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THREE-DIMENSIONAL CRYSTALLIZING π-BONDINGS AND UNIAXIAL TENSILE DEFORMATION IN POLYCRYSTALLINE METALS

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ABSTRACT

It is visualized that dislocations move straightly in polycrystalline structure and the trans-grain dislocation moving occurs from yield point to ultimate tensile stress. Some fracture modes in uniaxial tensile test are illustrated in order to explain that after the ultimate point the grains deforms by twins and the rotations of grains make cracks at the grain-boundaries by the incompatibility. The *Lüders* banks, which propagates along the axis of the specimen, are twin bands which are formed by rearrangement of the atoms within the structure of three-dimensional crystallizing π-bondings. The fatigue limit can be found through the atom's rolling back motion during elastic deformation in the uniaxial tensile test by the change of the gradient.

1. TRANS-GRAIN DISLOCATION MOVING AND STRAIN-HARDENING

Most of engineering metals are polycrystalline. Each single crystal in them has different orientations. But the slip bands in the specimen after monotonic tension have the same directions as the loading direction (Fig.1 (a)) (Ref.1). It implies that trans-grain dislocation moving can advance forward straightly in polycrystalline structure. Combinations of edge and screw dislocations can accomodate any directional movings in the grain as in Fig.2 (Ref.2).

It is possible that dislocations move straightly in polycrystalline structure. In the uniaxial tensile test the trans-grain dislocation moving occurs from yield point to ultimate tensile stress point. It is hindered by grain boundaries, solid solutions, second phase hard particles and intersection of dislocation. Many strain-hardening mechanisms obstruct the trans-grain dislocation moving.

2. ROTATIONS OF GRAINS BY 3-D CRYSTALLIZING π- BONDINGS (TWINS) AND GRAIN-BOUNDARY CRACK

After the ultimate tensile stress point in the uniaxial tensile test the grains rotate because the atoms of 3-D crystallizing π-bondings (Ref.6) in the grain rearrange and they form twins.

After the ultimate point the grains deform by twin because the trans-grain dislocation moving becomes difficult. The rotations of grains make cracks at the grain-boundaries by the incompatibility of the motion at grain boundary corners and irregularities. Particularly the grains in the slip bands make many grain boundary cracks and intrusions and extrusions on the surface. Some fracture modes in uniaxial tensile test are illustrated in Fig.3 (Ref.3).

Fig.3 (a) is a separation of single crystals by shear on slip plane.

Fig.3(b) is a fracture of f.c.c. single crystals by necking down to knife edge because many slip planes in f.c.c. structure intersect each other and make necking.

Fig.3(c) is a fracture of f.c.c. alloy crystals in band of localized deformation. It is fractured by the cracks in the rearranged slip band and intrusions and extrusions on the surface.

Fig.3(e) is a " cup and cone " fracture of moderately ductile engineering metals. It is fractured by the central cracks in the neck, which grow very fast because of great triaxial tensile stresses.

3. *LÜDERS BAND*

Many metals, particularly low-carbon steel, show a localized heterogeneous type of transition from elastic to plastic deformation which produces a yield point in the stress-strain curve. Rather than having a flow curve with a gradual transition from elastic to plastic behavior, such as is shown in Fig.4, metals with a yield point have a flow curve or, what is equivalent, a load-elongation diagram similar to Fig.5 (Ref.4).The load increases steadily with elastic strain, drops suddenly, fluctuates about some approximately constant value of load, and then rises with further strain. The load at which the sudden drop occurs is called the yield point. The constant load is called the lower yield point, and the elongation which occurs at constant load is called the yield-point elongation. The deformation occuring throughout the yield-point elongation is heterogeneous. At the upper point a discrete band of deformed metal, often readily visible with the eye, appears at a stress concentration such as a fillet, and coincident with the formation of the band the load drops to the lower yield point. The band then propagates along the length of the specimen, causing the yield-point elongation. In the usual case several bands will form at several points of stress concentration.

These bands are generally at approximately 45° to the tensile axis. They are usually called *Lüders* bands, Hartmann lines, or stretcher strains, and this type of deformation is sometimes referred to as the Piobert effect. When several *Lüders* bands are formed, the flow curve during the yield-point elongation will be irregular, each jog corresponding to the formation of a new *Lüders* band. After the *Lüders* bands have propagated to cover the entire length of the specimen test section, the flow will increase with strain in the usual manner. This marks the end of the yield-point elongation.

The yield-point phenomenon was found originally in low-carbon steel. A pronounced upper and lower yield point and a yield-point elongation of over 10 percent can be obtained with this material upper proper conditions. More recently the yield point has come to be accepted as a general phenomenon, since it has been observed in a number of other metals and alloys. In addition to iron and steel, yield points have been observed in polycrystalline molybdenum, titanium, and aluminum alloys and in single crystals of iron, cadmium, Zinc, alpha and beta brass, and aluminum. Usually the yield point can be associated with small amounts of interstitial or substitutional impurites. For example it has been shown that almost complete removal of carbon and nitrogen from low-carbon steel by wet-hydrogen treatment will remove the yield point. However, only about 0.001 percent of either of these elements is required for a reappearance of the yield point. A number of experimental factors affect the attainment of a sharp upper yield point. A sharp upper yield point is promoted by the use of an elastically rigid (hard) testing machine, very careful axial alignment of the specimen, the use of specimens free from stress concentrations, high rate of loading, and, frequently, testing at subambient temperatures. If, through careful avoidance of stress concentrations, the first *Lüders* band can be made to form at the middle of the test specimen, the upper yield point can be roughly twice the lower yield point. However, it is more usual to obtain an upper yield point 10 to 20 percent greater than the lower yield point. The *Lüders* band is a twin band which is formed by rearrangement of the atoms within the structure of three-dimensional crystallizing π-bondings.This can be easily accomodated by rolling of impurity atoms, for example nitrogens and carbons. The band propagated along the specimen because the twinned band strain-hardens very rapidly. Because the stress for twin action is very low the yield point decreases very fast.

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4. FATIGUE LIMIT

Fig.6 shows the successive development of slip bands in Armco iron below the fatigue limit (Ref.2). The slip bands, caused by the 3-D crystallizing π-bondings, are not developed from the interior to the surface because the alternating stress is not sufficient for active reorientations of the bondings. The reorientations of the atoms by the bondings needs a minimum level of stress for their moving from one state to other one. Nitrogen and Carbon atoms obstruct the moving from one state to other by their lubricating rolling back, which elevates the fatigue limit in the case of iron and titanium alloys. It has been shown that Lüders band yield point phenomenon is caused by this and almost complete removal of carbon and nitrogen from low carbon steel by wet-hydrogen treatment will remove the yield point (Ref.4). However, only about 0.001% of either of these elements is required for a reappearance of the yield point. Fatigue limit also is caused during elastic deformation after proportional limit by the rolling back movement. The rolling movement changes the gradient of the proportional modulus by adding up horizontal rolling motion. The microplastic deformation from the elastic limit to some forward distance point, which is fatigue limit, can not be accumulated because of its rolling back motion. The searching method in the tensile test is as follows. The straight line at proportional limit is extended to the horizontal elastic limit stress line (Ref.5).

The right symmetrical point with the meeting point is drawn out. A vertical line is drawn from the symmetrical point to the original tensile test curve. The meeting point is fatigue limit. This is explained in Fig.7.

5. CONCLUSIONS

(1) Dislocations can move straightly in polycrystalline structure and the trans-grain dislocation moving occurs from yield point to ultimate tensile stress.

(2) After the ultimate point the grains deform by twins and the rotations of grains make cracks at the grain-boundaries by the incompatibility.

(3) The *Lüders* band is a twin band which is formed by rearrangement of the atoms within the structure of three-dimensional crystallizing π-bondings.

(4) The fatigue limit can be found during elast deformation in the uniaxial tensile test by the change of the gradient through the atoms' rolling back motion.

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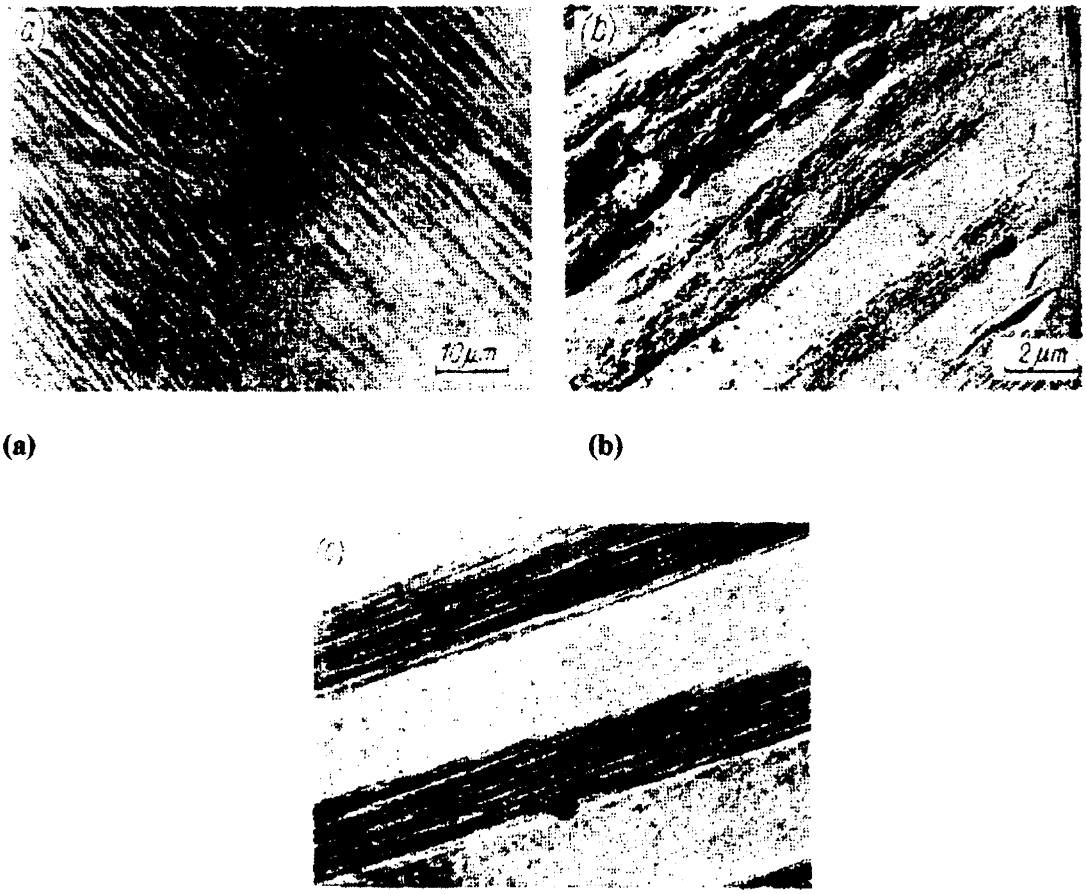


(a)

(b)

(c)

Fig.1 Slip bands : (a) in Armco iron specimen after monotonic tension
(b) in Armco specimen after completely reversed cyclic bending
(c) in aluminium single crystal after monotonic tension at -196°C, magn. × 150

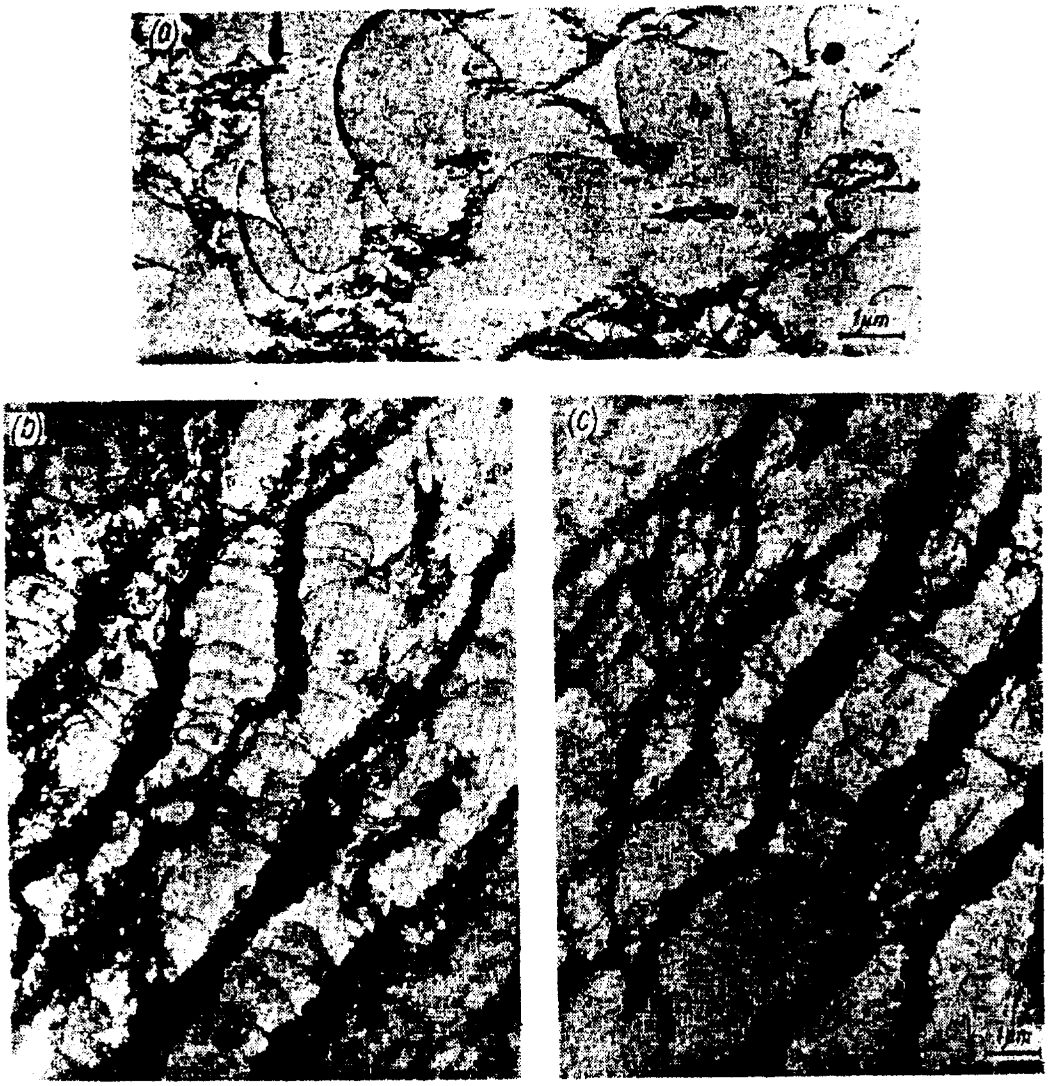


Fig.2 Dislocation structure in copper single crystal pinned in the loaded state by neutron irradiation : (a) in the rapid hardening stage, and in the saturation stage with groups of equal signs (b) and unequal signs (c), b_p primary Burgers vector. Numerous black dots in the background are marks of damage by neutron irradiation (Courtesy of H.Mughrabi)

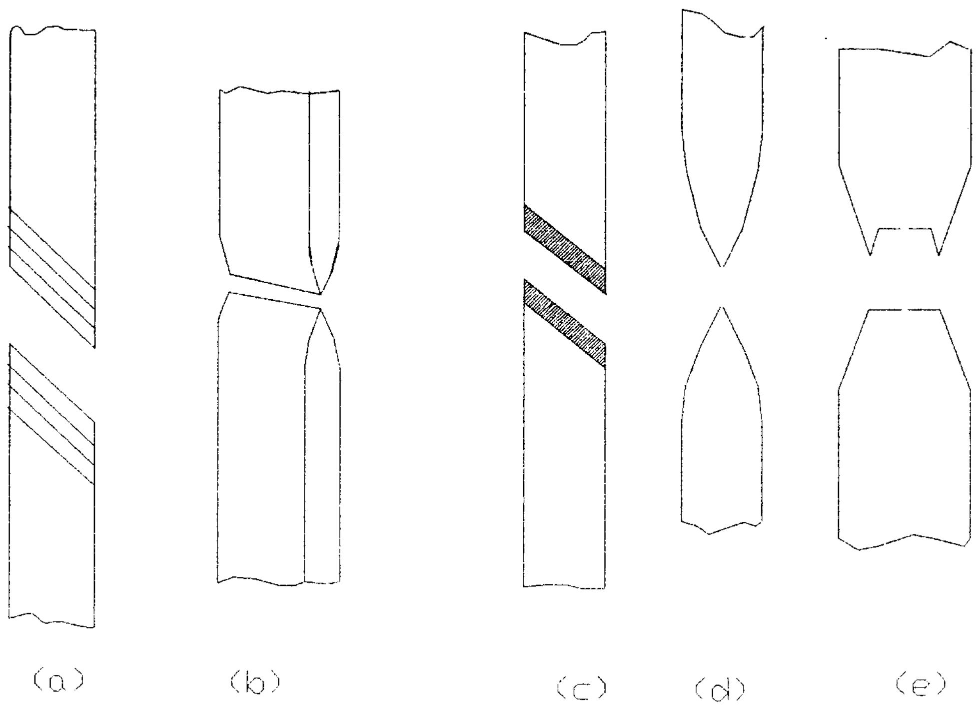


Fig.3 Types of fracture produced under uniaxial tension : (a) separation of single crystals by shear on slip plane ; (b) fracture of f.c.c single crystals by necking down to knife edge; (c)fracture of f.c.c alloy crystals in band of localized deformation ; (d)fracture by necking to point;(e) “cup and cone”fracture of moderately ductile materials.

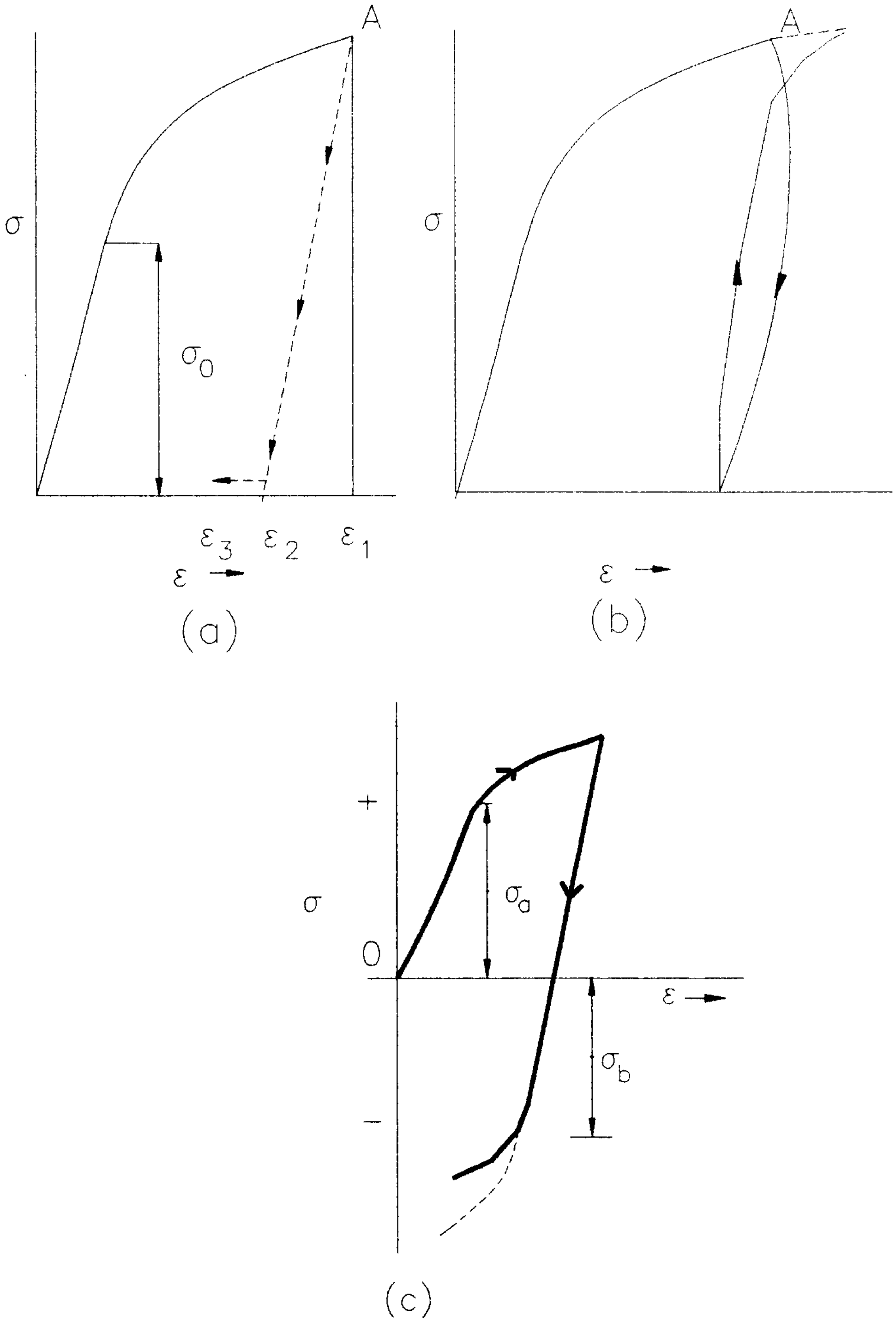


Fig.4 Typical true stress-strain curves for a ductile metal.

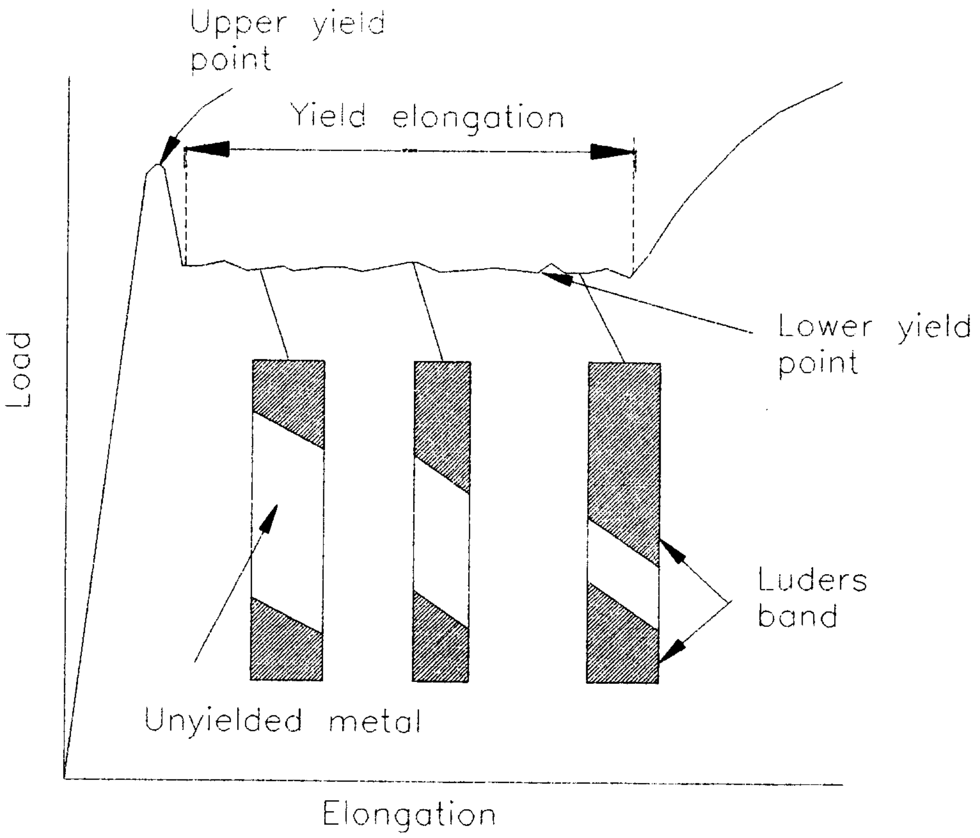
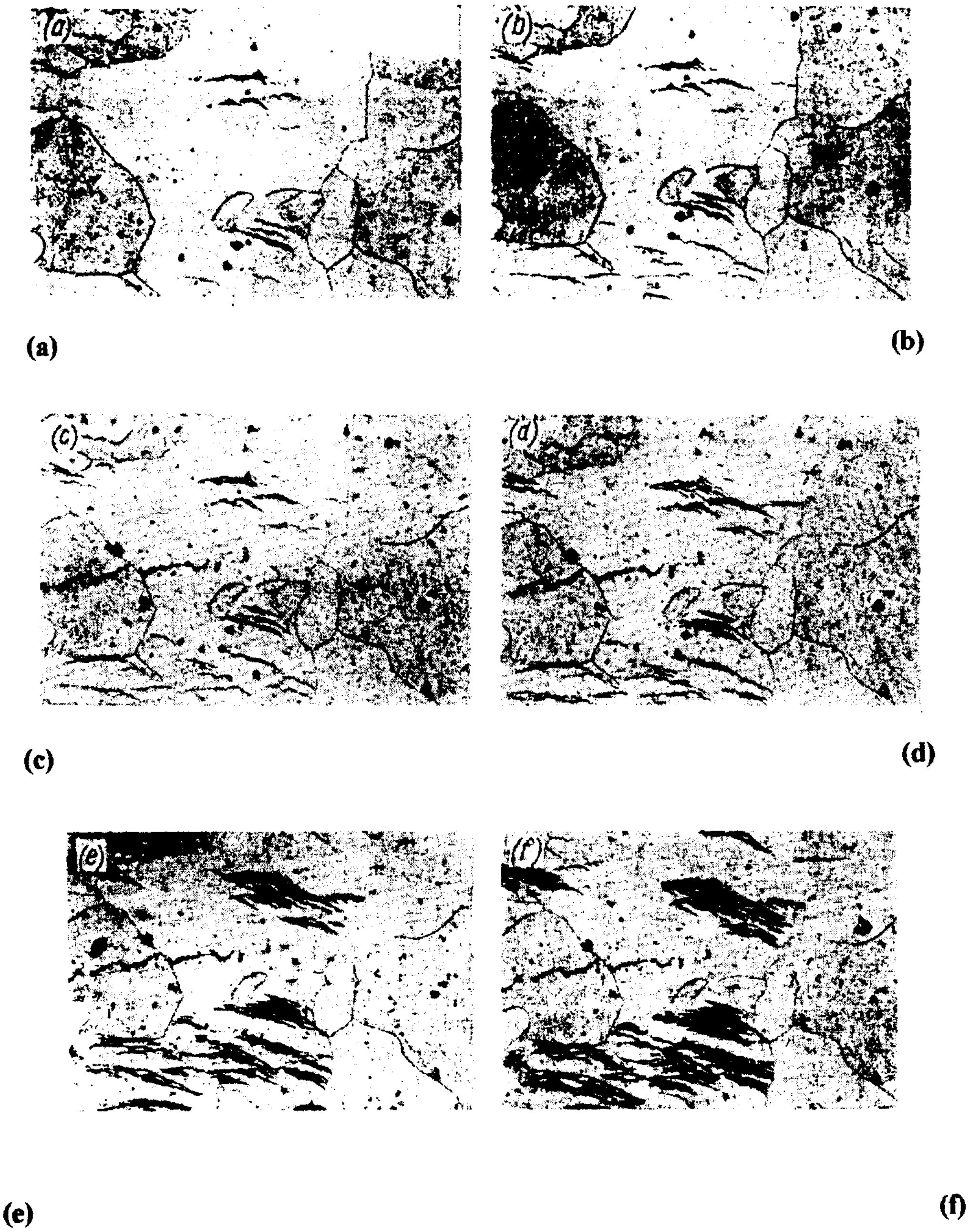


Fig.5 Typical yield-point behavior.



(a) (b)

(c) (d)

(e) (f)

Fig.6 Successive development of slip bands in Armco iron below the fatigue limit at σ_a =0.8 S_{br} after : (a) N = 1 × 10^5, (b) N = 5 × 10^5,(c) N = 1.5 × 10^6, (d) N = 3 × 10^6,(e) N = 6 × 10^6,and (f) N = 4 × 10^7 cycles (× 250) (Ref.2)

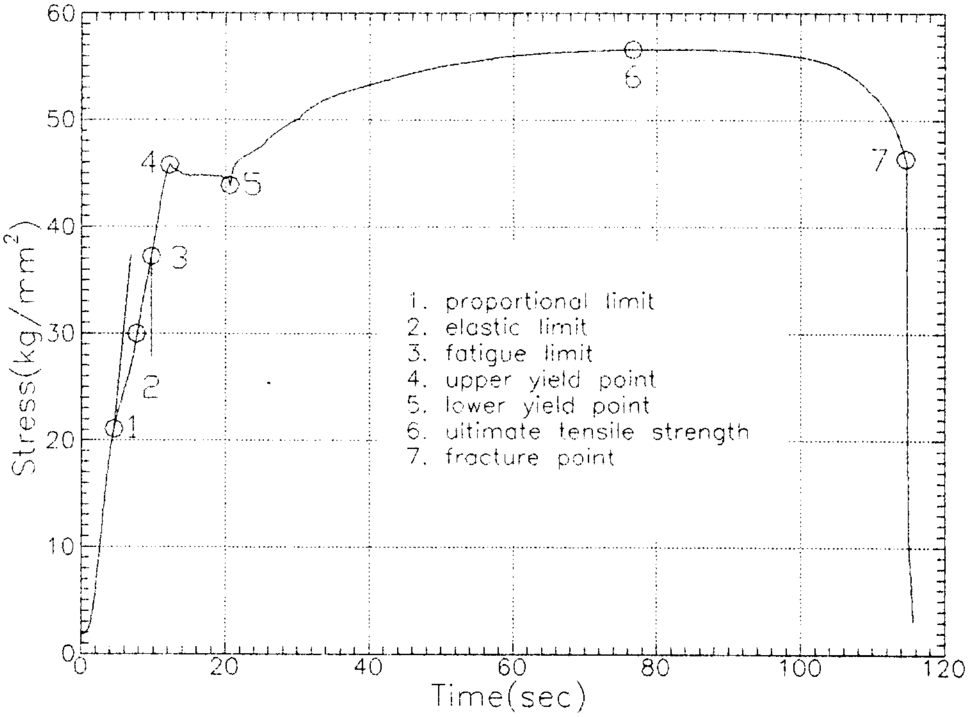


Fig. 7 Determination of the fatigue limit from the tensile-test curve