The Superconductor as Model for the Hardening Stages in a Dislocated Crystal

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A model describing the main hardening stages of a single crystal, deformed plastically, is presented. A qualitative modification in the arrangement of the topologically stable line defects called dislocations causes the change from one stage to another one. In the present theory such changes are treated as phase transitions. The proposed model derives consistently from a new analogy between the superconductor and the dislocated crystal. The mechanical resistance displayed by a rigid crystal to the gliding of dislocations is considered as an analogue to the characteristic resistance of the superconductor to the spreading of the magnetic field inside it. Thus the Meissner state in a superconductor becomes the analogue of the elastic stage, where no gliding dislocation exists. The superconductor's Shubnikov state corresponds analogously to the easy glide stage, where only a small fraction of the dislocations are allowed to glide. The destruction of superconductivity is the corresponding state to the loss of the crystal's rigidity due to the large accumulation of gliding dislocations.

Based on this analogy, a complete formulation derives where the role of the magnetic field in the superconductor's equations is formally played by the density of those dislocations which are able to glide. Similarly, the formal roles of the electric field and of the electric current correspond here, respectively, to the flux or current of mobile dislocations and to the external applied shear stress. The gauge invariance, characteristic of the superconductivity's model, becomes in the present formulation the invariance under compatible deformations. Depending on the periodic or non-periodic character of this gauge invariance, the model is able to describe respectively secondary slip or crystals where only the primary slip system is active. In the first case, from the theory derives a new state (different from the three mentioned above), which is characterized by the confining of the current of glinding dislocation inside delimited spatial regions. And in a crystal with active secondary slip, this confinement is just the expected behaviour for the rapid hardening stage.

Further, the dislocation's Burgers vector sets a scale for a fundamental uncertainty in any position measurement within a dislocated crystal. This uncertainty allows us to construct an effective energy scale η for fluctuations, and to define a partition function as well as correlations functions. The latter characterize the different phases of the model, and thus, the corresponding different hardening stages in a dislocated crystal.