Mechanical behavior of materials

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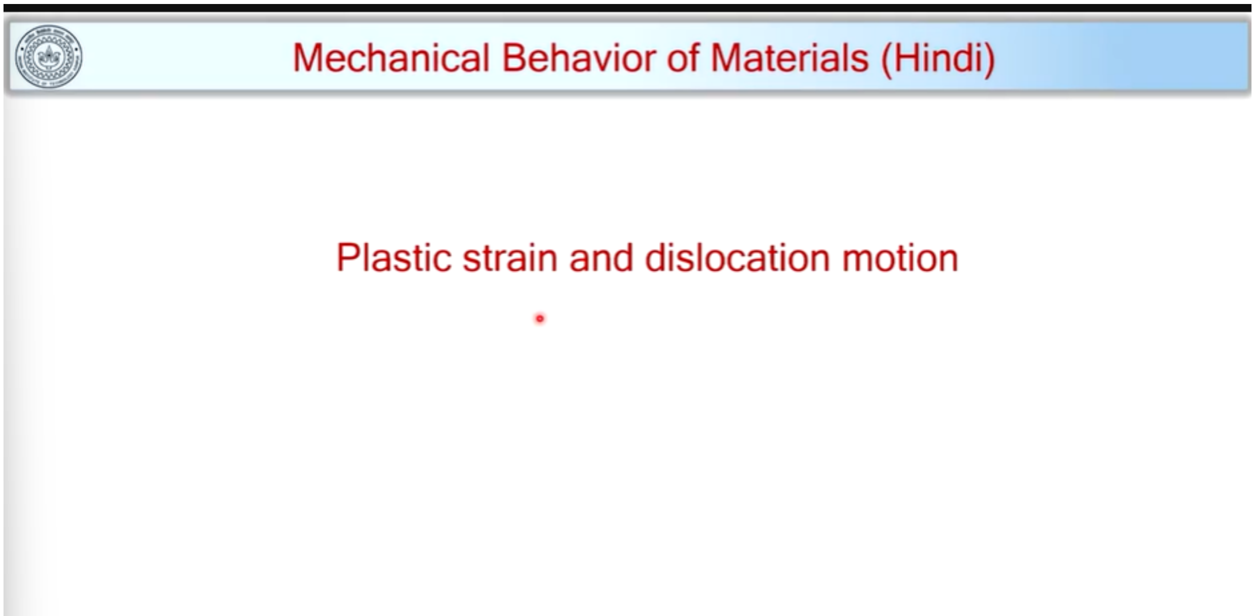
Week-6

Lecture-28

Plastic Strain and Dislocation Motion



Namaskar phir se swagat karta hoon aapka is course mein Mechanical Behavior of Material jo hum Hindi mein padhenge. Last part mein humne dekha tha ki Dislocation Motions kya hota hai. Dislocation motion main yahan par likh leta hoon Glide, Cross-Slip aur Climb yeh humne dekhe the aur ye kisi dislocation ke liye bhi hum dekhe the ki Glide humne dekha tha jo hota hai Edge nature aur Screw nature dono ke liye bhi hai. Cross-Slip hum dekhe the ki sirf Screw ke liye possible hai Edge ke liye nahi hai. Climb hamara Edge ke liye possible hai Screw ke liye nahi hai. To aap dekhenge ki ye jo plastic strain hai is dislocation motion ke wajah se yani in inke wajah se kya plastic strain yahan par develop ho sakta hai. To chaliye dekhte hain iske baare mein.

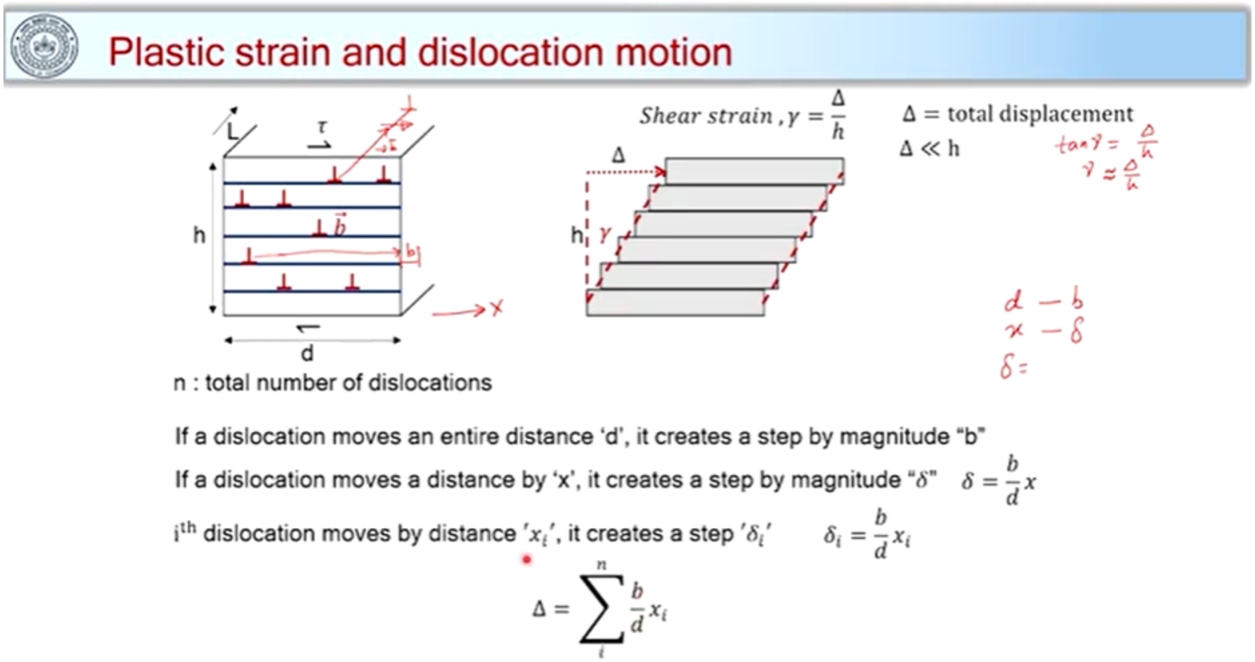
Maan lete mere paas ek crystal hai aur crystal ke dimension kuch is tarah se maine mark kar diye yeh d hai h hai aur yeh uski length hai is tarah se aap dekhenge yeh mera crystal hai aur yahan par main kuch slip planes mark kar leta hoon yeh jo slip planes hai ya glide planes hai aur yahan par kuch dislocation hai is is crystal mein aur ye jo dislocations hai ye kisi ek nature ke honge Edge ya Screw yahan pe koi mention nahi hai yahan pe maine Edge mark kiye uska koi fark nahi padega agar yahan pe Screw hote to bhi koi fark nahi padta aur yahan pe symbol jo Edge ka hai woh aasani se samajh jata hai to yeh maine yahan pe Edge dislocations yahan pe mark kiye hai. To yane ye samjhe ki Edge dislocation is tarah se agar main is dislocation ko is tarah se draw karunga to ye tangent vector jo hai dislocation ka kuch is tarah se hai. To ye jo dislocation hai yeh saare dislocation is tarah se hai iski length is tarah se ek to yeh pure Edge hai ya pure Screw hai iska hum mark kar lete ki Burgers vector kya hai is is saare dislocation ka Burgers vector same hai jo Burgers vector b maine mark kiya yahan pe.

Abhi main ek shear stress apply karta hoon is crystal ko agar ye shear stress jab main apply karta hoon τ to yeh shear stress jab apply karunga to yeh jo crystal hai woh shear hoga ya iska plastic deformation hoga ya shape change hoga maan lete uska shape change kuch is tarah se ho raha hai. Yeh mera shape change is tarah se ho raha hai aur humne jaana tha ki yeh shape change isliye hoga kyunki jab main shear apply karunga to ye dislocation move honge aur move hoke yahan par surface par aayenge aur surface par aake woh steps taiyar karenge. To yeh single crystal ke liye main maan ke chal sakta hoon ye assumption valid hai mera. Abhi hum dekhenge ki agar steps taiyar ho rahe hai to ek strain bhi taiyar hoga is iske wajah se ye shape change jab main baat karunga shear stress ke wajah se. Shear stress jab maine apply kiya to kuch is tarah se main mark kar leta hoon dimensions. To yeh jo length hai meri yeh meri initial length ho jayegi h yeh meri h ho jayegi aur is jo displacement ye jo displacement taiyar hua hai dislocation ke motion ke wajah se yeh ho jayega mera δ. To aap dekhenge ki mera Burgers vector is direction mein tha Burgers vector is direction mein tha aur ye saare dislocation ka jo motion hoga woh perpendicular unke tangent line ki wajah se perpendicular hoga theek hai. To yani aap dekhenge ki saare dislocation jo move honge woh is direction mein move honge aur yeh jab move honge tab mujhe total displacement milega δ. To yeh mera ho gaya total displacement aur yeh jo δ yahan par dikha hai ye exaggerated way se dikhaya ya zyada badha chadha ke dikha hai par aap maan jab hum ye assumptions le rahe to ye δ hai bahut small hai bahut chhota hai is h se ye height of crystal se woh chhota hai. Tab hum agar shear strain jo develop hoga ye shear stress ki wajah se woh is tarah se hoga is ye jo angle change agar main nikalunga γ to main kuch is tarah se likh paunga shear strain ko $\gamma = \delta/h$. Humne dekha hai ki shear strain hum main nikalta hoon tab main $\tan\gamma$ is tarah se define karunga mere paas δ/h aa jayega aur jab γ δ bahut chhota hai to mere paas yeh δ/h aa jayega shear strain yani main shear strain ko is tarah se define kar sakta hoon.

Abhi maan lete hain ki mere paas total number of dislocations is crystal mein n the aur jab koi bhi ek dislocation move hota hai jaise maan lijiye yahan par agar mera ek dislocation hai aur entire distance yahan move ho gaya d distance agar move ho raha hai to step kya create karega woh step kar create karega b se. Yani jo ek displacement ek jo dislocation hai maan lete dislocation yahan se pura d distance agar cross karke yahan par aa raha hai to yahan par jo step create hoga woh by magnitude b hoga. Yani jo b Burgers vector hai woh step create karega surface par to yahan par mujhe displacement milega b. To yeh maan yeh humein pata hai to main is tarah se likh sakta hoon kuch is tarah se likh sakta hoon agar main d distance calculate kar raha hoon to main mujhe displacement milta hai b ka. To agar mera dislocation koi x distance travel kar raha hai zaroori to nahi hai jab main shear stress apply karunga to saare dislocation surface par hi aa jaye kuch x distance move honge. x distance main is tarah se mark karta hoon is direction mein ye mera x direction hai to is direction mein move kar rahe to woh kya step create karenge woh step create karenge δ_i. To maan lete kuch is tarah se agar woh x distance move karenge to mere paas aa jayega ek δ_i step. To main δ_i kuch is tarah se likh paunga idhar likha hi hai maine to δ_i main kuch is tarah se likh paunga $b/d \cdot x$. To agar mere i-th dislocation hai ye koi bhi ek dislocation ki baat kar raha tha main agar koi i-th dislocation agar move kar raha hai koi bhi distance se x_i agar main maan ke chal raha hoon to create kar raha hai ek step δ_i. Yani main isko generalize kar raha hoon to δ_i jo step rahega jo displacement create karega koi bhi i-th dislocation ki wajah se woh aayega mera

$b/d \cdot x_i$. Yeh koi bhi specific dislocation ki baat nahi kar raha generalized way se main baat kar raha hoon.

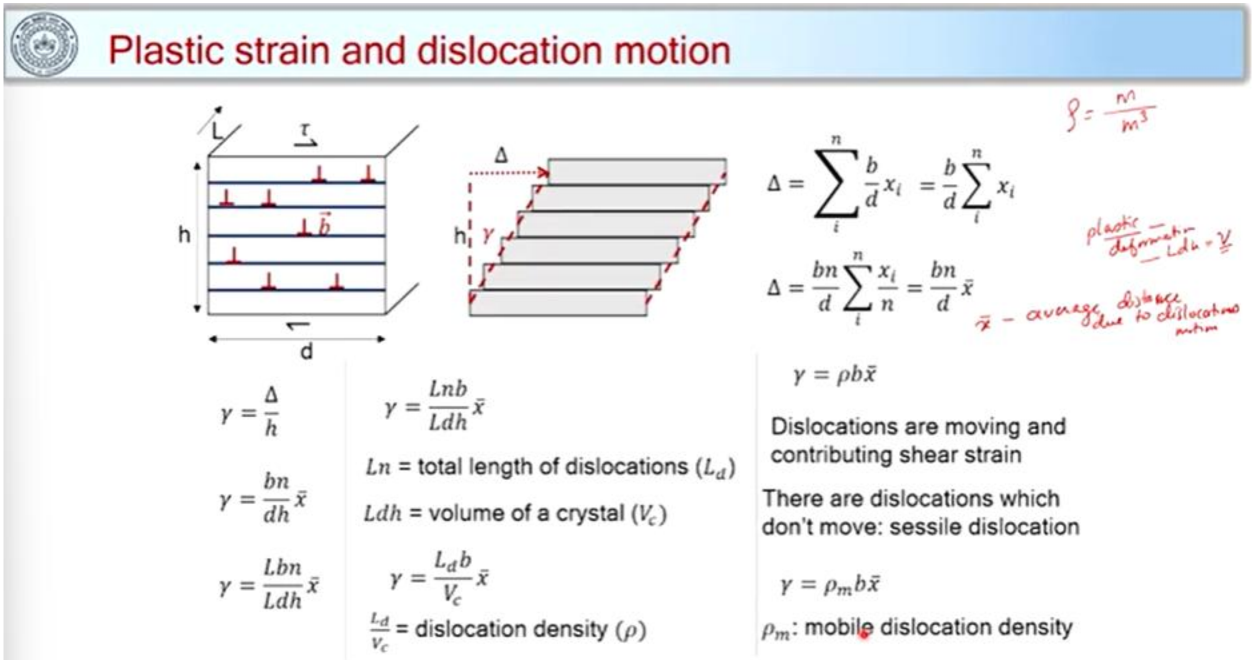
To jo Δ hai yahan par main Δ ki baat karunga yeh jo Δ hai total displacement ki baat kar raha hoon total displacement kya hoga yeh mera summation ho jayega saare dislocation ka yani i se lekar n tak. To main isko is tarah se likh sakta hoon summation of $b/d \cdot x_i$.



Yeh total displacement main is tarah se kuch samajh sakta hoon. Abhi humne ye sabna dekha jo total displacement humne yahan par calculate kiya ye aa raha tha mera $b/d\sum x_i$. b/d aap janenge ki b mera Burgers vector hai woh change nahi ho raha yahan par dislocation ke liye aur yeh jo d hai yeh yeh jo hai woh small change hi deformation hai to hum maan ke chalte b/d jo hai woh constant hai aur isliye hum isko summation sign ke bahar lekar aayenge aur yeh mere paas yeh relation rahega. Abhi hum kya karte hum karte yahan par mere paas number of dislocations the ab main karta hoon yeh jo isko main divide karunga n se number of dislocations jo bhi constant hai mere mere material mein isko main divide karunga aur multiply karunga yeh main kar sakta hoon kyunki constant value hai. Agar aap yeh value dekhenge aap yeh jo value hai isko hum replace karenge kyunki yeh jo ho gaya yeh ho gaya mera displacement because of any dislocation i-th dislocation aur usko main divide kar raha hoon number of dislocation se to yeh mera kya aa jayega yeh mera aa jayega average value of displacement. To yeh hogi meri Average Value of Displacement $\bar{x}$. Aur main γ ko δ/h likha tha previously abhi main γ ko kuch is tarah se likh paunga yahan par δ ki value main replace karta hoon to yeh value aa jayegi $b \cdot n \cdot d \cdot \bar{x}/h$.

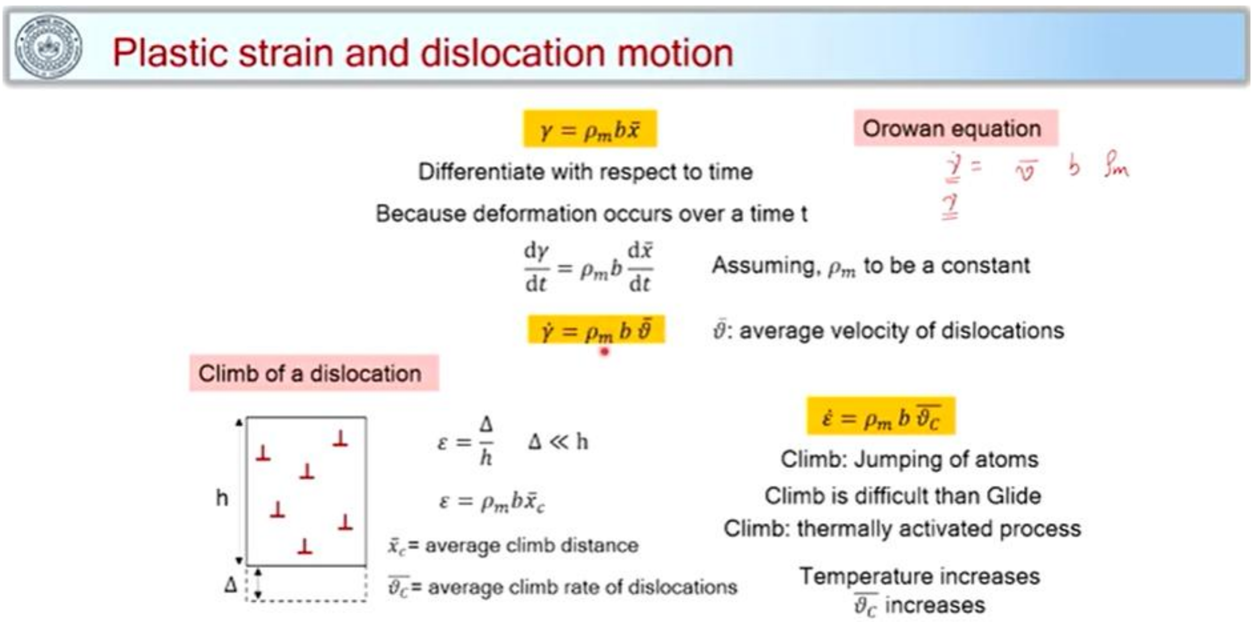
To yeh value mujhe aa jayegi mere paas aa jayegi ye shear strain ki value hum nikal rahe hain. Abhi main kya karta hoon main yeh jo length hai crystal ka isse multiply aur divide karunga yeh isliye kar raha hoon kyunki aap dekhenge ye agar main is tarah se arrange kar dunga $l \cdot d \cdot h$ bottom mein to ye jo $l \cdot d \cdot h$ yeh kya ho jayega yeh mera ho jayega Volume of a Crystal aur yeh main is isliye consider kar sakta hoon to kyunki maine bataya ki plastic deformation mein volume conserved hota hai agar Glide aur Climb ho raha hai to Glide aur Slip ho raha hai to plastic deformation to main maan ke chal sakta hoon ki yeh $l \cdot d \cdot h$ jo hoga woh mera volume aayega. To $l \cdot n$ agar main dekhunga yeh mera l hai aur yeh number of dislocations yahan par maine dekhe to $l \cdot n$ jo hoga woh mera Total Length of Dislocations hoga kyunki maine dekh bola tha ki yeh jo dislocation hai yeh throughout its length hai yahan pe humne draw kiya tha. To ye jo $l \cdot n$ ye jo ho gaya mera total length of dislocations yeh mera total length of dislocation ho gaya aur yeh ho gaya mera Volume of a Crystal V_c. Agar hum dekhenge ki isko $l \cdot n$ ko main L_d likh raha hoon yeh Total Length of Dislocations ho gaya divided by Volume of a Crystal ye Burgers vector isi tarah se aur $\bar{x}$ ye jo total displacement total distance traveled by all the dislocations average dislocations Average Distance Traveled by all the Dislocations $\bar{x}$. To ye jo term hai L_d/V_c ye ho jayegi meri Dislocation Density. Ye aap dekhenge ki number of yani Total Length of Dislocations per unit Volume ye ho jayegi meri Dislocation Density ye term new term main yahan pe aapko introduce kara raha hoon. To iska unit hoga Dislocation Density ka iske baare mein bhi aage hum janenge iska unit hoga meter per meter cube (m/m^3) to yeh ho gayi meri Dislocation Density. Yeh jo term hai abhi main yahan par dislocation density se replace karunga aur main kuch plastic strain jo shear strain develop ho raha hai usko likh sakta hoon $\rho b\bar{x}$. $\bar{x}$ kya hai mera yahan par yahan par likh sakte hain Average Distance due to Dislocation Motion. To yeh mera average distance hai.

Ye mere paas aa gaya plastic strain aur mere paas ek average distance agar mujhe pata hai to main calculate kar sakta hoon ki plastic strain kya hai material ka. To yeh jo jo jab dislocation move ho rahe hai iska matlab hum ye dekh sakte hain ki jab dislocation mere move hote hain to woh contribute karenge shear strength ko jitna zyada displacement utna zyada shear strength but yahan pe kuch aise bhi dislocations ho sakte hain ki jo move nahi hote us dislocation ko hum kehte hain Sessile Dislocation. To jo dislocation move nahi karte unko hum kehte hain Sessile Dislocation iske baare mein bhi hum aage janenge par abhi hum yahan pe is ρ ko jo dislocation density hai kuch is tarah se replace karenge ya thoda aur accurate ho jayega hamara analysis. To yeh jo ho gaya plastic strain aur yeh jo ρ_m yahan pe ρ_m jo maine likha hai yeh ho gaya mera Mobile Dislocation Density. Mobile Dislocation Density yani jo dislocation jo mobile hai jo move ho sakte hain wahi dislocation ki density main yahan pe consider kar raha hoon aur Sessile dislocation yahan pe main consider nahi kar raha hoon plastic strain mein jo contribute kar rahe hain. To yeh mere paas aa gaya ek simple relation. Yeh jo relation hai $\gamma = \rho_m b\bar{x}$.



Aap dekhenge ki agar main isko differentiate karunga time ke saath agar yahan par ρ_m mera time ke saath agar variable rehta hai to magar isko main differentiate le raha hoon assumption kya hai mera ki ρ_m constant hai mera tabhi jaake main ye is tarah se likh paunga. To yahan par aap dekhenge yeh ho ho jayega ye mera strain tha Strain Divided by Time aur Change in Strain with respect to Time yeh ho jayega Strain Rate. Yeh jo agar yeh term aap dekhenge yeh term ho jayegi meri Velocity of Dislocation. To yeh yeh ho gaya mera strain rate isko main $\dot{\gamma}$ is tarah se replace kar raha hoon aur yeh jo hai yeh meri average velocity of dislocation hogi ye $\bar{v}$ to yeh ho jayegi meri Average Velocity of Dislocation. Mere paas ek simple relation aa gaya yahan pe Strain Rate is equal to $\rho_m b v$ yani ye Mobile Dislocation Density into Burgers Vector of Dislocation and Average Velocity of Dislocation.

Abhi yeh ho gaya mera plastic strain jab main Glide ki baat kar raha tha ya Slip ki baat kar raha tha. To Climb Dislocation bhi kuch main is tarah se maan sakta hoon ki mere paas ek crystal hai h aur yeh mere paas kuch dislocations hai aur kuch high temperature par yeh move hote hain kuch is tarah se strain develop karte hain. Small strain agar yeh develop karte hain to main kuch is tarah se likh paunga ye ye agar main strain dekh raha hoon to isko main ϵ likh raha hoon kyunki yeh jo strain hai yeh mera normal strain hai isliye main isko ϵ likhunga aur isko likhunga δ/h. To yeh jo δ/h hai yahan par δ main consider kar raha hoon hamare previous case ki tarah ki bahut chhota hai h ke hisaab se. To main agar same methodology agar istemaal karunga to mere paas kuch is tarah se aayega. To yahan par maine $\bar{x}_c$ jo likha hai ye suffix c ye climb ke liye likha hai yani jab dislocation climb ho gaye yahan par aayenge aur strain kuch develop karenge to mujhe kuch is tarah se relation milega. Agar main phir se isko differentiate karunga with respect to time to mujhe normal strain rate milega, normal strain milega mobile dislocation densities milengi yani jo dislocation jo climb ho sakte wahi unki baat kar raha hoon main aur yeh mere paas unka Burgers vector aur yeh jo aayega mera Average Velocity of Dislocation while they are Climbing yani jab woh climb karte unka average velocity kya rahega. To Average Climb Rate of Dislocation yahan par likh diya maine aur yeh yahan par maine Average Climb Distance likh diya. To climb hum jab baat karte hain tab jumping of atoms ki baat karenge ye atoms jump honge tabhi baat karenge aur climb ye difficult hai glide ke hisaab se kyunki aapne dekha tha ki cli climb ke liye mujhe diffusion chahiye atoms ka yani jumping of atoms chahiye aur yeh possible hai mera jab main kuch high temperature par jaunga yani climb jo process hai yeh thermally activated process hai yani jis tarah se temperature increase hoga us tarah se mera yeh jo Average Climb Rate of Dislocation se woh bhi increase hoga. To aap dekhenge ki glide sabse aasaan hai climb ke tulna mein kyunki climb jo hai meri thermally activated process hai yeh aapko yaad rakhna hai.



Abhi ek aur point main yahan par mention karunga aap textbook mein jab padhenge to yeh relation $\gamma = \rho_m b\bar{x}$ yeh jo relation humne humko mila hai aur yeh jo relation humein mila hai strain rate ka shear strain rate ka is equal to $\rho_m b\bar{v}$ yani average velocity of dislocation ke saath isko hum kehte hain Orowan Equation. To aapko ek Orowan equation is tarah se textbook mein milega. Iska importance yeh hai ki agar mujhe average velocity dislocation ki pata hai mujhe Burgers vector pata hai kaun se dislocation hai aur mujhe dislocation density pata hai to main kitna strain rate develop hoga material mein ya kitna strain develop hoga yeh nikal sakta hoon. Humne kya dekha tha humne is part mein yeh dekha hai ki agar meri dislocation ki kuch movement ho रही hai us movement ki wajah se kya plastic strain develop ho raha hai aur ye jo plastic strain develop hota hai yahi mujhe Orowan equation se pata chalti hai iska hum istemaal bhi karenge aage jaake. To aapko yeh cheez yaad rakhni hai plastic strain jo develop hoga woh directly proportional rahega dislocation density ke saath uske Burgers vector ke saath aur average jo displacement hai aur distance hai uske saath. Ya jo strain rate develop hoga woh directly proportional rahega mere dislocation density ke saath yani mobile dislocation density ke saath Burgers vec vectors ke saath ya average velocity of dislocation ke saath.

To yahan par humne dekha tha is part mein ki agar dislocation motions ho rahe motions yani dislocation motion ki jab baat karenge to humne yahan par simple glide ke liye dekha hai glide ya slip ke liye aur climb ke liye bhi ek udaharan dekha tha aur humne derive kiya yahan par Orowan equation. Yeh jo Orowan equation hai woh humein batayega ki plastic strain kya develop hoga material mein. Abhi ke liye main yahin par rukta hoon next part se hum janenge is plastic strain ke baare mein aur kis tarah se stress strain ke relation hum la sakte hain dislocation ke saath. Dhanyavad.