E-6 Effect of hydrostatic pressure on dislocation arrangement in metals

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It is a well-established fact that the ductility of metals is increased under confining pressure, while test results from various sources are at variance as to whether or not the yield criterion, flow stress and entire stress-strain curve are affected. One of the present authors designed and constructed a triaxial testing machine, which accommodated tension and compression tests of metals and rocks under the confining pressure up to 5,000 atm.(1) Among several kinds of metals tested a commercially pure polycrystalline zinc showed a tremendous increase in ductility and stiffness when the confining pressure was raised beyond 1,000 atm. It is the purpose of the present paper to explain this macroscopic mechanical behavioral characteristic from the microscopic view of structures and dislocations, and also to examine if this effect of hydrostatic pressure is irreversible.

The polishing and etching reagents recommended by J.J.Gilman(2) were used to reveal grain boundaries and dislocations, and the following results were obtained:

(1) Twin formation and the movement of twin and grain boundaries are responsible for a large plastic flow of this metal during uniaxial stressing, creep, relaxation and fatigue testings without confining pressure. This is illustrated by several photomicrographs.

(2) By the application of high hydrostatic pressure of the order of thousands atm. Dislocations line up along grain boundaries. Twin formation is suppressed to a great extent, and the movement of twin and grain boundaries is completely blocked. However, multiplication and movement of dislocations are still persistent and cause a plastic strain of the order of one ten thousandth. This is illustrated by photomicrographs taken at several stages of pressurization.

(3) The effect is irreversible. Once the above-mentioned structures of dislocations are formed the polycrystalline zinc is stiffened. This is illustrated by a stress-strain curve under uniaxial compression and a compressive relaxation curve without confining pressure, comparing a pressure treated specimen with not-treated one.

(4) The pressure treated zinc is stiffer than not-treated one but is still brittle when tested without confining pressure. Photomicrographs show twin formation and extensive movement of twin boundaries but little change to grain boundaries. Dislocation line-ups are seen along grain boundaries but not along twin boundaries formed by the uniaxial stressing without confining pressure.

(5) Photomicrographs are taken for the specimen stressed under confining pressure. Dislocation line-ups are observed along grain boundaries and also along twin boundaries this time.

The concluding discussion will include the results of hardness testing and reference to other metals.

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References

1. M. Nishihara and others, Proc. 7th Japan Congress on Testing Materials, 154 (1964)

2. J. J. Gilman, J. Metals, Transactions AIME, 6, 998 (1956)

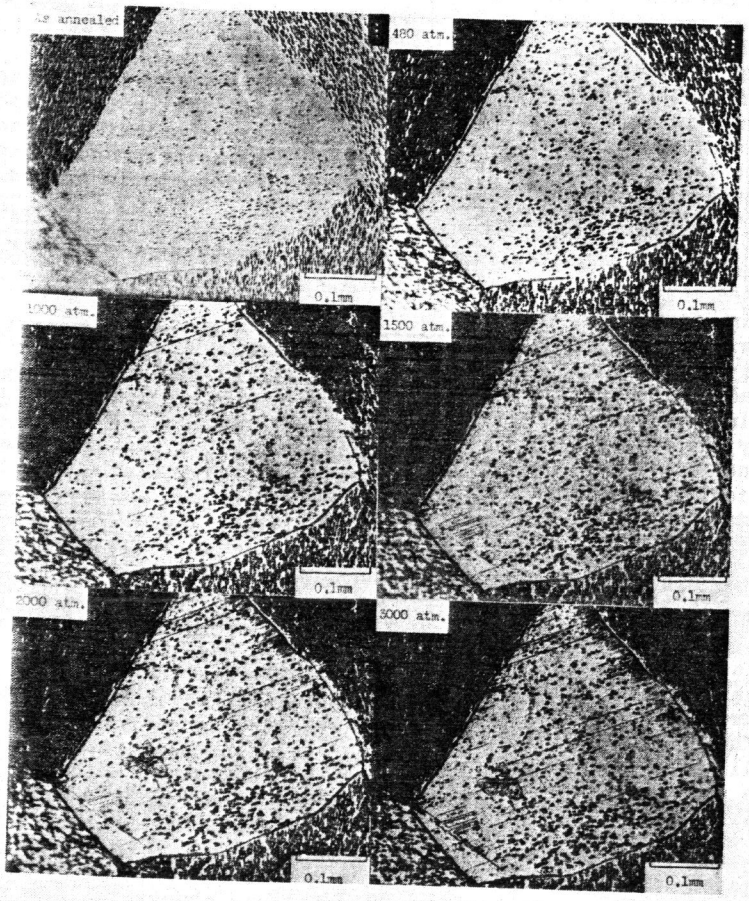

Fig. 1 Gradual build-up of dislocation lining along grain boundary, multiplication of dislocations, slipping and twinning due to hydrostatic pressure.

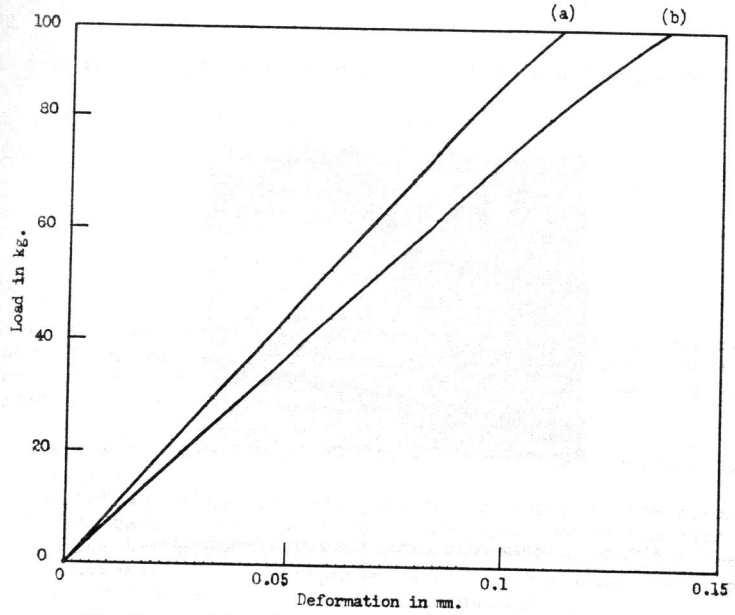

Fig. 2.a Uniaxial compression tests of (a) the pressure-treated and (b) not-treated specimens. Gauge length = 12 mm, bearing area = 36 mm^2. Crosshead speed = 0.5 mm/mn. Applied pressure = 3000 atm. for one hour.

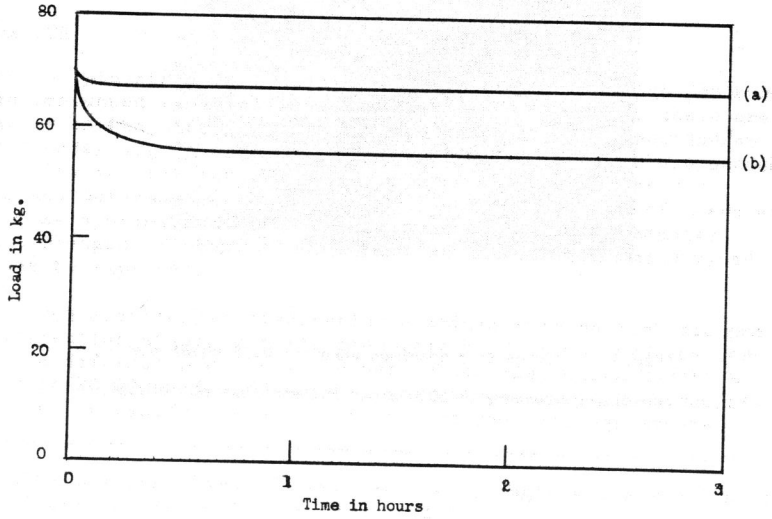

Fig. 2.b Uniaxial relaxation tests of (a) the pressure-treated and (b) not-treated specimens. Gauge length = 12 mm, bearing area = 36 mm^2. Initial load of 70 kg was applied at the crosshead speed of 0.5 mm/mn. Applied pressure = 3000 atm. for one hour.

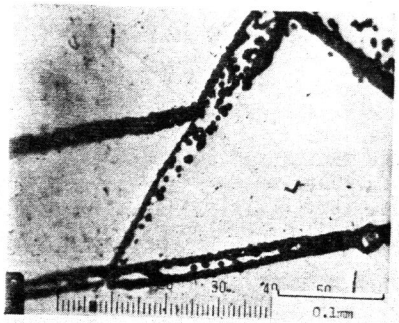

Fig. 3 Dislocation lining along twin boundaries.

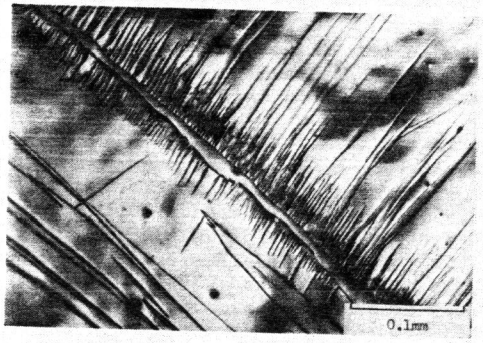

Fig. 4 Twins in a specimen strained 0.6% under the confining pressure of 2000 atm. Polished but not etched.