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Grain size strengthening – Just another length-scale effect?

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GRAIN SIZE STRENGTHENING – JUST ANOTHER LENGTH-SCALE EFFECT?

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The grain-size dependence of the strength of polycrystalline metals has been described by the Hall-Petch relation (equation 1) since 1951, where the yield or flow stress, σ, is related to the inverse square root of grain size, d, and the Hall-Petch constant k_{HP}.

$$\sigma = \sigma_0 + \frac{k_{HP}}{\sqrt{d}} \qquad (1)$$

We have surveyed many of the classical data sets in the literature and find that, in fact, very few support this relationship [1]. Figure 1 shows that values of k_{HP} are a function of the inverse square root of the grain size rather than being an independent constant, implying that both the constant and the relationship are mutually incorrect. Where data in the literature are sufficiently well described to know how grain sizes where obtained and measured, we find that data can be described by a simple inverse relationship with grain size (Figure 2 & equation 2). This is the same as that found for micro- pillar compression experiments and other size effects that depend on a length-scale [2].

$$\sigma = \sigma_0 + \frac{k \ln d}{d} \qquad (2)$$

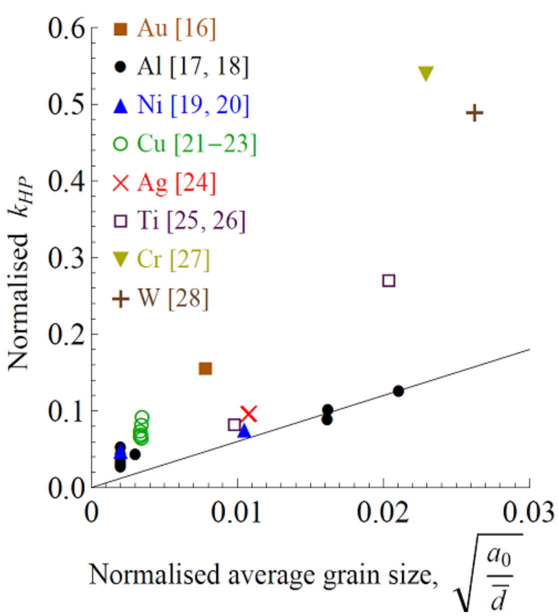

Figure 1 – Literature values of k_{HP} versus $1/\sqrt{d}$ for a range of metal systems.

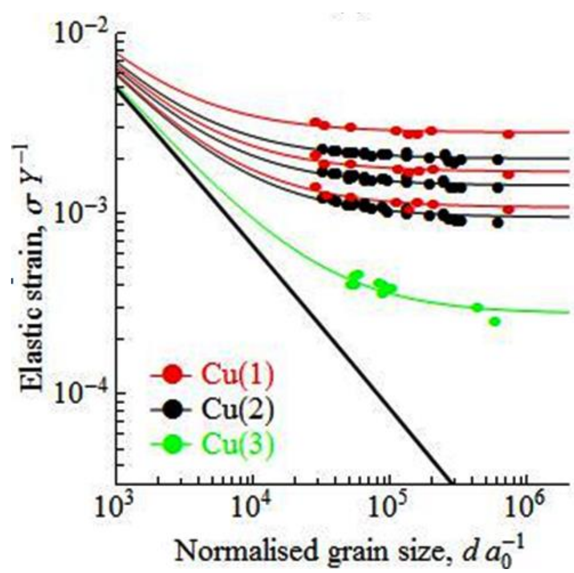

Figure 2 – Three data sets from the literature for copper with different states of work-hardening

These results suggest that the grain-size effect in plastic deformation is the same as those observed in nano-mechanical testing, where the minimum strength is determined by the length-scale available to allow dislocation curvature. The implication for nano-mechanical testing on small polycrystalline samples is that the observed strength will be dominated by the length-scale in the material that restricts dislocation curvature.

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