

## Mechanical behavior of materials

Dr. Niraj Mohan Chawake

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

Week-8

Lecture-42

Strain Hardening Stages in an FCC Single Crystals



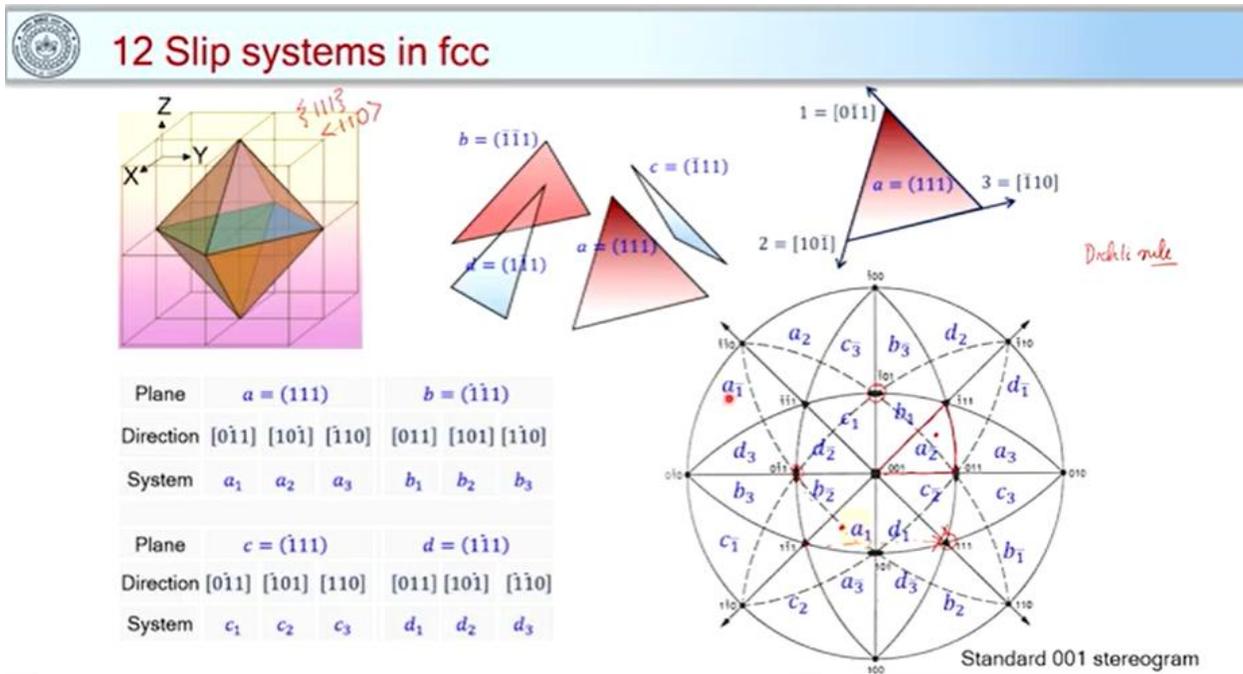
### Mechanical Behavior of Materials (Hindi)

#### Strain Hardening Stages in an FCC single crystal

•

Namaskar phir se swagat karta hoon aapka is course mein mechanical behavior of material jo ki hum hindi mein padhenge last part tak humne dislocation interaction kya hai dislocation intersection kya hai yeh padhe the is part mein hum jaane ki strain hardening stages kya hoti hai wo bhi FCC single crystal mein agar hum FCC single crystal mein strain hardening kaise hoti hai yeh agar samjhenge to hum yeh gyaan kisi bhi dusre material ke liye bhi apply kar sakte hain to sabse pehle FCC single crystal mein strain hardening jaanne se pehle pehle kuch cheezein revise kar lete jo ki is part ke liye kaam mein aayegi hamare paas 12 slip system se kul FCC mein to yeh slip systems kuch is tarah se hai humne dekha tha ki yeh slip systems hoti hai isko likh lete hain hum yeh slip system hoti hai meri  $\{111\}$  planes pe aur along  $\langle 110 \rangle$  direction to ye slip system se aur yahan pe maine ye kuch  $\{111\}$  plane mark kiye hain abhi ye jo  $\{111\}$  plane hai agar aap dekhenge ki ye aath  $\{111\}$  plane hai to agar main chaar  $\{111\}$  plane consider karu to dusre chaar remaining chaar jo hai baaki chaar jo hai woh isse geometrically equivalent hote hain to isliye abhi main upar ke sirf chaar  $\{111\}$  plane consider kar raha hoon aur is  $\{111\}$  planes ko main thoda separate karta hoon kuch is tarah se to mere chaar yeh  $\{111\}$  plane hai abhi yeh agar main

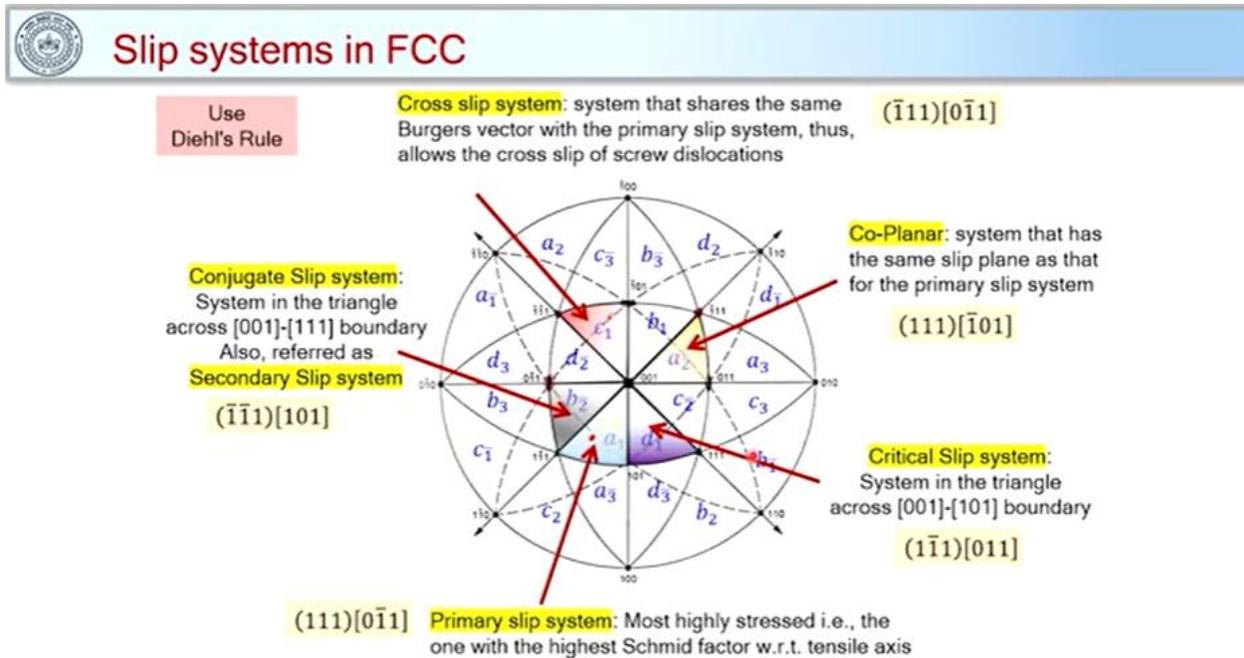
coordinate axis kuch x y z is tarah se maan ke chal raha hoon to yeh chaar {111} plane main kuch is tarah se likh sakta hoon aur in ke main naam de deta hoon A B C aur D to ye chaar {111} plane hai abhi ek plane mein consider karta hoon jaise yeh plane mein consider kar raha hoon iska naam diya hai maine A to A plane kya hai mera (111) plane hai aur jaise B plane jo hai woh ( $\bar{1}\bar{1}1$ ) plane hai to isi tarah se baaki ke naam diye aur baaki jo niche ke chaar planes hai wo equivalent rahenge geometrically chaar plane ki tarah yaani wo parallel rahenge to yahan pe abhi main ek {111} plane consider kar raha hoon abhi main kuch slip directions consider karunga is plane pe kuch is tarah se to slip direction mujhe pata hai kuch is tarah se hogi humne dekhi thi FCC slip system jab padh rahe the tab ab in slip direction ko bhi main naam de deta hoon to is tarah se maine naam de diye jaise slip direction one jo hai wo  $[0\bar{1}1]$  hai two jo hai wo  $[10\bar{1}]$  hai three jo hai woh  $[\bar{1}10]$  hai yeh teen slip direction hogi mere {111} plane mein usi tarah se kuch teen teen slip direction hogi mere B plane mein C plane mein aur D plane mein abhi agar main is plane ko A naam de raha hoon to main kuch slip systems ko naam de sakta hoon.



Unka nomenclature kar sakta hoon to ya unka naamkaran kar sakta hoon to yeh 12 slip system kuch is tarah se hum dekhte hain to mere paas ye plane hai A plane B plane C plane aur D plane aur maine kuch directions mark kiye yahan pe kuch is tarah se to agar main slip system A1 consider kar raha hoon to mera plane kaun sa hoga mera plane hoga (111) aur direction hogi wahan pe  $[0\bar{1}1]$  kuch dusra example lete hain jaise D plane agar main consider kar raha hoon to D plane mera yeh ho gaya yahan pe ( $1\bar{1}1$ ) ho gaya aur main kuch dusri direction ka consider kar raha hoon ye ek direction consider kar raha hoon  $[10\bar{1}]$  to yeh ho jayegi meri direction two to isko main naam likhunga D2 jab main D2 kahunga to aapko samajhna hoga ki main is plane ki aur is direction ki baat kar raha hoon yeh 12 slip system hai kul mila ke isko hum acche se stereogram pe represent kar sakte hain to agar aap stereogram nahi jaante to aapko uske baare mein padhna padega wo aapko kisi bhi standard physical metallurgy ke book mein mil jayega to ek maine standard (001) stereogram yahan pe plot kiya hai humne yeh dekha tha jab hum slip systems determine kar rahe the tab.

Abhi is slip system mein maan lete ki meri tensile axis kuch yahan pe hai humne dekha tha agar hum meri tensile axis is plane pe hai maan lete hain yahan pe hai is triangle mein to hum yahan pe slip system kaise determine karenge to humne kuch Schmid's rule apply kiya tha aur abhi hum dekhenge ki agar meri slip direction ismein hai isko bhi likh lete hain agar main yahan par hoon to humne dekha tha ki jo slip plane hoga woh is (111) ke opposite hoga yahan par yeh mera slip plane hoga aur direction hogi yeh [100] [110] yahan par hai to direction meri yeh hogi jo ki  $[0\bar{1}1]$  hai to aap dekhenge yahan par ki jo slip plane hai agar meri tensile axis yahan pe aur mera single crystal deform kar raha hai to slip plane jo hoga mera (111) hoga aur slip direction hogi  $[0\bar{1}1]$  yeh kyun hoga kyunki yeh slip system pe agar aap calculate karoge to Schmid factor jo hai woh highest aayega to agar hum (111) plane aur  $[0\bar{1}1]$  direction dekhe is table mein to yeh aa rahi hai yahan pe A1 mera plane one hai aur direction  $[0\bar{1}1]$  hai to agar meri tensile axis in saare triangles mein move hoti hai ya rehti hai to meri slip system yahan pe change hogi woh change isliye hogi kyunki wahan pe Schmid factor us slip system ke slip system pe sabse jyada hoga to main agar main saare triangles consider karunga to mere paas kuch aise slip systems operative hogi abhi main ek slip system consider karunga is is triangle pe agar main yeh triangle consider kar raha hoon yahan pe to aap dekh paa rahe honge ki yahan par maine A2 bar likha hai agar mere tensile axis yahan pe hai agar main Schmid's rule apply karta hoon to direction meri yeh hogi yeh meri slip direction hogi iske liye aur mera slip plane jo hoga ye plane hoga (111) to aap dekh paa rahe honge ki mera slip plane (111) hai slip plane (111) hai aur direction meri hai  $[\bar{1}01]$  agar main yahan par dekhu to iska agar main inverse karu yeh direction ka to iska inverse aayega  $[\bar{1}01]$  to isliye maine is system ko yahan par A2 bar likha hai jaan paa rahe honge ki is slip system ko main A2 bar likhunga usi tarah se agar main kisi bhi triangle mein mera tensile axis rehta hai to aap us triangle ke corresponding slip systems yahan pe dundh sakte hain aur naam de sakte hain in slip systems ke to aaiye isko aur acche se jaante maan lete hain mere slip system yahan pe hai is is region pe jo shaded region hai to abhi main Schmid's rule apply karunga to yahan par slip system aayegi meri (111) aur  $[0\bar{1}1]$  yeh jo slip system hai agar meri tensile axis kuch is tarah hai yahan pe hai to yeh jo slip system hai yahan pe mujhe A1 mil rahi hai to is slip system ko main kahunga Primary Slip System kyunki is tensile axis ki wajah se yeh most highly stressed slip system hogi mere FCC material mein jab main Schmid factor ko consider karunga tensile axis ke corresponding to meri yeh plane hai aur yeh meri direction hai isko main kahunga primary slip system abhi is primary slip systems ke corresponding mein baaki slip systems ko naam de sakta hoon kuch is tarah se agar main ye triangle consider karunga to aap dekhenge is triangle mein kaun si slip system active hogi agar main yahan pe hoon yahan pe bhi likh sakte hain agar main is triangle mein hoon to mere paas slip direction aayegi ye aur slip plane aayega kuch is tarah se to aap dekh paa rahe honge ye jo slip system hai yeh hai Cross Slip System cross slip system isliye kyunki yahan par aap dekh paa rahe honge ki jab main yahan par hoon is triangle mein to yeh jo direction hai  $[0\bar{1}1]$  aur yeh jo primary slip system mein direction mili mujhe  $[0\bar{1}1]$  yeh dono same hai in dono slip systems mein to isiliye hum isko kehte cross slip system cross slip system yaani humne jab cross slip consider kiya tha screw dislocation ka to agar screw dislocation is direction pe hai wo aasaani se cross slip ho sakta hai to isliye hum is slip system ko kehte hain cross slip system yaani hamara requirement kya hai cross slip system jab hum baat karenge primary slip system ke corresponding yaani slip direction dono ki same honi chahiye to yeh ho gayi meri cross slip system abhi kuch aur slip systems dekhte hain yeh jo slip system hai yahan pe agar aap Schmid's rule apply karenge aur find out karenge ki yahan pe yeh jo plane aa raha hai is triangle mein jab hu tab jo jo plane aa raha hai ye aa raha hai mera (111) aur ye jo direction aa rahi hai  $[1\bar{1}0]$   $[0\bar{1}1]$  yahan par aap dekh paa rahe honge ki plane mere same hai to isko hum kehte hain Coplanar System aasaan hai samajhna

dono mein plane same hai primary slip system mein jo plane hai wo agar dusre slip system mein plane same rahega usko main coplanar system kahunga abhi kuch aur important slip systems dekhenge yeh jab mere tensile axis yahan pe hai jo meri primary slip system hai uski jo bagal wali slip system mujhe milegi jahan par agar main yeh consider karunga ye line agar draw kar raha hoon  $[001]$  aur  $[\bar{1}\bar{1}1]$  to mujhe jo slip system milegi mujhe ye slip system milegi jo ki  $(\bar{1}\bar{1}1)$  hai aur  $[101]$  hai is slip system ko main kehta hoon Secondary Slip System ya Conjugate Slip System secondary slip system kyunki agar main is line ke dusri taraf jaunga jaise  $[001]$  aur  $[111]$  boundary ke cross karke jaunga jo mere paas triangle aayega stereogram mein us triangle mein jo slip system operate hogi usko main kahunga conjugate ya secondary slip system usi tarah se main is boundary pe ja sakta hoon  $[001]$  aur  $[110]$  to aap is boundary ke cross aaoge aur yahan par jo slip system operate hogi woh hogi meri  $(\bar{1}\bar{1}1)$  aur  $[011]$  is slip system ko main kehta hoon Critical Slip System to is tarah se main kuch slip systems ke naam dunga primary slip system ke corresponding yeh naam hum abhi isliye jaan rahe hain kyunki humein strain hardening dekhni hai FCC material mein.

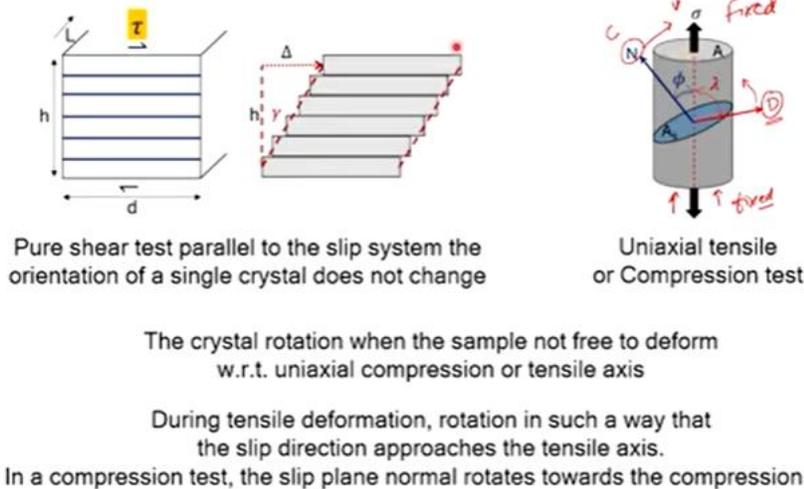


To is introduction ke saath hum aage badhte hain aur dekhte hain ki plastic deformation ke dauran kya hota hai agar mere paas kuch crystal is tarah se hai aur main sirf shear stress apply karta hoon to iska shape change ho jayega kuch is tarah se humne dekha tha ki ye shape change is tarah se milega to agar mere paas pure shear test hai aur ye slip system jo hai uske parallel hai ye jo shear stress jo main apply kar raha hoon to wahan pe mujhe koi orientation change nahi milega single crystal mein par yeh cheez possible nahi hogi jab main uniaxial tensile ya compression test karunga to mere paas kuch is tarah se single crystal hai aur main isko is tarah se tensile deformation kar raha hoon aur maine ek condition rakh di yahan par ki yeh jo do end hai yeh fixed hai to isko bhi yahan pe likh dete hain ki mere end fixed hai yeh move nahi ho sakte tab yahan pe jo crystals hai single crystal mein yahan pe jo slip plane hai uska rotation hoga to rotation kuch is tarah se hota hai yaani yahan pe crystal rotation hoga jab ye ends fixed rahenge aur rotation kuch is tarah se hoga jaise agar main tensile deformation kar raha hoon yaani force agar tensile hai to ye jo rotation hoga wo is tarah se hoga ki meri jo slip direction hai yahan pe slip direction kaun si hai ye meri

slip direction hai red wali ye approach karegi tensile axis ke taraf yaani ye is tarah se rotate hoga ye slip plane ki yeh jo direction hai wo tend karegi meri tensile axis ki taraf agar main compression mein hoon to kya hoga ye jo slip normal hai ye slip normal hai ye rotate karega compression axis ki taraf agar main compression mein hoon to compression mein slip plane move karega aur tension mein slip direction move karegi meri tensile axis ki taraf to aaiye jaante hain jab main single crystal ko deform karta hoon to kya cheezein ho sakti hai.



## Crystal rotation during deformation



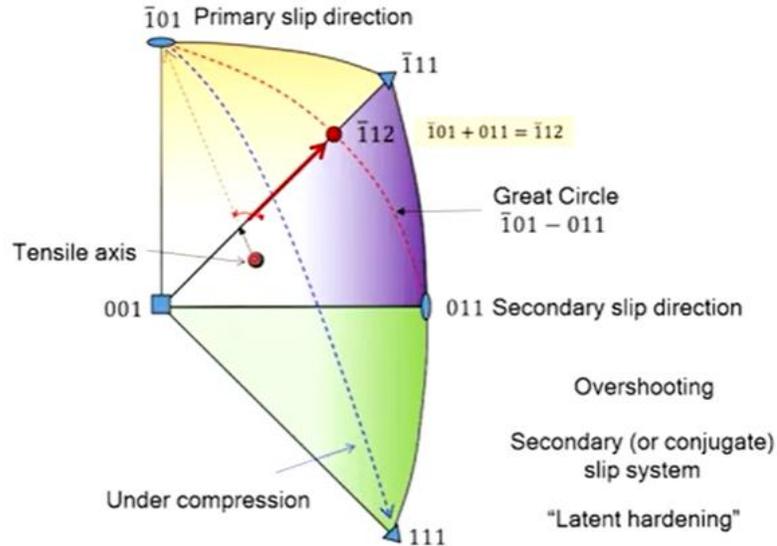
To jab main consider karta hoon ek stereogram aur yahan par (001) stereogram yahan par consider kar raha hoon aur maan lete hain meri tensile axis yahan pe kuch is tarah se yeh meri tensile axis ho gayi yahan pe abhi main yahan par slip system jab determine karunga to mujhe do aur rigram lagenge ye humne dekha do do do triangle lagenge stereogram nahi lagenge do triangle lagenge kuch is tarah se aur main yahan par agar meri tensional axis is triangle mein hai to Schmid's rule ke hisaab se sabse highest Schmid factor is slip system pe aayega aap dekh paa rahe honge ki yeh meri yeh direction hogi  $[\bar{1}01]$  aur yeh mera plane hoga (111) yeh meri primary slip system ho gayi to main kuch is tarah se mark kar leta hoon ye meri primary slip direction ho gayi ab humne dekha tha ki jab main agar tensile deformation kar raha hoon to yeh jo mera crystal hai woh orient karega tensile axis ke taraf agar main crystal ko constant maan ke chal raha hoon crystal plane move nahi kar raha hai to main yeh bhi samajh sakta hoon ki tensile axis move kar rahi hai meri slip direction ki taraf is tarah se bhi main rotation ko samajh sakta hoon to maan lete ki meri tensile axis move kar rahi hai slip direction ki taraf kuch is tarah se yaani ye tensile axis move karegi is direction mein jab main iska tensional deformation karunga single crystal ka to kya hoga jab main yahan se move karunga aur tensile axis jaise hi is triangle mein aayegi ye yellow triangle mein aayegi to aap dekh paa rahe honge ki slip system change hogi yahan pe kyunki is triangle mein slip system kaun si hogi meri ye direction hogi aur kuch plane is tarah se hoga is triangle mein to abhi maan lete hain ki jaise hi main yahan pe aa gaya is point pe aa gaya to to slip system change hogi aur slip direction change hogi yahan par slip direction kuch is tarah se hogi yeh meri secondary slip direction ho jayegi aur humne dekha ki hamare humne jab bataya ki jab slip system dusri operate hona chalu karegi main isko secondary slip direction bol raha hoon to yeh jo hai

tensile axis phir is direction mein move hona chalu karegi  $[001]$  ki taraf is tarah se to kya hoga jaise hi wo apni direction change karegi to yahan par vector addition hoga dono directions ka kuch is tarah se kyunki pehli direction meri  $[\bar{1}01]$  thi dusri direction meri  $[0\bar{1}1]$  hai to inka vector addition mujhe milega  $[\bar{1}\bar{1}2]$  to meri tensile axis kuch is line pe aa jayegi dono triangle ke line pe aur ek equilibrium maintain karegi aur is direction mein move karna chalu karegi to yeh jo point hai  $[\bar{1}\bar{1}2]$  yeh point lie karta hai mere great circle pe agar main great circle draw karunga  $[\bar{1}01]$  aur  $[0\bar{1}1]$  ke beech mein to kuch is tarah se mujhe great circle milega aur yeh point jo rahega yahan par yeh rahega  $[\bar{1}\bar{1}2]$  abhi meri jo tensile axis hai woh kuch is direction mein move karegi agar dono equilibrium mein maintain hai to par actually jaise hi aap dekhenge yeh kuch is tarah se move hoga yahan pe practically ye observe kiya gaya hai ki meri slip direction kuch isi triangle mein rehti hai yaani mera jo tensional axis hai kuch isi direction mein rehti hai aur meri sirf primary slip system active rehti hai jab yeh transition hoga to isko hum kehte hain Overshooting yaani ye overshoot ho gayi aur yeh sirf primary slip direction ke along hi deformation ho rahi hai ideally kya hona chahiye tha ki ye is direction mein hona chahiye tha par overshoot hoke sirf wo primary slip direction mein deformation meri continue move ho rahi hai yaani meri tensile axis se primary slip direction ki taraf rotate ho rahi hai to hum yeh keh sakte hain ki yeh jo slip system yahan pe operate karegi is triangle mein yaani  $[0\bar{1}1]$  aur yeh dusra plane yahan pe yeh jo slip system hai yeh hard ho gayi hai yaani hum keh sakte hain ki jab primary slip direction active rahegi ya overshoot ho jayega tab ye yahan pe jo slip system hai aur humne dekha tha ki yeh jo slip system yahan pe hogi  $[0\bar{1}1]$  aur  $(\bar{1}11)$  isko hum kehte hain secondary slip system ya conjugate slip system to meri jo secondary slip system ya conjugate slip system yeh activate nahi hogi yahan pe to hum keh sakte ki ye jo slip system hai wo harden ho gayi hai aur harden kyun ho gayi hai kyunki mera jo deformation hai wo primary slip system mein chal raha hai is terminology ko kehte hain is phenomena ko kehte hain Latent Hardening latent hardening kya hota hai jab meri primary slip system operative rehti hai tab meri dusri jo probable slip system hai secondary ya conjugate slip system woh operate nahi hogi aur yeh jo slip system operate nahi hogi to hum keh sakte ki ye jo slip system hai wo harden ho gayi hai aur harden kyun ho gayi hai kyunki mera jo deformation hai wo primary slip system mein chal raha hai is terminology ko kehte hain is phenomena ko kehte hain latent hardening.

To abhi ye humne consider kiye 12 slip systems humne consider kiya hai ki primary secondary cross slip conjugate slip system coplanar slip system ye sab saari consider ki abhi hum jaante hain ki strain hardening kya hota hai FCC ke single crystal mein haan ek aur baat jab main compression ki baat karunga tab yeh jo direction hai agar mere yahan pe compression direction thi to yeh move hogi is great circle pe under compression  $\langle 111 \rangle$  direction ki taraf abhi hum strain hardening stages dekhenge strain hardening stages ke liye hum pehle kuch equations likh lete hain jo humne pehle hi padh chuke hain jaise

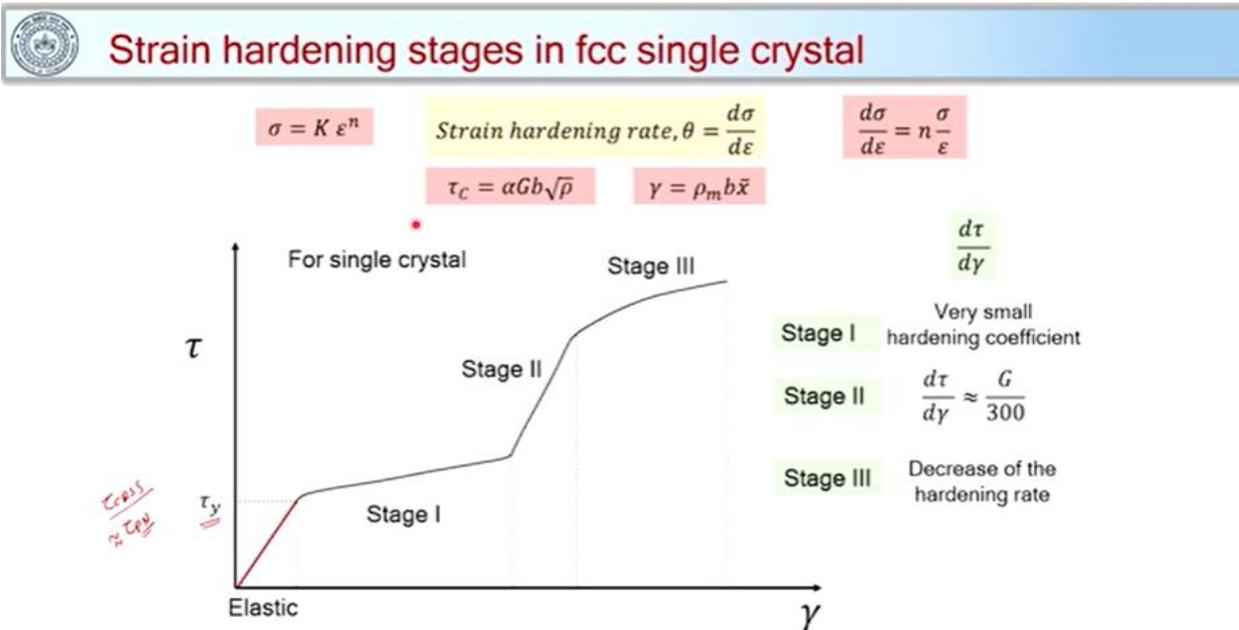


## Slip systems and crystal rotation during deformation



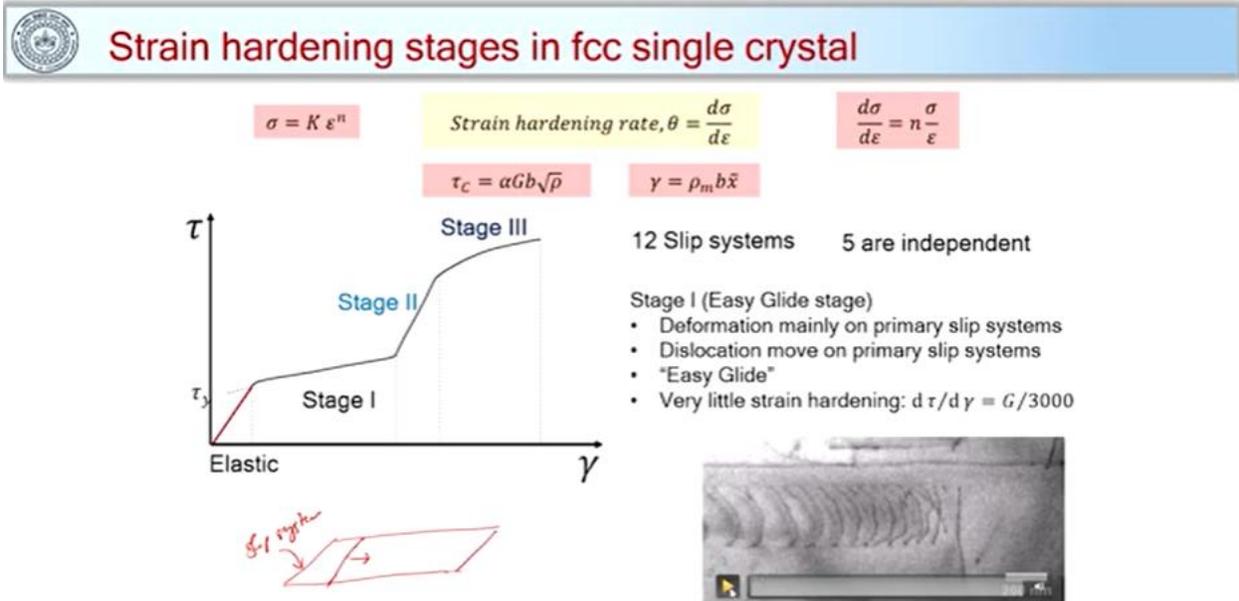
humne  $\sigma = K\epsilon^n$  Yahan pe  $\sigma$  hum likh sakte hain plastic deformation mein strain hardening exponent hai mera aur maine strain hardening rate kuch is tarah se define kiya tha  $\theta = d\sigma/d\epsilon$  aur  $d\sigma/d\epsilon$  humne likha tha  $n\sigma/\epsilon$  ye humne initial classes mein hi derive kiye the saare relations uske baad humne kuch is tarah se Taylor hardening relation likha tha aur kuch is tarah se Orowan equation likha tha to humne dekha tha jaise plastic deformation badhta hai to meri mobile dislocation density badhti hai aur ye jo mobile dislocation density badhegi tab meri shear stress jo deformation ko cause karegi ya continue rakhegi wo bhi badhegi jaise jaise mera plastic strain badhega ye humne dekha tha abhi jab main shear stress aur shear strain ki baat kar raha hoon to main kuch is tarah se plot karta hoon aur mere paas single crystal hai aur yahan pe main plot karunga  $\tau$  aur yahan pe main plot kar raha hoon shear strain  $\gamma$  to ye pure shear stress hai aur ye pure shear strain hai aur mere paas single crystal hai aur main usko deform karunga to kuch is tarah se mujhe variation milega yeh jo point hai yahan pe pehla jo behavior hai wo linear hai aur yeh jo behavior hai wo elastic behavior hai yahan pe ye humne bhi dekha tha jab hum Schmid law padhe the to yahan pe jo  $\tau_y$  Hai  $\tau_y$  To  $\tau_y$  Ko main  $\tau_{CRSS}$  Bhi likh sakta hoon ek perfect condition mein ye yeh jo hai Critical Resolved Shear Stress hai aur yahan par mera plastic deformation is point ke baad chalu hoga ye meri  $\tau_{CRSS}$  Value hai isko agar theoretically bhi consider karna hai to isko  $\tau_{PN}$  Bhi likhte hain ya Peierls-Nabarro stress bhi likh sakte hain to theoretically kuch is tarah se relation likhte hain par yeh single crystal ke liye bahut ideal cases hai abhi iske baad elastic behavior ke baad material plastic behavior dikhana chalu karta hai to main agar jaise jaise plastic strain badhaunga mere single crystal ke liye to deformation kuch is tarah se badhegi to mujhe stress ka variation kuch is tarah se milega to ye mujhe mil raha hai FCC crystal ke liye ye aapko yaad rakhna hai to mujhe kuch is tarah se milega abhi yeh jo deformation behavior hai main isko teen stages mein divide kar sakta hoon agar aap dekhenge slope dekhenge  $\tau$  ka  $\gamma$  ke saath to yahan par slope variation hai aur is variation ke saath main yahan pe teen stage mein is deformation behavior ko change kar sakta hoon ya likh sakta hoon to isko main naam deta hoon Stage 1 Stage 2 aur Stage 3 to aaiye jaante hain ki in teen stages ka naam kaise diya hai aur kis प्रकार se diya hai to maine likh liya yahan pe Stage 1 Stage 2 aur Stage 3 aur isko hum identify kaise karte hain hum identify karenge is slope se slope yaani mera strain hardening rate to jab main is plot ko shear

stress versus shear strain plot ko kuch is tarah se likhunga tab main strain hardening rate ko define karunga stages ko bifurcate karne ke liye to yahan par stage 1 mein aap dekhenge is stage mein yeh jo value hai yaani slope jo hai woh bahut small hai to main keh sakta hoon ki yahan par is stage 1 mein bahut kam strain hardening rate hai ya strain hardening coefficient small hai yahan pe yahan par aap dekh paa rahe honge stage 2 mein ek steep change mil raha hai yaani mera slope badh gaya yahan pe aur yeh slope hota hai generally around  $G/300 G$  jo ki mera shear modulus hai material ka aur stage 3 mein phir se slope change hota hai kam hota hai yaani decrease mil raha hai mujhe strain hardening rate pe to jaise jaise main plastic strain badha raha hoon waise stress jo hai us hisaab se nahi badh raha hai to yahan pe mujhe decrease milega strain hardening rate pe to main is parameter se teen stages ko likh sakta hoon ye plastic behavior ki stages hai mere material ki single crystal FCC material mein.



To aaiye in stages ke baare mein jaante hain ki inmein kya ho raha hai to jab main aise kuch baat kar raha hoon to aap dekh paa rahe honge jaise mere paas FCC material hai to main mere paas 12 slip systems hai aur usmein se paanch independent honi chahiye humne hum yeh padhenge ki paanch independent kyun honi chahiye to yahan pe hum dekhenge Stage 1 mein Stage 1 ko maine naam diya hai Easy Glide Stage aur easy glide stage mein hum dekhenge ki yeh jo deformation hai woh mainly Primary Slip System par humne primary slip system define ki thi to jahan par meri tensile axis hogi us triangle mein jo slip system rahegi woh meri primary slip system rahega let's say mere paas ek slip system hai yeh meri slip system hai aur yahan par kuch dislocation hai yeh dislocation aasaani se is primary slip system par hi move karenge stage 1 mein to yahan pe koi resistance nahi hai mere dislocation ko to yahan pe aap dekhenge ki jo stress required hai mere dislocation ko move karne ke liye wo kam rahega to isliye aap dekhenge ki yahan pe koi yeh jo yeh jo strain hardening rate hai yeh jo rate hai yeh kam hai yahan pe to yeh jo movement hai dislocation ka isko main kehta hoon easy glide kyunki yahan pe dislocation aasaani se move ho raha hai aur aap dekh paa rahe honge ki is yahan pe mujhe strain hardening rate kam milega uski value  $G/3000$  rehti hai to ye meri primary slip system par hi mostly dislocation move hote hain yeh stage 1 ho gayi isko hum isko hum jaanenge is video ke dwara yahan par aap dekhenge ki ye

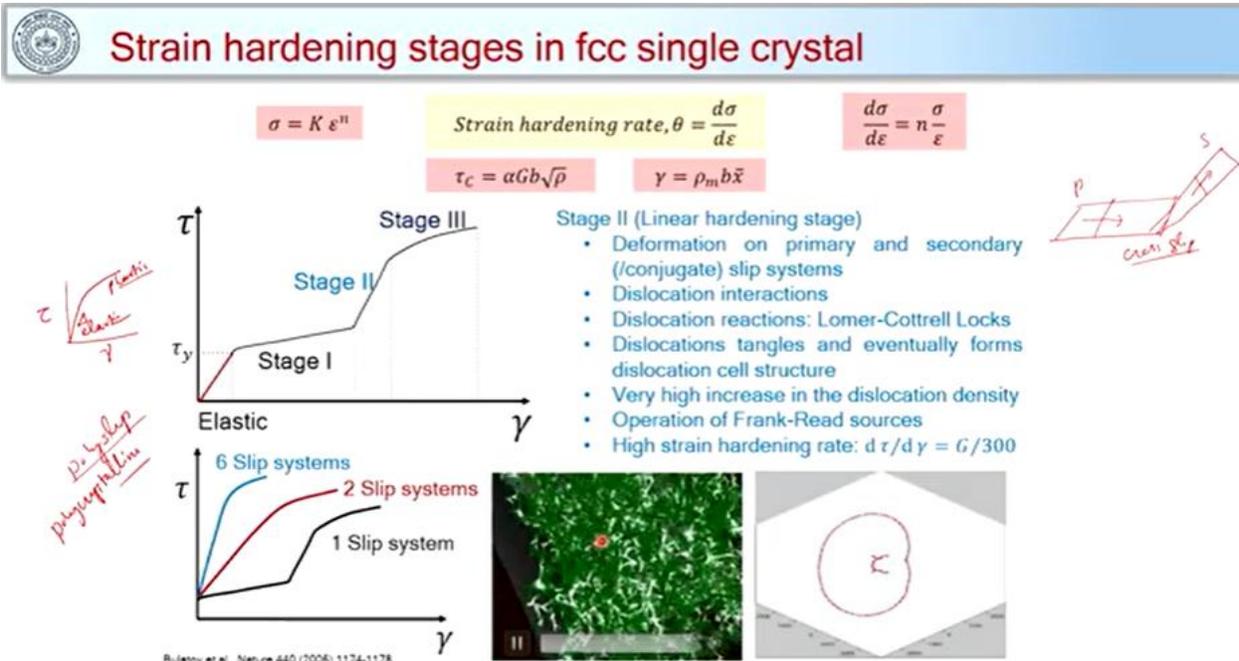
jo dislocation hai mere sirf primary slip system par move ho rahe hai aap dekh paa rahe honge ki ye jo dislocation hai primary slip system par hi glide kar raha hai isliye isko easy glide kehte hain to yeh ho gayi meri stage 1



abhi jaante hain Stage 2 pe uske pehle kuch is tarah se jaanenge agar mere paas ek slip system operative hai to mujhe jo shear stress shear strain behavior kuch is tarah se milta hai agar mere paas do slip system operative hai to main keh sakta hoon ki mujhe jo shear stress shear strain behavior kuch is tarah se milega humne dekha tha ki primary slip aur secondary slip ya ya conjugate slip operate ho sakti hai ek saath to us case mein mujhe kuch is tarah se shear stress shear strain behavior aur mere paas agar multiple slip system operative hai to mujhe shear stress shear strain behavior is tarah se milta hai isko naam bhi diya jaata hai isko naam diya jaata hai Polyslip behavior kyunki yahan pe multiple slip behavior hai to aap dekh paa rahe honge ki ye to maine single crystal ki baat kar raha hoon aur jab main polycrystal line material ki baat karunga to humein stretch strain curve kuch is tarah se milega jahan par elastic behavior aur plastic behavior milta hai to yeh elastic behavior ho gaya aur yeh plastic behavior ho gaya mera kuch is tarah se mujhe behavior milenge to aap dekh paa rahe honge ki number of slip systems jaise jaise badh rahi hai mera behavior change hoga.

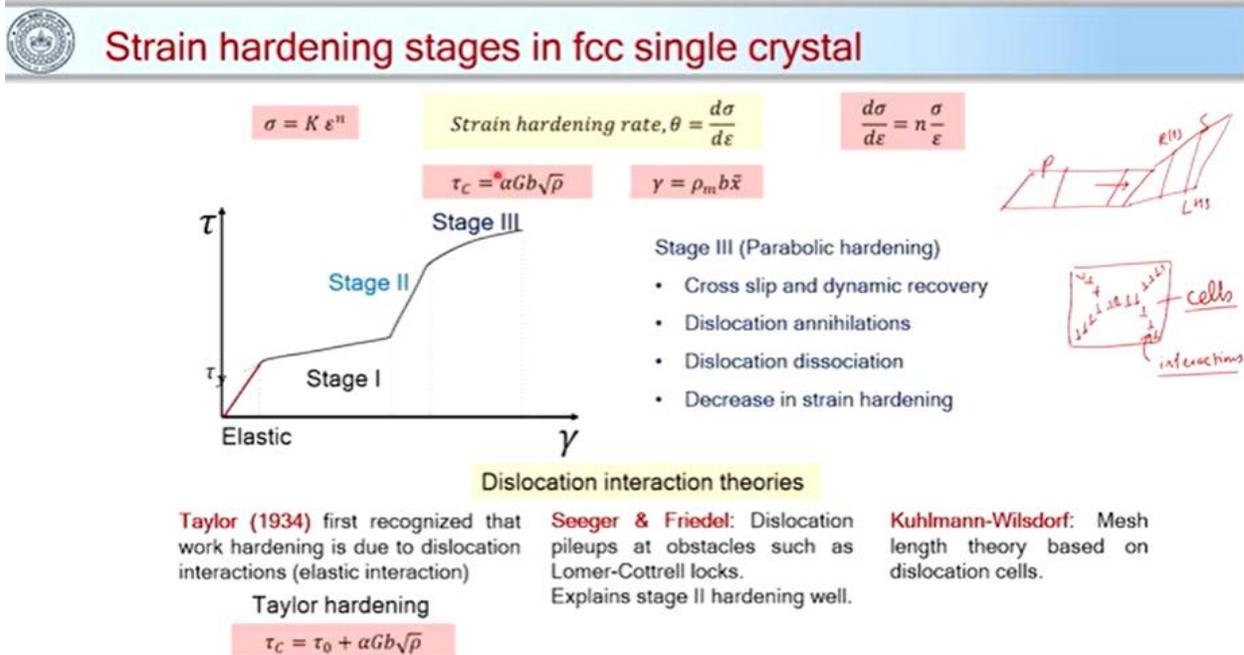
Abhi hum single crystal pe aate hain aur Stage 2 ke baare mein jaante hain to Stage 2 mein kya hota hai stage 2 mein mere paas do se jyada slip system operative hogi yaani mere paas deformation bhi hoga primary slip system aur secondary slip system ya conjugate slip system pe yahan pe aap dekh paa rahe honge ki jaise jaise stage 1 khatam ho raha hai wahan pe dislocation interactions mere badhte jayenge dislocation interaction humne padha tha acche se ki stress field hoti hai dislocation ke around wo interact karenge ek dusre ke saath aur wo kuch hardening karenge humne dislocation locks ke baare mein bhi padha tha jaise Lomer-Cottrell locks to dislocation reactions hogi stage 2 mein uske baad yahan par aap dekhenge ki dislocation tangles banenge aur kuch cell structure evolve honge isko hum dekhenge baad mein kuch cell structure yahan pe dislocation cell structure yahan pe evolve honge aap dekh paa rahe honge ki stage 2 mein yahan pe dislocation density bhi badhegi dislocation density kyun badhti hai kyunki mere Frank-Read

sources bhi is stage mein operative honge aur in saari reasons ki wajah se mere paas ek strain hardening rate milegi jo ki sabse jyada hogi plastic behavior mein ye milegi  $G/300$  to aap dekh paa rahe honge jaise mere paas ek primary slip system hai aur mere paas kuch secondary slip system hai kuch is tarah se aur dislocation yahan par move hoke yahan par aayega aur is secondary slip system ye primary hai secondary ismein bhi cross slip ho sakta hai aur yahan par aap dekh paa rahe honge mere paas kuch locks banenge kuch interactions hogi aur isko hum video ke dwara bhi samajh sakte jaise main yeh video play karunga yahan par aap dekhenge ki mere paas yeh Orowan looping yahan pe ho rahi hai yeh mera Frank-Read source ki tarah kaam karega aur yeh Frank-Read source jab kaam karta hai tab aap dekh rahe honge ki dislocation density badhegi aur jitni dislocation density badhegi utne interactions badhenge aur Lomer-Cottrell locks jo banne hain unki sambhavna bhi badhegi abhi yahan pe aap dekh paa rahe honge ki jaise jaise mera deformation badh raha hai plastic strain badh raha hai waise waise dislocation aur yeh dislocation density badhegi interactions badhenge aur yeh strain hardening karenge aap dekh paa rahe honge ki maine ek term istemal kiya ki dislocation tangles to aap dekh paa rahe honge ki jo white hai yahan pe yeh jo is tarah se yeh bana rahe hain mere dislocation tangles yaani ek dusre ke saath woh jud rahe hain aur interact hone ke liye ek ek cluster taiyaar kar rahe hain to yeh deformation mein strain hardening ki zimmedari ya strain hardening ko nibhata hai aap dekh paa rahe honge ki ye dislocation is tarah se interact ho ra hai ek dusre ke saath aur yahi reason hai mera material ka strain hardening ka stage 2 mein hai.



Abhi hum Stage 3 ke baare mein jaante hain jab main Stage 3 ke baare mein jaanu to aap dekh paa rahe honge ki yahan par jo strain hardening rate hai wo decrease ho raha hai aur yahan par kya ho raha hai yahan par ek meri cross slip badh rahi hai humne dekha tha ki secondary mein bhi second stage mein bhi cross slip hoti hai to yahan par meri cross slip aur Dynamic Recovery hogi aur dislocation annihilation hoga dislocation dissociation hoga decrease in strain hardening rate milegi humein to kuch is tarah se milegi jaise mere paas ek primary slip system hai humne yeh draw kiye aur mere paas kuch secondary slip system hai kuch is tarah se meri primary slip system hai secondary slip system hai yahan par mujhe cross slip mili ye dislocation yahan pe aa tangle hoke

aur cross slip hoke is idhar aaye to maan lete ye mera right hand screw tha aur maan lete hain is secondary kuch left hand screw tha yeh dono milke ek dusre ko annihilate karenge aur annihilation se yahan par aap dekh rahenge ki annihilation se dislocation density thodi kam hogi aur yeh bhi ho sakta hai yeh jo dislocation hai inka interaction kuch is tarah se hoga jab yeh annihilate honge tab isi ko isi cheez ko hum kehte hain Dynamic Recovery kyunki sab ho raha hai mere jaise jaise main plastic strain badha raha hoon mere material pe us hisaab se ho raha hai to isliye jo recovery jo milegi us recovery ko main kahunga dynamic recovery yahan pe mere dislocation annihilations hote hai aur dislocation dissociation bhi ho sakte hain aur yeh cause karegi meri yaani decrease karegi meri strain hardening to jab main in teen stages ki baat karta hoon to teen models yahan par log baat karte hain jo mainly accepted hai hum Taylor hardening ke liye Taylor hardening humne equation dekha tha jab meri dislocation density badhti hai tab mujhe kuch hardening milti hai yeh hota hota hai mainly dislocation ke elastic interactions ki wajah se yeh humne dekha tha dusra model hai Seeger and Friedel ka jahan pe humne dekha tha ki Lomer-Cottrell locks jo ki obstacle ki tarah kaam karenge mere dislocations ko aur ye pile up karenge mere dislocation ko kisi bhi plane pe to yeh second stage hai hardening ki usko acche se explain karte hain to Seeger and Friedel ka ek model hai aur ek model hai Kuhlmann-Wilsdorf ka jahan par Mesh Length Theory ki baat ki hai aur dislocation cells ki baat ki dislocation cells ki baat yaani jab mere paas ek single crystal hai agar main is tarah se dekhun aur bahut saare dislocation ho gaye to dislocations kuch is tarah se arrange honge humne dekha tha dislocation ek dusre ke saath arrange ho sakte ek slip plane pe ek ke upar ek aur humein kuch is tarah se cells milenge dislocation cells to aap dekhe honge ki yeh jo interactions ki wajah se hi humein dislocation cells milti hai aur yeh Kuhlmann-Wilsdorf model jo hai yeh mera dynamic recovery dislocation annihilation aur stage 2 dono ko explain kar sakta hai to yeh ho gaye kuch dislocation interaction theory abhi humne FCC crystal mein dislocation ki wajah se strain hardening kaise hoti hai ye jaana hai



To is part mein humne jaana hai ki dislocations kis tarah se interact karte hain woh intersect bhi kar sakte hain Lomer-Cottrell locks bhi form kar sakte hain different slip systems kitni active hoti hai primary slip system secondary slip system in saaron ka kya role hai strain hardening ke upar yeh humne dekha next part mein hum jaanenge ki humein kitni slip system active chahiye ek

plasticity ko microscopic macroscopic plasticity ko define karne ke liye abhi ke liye rukta hoon  
dhanyavad