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Development of Low Temperature Powder Spray Process for Manufacturing Fuel Cladding and Surface Modification of Reactor Components

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ABSTRACT:

The proposed research will focus on the development of low temperature, high velocity solid-state powder spray deposition process for: **(i)** the manufacture of fuel cladding tubes of oxide dispersion strengthened (ODS) steels, and **(ii)** the deposition of coatings (single material, compositionally-graded, and multilayered) to address corrosion and wear in reactor components. While the research will focus on specific materials and applications of interest, the findings will be applicable to the rapid manufacturing and surface modification of a wide range of components for Advanced Light Water Reactors (ALWR) and Small Modular Reactors (SMR). It is anticipated that this manufacturing approach will also enable the near-term deployment of materials in nuclear reactors, which are presently either not cost-competitive to manufacture or are restricted by scientific barriers in conventional manufacturing processes.

ODS steels containing Y-Ti-O nanoparticles (0.2 to 0.3 wt.%) provide a combination of high temperature creep strength and radiation damage tolerance. However, fast, effective, and economical fabrication of components such as fuel cladding tubes with ODS steel continues to be a challenge. In the cold spray process, powder particles of a material (ODS powders in this case) are propelled at supersonic velocities on to the surface of a substrate to form coatings or near-net shape components. The particle temperature is low and deposition occurs in solid state. For manufacturing tubular cladding, ODS powders will be spray deposited on to the surface of a cylindrical mandrel which is rotated about its axis, while the spray beam is translated along its length. After deposition, the mandrel will be removed by the dissolution or melting, resulting in a free-standing ODS steel cladding tube. The tube will be subsequently subjected to thermal treatments to achieve fine grained recrystallization and oxide nanoparticle precipitation.

The cold spray process will also be investigated as a low temperature surface modification/coating alternative for mitigating corrosion and wear in reactor components. Several conventional and innovative coating approaches will be investigated. These include deposition of NiCrAlY coatings for corrosion resistance and Nitronic 60™ for resistance to scuffing. Additionally compositionally-graded coatings of FeCrAl on ODS steels and multilayer Ni/Ni-50%Cr coatings will be investigated. Incorporating FeCrAl into the surfaces of ODS steel would confer extremely high oxidation resistance to ODS steel while preserving the high strength and radiation damage resistance of ODS steels. The Ni/Ni-50%Cr multilayered coatings are expected to impart corrosion and stress corrosion cracking resistance. Additionally, these coatings are expected to “self-grade” compositionally during high temperature service which may have beneficial implications in corrosion performance and mechanical behavior.

Characterization will be conducted using SEM-EDS, EBSD, and XRD, HRTEM, APT, and neutron diffraction techniques. Irradiation testing of cold spray manufactured ODS cladding tubes will also be performed and bench-marked against those manufactured by conventional methods. Tensile and ductility testing, high temperature nanoindentation testing, tests for coating-substrate adhesion strength, thermal cycling, and high temperature/high pressure ASTM G2 steam autoclave tests will also be performed.