Metallic-based composite materials have long been recognized as a way to enhance the performance of metals and continue to receive attention as a way to design new materials for novel applications. This material design process has been facilitated by the recent rapid development of nanometer-scale mechanical probes, high-resolution imaging techniques, and advanced theory and computational tools. These metallic multilayer composites have typically been produced by physical vapor deposition techniques producing thin foils, or by traditional cold-worked rolling processes with intermediate annealing steps producing plates [1,2]. The latter of these processes is achieved through an accumulated series of rolling passes and is able to produce a practical amount of plate material and therefore has the better potential for commercial manufacture of bulk materials. It is this accumulated roll bonding (ARB) process that we wish to examine here—both the resulting material and its evolution of properties. In particular, this work presents efforts to represent the evolution of the structure of the individual layers and predict the evolution of crystallographic texture for a single rolling pass at a point in time late in the process but before the layer thickness is small enough to significantly alter the dislocation behavior within the layers.

Over the past two or three decades crystal plasticity theory and simulation capabilities have developed into a commonly used and successful predictive tool for large plastic deformation of metallic materials [3]. Here we begin to apply crystal plasticity theory to the study of layered composite materials to examine the evolution of crystallographic texture well above the layer thickness where confined layer slip and interface dominance become important. This will demonstrate the applicability of existing theory to problems of this type and also provide insight into the kinematics and kinetics of composite deformation through the rolling process.

Many approaches have been implemented for generating synthetic or digital representations of polycrystalline microstructures. Here we follow on the work of Sintay [4,5] and extend it to include 3D layered materials as the foundation for the 2D simulations. Initial textures were assigned to the virtual grains using data from the five 200×200 µm EBSD scans (see Fig. 1) comprising a total area of 2×10^5 μm². A total area of 2×10^5 μm² is represented by the combined 40 simulations. The dislocation state of each layer (which cannot be assumed to be fully annealed) is represented through nano-hardness measurements.

A schematic representation of the isochoric boundary conditions used for the numerical simulations is given in Fig. 2. Each of the numerical models assumed an initial aspect ratio of 1:2. Plane strain was used as an approximation of the actual rolling process and therefore six-noded plane strain triangular hybrid elements were used within commercial finite element method software (ABAQUS) [6]. A constant displacement rate was imposed on the top surface to produce a 50% height reduction in 5 seconds. The simulations were performed isothermally at a temperature of 298 K.

Crystallographic orientation at each of the material points within the 40 models were combined to give the resulting pole figures in Fig. 3. In all, these results contain sampling of 420 Cu grains and 395 Nb grains for the combined numerical simulations. In general, the numerical technique developed for this layered composite system represents the
An example of the morphology and internal stress developed as a function of height reduction is given in Fig. 4 for one realization. It is interesting to note the discrepancy between the von Mises stress developed between the two layers. This suggests that the mechanical response of the composite introduces unique boundary conditions at the interface that allow for substantially different equivalent stress states in the two different materials. The simulation results also demonstrate the substantial evolution in interface shape, which qualitatively agrees with experimental observation.

A technique for representing the processing response of bi-metallic layered composite materials was presented here and successfully used to predict the single-pass rolling texture in each layer of the Cu/Nb system reduced from 24 to 12 μm average layer thickness. Each layer was represented by a statistically equivalent polycrystal morphology based upon EBSD data for each of the layered materials at the heat-treated 24-μm thickness condition. Nano-indentation experiments performed on the independent material layers for the heat-treated 24-μm condition were used to initialize the single crystal model for un-annealed conditions between rolling passes. Eight different morphological realizations and, within each of those, five different crystallographic realizations, resulted in a total of 40 numerical realizations used to compare to the experimental crystallographic texture data. This number proved to be adequate to provide the proper statistical diversity to allow for representation of the initial morphology and crystallographic texture for these layered composite systems.

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