Investigating Impact-Induced Deformation in Cold-Sprayed Aluminum-Quasicrystals Composite Coatings

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Introduction

From the perspective of engineering metallic coatings, it is typically challenging to meet diverse requirements using single-phase coating materials, which often fall short in satisfying industrial needs. With metal matrix composite coatings, however, it becomes feasible to meet these diverse needs effectively. Cold spraying (CS) is a solid-state coating deposition and additive manufacturing technology that is promising for several industrial applications. It is effective in the deposition of a variety of materials, including metals, alloys, polymers, and ceramics, but also it stands out because of its compatibility with heat and oxygen-sensitive materials and capacity to create composite deposits. The CS process in general involves accelerating solid feedstock particles using pressurized and preheated gas, resulting in supersonic particle impact on a substrate. This impact leads to coating formation from deformed particles. During coating processing, impacted metal particles undergo high strain rate deformation, triggering phenomena such as grain refinement and phase transformation. These microstructural changes within CS deposits significantly influence their local mechanical properties. At the micron and submicron scale, these alterations can either enhance or compromise coating performance. Notably, phenomenon such as dynamic recrystallization occurs at interfaces—between particles and between particles and substrates—due to significant plastic deformations and adiabatic shear instability conditions during solid-state deformation. Consequently, heterogeneous microstructures might emerge at these critical locations, accompanied by localized variations in mechanical properties. However, despite numerous efforts to have a clear understanding of such featured developed in CS alloys, the precise relationship between local microstructure and mechanical behavior remains elusive for cold-sprayed composite coatings containing multiple ingredients. To engineer coatings with specific mechanical characteristics, a comprehensive understanding of microstructural features is essential. Investigating how variations in grain size, phase distribution, texture, and defects influence mechanical properties is crucial. Bridging this knowledge gap can optimize cold-sprayed coatings for diverse applications, ensuring reliability and advancing materials science.

Aluminum alloys are in high demand in light-weight structures; however, it has the potential short fall of tribological and mechanical properties. Our research team has made significant strides using cold spraying (CS) to produce compact and well-incorporated aluminum alloy (AA6061)-quasicrystal composite coatings (referred to as Al-QC). The coatings have shown superior tribological characteristics and increased hydrophobicity compared with conventional Al-based coatings and bulk metallurgical counterparts.

Materials and methods

Expanding on our previous works, our current research explores the detailed microstructural intricacies of CS Al-QC composite coatings, particularly emphasizing bonding states and particle-particle interfaces and micromechanical properties. To achieve this, we sprayed the composite coatings using a high-pressure CS system with optimized parameters, utilizing pressurized nitrogen (N_2) as the propellant gas. Additionally, we fine-tuned process settings to accelerate a limited number of particles, facilitating particles impacts on the substrates to study the deposition mechanism. Analytical scanning and [scanning] transmission electron microscopy (SEM) and (S)TEM) played a pivotal role in evaluating the microstructure of our specimens and forming scenarios regarding deposition behavior. Electron backscatter diffraction (EBSD) technique (by conventional and transmission Kikuchi diffraction TKD) was also used to collect crystallographic data from cross-sections of cold-sprayed coatings and to narrate the state of deformation. In-situ nanoindentation mapping (+1600 indents) was performed on the top surface of composite Al-QC coating, embracing both Al and QC phases, to provide detailed micromechanical insight completing the production/microstructure/properties chain.

Results and Conclusions

While QC particles mostly underwent brittle fracture and shattering upon impact, their contribution to in-situ hammering of the coating structure significantly contributed to densification and elimination of pores in the structure. Impact-induced grain refinement close to the exterior of impacted particles and alternation of texture and pattern quality due to high degree of deformation in Al-based matrix was found to be significant. Evidently, these features can endow a reliable bonding between dissimilar constituents in the composite coating structure. Presence of QC fragments turned out to provide enhanced bonding to Al particles within the composites. In addition, hardness and elastic modulus variations were found to be consistent with the heterogeneity of the microstructure induced by particle impacts and their deformation. However, intimate bonding at the interface of Al-QC and formation of interlayer enhanced the coating integrity. The findings regarding the bonding state can potentially justify the enhanced mechanical and tribological properties of composite coatings, and extended retention of the reinforcing phase in the structure under load, as observed in our previous works.

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Keywords:

Electron Microscopy, Aluminum-Alloys, Quasicrystals, Microstructure

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