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Carbide Coatings for Nickel Alloys, Graphite, and Carbon/Carbon Composites to be Used in Fluoride Salt Valves

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ABSTRACT

The proposed work is concerned with developing materials technology that supports the evolution of Generation IV Advanced High-Temperature Reactor (AHTR) concepts. Specifically, we propose to develop novel refractory carbide-coated materials suitable for use in components such as valves in molten fluoride heat exchanging systems.

Several next-generation AHTR designs incorporate molten fluoride salts as the heat exchange cooling fluid. Considerable research has been conducted on nickel-based alloys for salt containment to assess and mitigate the severe corrosion challenges of these working fluids on valve, piping, and vessel materials. While there certainly was justification for pursuing molten salt compatible of superalloy systems, advanced carbon-based materials available today present an alternate path to mitigate the fundamental limitations of these superalloys. We propose to investigate a number of carbon and carbide-based systems for molten salt containment. Specifically, we propose to investigate refractory carbide-coated (1) nickel alloys, (2) nuclear grade graphite, (3) commercial carbon-carbon composites (CCCs), and (4) matrix-modified CCCs. Numerous compelling reasons have driven us to focus on carbon and carbide materials. First, unlike metals, the strength and modulus of CCCs increase with rising temperature. Second, graphite and carbon composites have been proven effective for resisting highly corrosive fluoride melts such as molten cryolite [Na3AlF6] at ~1000°C in aluminum reduction cells. Third, graphite and carbide materials exhibit extraordinary radiation damage tolerance and stability up to 2000°C. Finally, carbides are thermodynamically more stable in liquid fluoride salt than the corresponding metals (i.e., Cr, Mo, Zr) found in nickel-based alloys.

Our research aims to: (1) understand the corrosion mechanisms of graphite, CCCs, and carbide-coated super alloys in the presence of fluoride, (2) develop carbide-coating techniques, (3) demonstrate and quantify erosion protection, and (4) fabricate and test valve and seal features utilizing these materials. Candidates include carbides of Si, Cr, Zr, Mo, Ta, and Ti. Various carbide-coating formation techniques will be investigated including (1) liquid metal infiltration of porous graphite and other carbon materials, (2) molten salt deposition of carbides on graphite, CCCs, and alloys, (3) vapor-phase formation using metal carbonyl precursors, and (4) refractory carbide coating of nickel alloys with a vapor-phase carburization process.

Our research will focus on coatings rather than monolithic carbides, because it is extremely difficult to fabricate refractory carbide hardware in complex shapes. In contrast, graphite is available in block form that can be machined to desired geometries prior to being carbide coated. The pore structures of graphite can be engineered so that during the carbide conversion process no dimensional changes occur, and we have a great deal of experience in producing carbon preforms with optimal pore structure for carbide conversion. We believe that these coated materials will offer properties unachievable by other material systems and will enable the manufacture of highly durable components such as valves and seals for containment of molten salts.