless steel with a gradation of Cr composition gradually increasing from the surface to the interior to that of the 316 stainless steel.

Corrosion testing will be performed in both FLiBe and FLiNaK salts, and with and without UF_4 additions to cover both liquid-fuel and solid-fuel MSR designs. The role of cationic impurities in corrosion kinetics will also be investigated adding low but controlled quantities of iron- and nickel-fluoride to the salt. Given that in MSR graphite will coexist with metallic alloys in the molten salt, its effect on corrosion of the alloys will be investigated as well. Electrochemistry of molten salt will be performed for measurements of its redox potential and anionic impurity concentrations with the goal of better understanding and controlling corrosion. The propensity for radiation embrittlement of the alloys will be evaluated by ion irradiation and introducing the tellurium fission product into the alloys' surface via the salt. Weldability of the alloys, including solidification and heat affected zone (HAZ) microstructures, and any associated embrittlement and corrosion effects will be evaluated using commercial welding processes.