MECHANISM OF SLIP & TWINNING

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Prerequisite Knowledge: elementary knowledge of: metal structure, specimen preparation, measurement of mechanical properties of materials, examination of microstructure of a polished surface with a metallurgical microscope.

Objectives: To demonstrate the mechanisms of deformation in bcc, fcc, and hcp-structure metals and alloys and in some ceramics as well. To examine the deformed microstructures (slip lines and twin boundaries) in different grains of metallic and ceramic specimens. To study visually the deformed macrostructure (slip and twin bands) of metals and alloys.

Background: Two of the most important mechanisms of plastic deformation are slip and twinning. Slip, which is the principal one, can be considered as a result of a distorted boundary, a line imperfection called dislocation, between two perfect regions of a space lattice, figure 1. Two types of dislocation segments are identified: edge dislocation, which causes axial strains in the space lattice, figure 2 ; and screw dislocation which causes the lattice to experience shear strains and to distort through a helical path, figure 3. The passage of a dislocation through a crystal results in the relative motion of one part of the crystal past the other part; this process is called **slip.** Figure 4-a shows a slip resulting from the movement (right to left) of a pure edge dislocation, and figure 4-b shows a slip resulting from the movement (front to back) of a pure screw dislocation through a simple cubic lattice. Slip occurs on the planes of the densest pack of atoms and in the direction of least distance between atoms. For example, in a face-centered-cubic (fcc) lattice, slip occurs on the four planes of ABC type, {111} planes, and in the direction of the diagonals of cube faces or the three sides of triangle ABC, $<1\bar{1}0>$ directions, figure 5. Slip planes and directions for some type of structures are shown in table 1. In a monocrystalline specimen under axial loading, figure 6-a, if the slip plane is oriented parallel with or at a right angle to the axis of loading, figures 6-b and 6-c, the crystal will fail with no plastic deformation at all. When the orientation lies between the above two extreme cases, figure 6-d, the fracture is preceded by an appreciable plastic deformation. The closer in value the angle of slope of the slip plane is to 45^{o}, the less load P is required to start the slip and the greater the plastic deformation is before the failure. In a polycrystalline specimen under axial loading, slip occurs first in grains whose slip planes are oriented at an angle of 45^o with respect to the direction of applied force, while adjacent grains are affected by elastic deformation only. Surface examination of a deformed material under the optical microscope reveals a series of lines arising from steps on the surface called **slip lines**; this is shown in experiments number 1 and 2 for metallic and ceramic specimens. Also, these slip planes open up on the surface of the specimen as **slip bands**; this is shown in experiment number 3. The other mechanism of deformation is twinning. Twinning is the result of identical motions of atoms of a plurality of rows parallel to a twinning plane in the original lattice. The twin plane is a boundary which separates two orientations that are mirror images of one another. In other words, twinning is formed by a uniform shearing of atoms parallel to the twin boundary, figure 7. The strained part of the crystal becomes a mirror image of the zone free from twin crystals with respect to the twinning plane. When the polished surface of such a material is subjected to etching , usually the regions on both sides of the twin boundary will be attacked differently because of a difference in the atomic configurations. Hence, viewed under a reflected-light microscope the surface will show dark and bright parallel regions (twin boundaries) within each grain. Similar to slip bands, twin bands could be viewed on the surface of the specimen. Examples of twin boundaries and bands are shown in experiments number 4 and 5. Twinning occurs along with the slippage. The fraction of deformation by twinning is greater in hexagonal-lattice metals and in deformation occurring at great speed, as explosion stamping or extrusion.

Exp. # 1: Slip Lines in Metals

Equipment: UTM, Metallurgical Microscope, Specimen Preparation Station, 4 copper (fcc), one iron (bcc)

PROCEDURE: 1) One side of the specimens of copper and iron is ground and polished. 2) Measure the hardness of one of the copper specimens.
3) Examine the microstructures of the polished surfaces with a metallurgical microscope. 4) Keep one of the specimens of copper in the UTM in such a way that the polished surface is not in contact with the grips and deform the specimen approximately 10 percent in compression. 5) One specimen of copper is lightly etched and operation 4 is repeated to observe the change in deformed structures from grain to grain, figure 8. 6) Repeat operations 4 and 5 on iron specimen, figure 9. 7) The remaining two specimens of copper are deformed 5 percent and 20 percent, respectively. 8) Examine the microstructures of the polished surfaces of the deformed specimens. 9) Measure hardness of copper specimens. Plot hardness vs percent deformation for copper specimens, figure 10, and conclude why does hardness change as a function of percent deformation?

<u>Exp. # 2: Dislocation in Ceramic by Etch Pit Pattern</u>
Equipment: Reflected light microscope, Sodium Chloride crystal, anhydrous methyl alcohol, ether, blade

<u>PROCEDURE:</u> 1) Cleave the sodium chloride crystal with a single-edge razor blade. A slight press given to the blade placed on the crystal surface will bring about cleavage if the blade is properly oriented with respect to the cleavage planes. In sodium chloride these are {100}. 2) Dip the crystal in anhydrous methyl alcohol and keep it there for a few seconds. 3) Take out the crystal, wash it in ether, and quickly dry it on a filter paper. 4) Put the specimen on a glass slide, mount the latter on the stage of the microscope and observe the etch pit patterns, figure 11.

<u>Exp. # 3: Slip Bands</u>
Equipment: Tensile specimen of mild steel, furnace, UTM

<u>PROCEDURE:</u>1) Select a tensile specimen of mild steel. 2) Fully anneal the specimen and then polish the surface. 3) Load it in tension at a rate of 0.05 in/min. 4) Study the surface pattern just as the yield load is reached (Slip plane opens up on the surface as a band with an angle of 45^{o} with respect to the load axis), figure 12.

<u>Exp. # 4: Twin Boundaries</u>
Equipment: Alpha-brass specimen, reflected-light microscope, etching solution, specimen preparation station

<u>PROCEDURE</u>: 1) The specimen is ground and polished to a mirror like surface. 2) Wash the specimen thoroughly with water and dry it with alcohol. 3) Immerse the specimen with polished surface upward in the etching solution for about 2 seconds. 4) Locate the specimen on the glass slide and mount the slide on the microscope stage and view it in the reflected light, figure 13.

<u>Exp. # 5: Twin Bands</u>
Equipment: A CPH-structure specimen such as zinc, specimen preparation station, UTM, reflected-light microscope.

<u>PROCEDURE:</u> 1) Select a CPH-structure metal such as magnesium, titanium, or zinc. 2) Cut the specimen about 8-in long and obtain a metallographic polish on the surface. 3) Place the specimen in a tensile stress and slowly load it while viewing the surface reaction (Twin planes appear as broad lines).

Table 1: Slip planes and slip directions for some type of structures

structure	slip plane	slip direction
fcc	$\{111\}$	$\langle 1\bar{1}0 \rangle$
bcc	$\{101\},\{112\}$	$\langle \bar{1}11 \rangle,\langle 11\bar{1} \rangle$
hcp	$\{0001\},\{1010\}$	$\langle 11\bar{2}0 \rangle$

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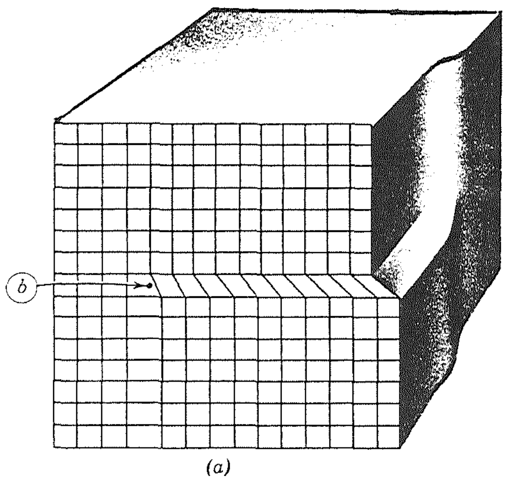

Figure 1. The lattice distortion at the boundary between two perfect regions in a slip.

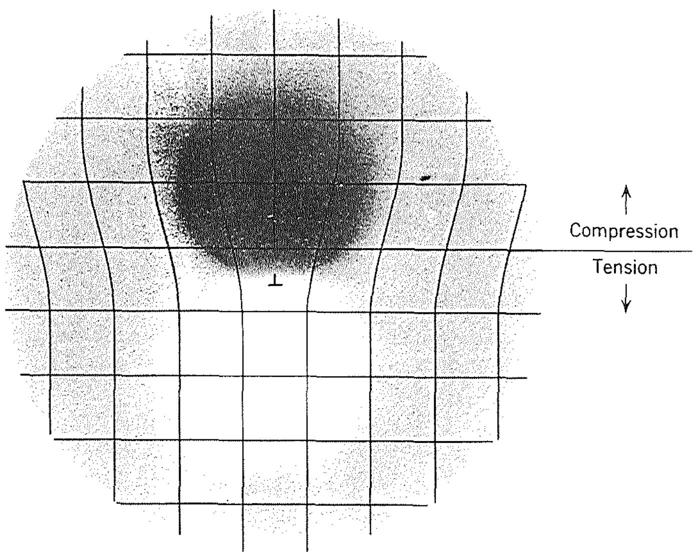

Figure 2. The regions of tension (light) and compression (dark) around an edge dislocation in a simple cubic lattice.

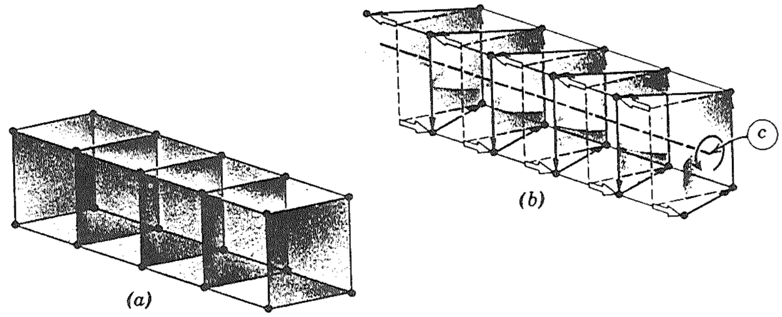

Figure 3. (a) A simple cubic lattice before slip, (b) the lattice traces a helical path in a screw-dislocation slip.

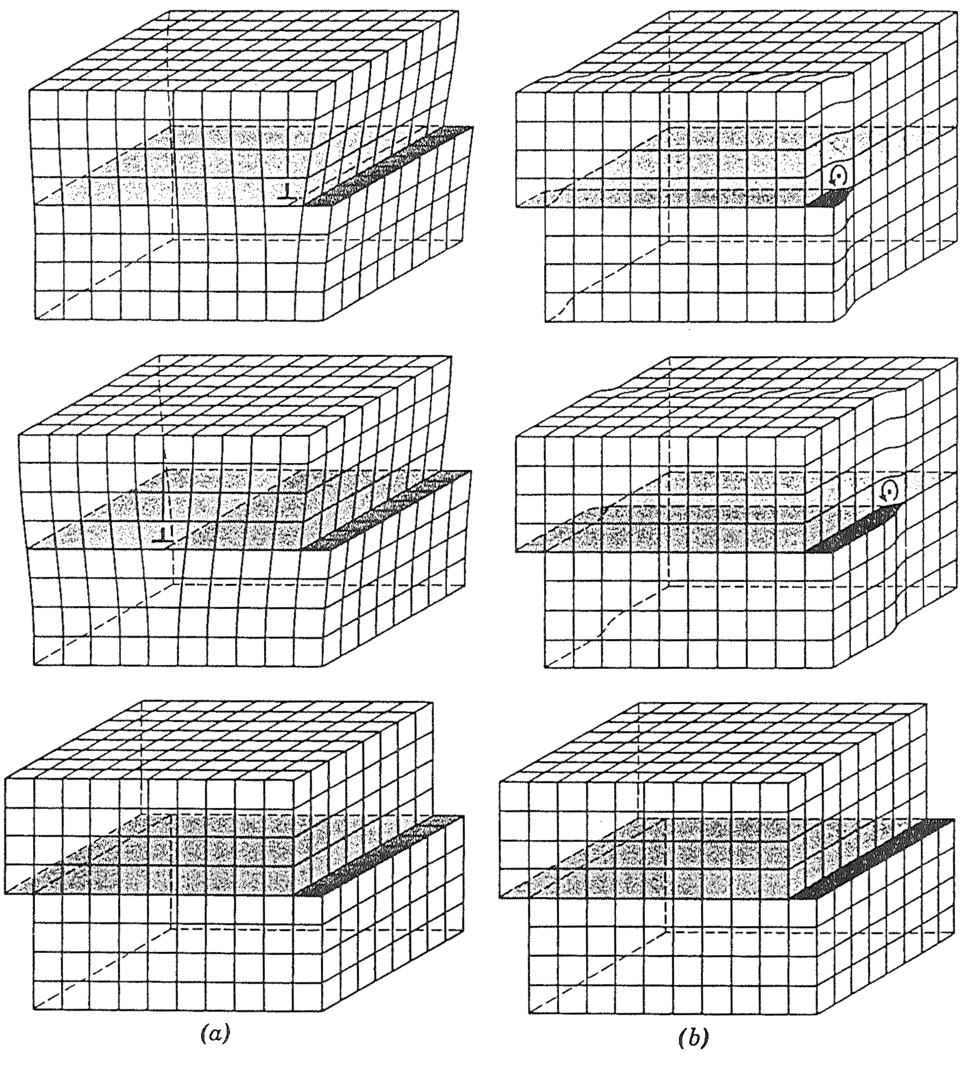

Figure 4. (a) Slip resulting from a pure edge dislocation, (b) Slip resulting from a pure screw dislocation.

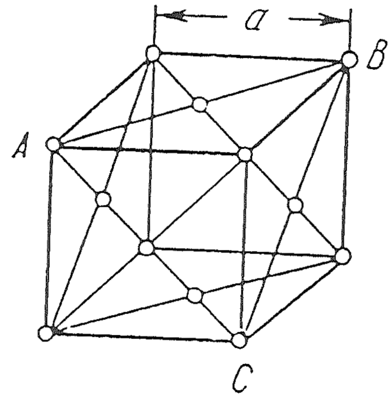

Figure 5. Slip planes and their directions in an fcc crystal lattice.

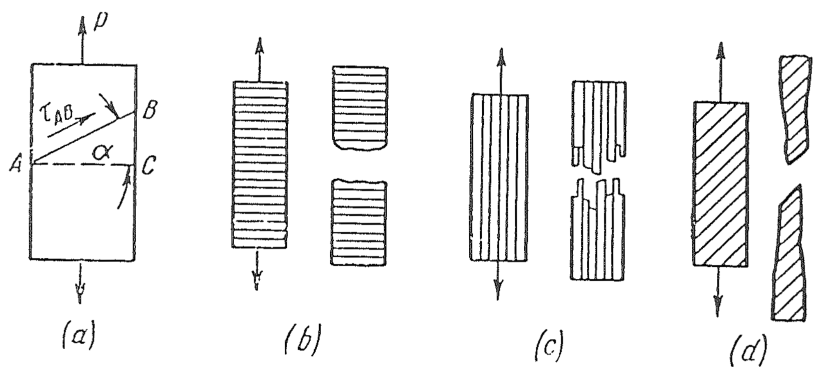

Figure 6. Effect of orientation of slip plane upon character of deformation of monocrystals.

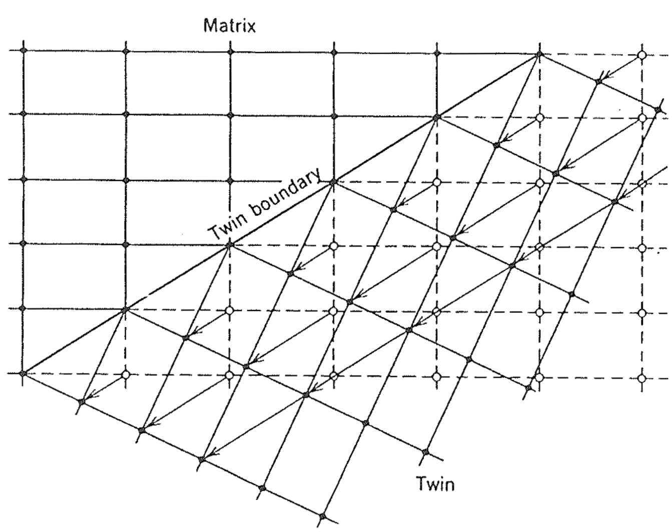

Figure 7. The formation of a twin in a tetragonal lattice.

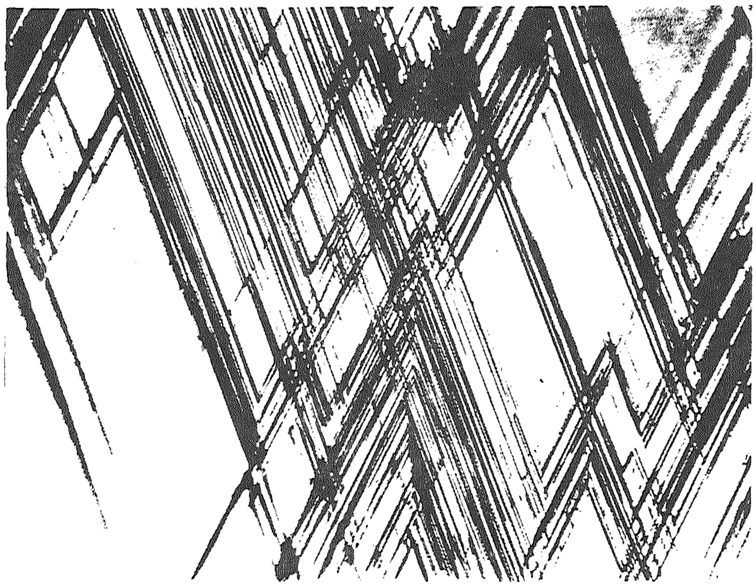

Figure 8. Slip lines in a plastically deformed copper, 200X.

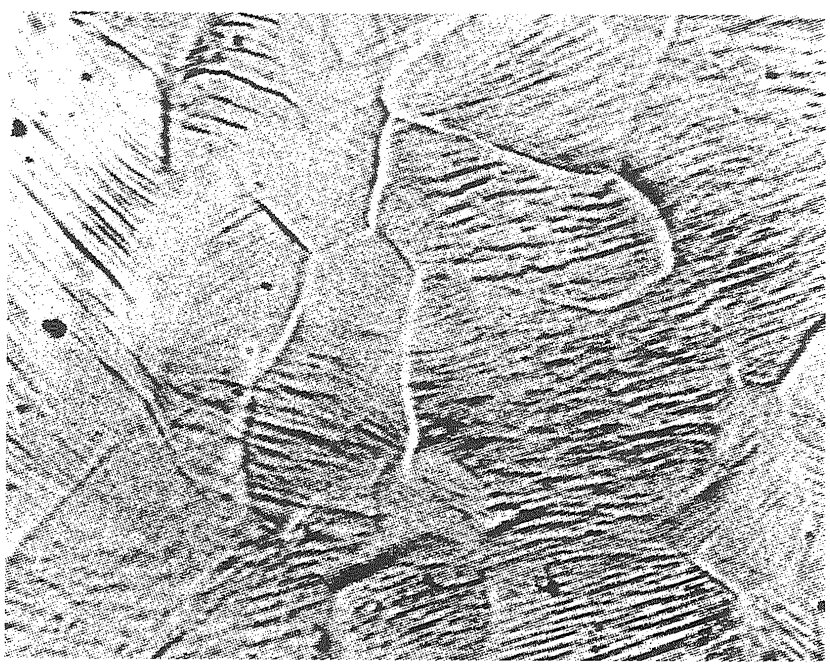

Figure 9. Slip lines in a plastically deformed iron, 300X.

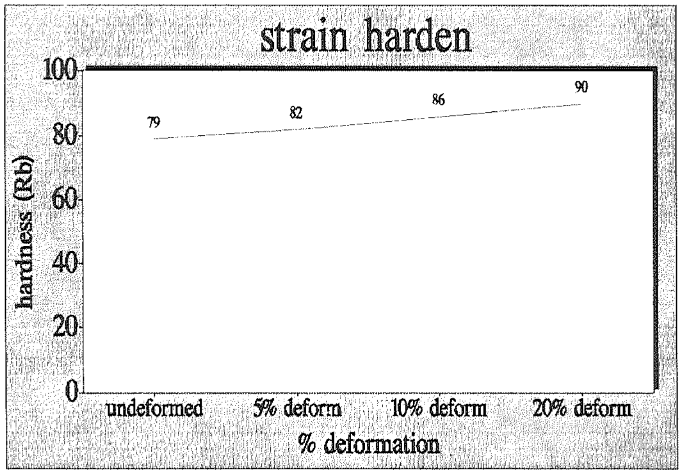

Figure 10. Variation of hardness vs deformation.

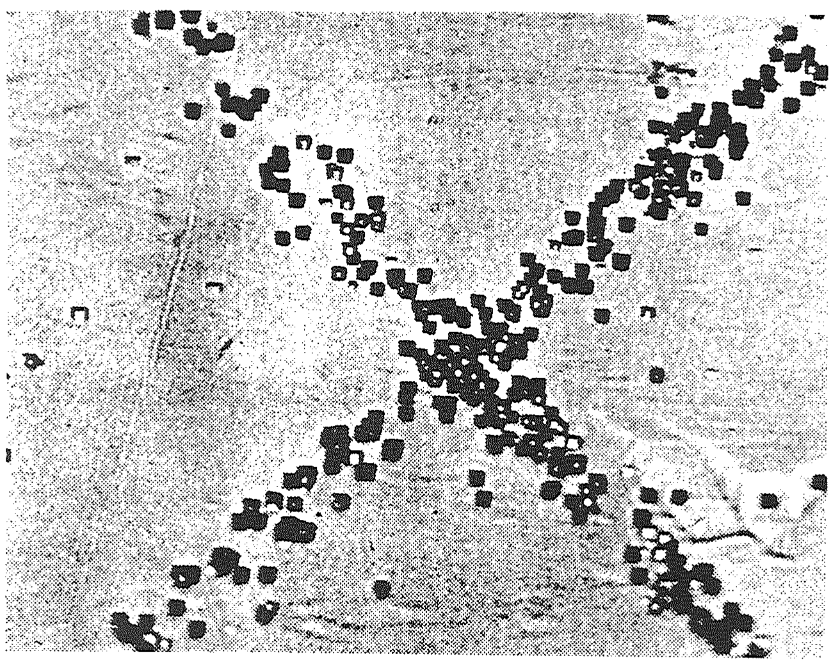

Figure 11. Etch pit pattern (slip bands) in sodium chloride, 375 X.

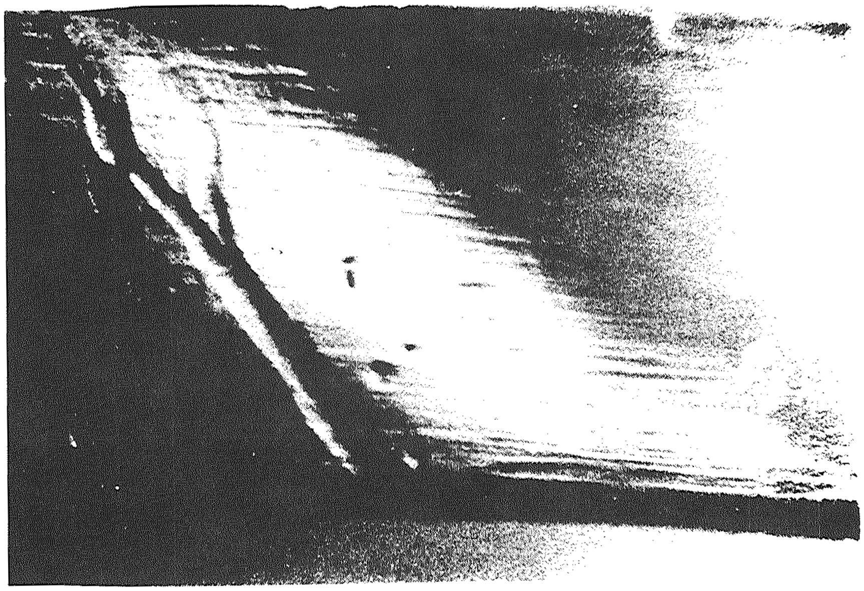

Figure 12. Slip band of a deformed mild steel that makes a 45^o angle with the tensile load axis.

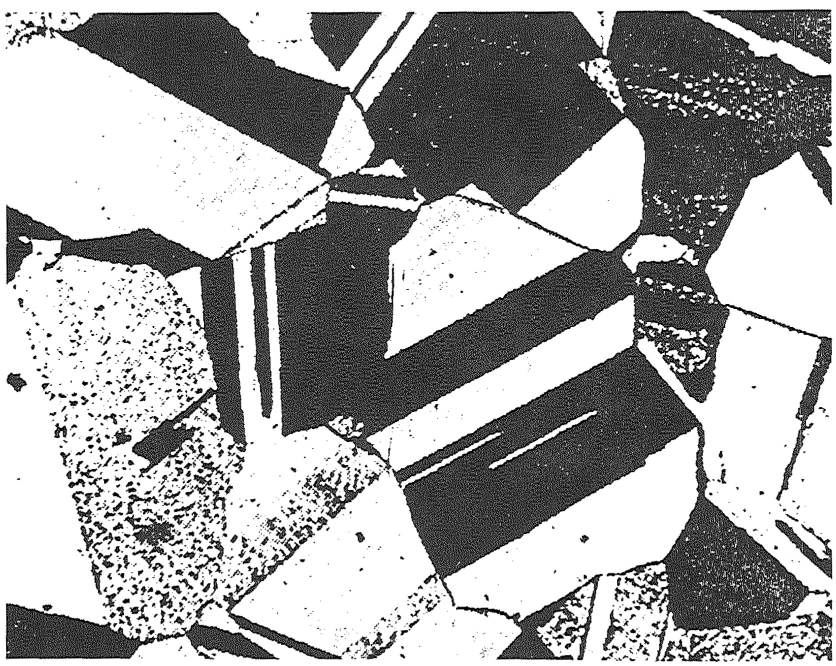

Figure 13. Twin boundaries as dark and bright regions within each grain in an α-brass specimen, 400X.