Zhang, F., Saha, R., Huang, Y., Nix, W., Hwang, K., Qu, S., and Li, M., Indentation of a hard film on a soft substrate: Strain gradient hardening effects, International Journal of Plasticity, 23, no. 1, 2007, pp. 25–43

Abstract

The strain gradient work hardening is important in micro-indentation of bulk metals and thin metallic films, though the indentation of thin films may display very different behavior from that of bulk metals. We use the conventional theory of mechanism-based strain gradient plasticity (CMSG) to study the indentation of a hard tungsten film on soft aluminum substrate, and find good agreement with experiments. The effect of friction stress (intrinsic lattice resistance), which is important in body-center-cubic tungsten, is accounted for. We also extend CMSG to a finite deformation theory since the indentation depth in experiments can be as large as the film thickness. Contrary to indentation of bulk metals or soft metallic films on hard substrate, the micro-indentation hardness of a hard tungsten film on soft aluminum substrate decreases monotonically with the increasing depth of indentation, and it never approaches a constant (macroscopic hardness). It is also shown that the strain gradient effect in the soft aluminum substrate is insignificant, but that in the hard tungsten thin film is important in shallow indentation. The strain gradient effect in tungsten, however, disappears rapidly as the indentation depth increases because the intrinsic material length in tungsten is rather small.

Keywords

Strain gradient, Layered material, Elastic–plastic material, Finite strain, Finite elements