$$\sigma_s = \frac{4P}{\pi D^2},$$

where P is the load, kg: D the diameter of the deformed zone, mm. The true tensile stress S_v was determined from the formula

$$S_v = 0.32 H_K,$$

where $H_K = \frac{4P}{\pi d^2}$ is the Ludwig hardness (d the diameter of the indentation, mm).

The results are shown in Fig. 3. It can be seen that both the mechanical characteristics fall as the loading temperature rises, but emerge to a constant level at 700°. An interesting fact is that, despite the lack of any essential difference in the grain size of the metal in the initial state and that of strengthening at 950°, it is much stronger. The explanation can probably be found by studying the substructure.

Figure 4 shows the hardness as a function of temperature during stress of copper specimens at ~ 220 kbar. The hardness was taken at a distance of 3 mm from the shock surface. Curve 1 is for specimens cooled in water after the explosion, and curve 2 for those cooled in air. In both cases there is a range of temperature in which the hardness falls rapidly. The range is not the same for different conditions of cooling. The drop in hardness is delayed when cooling occurs in water.

Metallographic analysis of specimens cooled in water showed that, at all loading temperatures right up to 400°, there had been no particular change in microstructure as compared with the original. However, in the specimens loaded at 500° (Fig. 5a) there is considerable grain refinement as compared to those loaded at temperatures up to 400° (Fig. 5b).

The same thing is observed in the specimens loaded at 400° and cooled in air. At higher temperatures there is a gradual increase in grain size; they reach their original size after loading at 800 and 900°. The grain refinement and drop in hardness must be due to recrystallization of the shock-strengthened metal. The structural changes resulting from shock loading Armco iron must be due to phase transitions under pressure. The transition from the α to hexagonal x phase, which is accompanied by a big rise in hardness, has been described a number of times [2, 4, 5, 9]. In this case the grains retain their old boundaries and most of the deformation within them is by twinning. In contrast to this, the α-γ phase transition is accompanied by secondary recrystallization [4]. In our experiments it has been established that the hardness of the recrystallized metal is higher than in the original state, but lower than in the twinned state achieved on the first transformation. Loading in the γ range has caused a very slight change in the grain size and big changes in the mechanical properties of iron.

Copper is not subject to polymorphous transformation as a result of shock loading. But its behaviour is like that of iron subjected to a pressure of 210 kbar. The softening curves have the same shape: in both cases there is a sudden drop in hardness as the pre-heating temperature rises, and this is accompanied by grain refinement. While this is due to phase transformations in iron, such an explanation is not suitable for copper. But total recrystallization also occurs in this metal.

The most logical explanation of this phenomenon is recrystallization of the shock-hardened metal, during the actual process of shock compression. Observations do not contradict this proposition. The drop in hardness and secondary recrystallization of copper cooled in water after deformation occurs at a higher temperature than for those cooled in air (Fig. 4). Since primary recrystallization is a duffusion