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# This Week's Citation Classic

**Fleischer R L.** Solution hardening by tetragonal distortions: application to irradiation hardening in FCC crystals. *Acta Metall.* **10**:835-42, 1962 and Rapid solution hardening, dislocation mobility, and the flow stress of crystals. *J. Appl. Phys.* **33**:3504-8, 1962. [General Electric Res. Lab., Schenectady, NY]

The first of these associated papers identified two classes of hardening of crystals by atomic imperfections —weak and strong, the strong hardening being due to asymmetrical lattice distortions. The new theory fit observations of hardening both by solute and by irradiation-produced defects. The other paper gave a simplified theory of how temperature affects hardening by activating dislocations past the stress barriers of atomic imperfections. [The *SCI*® indicates that each paper has been cited over 245 times since 1962.]

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"These papers are special for me because they were my first new contributions since coming to the General Electric Research Laboratory. I made that transition because it was clear to me then that in the field of crystal plasticity the Laboratory was the exciting scientific place in the world. Johnston and Gilman had just done classic experiments on LiF in which they observed how rapidly dislocations moved under stress.[1] This work led to the ultimate experiment in mechanical properties —to use the observed characteristics of individual dislocations (the elementary particle of crystal plasticity) to calculate stress-strain behavior correctly. My work started as an attempt to take the other direction —starting from the observed properties of dislocations —to decide what controlled their motion. One thing I realized is one of the two main points that were new in the first paper—that there are two separate ranges of strengthening produced by an array of atomic defects. The greater strengthening is caused by asymmetrical defects (usually stress dipoles from interstitial atoms or defect pairs) and the lesser by defects of higher symmetry (such as substitutional atoms or vacant lattice sites).

"In that paper I also calculated interactions between asymmetrical detects and dislocations in face-centered cubic crystals using a method devised by Cochardt et al. for carbon in iron.[2] They had recognized how strong that important interaction was and that it immobilized dislocations in steels.

"In trying to find the strengthening from the interactions I had calculated, another point emerged, that for dislocations which are confined to moving on atomic planes the obstacle spacing, which controls the stress needed to overcome the barriers, varies as $C^{-1/2}$ where C is the concentration of the barriers. Hence, the flow stress varies as $C^{1/2}$. This relation fits the great bulk of the observations of hardening by asymmetrical defects, and the strengthening at low temperatures compares well with the calculated numbers.

"The other paper described how thermal energy can aid dislocations in passing atomic defect barriers. The paper returned to explaining Johnston and Gilman's observations. Using a simple algebraic form to approximate the calculated force vs. distance curve for a dislocation moving near a divalent impurity that was bound to a vacancy, simply expressed values were found for the flow stress, dislocation mobility, and the activation energy and volume for flow. Many data have been readily interpreted using these formulae for such diverse systems as impurities in alkali halides, dislocation loops in copper, irradiation-produced interstitials in various crystals, and carbon in iron.

"Why have these two papers been cited frequently? Partly, I think because they filled the needs of the time. Following the pioneering work of Mott and Nabarro,[3] which began in 1940, there had been a hiatus in theoretical study of solution hardening. Their calculation of a mean volume stress around defects had been so widely accepted that few workers in the field thought to assess the state of the field critically. This absence of further theory was possible because extensive experimental data were lacking. The recognition of the two classes of hardening, and the sudden availability of simple formulae predicting how stress and other measurable parameters should vary with the concentration of defects and with temperature were a convenience to the many experimentalists who in 1962 were producing great reams of data that needed to be interpreted. Formulae that were more precise but less simply used would probably have received much less attention. The real test of why the theory is used, however, is whether it fits experimental facts. The two papers have agreed with observations well enough that they continue to be cited regularly."

1. **Johnston W G & Gilman J J.** *J. Appl. Phys* **30**:129-44, 1959.
2. **Cochardt A W, Schoek G & Wledersich H.** *Acta Metall.* **3**:533-7, 1955.
3. **Mott N F & Nabarro F R N**. *Proc. Phys. Soc.* **52**:86-9, 1940.