Enhanced Strength of Cu-Gr-Cu nanolaminate

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Understanding the deformation mechanism in nanocomposites is critical to realizing a host of next-generation technologies. Graphene's unparalleled mechanical properties -- owing to its two-dimensional geometry, high intrinsic strength, and Young's modulus -- provide us with an opportunity to engineer metal/graphene composites with strengths that do not naturally occur. Graphene's (Gr) ability to act as a strength enhancer depends on the interface interactions and the composite's microstructure. Here we demonstrate an industrially scalable and transfer-free microstructure design of Cu-Gr-Cu nanolaminate that enhances the composite's strength. Bending tests performed on fabricated Cu-Gr-Cu nanolaminate cantilever beams exhibit a remarkable strengthening effect over a control Cu-Cu nanolaminate. A significantly higher load is required to deflect a Cu-Gr-Cu cantilever beam indicating that the presence of single atomic layer of graphene enhances the strength of the composite. The enhancement in strength of Cu-Gr-Cu nanolaminate suggests a build-up of dislocations at the Cu-Gr interface, which limits the plastic slip that can occur at the internal interface. We developed a strain gradient plasticity computational model of the experimental system based upon Gudmundson's higher order theory and implemented it as a user element in ABAQUS. A set of material parameters is identified that reproduce the experimental force vs. displacement results for both the Cu-Cu and the Cu-Gr-Cu nanolaminate. The only difference in the simulations is that zero plastic strain boundary conditions are enforced at the Cu-Gr interfaces in the Cu-Gr-Cu nanolaminate. The results give insight into the design of metal-graphene composites as well as structure of strain gradient plasticity theories.