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The Elastic-Plastic Transition of Metals

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ABSTRACT

Uniaxial stress-strain curves are known to exhibit significant curvature and hysteresis even in the nominally elastic regime, i.e. before the standard yield stress is attained. In order to probe the nature of this behavior, hundreds of high-precision loading-unloading-loading tensile tests were performed using 26 commercial sheet alloys exhibiting a wide range of strength, ductility and crystal structure. Corresponding analysis shows that:

1. There is no significant linear elastic region, that is, the proportional limit is 0 MPa. While the first increment of deformation shows a stress-strain slope equal to Young's modulus, progressive deviations of slope start immediately.
2. The shape of the transitional stress-strain curve can be represented by a simple one-parameter equation representing the "modulus reduction rate." It captures ~80% of the measured variation and can be determined from a single test. This approach reduces the error inherent in standard Young's modulus or chord modulus approximations by a factor of 3 to 6.
3. A "Universal Law" having no independently-determined parameters, i.e. no testing or fitting required, was developed. It captures ~90% of the variation represented by the one-parameter representation for the materials tested.

The practical and theoretical implications of these results are discussed. On the practical side, the results provide an immediate path to improving applied constitutive models in the transitional regime. An example of an application and results is provided. On the theoretical side, the consistency of the effect for a wide range of metals suggests answers to questions about the governing deformation mechanisms.

Keywords: steel, Young's modulus, microplastic transition, QPE, elastic-plastic transition.

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