JOM, Vol. 64, No. 10, 2012
DOI: 10.1007/s11837-012-0428-8

Structure–Property–Functionality Relationships in Bimetal Composites

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Future energy technologies demand novel materials that tolerate extremes in temperature, strain, strain rate, and radiation to an extent that far exceeds the limits of even the most advanced materials to date. To meet these needs, promising new material candidates are nanostructured multiphase/multi-interface materials containing a high density of interfaces. Interfaces are important in materials of any microstructural size scale because they can act as sources, sinks, barriers, and storage sites for defects, and they accommodate many deformation modes including interface instability, interface migration and sliding, deformation twinning, shear band formation, and intergranular fracture, etc. In nanostructured materials, interfaces will dominate material response and can lead to extraordinary and unusual properties that far exceed those of their coarse-grained counterparts.

To best elucidate interface structure–property–functionality relationships, the research group at Los Alamos National Laboratory has been devoted to understanding the role of bimetal interfaces in material properties. Simple-layered composites in the forms of film and bulk are chosen. These nanocomposites were fabricated by either (I) physical vapor deposition or (II) accumulative roll bonding (ARB) or (III) eutectic reaction to produce distinct interface types, thermally preferred interfaces in similar and dissimilar crystals and mechanically driven interfaces in dissimilar crystals.

Three articles included in this issue represent the current understanding of the structure–property–functionality relationships. The first, by I.J. Beyerlein et al., focuses on the atomic-level study including characterizing interface structure, exploring interface properties and the role in plastic deformation, such as interface shear resistance and its ability to absorb point defects and nucleate dislocations nucleation. Atomic-level studies have led to vastly improved understanding how interface structure impacts interface properties and how these properties drive material behavior in deformation. The second, by J. Wang et al., focuses on the formation and role of a predominant, steady-state interface in bulk Cu/Nb multilayered composites that are fabricated by accumulative roll-bonding method. With application of an automated heterophase interface characterization distribution method for ARB composites with submicron layer thicknesses, a remarkable discovery is the development of a narrow distribution of interface orientation relationships after extreme straining. A {112}face-centered cubic (fcc)||{112}body-centered cubic (bcc) $<110>$ fcc|| $<111>$ bcc interface seemed to prevail over the entire sample. For understanding how the interface structure and properties drive material behavior, the authors carried out a systematical study for two typical interfaces, $\{111\}_{Cu}$// $\{110\}_{Nb}$ KS interfaces in thin films and {112}fcc|| {112}bcc KS interfaces in bulk material, including interfacial shear response, dislocation nucleation at interfaces, dislocation transmission across interfaces, recovery of interface structure under deformation or other extreme environments, and interface-driven response including texture evolution, shock, and twinning. The important result is that the well-defined, ordered interface structures can be fabricated via severe plastic deformation and prevail uniformly over the entire composite. The nanocomposites themselves possess many desirable properties, such as ultrahigh strength, hardness, and thermal stability, which are vastly superior to those of the individual constituents. The third, by N.A. Mara et al., is about deformation twinning in eutectic Cu/Ag composites. Experimental studies revealed unusually profuse deformation twinning in Ag-Cu layered eutectic composites with bilayer thicknesses in the submicron regime at room temperature and low strain rates. Using atomistic simulations and dislocation theory, they proposed that twins in Ag can provide an ample supply of twinning partials to Cu to support and sustain twin

 (Published online August 30, 2012)

growth in Cu during deformation. Interface-driven twinning suggests the exciting possibility of altering the roles of dislocation slip and twinning through the design of a heterophase interface.

The development of the structure–property–functionality relationships of multi-interface composites is still subject to enormous challenge including the creation of desired interface structures in composites, characterization, and measurement of interface structure and properties, and understanding the role of interfaces under deformation and other extreme environments. Multiscale study including experiment, theory, and modeling is extremely desired, in particular, the development of high-length-scale models incorporating interface physics discovered at different scales.