Study of Slip Plane Dislocation in Propagation of Fracture

Dr. J. S. Behal, Ish Kakkar, Anoop Pandey and **Mayank Gupta**
Department of Mechanical Engineering,
A.B.E.S. Engineering College, Ghaziabad 201009 UP India
behljs111@yahoo.com, ish_kakkar@yahoo.com, anooppandeyeck@gmail.com

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Abstract -- **This study is done to gain the knowledge and to minimize the effects of slip dislocation through mathematical modeling and the role in fracture. Slip occurs in the plain due to presence of any discontinue between or within the planes, from where dislocation propagate. It comes in initial phase of material preparation i.e. during casting; if the grain growth formation is not controlled carefully then the imperfection in the material comes into the existence which weakens the material. When the material is subjected to any type of loading, the stresses produced in the material may lead to the slip propagation in the particular direction of slip planes (the direction which needs lowest critical shear stress for slipping; stress). Due to the slipping mechanism the material fails at very low stress value as compared to its yield or ultimate tensile strength value. Case studies show that any type of fracture gets initiated from the slipping; hence it is a shiver defect, which needs focus for study.**

Keywords: Slip, Banding, Trans granular fracture, Inter granular fracture.

I. INTRODUCTION

Slip is the movement of *dislocations* under an applied stress. Due to this slip mechanism the plastic deformation of real crystalline materials can occur at a much lower yield stress than for a theoretical perfect crystal. We can enhance materials performance by creating materials with microstructures that limit slip. Improper method of casting and mishandling during the grain growth are the major sources of dislocation, they effect the orientation and direction of plane in the crystal structure which leads to lower the shear strength of the material, hence material failure may occur at very low shear stress value. The other reason of slip is mechanical deformation.

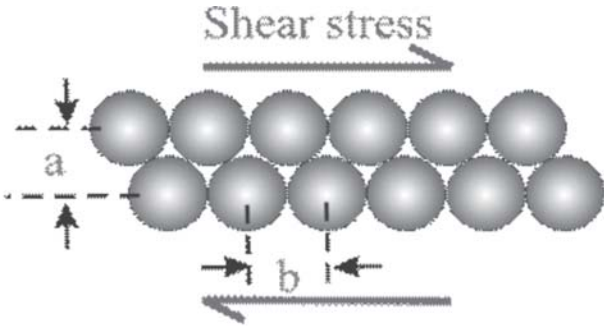


Figure 1(a). Starting Configuration

Consider two planes of atoms subjected a shear stress under applied load. Let's assume, as shown in Fig-1(a), distance between atoms in slip direction is *b*, and spacing between the two planes is *a*. As the shear stress applied, the entire rows of atoms slid pass another.

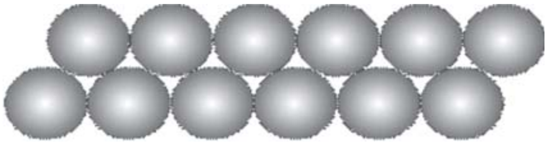


Figure 1(b). Final Configuration

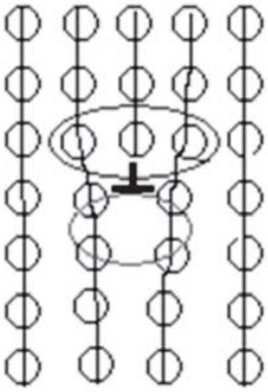


Figure 2(a). Burger Vector (Edge Dislocations)

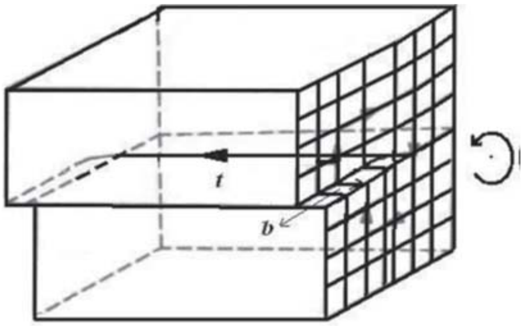


Figure 2(b). Screw Dislocations

II. TYPES OF DISLOCATION

There are mainly two types of dislocation namely; a) Taylor-Orowan, and b) Burger dislocations.

Former one is characterized by a Burger's vector that is perpendicular to the dislocation line (as shown in fig 2(a)) and the later one is by dislocation line parallel to the burger vector (shown in fig 2(b)).Mostly, both the dislocation occurs simultaneously in a material and hence gives rise to a third type of dislocation which is known as 'mixed dislocation'.

III. MECHANISM

There are two prominent mechanisms of plastic deformation, namely ***slip*** and ***twinning.*** Slip is the prominent mechanism of plastic deformation in metals. It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes. Slip occurs most readily in specific directions on certain crystallographic planes. This is due to limitations imposed by the fact that single crystal remains homogeneous after deformation. Slip plane is the plane of greatest atomic density, and the slip direction is the close packed direction within the slip plane. It turns out that the planes of the highest atomic density are the most widely spaced planes, while the close packed directions have the smallest translation distance. Feasible combination of a slip plane together with a slip direction is considered as a slip system. On an atomic level plastic deformation corresponds to the tearing of atomic bonds.

$<\bar{1}11>$

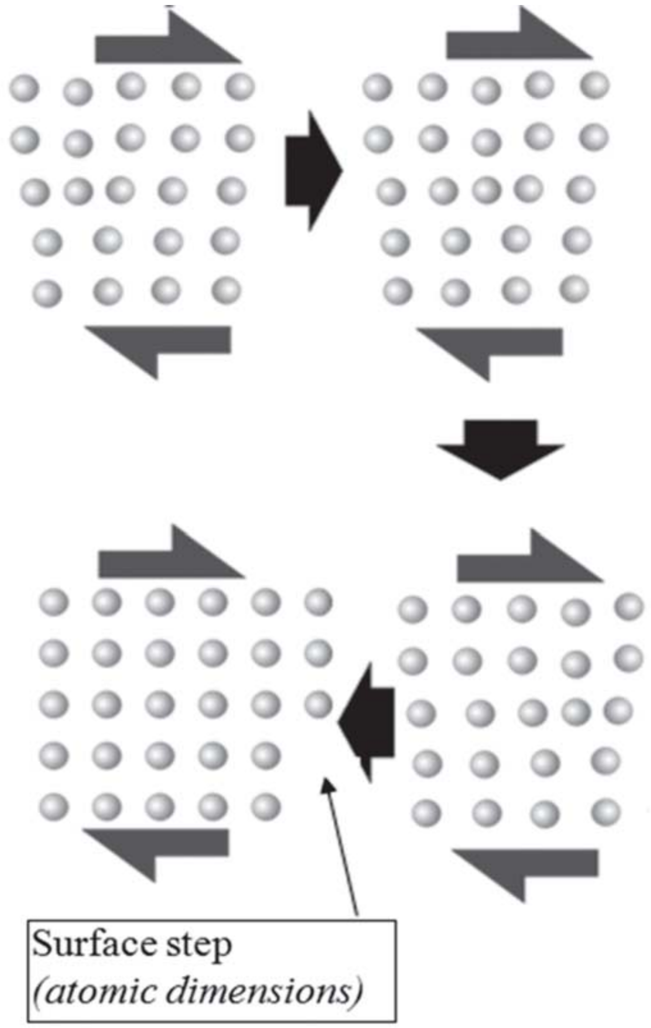
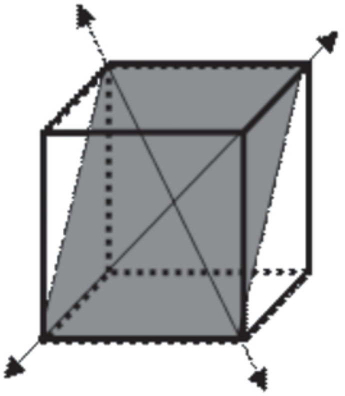
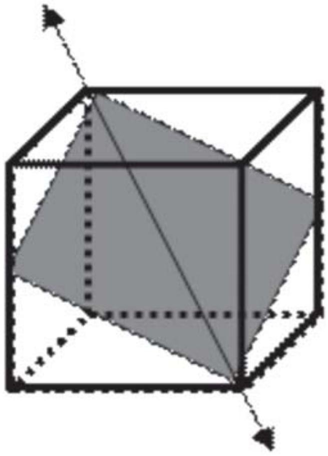


Figure 3. Mechanism of Slip Propagation.

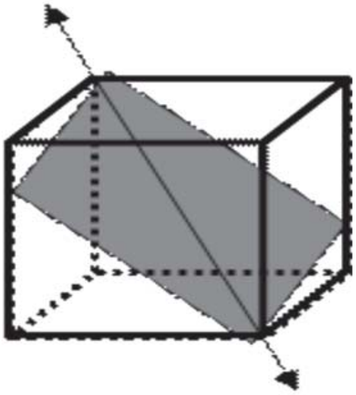
In a perfect crystal each atom has many bonds with its surrounding atoms. For plastic deformation of a perfect crystal to take place all these bonds would need to be broken. However at the site of an edge dislocation there is a line of free atoms (the dislocation line). The dislocation line can move through the crystal in the direction of the applied stress by breaking only one line of bonds at a time (shown in fig 3). This requires far less energy than breaking lots of bonds simultaneously, so the material can deform under a much lower applied stress. The magnitude of the distortion associated with a dislocation is measured by the burgers Vector. For metallic materials the burgers vector will point in a close-packed crystallographic direction and will be equal in size to the atomic spacing. The common slip systems are given in fig 4.



{101} Plane in the Direction of $<\bar{1}11>$



{211} Plane in the Direction of



{321} Plane in the Direction of

Figure 4. BCC Slip Planes and Direction.

IV. MATHEMATICAL MODELING

In a single crystal, plastic deformation is accomplished by the *slip*. The extent of slip depend on many factors including shear stresss produce corresponding to external load applied, geometry of crystal structure, and the orientation of active slip planes with the direction of shearing stresses generated. Schmid recognized that single crystals at different orientations but of *same material reqire different stresses to produce slip.*The dependence of various factor has been summarised using a parameter – critical resolved shear stress,

$$\Rightarrow \tau = \sigma cos\phi cos\lambda$$

where;

P- external applied load,
A- cross sectional area over which the load is applied,
ë- angle between slip direction and tensile axis, ø – angle between normal to the slip plane and the tensile axis and *m* – Schmid factor.

For slip, need angles between load and plane normal and load and slip direction

Initial Slip Systems (plane, direction) are then (111) [101], (111) [101], as it has the smallest critical stress.

TABLE 1 - Study of copper : FCC Cu with Loading axis [112] by applying 50 MPa stress.

Slip plane, n	Slip direction	$m = cos\phi cos\lambda$	
(111)	[011]	√6/9	184
	[101]	√6/9	184
	[110]	0	Undefine
(111)	[011]	√6/18	367
	[101]	-√6/6	-122 (smallest)
	[110]	√6/9	184
(111)	[011]	√6/6	122(smallest)
	[101]	-√6/18	-367
	[110]	√6/9	184
(111)	[011]	0	Undefine
	[101]	0	Undefine
	[110]	0	Undefine

V. CASE STUDY

*Failure of Titanic***:** A metallurgical analysis[1] of steel taken from the hull of the Titanic's wreckage reveals that it had a high ductile-brittle transition temperature, making it unsuitable for service at low temperatures; at the time of the collision, the temperature of the sea water was -2°C. *Charpy impact* tests were performed over a range of temperatures from -55°C to 179°C on three series of standard Charpy specimens: a series of specimens machined with the specimen axis parallel to the longitudinal direction in the hull plate from the *Titanic*, a series machined in the transverse direction, and a series made from modern ASTM A36 steel. A Tinius Olsen model 84 universal impact tester was used to determine the impact energy to fracture for several specimens at the selected test temperatures. A chilling bath or a circulating air laboratory oven was used to prepare the specimens for testing at specific temperatures. The specimens were allowed to soak in the appropriate apparatus for at least 20 minutes at the selected temperature. Pairs of specimens were tested at identical test temperatures.

In figure 5 cleavage planes, (100) in ferrite, are quite apparent. There are cleavage plane surfaces at different levels that are defined by straight lines. These straight lines are steps connecting parallel cleavage planes; the edges are parallel to the [010] direction. The crystallographic surfaces of the risers are the (001) plane. In addition, there are curved slip (transgranular fracture) lines on the cleavage planes, which propagate and leads to the failure of material.

*Wafer Failure In Furnace***:** Although the silicon wafer is strong at room temperature, it is weak at the elevated temperatures necessary for the fabrication of integrated circuits. During thermal processing, a non uniform elevated temperature produces a non uniform expansion within the wafer and the resulting lattice forces can cause local or widespread furnace slip. This disrupts the silicon crystal structure and permanently degrades the electrical and physical characteristics of the wafer [3].

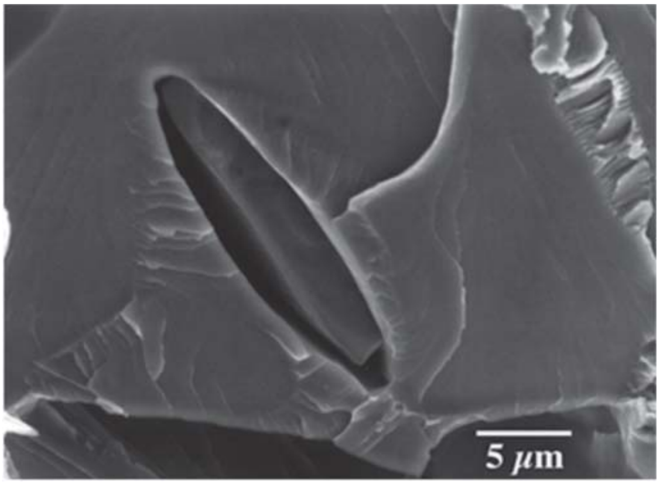


Figure 5: A scanning electron micrograph of a Charpy impact fracture surface newly created at 0°C, showing cleavage planes containing ledges and protruding MnS particles[2].

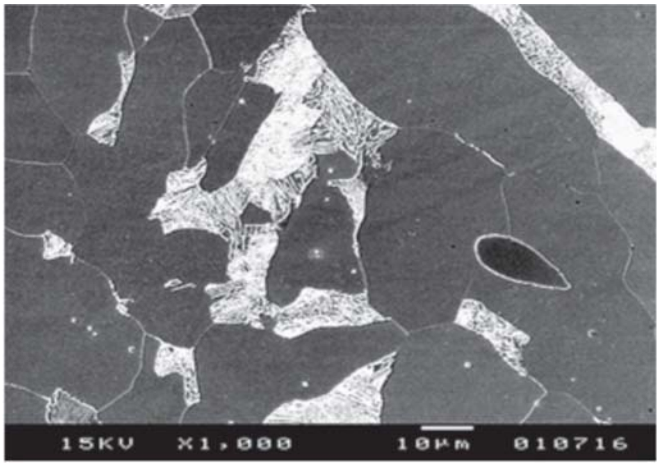


Figure 6. Shows a fractured lenticular MnS particle that protrudes edge-on from the fractured surface. There are slip lines radiating away from the MnS particle.

A non uniform temperature distribution may or may not produce furnace slip. Slip is more likely if the temperature is higher, if the temperature spatial gradient ishigher, if the amount of oxygen precipitation is higher, and if there are more surface or imbedded IC features which create and concentrate the stress. Since the silicon becomes softer or weaker with increasing temperature, the local temperature is an important factor in determining where in the wafer the slip takes place. Slip begins with a shearing of the layer of single covalent bonds between silicon atoms in adjacent (111) planes. As the(111) planes slip with respect to each other, dislocations are created. Although the change in wafer shape relieves some of the stresses caused by the non uniform temperature and expansion, the wafer will be deformed and new elastic stresses will be present when the wafer returns to room temperature. Furnace slip reduces IC fabrication yield and in some cases creates reliability problems.

VI. CONCLUSION

The study shows that initially active planes can be predicted primarily and then accordingly the corrective measures are taken. The directions which are more pretended for slipping should be avoided for the stress loading of the material. The imperfection concentration within the material should be avoided by taking corrective action during grain growth phase. In case of Titanic, when Titanic strikes with the ice berg then the pearlite structure elongates and slip propagates between MnS and elongated pearlite which leads to the material failure. Due to the structure failure, the accident was fatal. So, for the safety of human life, the material needs consideration during its transformation stage. The slip varies with temperature as in case of wafer, due to which the reliability and design life of the product gets reduced and the electronic circuit get fails before its predicted life.

VII. REFERENCES

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Prof. J. S. Behal has engineering background and vast industrial and teaching experience. He has done his B.Tech in Mechanical Engineering from H B T I Kanpur with gold medal and did his M. Tech and Ph. D. in Mechanical Engineering. Worked as Assistant Professor in AKG Engineering College for over six years and presently working as a professor in ABES Engineering College in the department of Mechanical Engineering.

Anoop Pandey is M. Tech in Manufacturing Technology & Automation from MD University, Rohtak. Presently working as Assistant Professor in Department of Mechanical Engineering, ABES Engineering College, Ghaziabad after completing his BE in Production and Industrial Engineering from University College of Engineering, Rajasthan Technical University (formerly Engineering College, Kota). Worked for renowned companies for over three years in various capacities. He has been continuously teaching B. Tech students since more than four years with specialization in Manufacturing and welding and has many research papers published in reputed journals.

Ish Kakkar is pursuing PhD from Dr. B R Ambedkar National Institute of Technology, Jalandhar, with his Master degree in Manufacturing Technology from NITTTR, Chandigarh (2007) and Bachelor degree in Mechanical Engineering from Karnataka University, Dharwad. He is serving as Associate Professor in Department of Mechanical Engineering, ABES Engineering College, Ghaziabad. He has served industries and many technical institutes in various capacities for more than 17 years. In his vast teaching experience of over 14 years he has two patents registered and more than 35 national & international research papers published in reputed journals. His area of interest and expertise is in the field of CAD/CAM and manufacturing & production.