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THREE - DIMENSIONAL CRYSTALLIZING π - BONDINGS AND CREEP OF METALS

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ABSTRACT

Creep of metals has been explained conventionally by dislocation climb and grain boundary sliding in diffusion controlled process. The reorienations of the atoms in the grains by three-dimensional crystallizing π-bondings are visualized as grain rotations during slow deformation, fold formation at triple point, increased creviced space between grains, grain boundary sliding, grain boundary migration and formation of cracks at the grain boundaries. And also the rupture time and average creep strain rate are explained by the three-dimensional crystallizing π-bondings and they can be determined by uniaxial tensile test.

1. DIFFUSION MECHANISMS IN CREEP.

There are a number of strain-producing processes which can occur only at elevated temperature and contribute to creep. For the temperature and stress conditions of engineering importance, the mechanism which limits the rate of creep is probably diffusion-controlled climb of dislocation. However, thermally activated glide of dislocations, grain boundary sliding, and direct mass transfer by diffusion may also contribute to the creep process.

Some of the mechanisms of creep are illustrated schematically in Fig.1. These process usually go on simultaneously and may be combined in various ways,but one mechanism is usually rate - controlling for a particular set of conditions. At relatively low temperatures close to one-third of the melting temperature, diffusion rates are small and direct thermal activation of dislocations probably accounts for most of the creep strain. At very high temperatures and low stresses, where dislocation processes are slow, the rate of diffusion may become sufficiently large that direct mass transport by diffusion becomes the rate-controlling process. In this mechanism, diffusion of atoms from the sides of the grain which are under compression to the sides of the grain which are under tension causes the grains and the whole body to elongate in the tensile direction. The atom transport can take place by bulk diffusion through the grain, in which case it is called Nabarrs - Herring creep, or along the grain boundaries, when it is called Coble creep.Grain boundary sliding contributes to creep strain in a polycrystal but by itself can not produce very much strain. Since grain boundaries do not extend on a single plane across a sample,sliding of the grain boundary is limited by the incompatibility of the motion at grain boundary corners and irregularities.

2. REORIENTATIONS OF THE ATOMS BY THE THREE-DIMENSIONAL CRYSTALLIZING π-BONDINGS.

Fig.2 is the micrograph (60X) showing inhomogeneous deformation in aluminum after 9% slow deformation in tension at 20°C (Wood et al.,1949-50).

Fig.3 is the micrograph (60X) showing decrease in density of slip bands after 8% slow deformation in tension in aluminum at 150°C (Wood et al.,1949-50).

Fig.4 is the micrograph (60X) showing few coarse slip bands and subgrains in aluminum after 9% deformation in tension at 200°C (Wood et al.,1949-50).They indicate that the subgrains are reoriented as the temperature increases.They are twins by the three-dimensional crystallizing π-bondings,which rotate the polycrystalline subgrains into the loaded direction as the viscous flow resistance decreases with the temperature rise.

Fig.5 is the micrograph(200X) showing fold formation at triple point in aluminum tested at 538°C under a stress of 40 psi. Vertical markings and short markings in fold are cracks in oxide skin (Grant et al.,1957). The fold formation at triple point means that the atoms in the folded grain are reoriented in such two directions as the other two grains.The fold is the boundary of the two differently reoriented regions in the folded grain.

Fig.6 is the electron transmission micrographs (7000X) showing change in dislocation substructure with creep strain in an austenitic stainless steel tested at 740° C under a stress of 13,190 psi (Garofalo et al.,1963).It shows that the reorientations of the atoms by the bondings make the new grain boundaries.

Fig.7 is the micrograph(580 X) showing grain boundary sliding in polycrystalline magnesium after 6 % creep strain at 316 °C (Couling et al.,1957).The creviced space between the grains increases as the creep deformation.It represents the rotations of the grains by reorientations of the atoms.

Fig.8 shows the distribution of sliding along a grain boundary of an Al - 1.9 % Mg alloy tested at 900 °F (Brunner et al., 1959).

Fig.9 is the micrograph (350 X) showing grain boundary migration during creep of a carbon steel at 593° C under a stress of 4000 psi (Courtesy of U.S. Steel Corporation). The reorientations of the atoms at the grain boundaries make the lines moved.

Fig.10 is the micrographs showing w-type cracks in an austenitic stainless steel tested at 593° C under a stress of 38,000 psi (Courtesy of U.S.Steel Corporation).

Fig.11 is the micrograph (320 X) showing r-type cavities in grain boundaries of Nimonic 80A tested at 750° C (Weaver, 1959-60).

Fig.12 is the electron micrograph showing grain boundary precipitation and migration following creep at (a) 593°C (b) 704°C (c) 816 °C and (d) 593°C after a pretreatment at 816 °C for 24 hours (Garofalo et al.,1961).

3. AVERAGE CREEP STRAIN RATE AND RUPTURE TIME BY UNIAXIAL TENSILE TEST.

The log-log presentation of stress versus Larson-Miller parameter is obtained by uniaxial tensile test instead of the long time creep test (Reg.9). The temperature of the uniaxial tensile test can be determined by the Larson-Miller parameter of the design stress and the 0.1 hr's rupture time of the uniaxial tensile test. The rupture time at the design temperature and stress can be determined by the Larson-Miller parameter of the stress. The average creep rate is the total deformation of the tensil test divided by the rupture time at the design stress and temperature.The linear trend and the order of the data of the average creep rate by this method is almost same as that of experimental results.

The rupture time is the duration for the reorientations of the atoms, rotations of the grains,formations of the cracks at the grain boundaries and crack propagations through the material.

The creep strain is a total strain for a given stress,which is yielded by the rotations of the grains through the reorientations of the three - dimensional crystallizing π-bondings.The average creep strain rate is the total creep strain devided by the rupture time.

4. CONCLUSIONS

Creep of metals is brought about by rearrangements of the atoms in the structure of the three dimensional crystallizing π- bondings, which induce the grain's rotation, dislocation climb, grain boundary sliding, fold formation at the triple point,grain boundary migration and crack formation at the grain boundaries.

The rupture time is he duration for the reorientations of the atoms, rotations of the grains, formations of the cracks at the grain boundaries and crack propagation through the material.

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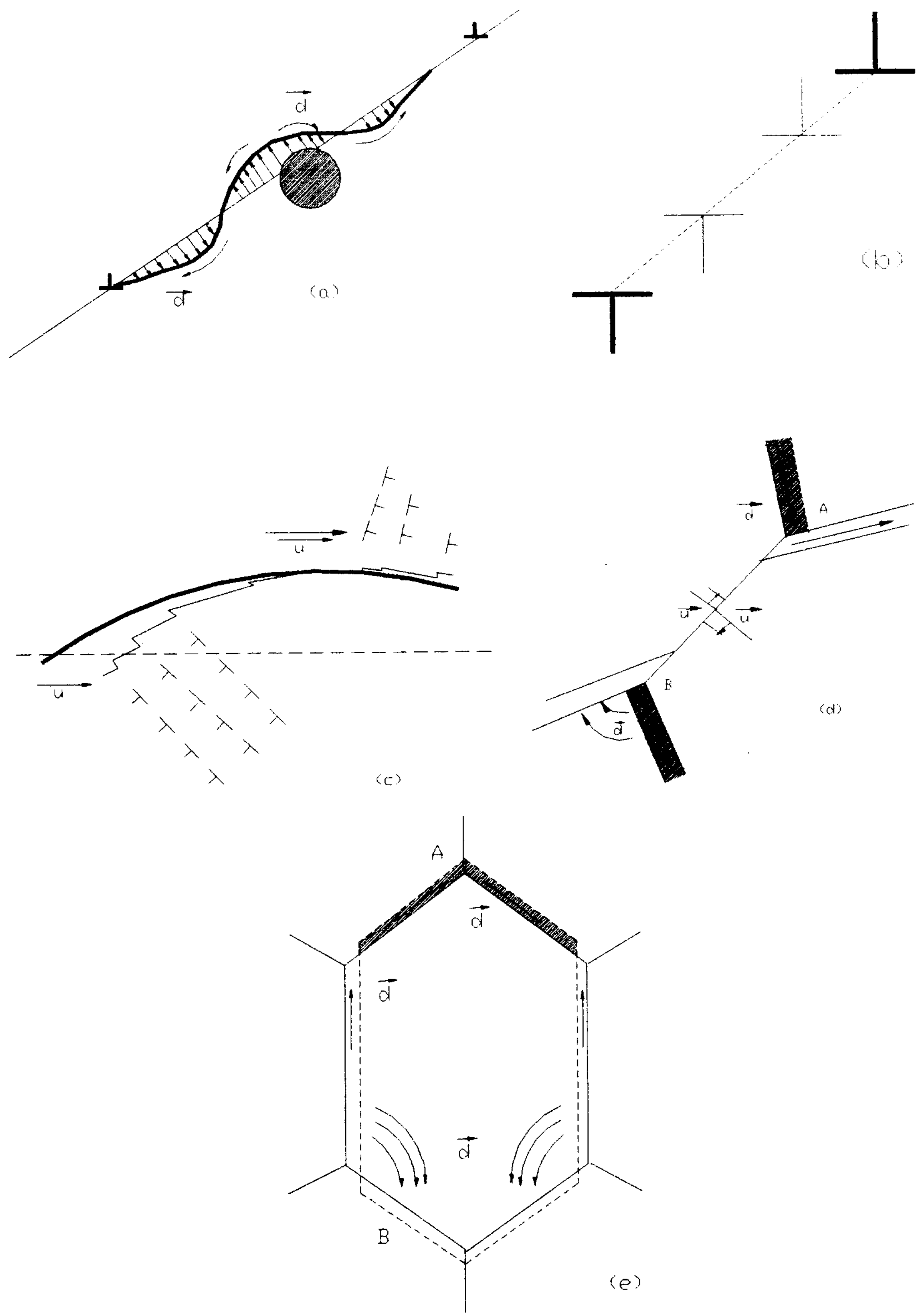

Fig.1 Mechanisms of creep. (a) A dislocation can climb to get around a particle which intersects its slip plane. Here climb is taking place by diffusion of atoms along the dislocation, as indicated

by d. Vertical arrows are the climb displacement of different parts of the dislocation.(b) The two edge dislocation of a dipole can climb together along the dashed line and annihilate each other.(c) At an irregularity on a grain boundary along the general direction indicated by the dashed line, grain boundary sliding through a distance **u** requires that the bump of the irregularity deform to accommodate the motion. Here accommodation is occurring by dislocation motion.(d) The interference to grain boundary sliding at tripe points of the grain boundaries can be accommodated by diffusion of atoms around the corners, as indicated by the vectors d. Diffusion can be either through the grain (B) or along the grain boundary (A). (e) Creep can occur directly by diffusional flow of atoms from one part of the grain to another. In Nabarro-Herring creep, the flow is through the grain ; in Coble creep, the flow is along the grain boundary.

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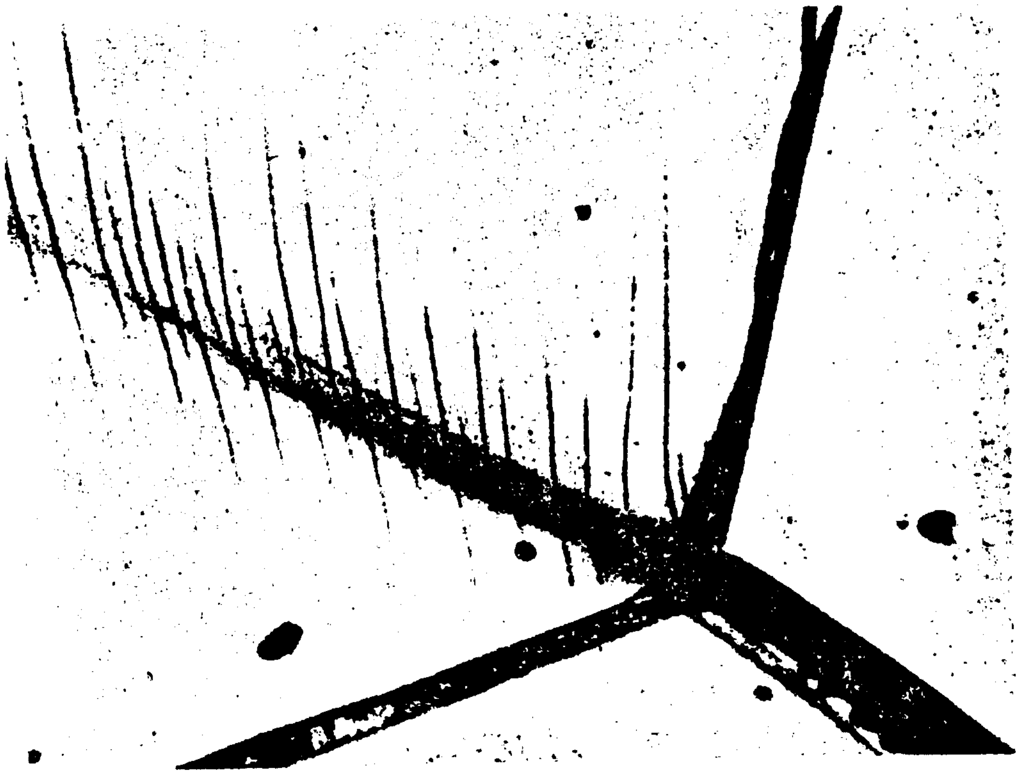

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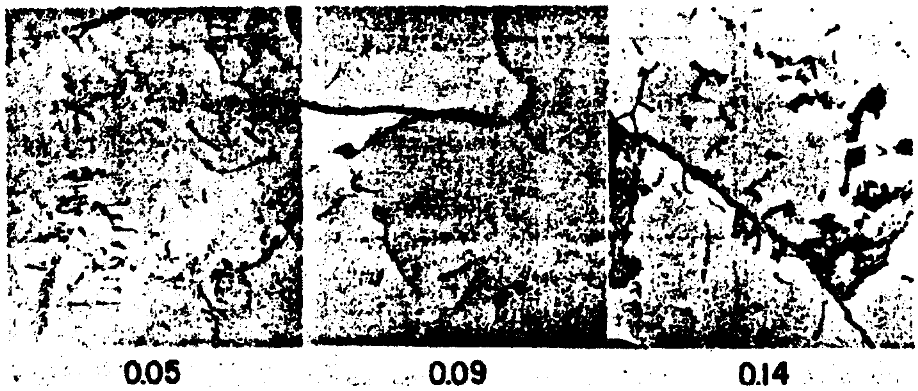


Fig.6 Electron transmission micrographs (7000 X) showing change in dislocation substructure with creep strain in an austenitic stainless steel tested at 704° C under a stress of 13,190 psi (Garofalo et al., 1963).

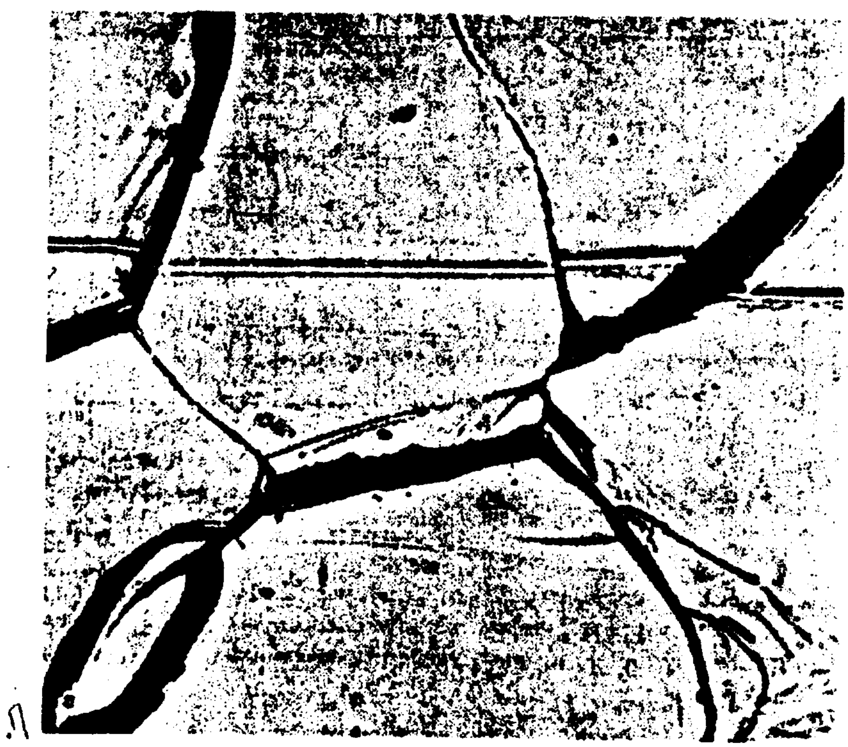


Fig.7 Micrograph (580 X) showing grain boundary sliding in polycrystal-line magnesium after 6 % creep strain at 316 ° C (Couling et al.1957).

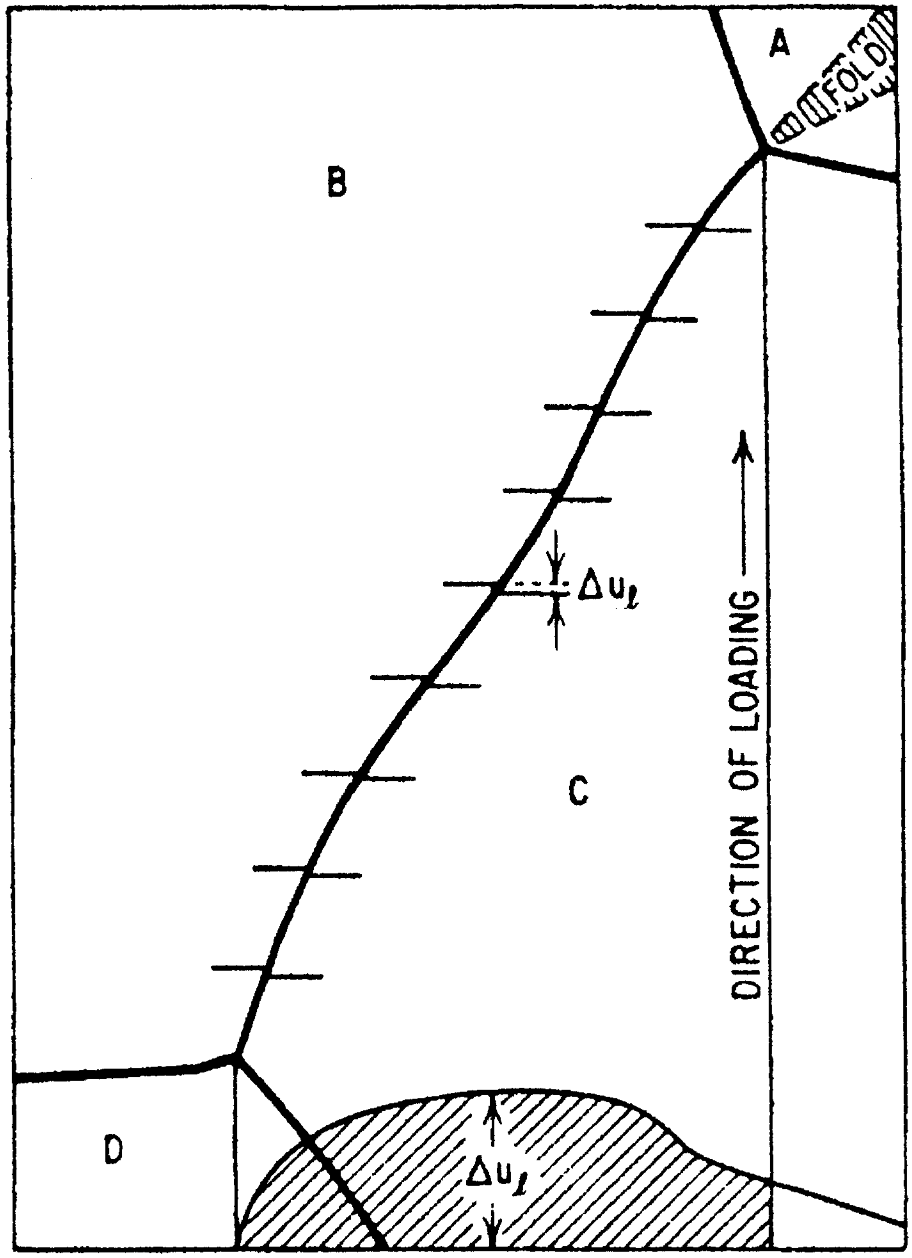
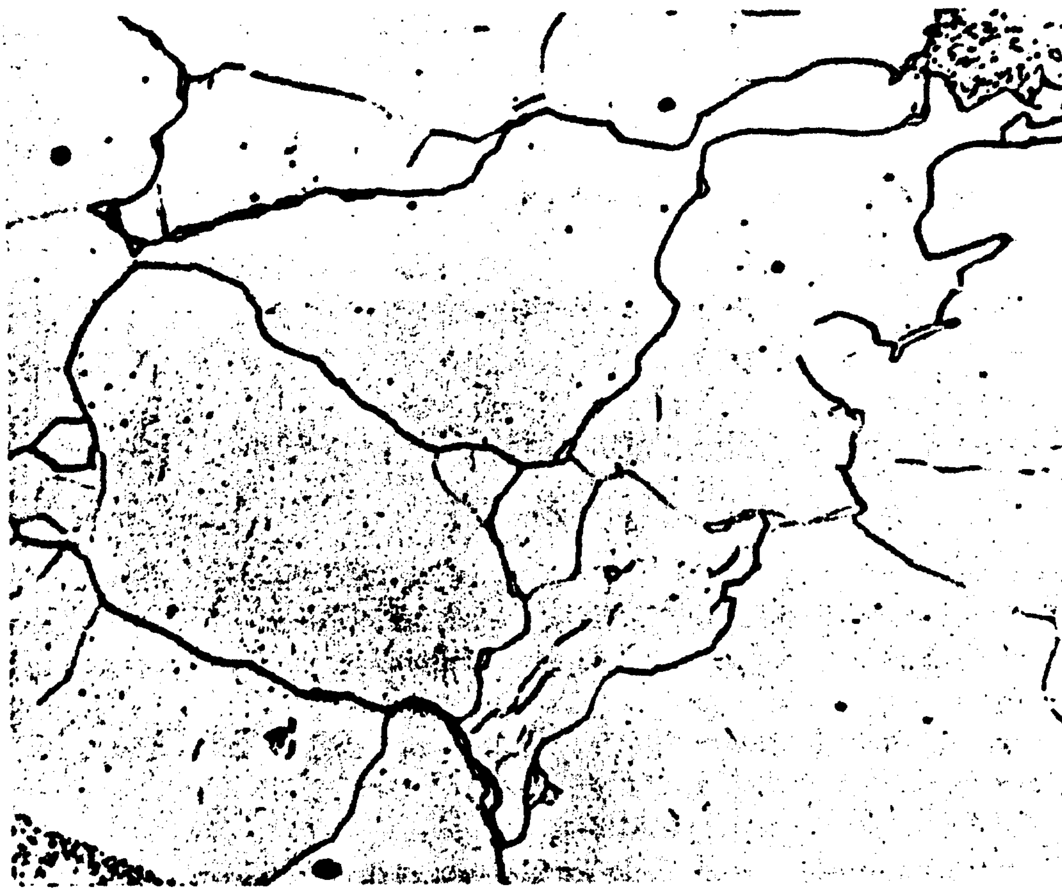


Fig.8 Distribution of sliding along a grain boundary of Al - 1.9% Mg alloy tested at 900° F

(Brunner et al., 1959)



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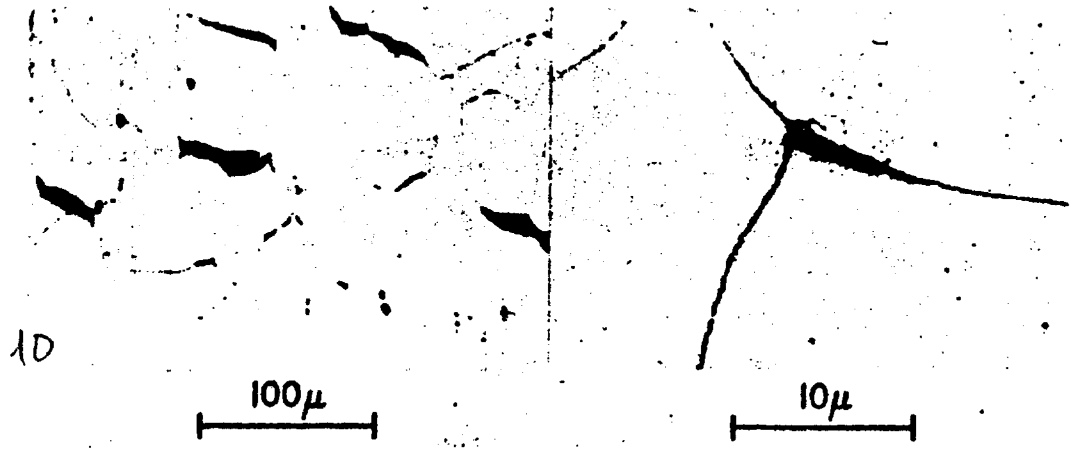

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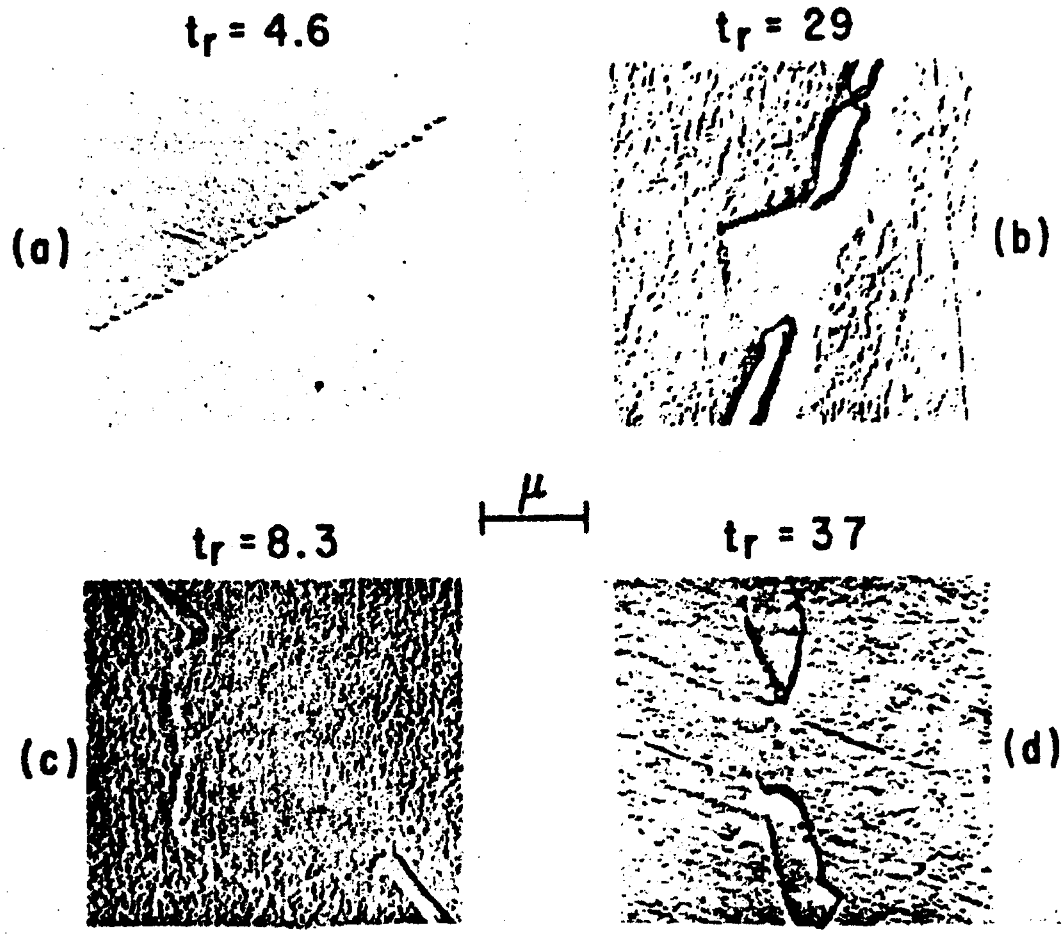

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