Nanostructured Composite Alloys for Extreme Environments

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ABSTRACT:

The objective of this proposal is to develop extreme performance nanocomposite alloys with engineered interfaces that can withstand irradiation doses up to 600 dpa at elevated temperatures (up to 700°C) for demanding nuclear environments such as fast reactor cladding applications.

The next generation of nuclear reactors require structural materials capable of withstanding very high irradiation doses and elevated temperatures while in contact with highly corrosive environments for long periods of time. One of the aims of the Fuel Cycle R&D (FCRD) program is to develop cladding materials for very high burn up (up to 60%) at high temperatures (up to 700°C). These demanding applications require new material concepts that are designed to perform at irradiation extremes rather than incremental improvements over conventional alloys.

We will accomplish this objective by producing nanolayered (~10-200 nm individual layer thickness) Cu/Nb and Zr/Nb composites using a severe plastic deformation technique called Accumulative Roll Bonding (ARB). The ARB technique allows tuning of the interface structure at the atomic level while producing kilograms of nanomaterial. The layered structure forms low energy atomic arrangements under extreme strains and exhibits remarkable mechanical and thermal stability. It is hypothesized that interfaces that are stable mechanically and thermally are also expected to be stable under irradiation. The proposal's unique approach suggests also that there exists an ideal layer thickness (not necessarily the minimum achievable) depending on the applied thermal and irradiation conditions which gives the material optimum mechanical, thermal and irradiation resistance properties. To achieve this goal, mechanical property and thermal stability studies up to 700°C and microstructural characterization will be performed. The selected alloys will be subjected to ion irradiations up to 600 dpa using 5-10 MeV self-ions at 200-700°C. A comprehensive microstructural investigation will be performed on the irradiated materials, as well as nanoindentation and small-scale mechanical testing across a variety of strain rates and temperatures.

ARB processed nanocomposites with engineered interfaces are scalable at commercial level and represent an innovative approach to designing materials that eliminates the trade-offs constraints in conventional alloy development. As such, this work aims at taking lab-scale alloys with great potential for nuclear applications into the technological stage by producing bulk alloys and investigating their irradiation resistance at very high doses and temperatures.