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On the Development of Stress State and Rate-dependent Micromechanical FE Models for Cold-Sprayed Ceramic-Metal Composite Coatings

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Abstract

This study investigated the quasi-static and dynamic uniaxial compressive behavior of aluminum-alumina (Al-Al_2O_3) composite coatings fabricated by cold-spray additive manufacturing. A split-Hopkinson pressure bar (SHPB) setup was employed to conduct the high strain rate experiments, where ultra-high-speed imaging was coupled with digital image correlation (DIC) technique to visualize the development of strain fields and crack growth in the material at different strain rates. Scanning electron microscope (SEM) images of the material were captured to characterize the microstructural features (e.g., porosity, reinforcing particle weight fraction, and particle size) before and after testing. Informed by the testing and characterization, physics-based micromechanical finite element (FE) modelling was used to computationally capture the rate-dependent behavior of the composite coatings. The SEM image-informed micro-scale characteristics were integrated into representative volume elements (RVEs) produced by using the Digimat software. In these models, stress state and rate-dependent constitutive material models were incorporated into the RVEs for the metal matrix and the ceramic reinforcing particles. This informed on the effect of loading rate and state of stress on the deformation and failure responses. The experimental quantitative measurements (i.e., stress versus strain curves, and lateral versus axial strain history) and qualitative observations (i.e., failure mechanisms such as ductile failure in the Al matrix, interfacial failure, and damage accumulation in the Al_2O_3 ceramic particles) were leveraged to validate the FE models. The results revealed that the computational model reasonably predicts the rate-dependency of stress versus strain behavior, compressive strength, and strain hardening behavior of the Al-Al_2O_3 composite coatings. Altogether, this research study provides improved understanding of the stress state and rate-dependent response of the material in terms of its mechanical properties and failure mechanisms through a combined experimental and numerical methodology. The outcomes of this study have implications for leveraging the model for virtual design and optimization of ceramic-metal composite coatings (e.g., improving the strength-density and strength-ductility trade-offs via microstructure tailoring).