2180
doi:10.1017/S1431927618011388

Microsc. Microanal. 24 (Suppl 1), 2018

Deformation Microstructures in Individual Cold Sprayed Al-Cu Alloy Particles Studied via Precession Electron Diffraction and Transmission Kikuchi Diffraction

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Cold spray (CS) is a relatively new material deposition technique for additive repair of large aluminum structures [1]. CS deposition is a solid-state deposition process in which high velocity (~800 m/s) metallic particles impact and adhere to a substrate. A coating or deposition is built up by the impacts of many millions of particles. As single particle impacts are the building blocks for cold sprayed materials, it is essential to understand the deformation processes and microstructures that form as each particle impacts the underlying substrate. While spatially-resolved, crystallographic information is essential for understanding the deformation process, the levels of plastic strain and the small length scale for a single particle are beyond the resolution of standard electron backscatter diffraction (EBSD) mapping techniques. Newer diffraction tools, such as precession electron diffraction (PED) and transmission Kikuchi diffraction (TKD) enable mapping of the crystallography of single deposited particles. In this paper, we will show the quantitative information that can be gained by PED and TKD applied to the study of small, highly deformed, metallic microstructures. We present PED and TKD data from exactly the same deformation microstructure, thus allowing a direct comparison of the relative strengths and weaknesses of these approaches.

A modified cold spray deposition experiment was performed for Al with 2-5 wt% Cu alloy powder particles deposited onto steel substrates. In this case, the feed rate during deposition was lowered until single particles impacted and adhered to the substrate. These depositions were performed using a low-pressure cold spray system with helium as the carrier gas. Thin foils about 100 nm thick from cross sections of deposited particles were prepared using focused ion beam. The foils were examined using a FEI Tecnai F-20 Scanning/Transmission Electron Microscope ((S)TEM) (200 keV). PED was conducted using the NanoMegas ASTAR platform with a precession angle of 0.3 degrees and a step size of 20 nm. Afterwards, TKD was also performed on the same foils in JEOL 7000 FEG-SEM (30 keV) and Oxford AZtec EBSD system with the same step size of 20 nm.

Both PED and TKD effectively display the deformation crystallography in single impacted particles. As an example, an originally spherical Al-5Cu particle is highly flattened in the impact direction after deformation (Figure 1). Both PED and TKD results show that the individual particles experienced large deformation upon impact (approximate average strain of 60%), and nano-scale grains were formed at the particle/substrate interface (Figures 2a and 2b inset). The kernel average misorientation (KAM) maps show a higher density of deformed regions near the particle/substrate interface (Figures 2c and 2d). The corresponding grain orientation spread (GOS) maps (Figures 2e and 2f) show the cumulative effect of these intragranular misorientations, which result in a band of deformation across the middle of the particle. The blue grains at the particle/substrate interface in the GOS maps suggest dynamic recrystallization, as has been hypothesized in the cold spray literature [2]. Similar analyses of Al-2Cu particles showed a larger grain structure after impact than that observed in the Al-5Cu particle pictured below. In some regions, PED mistakenly identified grain boundaries and smaller "island" grains within some larger grains due to a known 180-degree ambiguity in the PED indexing approach [3]. TKD does not show these artifacts; however, the indexing rate of PED data was higher and more consistent than TKD in the finest grain regions close to the particle/substrate interface.

References:

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[4] The authors acknowledge funding from Mr. William Nickerson of the Office of Naval Research, Grant N0001414WX00148, and the college of engineering at the University of Alabama.

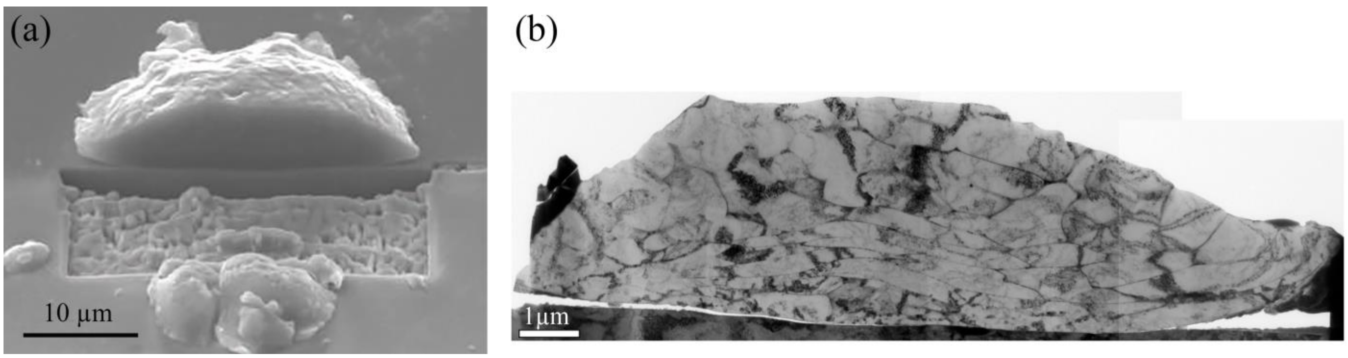

Figure 1. (a) Secondary electron image of a dissected Al-5Cu particle, (b) TEM bright field image of a cross-section from single Al-5Cu particle.

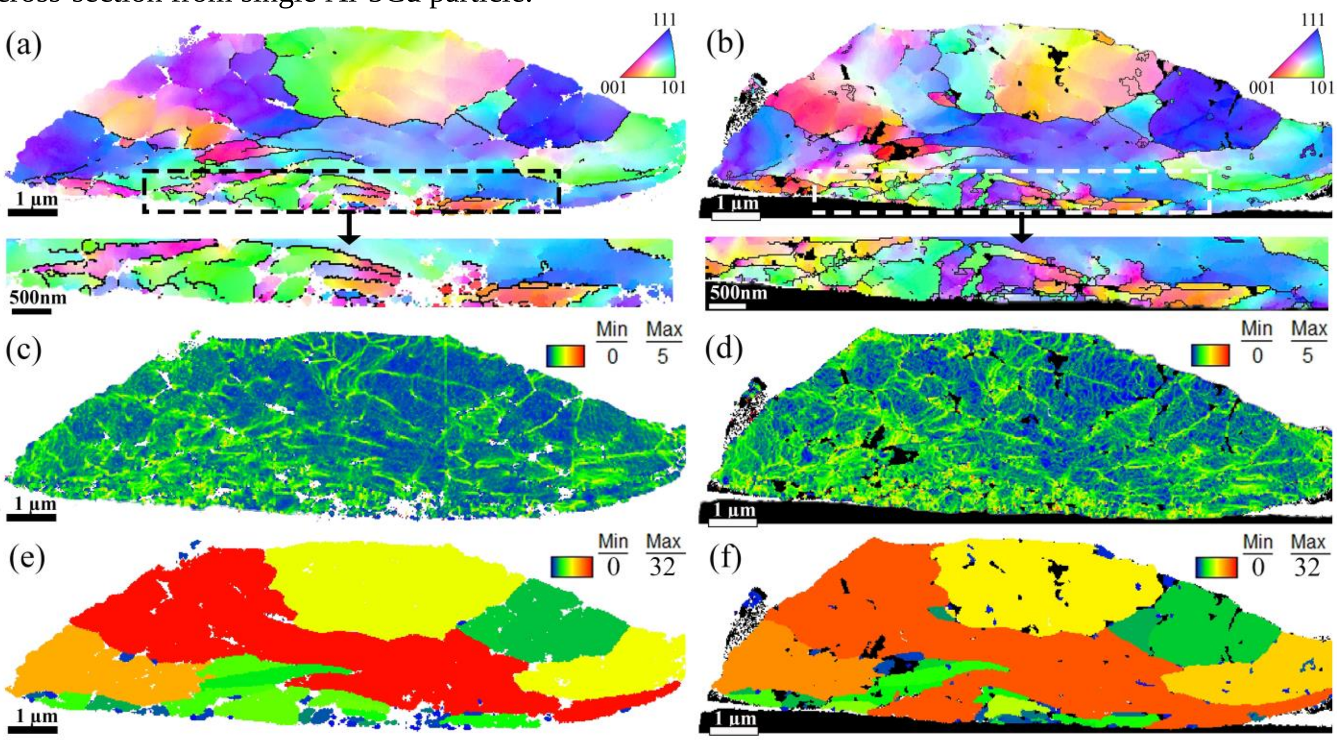

Figure 2. TKD (a, c, e) and PED (b, d, f) results from a deposited Al-5Cu particle, (a, b) inverse pole figure orientation maps (with respect to thin foil normal) overlaid with grain boundaries (black line) with misorientation angle greater than 10 degrees, (c, d) KAM maps, (e, f) GOS maps, color scale shown in degrees.