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Stored Energy of Room Temperature Deformed Copper

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Introduction Stored energy represents the debris left after plastic deformation. When a metal is deformed, about 5% of the energy required for deformation remains as the stored energy of cold work. This energy is released when the metal is heated during the process of annealing. The manner in which the metal returns to its lowest energy state is a clue to the state the metal was in, that is, the annealing spectrum gives a clue to the allocation of energy among the various point and line defects.

Stored energy researches have been made since 1901. A review of the existing literature shows a variety of methods, metals, and purities used. The simultaneous influence of several variables in most of the data available, along with lack of systematic research into the effect of impurities, modes of deformation, and temperature has made it difficult to verify theoretical models. As a result, the exact identity of the participants in the annealing curve has been made for only a few peaks.

The major reasons for this lack of satisfactory data are the experimental difficulties involved, namely low signal levels due to the small amounts of energy present. It was decided by the present authors to investigate the stored energy of deformation of high purity polycrystalline copper, since this metal has received more attention than any other.

Experimental procedure The apparatus used is described elsewhere (1) and only a brief description will be given here. The method used is a modification of the two specimen adiabatic-anisothermal method. Two specimens, one annealed and the other coldworked, were heated independently at the same rate under adiabatic conditions, and the energy difference between each specimen heaters is taken to be the stored energy. The calorimeter vessel is programmed to heat at

some constant rate, usually 1/10 deg/s. Thermocouples between specimens and the calorimeter note any temperature differences. The thermocouple outputs are amplified and converted to 400 Hz and are then fed into a summing circuit. This summing circuit controls the two specimen heater power amplifiers by noting the phases and amplitudes of the thermocouple outputs. This eliminates hunting and the pick-up of extraneous signals. The voltage and current to each specimen heater are processed by circuits which give the supplied power differences.

The 99.999+% pure copper was supplied by Jarrell-Ash. The deformation specimens were 3/4 in diameter ASTM tensile specimens with pre-drilled axial holes for the heaters. Following room-temperature deformation the specimens were quenched to 0 °C and the calorimeter sample, a 2 in long cylinder, was obtained by sectioning with a special hacksaw. The usual time lapse between deformation and the beginning of testing was around 20 min. The grain size was rather inhomogeneous, and estimated to be from 0.06 to 0.5 mm.

Results A total of eight samples were used. Table 1 below presents the results.

Table 1

total energy (cal/g-at)	elongation (%)
1.89	12
1.90	12
3.40	20
3.28	20
4.25	30
3.97	30
5.36	40
5.20	40

Examination of the energy release curves showed the absence of what is called recovery energy, or stage IV. The one peak present was the recrystallization peak.

Discussion Comparison with other available data on high-purity, room temperature deformed polycrystalline copper shows the following:

Loretto and White (2) using an anisothermal technique published data for two specimens, both deformed 30% in tension, with an energy value of 0.085 cal/g, compared to a value of 0.069 cal/g for the present work.

Comparison with the well-known values of Gordon (3) who used an isothermal technique, show the present values to be 20% lower, although the stored energy vs. elongation curves are nearly parallel. The differences could be due to either grain size or inherent differences in the methods. The only annealing stages which could be present are stages III, IV, and stage V (recrystallization in coldworked copper). Stages I and II are only observed at temperatures below 0 °C. Stage III occurs at room temperature in copper and therefore it is not surprising that it is absent in the present results. The absence of stage IV invites some examination. Review of existing data shows that stage IV is exhibited strongest in Cu and Ni, and usually the amount of energy increasing with the impurity content.

It is probable that the impurities influence the efficiency of dissipation of deformation energy. In addition to the migration of point defects, the impurities probably trap dislocations in some sort of high energy configuration, since it is hard to reconcile only point defects with the large amounts of stage IV energy sometimes observed. In the present results, the purity of the material was high enough so that whatever mechanism is responsible for stage IV was not activated.

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