한국소성가공학회 '95춘계학술대회 논문집 pp. 78～89

THREE-DIMENSIONAL CRYSTALLIZING π-BONDINGS AND WEAR OF METALS

HUNG-KUK OH

Dept. of Manufacturing and Automation ,Ajou Univ.,
Soowon Wonchondong San 5 442-749 SOUTH KOREA

ABSTRACT

Phenomelogical evidences for three-dimensional crystallizing π-bondings are investigated in case of the soft layer very near the surface of the metal, the surface layer of certain crystalline thermoplastics, the increased contact area of the metallic frictional interface and the delaminated sheet-like wear particles of the metal. The wear mechanisms are the cracks at the boundaries of the grains and their propagations parallel to the surface. The cracks are made by the reorientations of the atoms in the grains and the rotations of the grains.

1. MECHANICAL PROPERTIES OF METALS NEAR THE SURFACE

The metal very near the surface strain hardens less than the subsurface layer and thus can undergo large plastic deformation when the surface material is deformed plastically(Fig.1).
The dislocations very near and parallel to the surface experience image forces due to their proximity to the surface. When there is no continuous, coherent oxide layer adhering to the metal surface, the image force attracts the dislocations to the surface. When the image force is greater than the resisting drag force, commonly referred to as the dislocation friction stress, these dislocations are attracted to the surface and disappear. Therefore, there tends to be a layer near the surface with low dislocation density. Some of the dislocations generated when the surface is deformed are located below this layer and thus are stable. The thickness of the low dislocation density zone of the surface layer depends on the surface energy of the metal and the magnitude of the friction stress acting on the dislocations .The surface energy affects the thickness of this zone because the total surface area changes when dislocations emerge at the surface.

A rough estimate of the image shear stress τ_i acting on a dislocation parallel to the surface is given by (Ref.1) as

$$\tau_i = \frac{Gb}{4\pi(1-\nu)h} \text{------------} (1)$$

Where G is the shear modulus, b the magnitude of the Burgers vector, ν Poisson's ratio, and h the distance from the surface.

It can be explained in view of three-dimensional crystallizing π-bondings that the image shear force rearranges the atoms of the surface (, which is called twins) in order to make the dislocations disappear at the surface. The rearranged layer have a low dislocation density.

2. MECHANICAL PROPERTIES OF THE THERMOPLASTIC SURFACE

In certain crystalline thermoplastics the surface layer has different mechanical properties from the bulk. The existence of such a layer is attributed to the preferential nucleation of high molecular weight species during the crystallization process at certain nucleation sites(Ref.2). According to this reasoning, low molecular weight species of the polymer are rejected to the molten plastic-air interface during the crystallization process giving a weak surface layer. At a molten polymer-metal interface, a region of high cohesive strength is produced in the plastic if the metal surface provides nucleation sites.

Such a zone of high strength is shown in Fig.2 for the polyethylene/sulfochromated aluminum system. In the absence of nucleation sites, a weak plastic layer results at the plastic - metal interface.

It can be explained in view of three- dimensional crystallizing π - bondings that the side carbons of the mers get closer to each other by attractions of the three - dimensional crystallizing π - bondings at the surface, where gravitational force is negligible. The closer side carbons make back bones of higher molecular weight species during the crystallization process. At a molten polymer-metal interface, if the metal surface provides nucleation sites for the three-dimensional crystallization π - bondings, for example sulfur, higher molecular weight species are produced at the interface.

3. RABINOWICZ THEORY OF FRICTION

In the Rabinowicz theory of friction, the real contact area by normal load is increased by the surface energy of adhesion as follows (Ref.3) in the case of metals.

$$\pi r^2 = \frac{L}{H} + \frac{2\pi r}{\sin\theta}\frac{W_{ab}}{H} \qquad \text{-------------} \ (2)$$

where W_{ab} is denoted as the surface energy of adhesion and other notations are shown in Fig.3. On the other side for the adhesion theory for frictional behavior of polymers unlike the case of metals, the contact area does not increase linearly with the applied normal load L, indicating that the hardness of plastics depends on the magnitude of the applied normal load. The results of indentation experiments show that the diameter of the indented area varies as a function of the applied normal load as

$$d = \left(\frac{L}{k_0}\right)^{\frac{1}{n}} \qquad \text{-----------------} \ (3)$$

where k_0 and n are constants, and d is the indentation diameter(Ref.4).

If we compare equation (2) with equation(3), it can be seen that the surface energy of adhesion increases the contact area by an amount $(\frac{2\pi r}{\sin\theta}, \frac{W_{ab}}{H})$in the case of the metals, which is from the forming of the three-dimensional crystallizing π - bondings at the surface boundary of the contact area.

4. DELAMINATION THEORY OF WEAR AT LOW SPEEDS

(4-1) Subsurface Shear Deformation(Ref.5).

As shown in Fig.4, Fig.5, Fig.6, and Fig.7, which are sectional views of the material beneath the wear tracks on a number of samples, the sliding of the rider over the surface produces a layer of sheared material beneath the wear track. The strain in the material is maximum at the surface is usually quite large, exceeding 16 in the case of steel and over 100 in the case of copper. The thickness of the sheared layer depends on the material being worn, but it is usually between 25 and 80μm. In some cases, the boundary between the deformed and undeformed material is quite sharp, as , for example, in Fig.6.

(4 - 2) Subsurface Cracks(Ref.6).

As shown in the sectional views in Fig.4, Fig.5,Fig.6 and Fig.7, one result of the shear deformation in the. layer adjacent to the surface is the production of subsurface cracks.

Fig.4 shows a sectional view of a subsurface layer beneath the wear track on an annealed copper specimen. Note that the cracks run both perpendicular to and parallel to the wear track, but are longer in the direction parallel to the track. Fig.5 shows a similar long crack about 200μm in length in a sample of cold-rolled AISI 1020 steel. In this case, the crack has propagated along a line of hard carbide particles which are strung out along the rolling direction of the steel. The spacing between the lines of carbide particles in this case determines the spacing of the cracks and the thickness of the sheets which will be formed during the wear process. The spacing in this material is about 2 to 5μm. A careful examination of the photomicrograph also shows that at other points, voids have formed around the hard carbide particles. The process of crack formation and growth is affected by the grain size of the material . When the grain size of the metal is very small, a long contiguous crack is not usually formed. Fig.6 and Fig.7 show two different annealed AISI 1020 steels sectioned along the wear track. The primary difference between these two steels is the grain size. The material shown in Fig.6 has a grain size of 35μm while that in the material shown in Fig.7 is 6 μm. In the coarse-grained specimen, a long crack is present, while in the fine-grained material, there are many small cracks developing concurrently. The formation of voids around carbide particles is also seen in these figures.

The thickness of the deformed region in these specimens is about 20μm. One can also note ,from Fig.7, that the shear deformation is causing the cracks elongated in the shear direction , and that the crack lengths and the porosity of the metal are greater near the surface because of the increased shear deformation.

5. THREE-DIMENSIONAL CRYSTALLIZING π-BONDINGS AND WEAR MECHANISMS

The effect of the siding contact is to cause plastic shear deformation of the material at the surface. The shearing of the surface may be accomplished by the adhesion between asperities.

It may also result from the plowing of the surface by asperities on the harder body. This plowing action may be enhanced if a soft layer exists on the material.

The shear stress by the friction force at the surface makes reorientations of the atoms in the grains and rotations of the single grains. This induces cracks at the boundaries of the grains.

The cracks grow and propagate in regions where the hydrostatic component of stress is least compressive because the tensile component restores the reorientations by the three-dimensional crystallizing π-bondings (Reg.7)(Reg.8).

The delaminated sheet-like particles are formed by the wear mechanism. The crack can also be propagated along a line of hard carbide particles because the crack can be produced at the boundary of the hard particle very easily.

6. CONCLUSIONS

(1)The soft layer very near the surface of the metal is formed by reorientations of the atoms because of the three-dimensional crystallizing π-bondings.

(2)The thermoplastic surface are hardened during the crystallization process because the side carbons of the mers get closer to each other by attractions of the bondings at the surface, where gravitational force is neglgible.

(3)The surface energy of adhesion increases the contact area of friction in the case of metals by forming the bondings at the surface.

(4) The delaminated sheet-like wear particles are made by the cracks at the grain boundaries and their propagations because of the bondings.

REFERENCES

(1) N. P. SUH, A.P.L. TURNER, Elements of the Mechanical Behavior of Solids, 1975 Scripta Book Company ,page 516

(2) Schonhorn, H: Adhesion to Low Energy Plymers, "Adhesion, " Gordon and Breach Science Publishers, New York, 1969

(3) Rabinowicz, E . : "Friction and Wear of Materials", John Wiley, New York,1966

(4) Pascoe, M.W., and D.Tabor : The friction and Deformation of Polymers, Proc.Roy.Soc.(London),vol. A235, pp. 210-224, 1956

(5) Suh, N.P. : The Delamination Theory of Wear, Wear, vol.25, pp. 111-124,1973

(6) Suh, N.P.,S.Jahanmir, E.P.Abrahamson, II, and A.P.L.Turner : Further Investigation of the Delamination Theory of Wear,J,Lubr.Tech.,in press

(7) HUNG-KUK OH, THREE-DIMENSIONAL CRYSTALLIZING COMBINED π-BONDING ORBITALS AND COMPUTER AIDED MATERIAL TESTING SYSTEM, AJOU UNIV. PRESS 1995 ISBN 86161-01-X93400

(8) HUNG-KUK OH, THREE-DIMENSIONAL CRYSTALLIZING π - BONDINGS, FATIGUE AND FATIGUE LIMIT, Submitted in J. of Materials Processing Technology, 1995

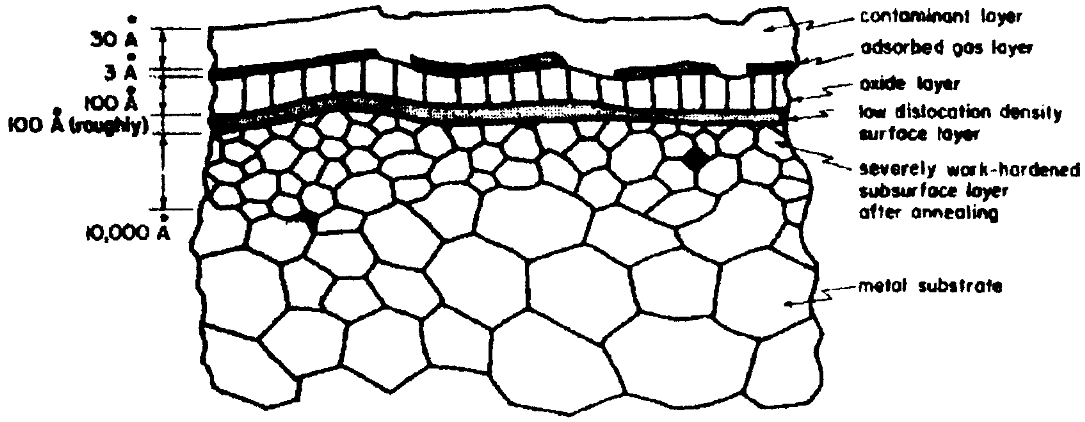

Fig.1 Schematic illustration of subsurface structure of an annealed metal with surface films. Dimensions are very approximate(modified from Ref.3)

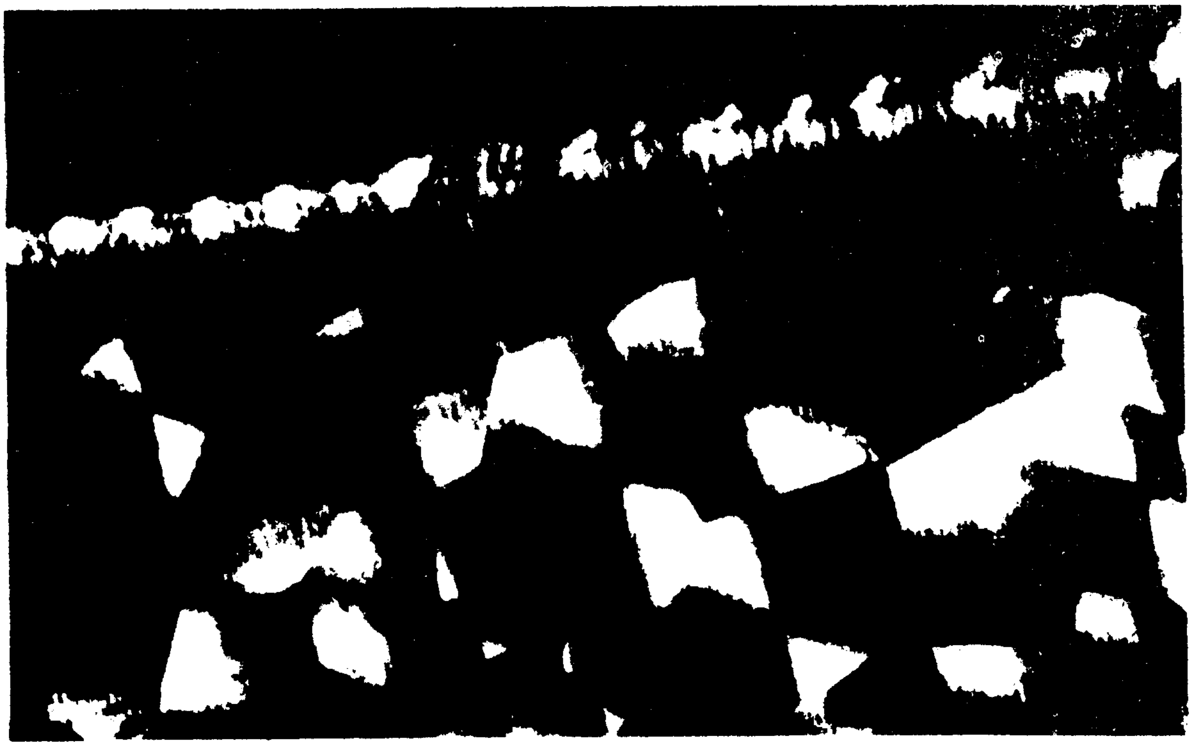

Fig2. Photomicrograph showing the region of high cohesive strength at the polyethylene/sulfochromated aluminum interface(Ref.2)

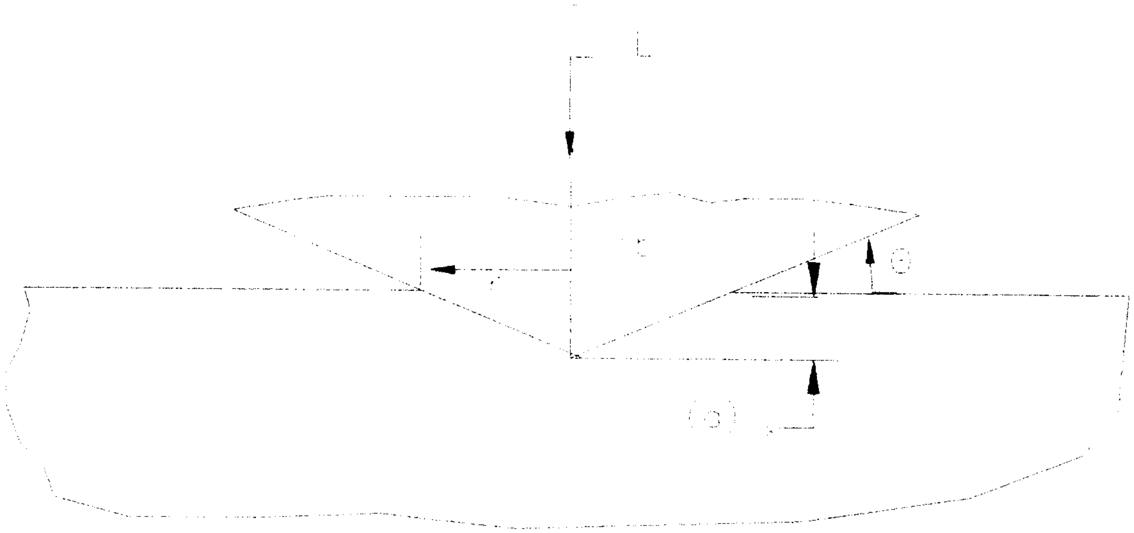

Fig3. Penetration of a conical indenter into a flat surface.

Fig4. Crack formation underneath the wear track of annealed, commerially pure copper:

(a) perpendicular to the wear track ;

(b) parallel to the wear track.

(Grain size =15µm ; 52100 bearing steel slider pin ; test temperature = 120° C ; normal load = 1,816 gm ; sliding speed = 0.5cm/sec ; argon was flushed over sliding surface ; $H_B = 40\ kg/mm^2$) (Reg.5)

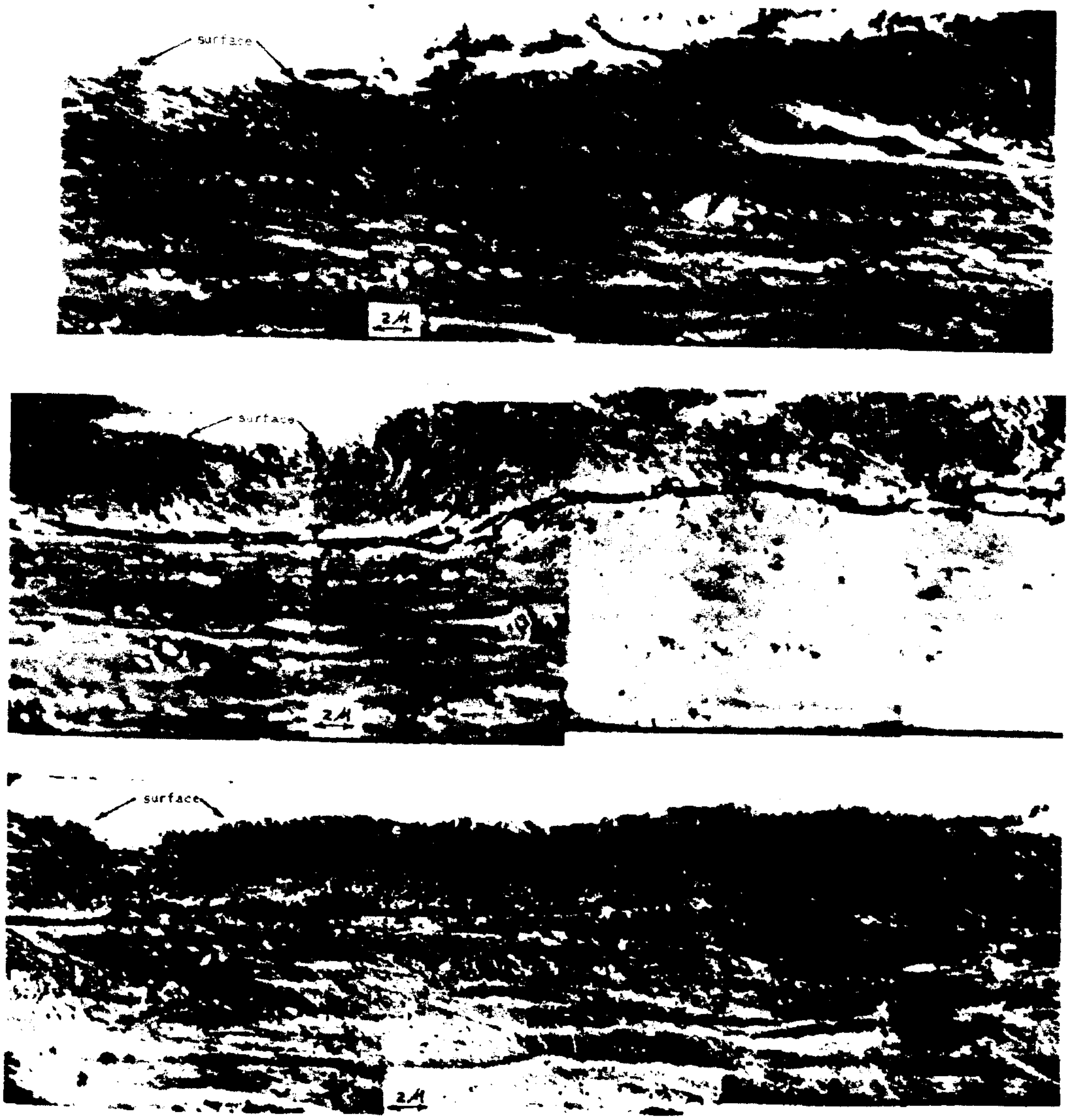

Fig5. Three segments of a subsurface crack in cold-worked AISI steel sliding against 52100 steel.(a) and (c)show the ends of the crack, while(b) shows the midsection of the crack. Not the crack propagation along carbide particles. The crack is 200μm long.($H_B = 184$ kg/mm^2 ; normal load = 1.81 kg;sliding velocity = 76 cm/min;wear factor = $1.5*10^{-8}$ cm/kg; argon was flushed over the surface) (Ref.6)

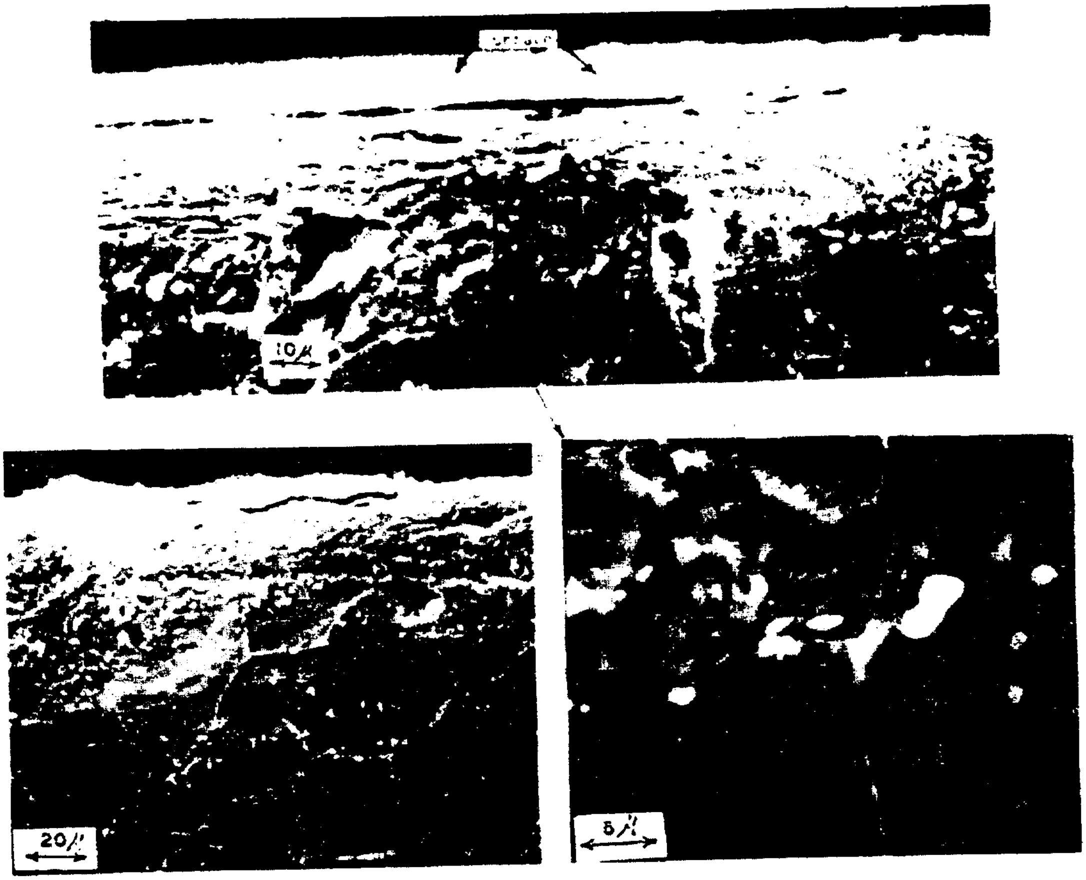

Fig6. Subsurface cracks and deformation of annealed AISI 1020 steel sliding against 52100 steel.Note the voids around inclusion and the sharp demarcation line between deformed and undeformed zones in(b).(Grain size = 35 μm ; H_B = 80 kg/mm^2 ; normal load = 1.81 kg; sliding velocity = 76 cm/mini ; wear factor = 2.3 * 10^{-8} cm^2 /kg ; the sliding surface as flushed with argon.) (Ref.6)

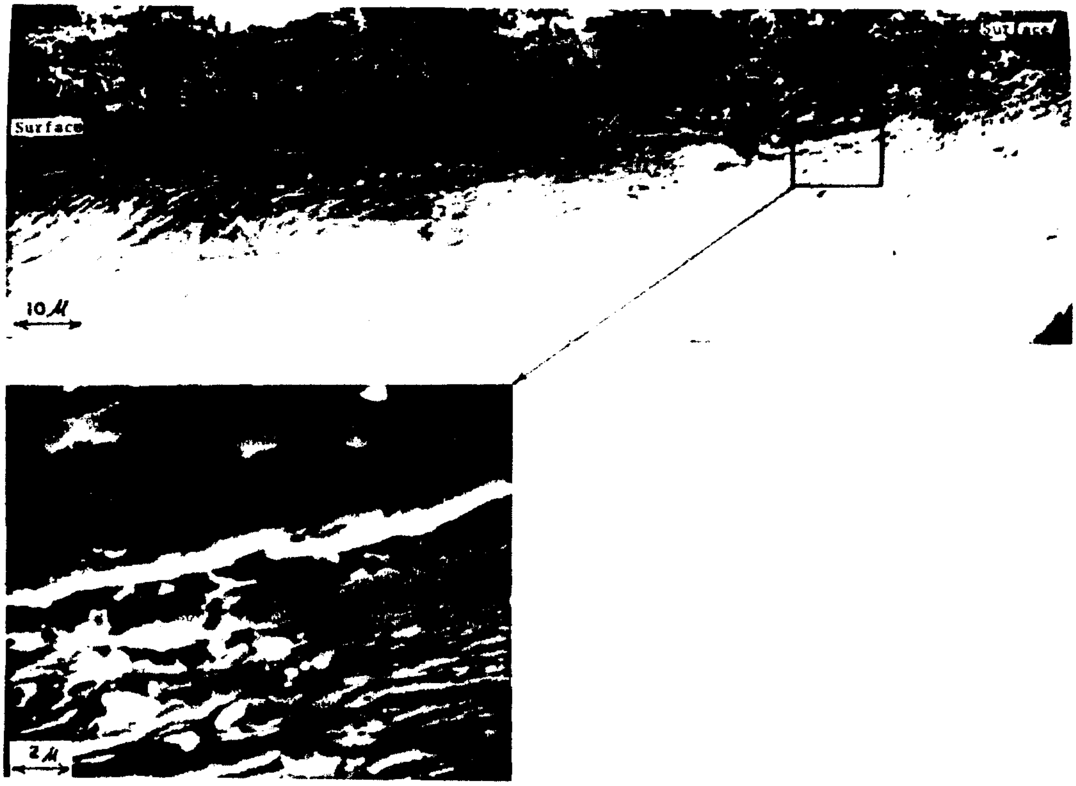

Fig7. Subsurface deformation and void formation in annealed AISI 1020 steel sliding against 52100 steel. Note the severe plastic deformation at the surface, the void formation around inclusions, and the cracks along inclusion in the grain boundaries of the undeformed region. One of the major difference between this specimen and that of Fig.6 is the grain size; chemical compositions of both steels were nearly indentical.(Grain size = 6μm ; H_B =102kg/mm^2 ; wear factor = 2.5* 10^{-8} cm^2 /kg ; argon was flushed over the sliding surface.) (Reg.6)