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Cottrell A H & Bilby B A. Dislocation theory of yielding and strain ageing of iron. *Proc. Phys. Soc. London Sect. A* 62:49-62, 1949.
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Common steel is unusual among the ductile metals for the exactness with which it obeys Hooke's law. The reason is that its dislocations, which are normally responsible for anelastic deviations from Hooke's law, are anchored or pinned by atmospheres of segregated carbon and nitrogen atoms. The strength of pinning, its temperature dependence, and the rate of formation of an atmosphere have been estimated. [The *SCI*® indicates that this paper has been cited in more than 730 publications, making it the most-cited paper from this journal.]

Why Steel Obeys Hooke's Law

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May 25, 1990

Common steel is remarkable among the metals for its almost perfect obedience to Hooke's law of elasticity up to a certain high stress, the upper yield point. But when the elasticity of the metal fails it does so in spectacular fashion, with a sharp drop in stress to the lower yield point before normal metallic work-hardening properties are exhibited. In this overstrained condition, the metal shows the anelastic deviations from Hooke's law that are typical of metals generally, but upon resting at room temperature for a few days, or slight heating, a process of strain ageing restores the original perfect elasticity, up to an enhanced upper yield point.

In late 1946 I thought that these effects might be brought about by the migration to, and segregation in, dislocations of carbon and nitrogen atoms, which are known to exist as interstitially dissolved solutes in common steel and commercially pure iron. These atoms would be attracted into the dislocations by the local elastic strain fields round such defects. When segregated in sufficient numbers, they would anchor or pin the dislocations, so suppressing that dislocation mobility that is a major cause of anelastic deformation. The yield drop would occur when the applied stress, enhanced locally by whatever stress concentrators happened to be present, became strong enough to tear the dislocations free from these impurity atmospheres. In the overstrained state, the metal would contain such free dislocations. Strain ageing would then be the pinning of this fresh generation of dislocations by the migration of carbon and nitrogen atoms to them. In 1947 it was established that the activation energy for strain ageing coincided with that for the interstitial diffusion of these elements, which gave support to the theory.

At about that time, B.A. Bilby joined me as a research associate, and we set about calculating the upper yield point of steel on this basis. At first our values oscillated wildly between micrograms and megatons per unit area but gradually settled down to something sensible, approaching one-tenth of the elastic constant. This is a large value, but the observed upper yield point itself is extremely high at low temperatures.

It remained to understand the steep drop in yield strength at higher temperatures. We realised that the pinning barrier, although high, was also extremely narrow, being essentially only one atom thick. It could thus be overcome by a thermal fluctuation which, throwing forward a small section of the dislocation, could create a small free piece that the applied stress could then expand into a major breakaway. Our calculations of this gave the required steep temperature-dependence of the yield strength. In those early days, the strong Peierls force (an intrinsic resistance of the crystal lattice to dislocation motion) in body-centred cubic metals, such as iron, had not been discovered. It is now recognised[1] that both impurity pinning and Peierls stress contribute to the total temperature dependence.

We also calculated the rate of migration of the interstitial atoms to dislocations in strain ageing. Despite the diffusion mechanism of this process, the deduced ageing developed with time as $t^{2/3}$, not $t^{1/2}$, because the atoms were pulled along the lines of stress gradient in the field of the dislocation. We expected that this result would hold only in the very earliest stages of ageing, but it was subsequently shown to be more generally valid.[2,3]

The theory has found practical applications in the development of creep-resistant steels, in steel tensioning cables for prestressed concrete, and in steep sheets for pressings (e.g., for automobile bodies) where it is important to avoid ugly stretcher-strain markings produced by the yield drop. The concept of the attraction of impurity atoms to dislocations is of course important in semiconducting materials.

1. **Duesbery M S.** The dislocation core and plasticity. (Nabarro F R N, ed.) *Dislocations in solids.* Amsterdam, The Netherlands: North-Holland, 1989. p. 67-173.
2. **Harper S.** Precipitation of carbon and nitrogen in cold-worked alpha-iron. *Phys. Rev.* 83:709-12, 1951. (Cited 190 times.)
3. **Bullough R & Newman R C.** The flow of impurities to an edge dislocation. *Proc. Roy. Soc. London Ser. A* 249:427-40, 1959. (Cited 30 times.)

