Development of Ma-Wang model for solid-state bonding mechanism of cold spray additive manufacturing

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Abstract

Cold spray (CS) is a highly anticipated solid-state additive manufacturing (AM) technology. However, the lack of a suitable material model for a long time has brought great obstacles to quantitative CS modeling, limiting performance enhancement and technical improvement of CSAMed materials. In this research, a new material constitutive model (Ma-Wang model) was developed for CS based on dislocation dynamics to quantitatively describe the strain hardening, the normal strain rate hardening, the ultra-high strain rate hardening, the thermal softening and the grain refining due to dynamic recrystallization for elucidating the solid-state interfacial bonding mechanisms Although Ma-Wang model was originally developed for CS, this material model has the potential to solve other large deformation and ultra-high strain rate problems occurred in laser peening and friction stir welding, etc.

Background & Results

Additive manufacturing (AM) is widely used for the rapid and direct fabrication of near-net components via layer-by-layer metal deposition. Unlike in fusion-based AM technologies, in the cold spray (CS) process, powders are deposited by kinetic energy instead of thermal energy; hence, melting/solidification-related issues (e.g., oxidation, thermal stress, phase transformation, chemical degradation, and grain growth) can be minimized or eliminated. Particularly, the chemical composition and microstructure of raw materials remain almost unchanged, providing excellent flexibility in designing the final deposits. However, the lack of a suitable material model for a long time has brought great obstacles to quantitative understanding of CS process phenomena. In this research, the Ma-Wang model considering the roles of strain hardening, normal-range strain rate hardening, ultra-high strain rate hardening, and thermal softening was developed for CS to break through this technical bottleneck (Fig. 1). The most classical CS materials, Cu, Al, Ni and their alloys were targeted to elucidate the mechanisms of extreme deformation due to CS and its role on dynamic recrystallization for interface bonding (Fig. 2). In addition, an enhanced contour method combined with the XRD method was developed to achieve the three-dimensional measurement of CS residual stress, and the arbitrary Lagrangian-Eulerian (ALE) method was used to avoid the mesh distortion to accurately reproduce the CS residual stress and reveal its formation mechanism (Fig. 3).

Significance of the research and Future perspective

This research provides theoretical guidance for effectively regulating the grain size, interfacial bonding, residual stress in CS components and thereby improving the component quality and service reliability. The Ma-Wang material model is the cornerstone of future multi-scale CS simulations to quantify the process-microstructure-performance relationship. Besides the applications for CS process study, the Ma-Wang model is expected to be applied to clarify the large dynamic plasticity problems occurred in laser peening, friction stir welding and other ultra-high speed impacting processes in the future.

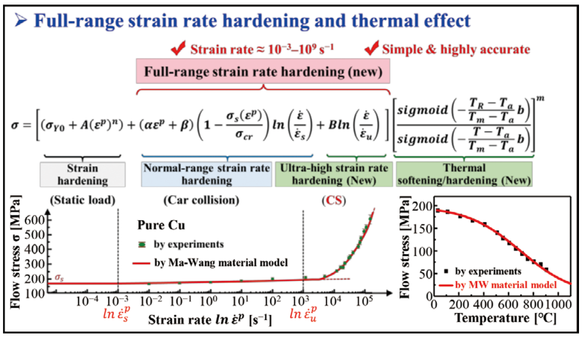

Fig. 1. Development of the Ma-Wang material model based on dislocation dynamics

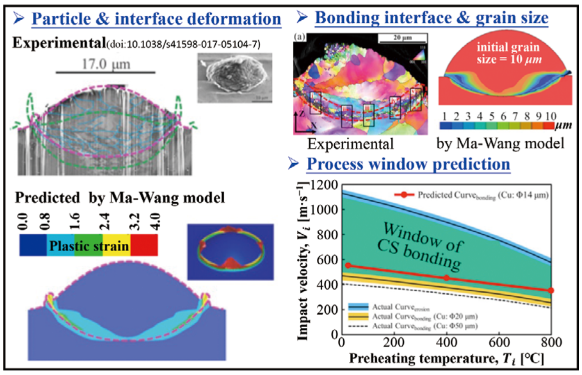

Fig. 2. High-accuracy prediction of deformation, grain size, and solid-state bonding during CS

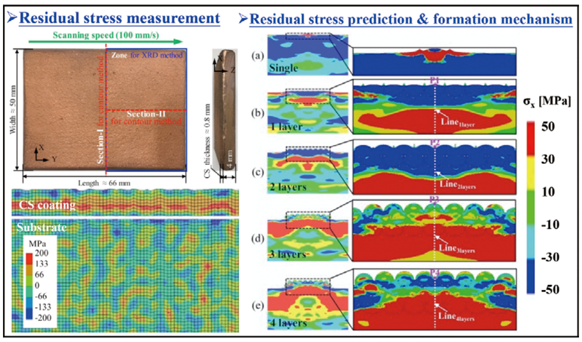

Fig. 3. Measured and predicted CS residual stress

Patent

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Keyword additive manufacturing, cold spray, material model, stress-strain, strain rate, residual stress

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