NANO HIGHLIGHT
A Dislocation Model for the Minimum Grain Size Obtainable by Milling

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Over the past several years, the characteristics of the crystal refinement and the development of nanostructures during ball milling have been studied extensively. These studies have led to several important observations and findings that include the following: (a) during milling, the grain size decreases with milling time, reaching a minimum grain size, d_{min}, that is a characteristic of each metal; and (b) The minimum grain size obtainable by milling, d_{min}, scales inversely with melting temperature, T_m, the bulk modulus, B, or the hardness, H, of the material.

In the present NIRT program, we made the first theoretical attempt to develop a dislocation model that can account for the origin of the aforementioned correlations between the characteristics of nc-structures and materials parameters. The approach taken was based on the suggestion that the minimum grain size obtainable during milling is the result of a balance between dislocation structure introduced by the severe deformation of milling and its recovery by thermal processes. Consideration of available information shows that the two processes of hardening and recovery, which are suggested to control the final grain size obtainable by milling, also occur during creep. So the analysis was based on the treatment of the kinetics of milling process as those associated with a creep process in which diffusion becomes fast as a result of the presence of dislocation density that enhances pipe diffusion and the generation of large concentration of vacancies during milling. The analysis led to the development of a dislocation model that predicts that d_{min} depends on hardness, stacking fault energy, and an exponential function of the activation energy for recovery according to the following equation:

$$d_{min}/b = A_3(e^{-\beta Q/4RT})\,(D_{po}Gb^2/v_o kT)^{0.25}\,(\gamma/Gb)^{0.5}\,(G/H)^{1.25}$$

where is A_3 a dimensionless constant, B is the Burger vector, β is about 0. 04, Q is the activation energy for lattice diffusion, R is the gas constant, T is the absolute temperature, D_{po} is the frequency factor for pipe diffusion, G is the shear modulus, k is Boltzmann's constant, γ is the stacking fault energy of the material, H is the hardness of the material. The predictions of the model agree well with experimental trends and findings including those reported for the dependence of d_{min} on materials parameters, as demonstrated in Fig. 1(a) and Fig. 1(b) for the normalized hardness, H/G, and the bulk modulus, B, of the material, respectively.
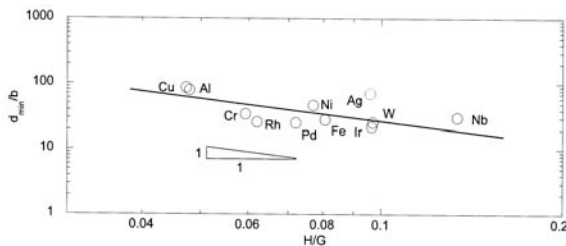

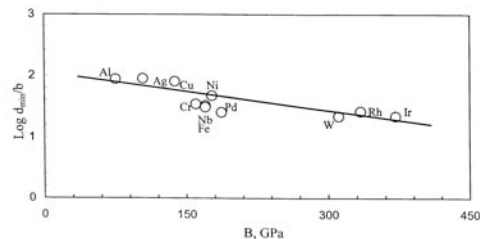Fig.1(a): d_{min}/b vs. melting temperature, H/G   Fig.1(b): d_{min}/b vs. the bulk modulus, B

References
F. A. Mohamed, A dislocation mechanism for the Minimum grain size obtainable by milling, Acta Materialia, 51, 4107 (2003).