Mechanical behavior of materials

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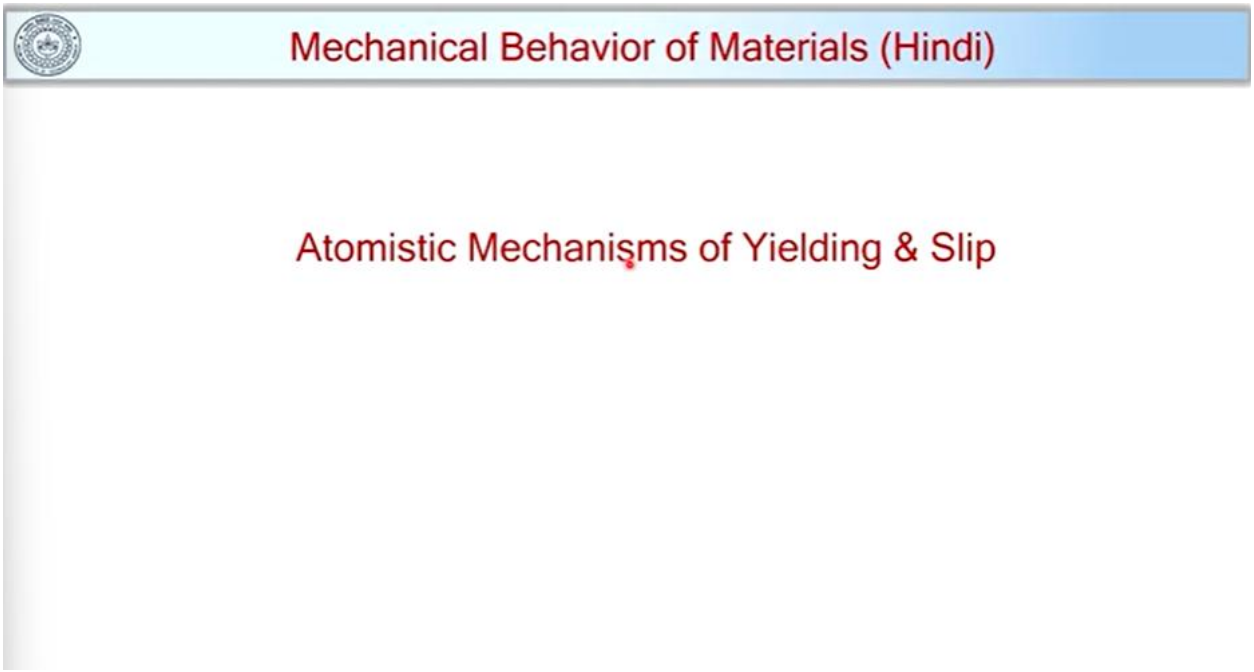
Week-4

Lecture-20

Atomistic Mechanism of Yielding & Slip



Namaskar aapka phir se swagat karta hoon is course mein Mechanical Behavior of Material jo hum Hindi mein padhenge. Last part mein humne dekha tha yielding criteria kya hota hai. Is part se hum dekhenge ki Plasticity jo plastic behavior hai material ka aur Yield Point jo hota hai aur Plastic Deformation kaisa hota hai iske atomistic mechanism kaise hain yeh hum janenge.

To pehle hum dekhte hain yeh hamare paas Stress Strain Curve hai Engineering Stress Strain Curve. Yahan pe aap dekhenge yeh linear portion tha yeh Elastic behavior dikhata hai material ka aur ye jo non-linear portion tha yeh Plastic behavior dikhata hai aur humne bataya tha ki jo Yield Stress hai wo wahan par hum baat karte ki hamara plastic deformation ki shuruat hoti hai wahan se.

To humne Elastic Deformation mein dekha tha ki jab hum material ko stretch karte ya material par koi force apply karte hain to usme deformation shuru hota hai Elastic Deformation. Agar humne wo load release kar diya to material apna original dimension prapt karta hai. To yahan par aap dekhenge ki yahan par kuch atoms dikha hai bonds dikhaye hai aur ye bond stretch ho rahe hai to

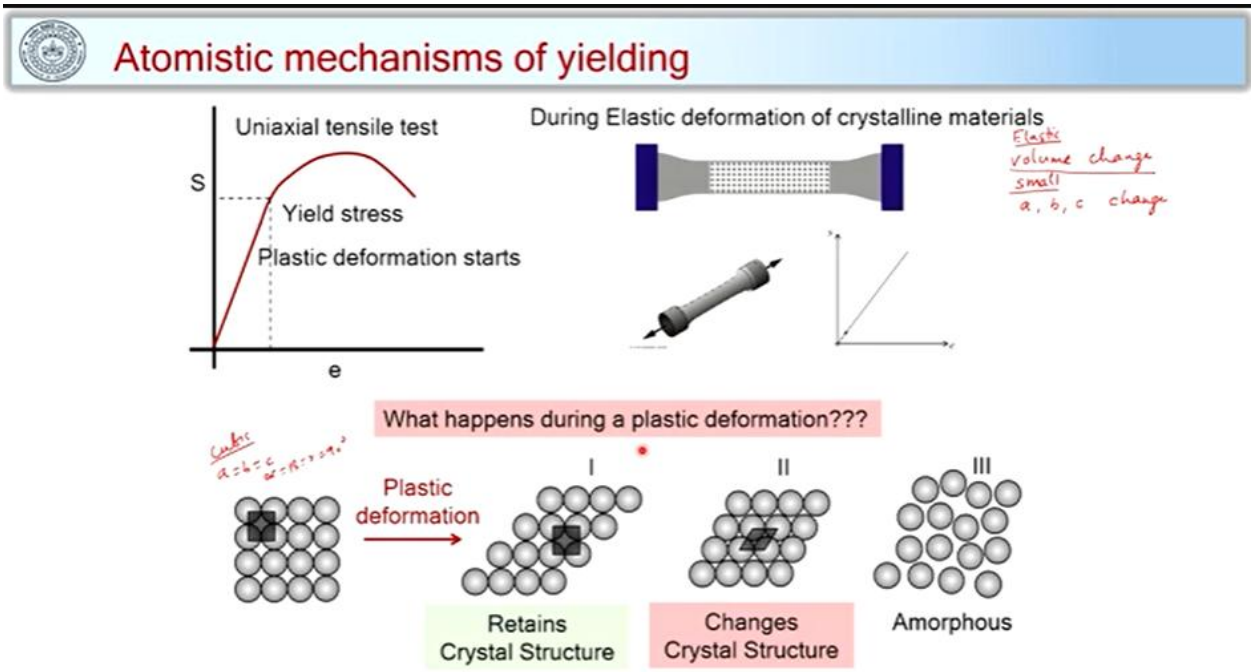
to jab jaise main force apply kar raha hoon to ye bond stretch ho raha hai release kar raha hoon to ye bond apne original position par aa rahe hai. Ye hamara Elastic behavior hai.

Yahan par hum dekhenge ek cheez important hai jo plastic deformation aur elastic deformation mein difference hai yahan pe elastic deformation volume change hota hai. Volume change yane small volume change hi hota hai to yahan par hamare paas ye elastic deformation ki main baat kar raha yahan par kitna bhi small rahe volume change hota hai. Jab main volume change ki baat kar raha hoon to main jab crystal ki baat karunga wahan par mere parameters jo a, b aur c Lattice Parameters se yeh change honge.

To abhi hum jante hain ki Plastic Deformation kya hota hai. Plastic Deformation mein kya cheez hoti hai. Elastic Deformation humne jaan liya abhi hum dekhenge ki Plastic Deformation mein kya hota hai. To mere paas ek crystal hai to agar hum dekhenge Plastic Deformation yani humne baat ki thi ki permanent change in shape yane jo yeh jo shape hai crystal ka ye permanent change hoga jab main stress apply karunga. To jante hain mere paas agar plastic deformation hai agar shape change mujhe kuch teen scenario main dekh sakta hoon ek simple teen scenario yahan pe aap dekhenge ki ye jo atoms hai ye deform ho gaye aur yahan pe mujhe ek shape change mila hai. Dusra scenario hai yahan pe bhi mujhe shape change mila hai to aur teesra scenario yahan par bhi mujhe ek shape change mil raha hai. To inmein se kaun sa ek scenario hai agar aap dekhenge yahan par mere paas ek crystal structure hai maan ke chal raha hoon mere paas ek crystal structure hai. Crystal structure yani main bol raha hoon yahan par Lattice Parameter se define karunga main crystal structure ko jaise cubic mein $a = b = c, \alpha = \beta = \gamma = 90°$ ye mera cubic structure hai usi tarah se main lattice parameters ya angles se main define karunga mera crystal structure.

Abhi hum dekhenge ki pehle case mein yeh jo crystal structure hai wo retain hai mera shape change ho raha hai par ye crystal structure retain ho raha hai. Dusre case mein hum dekhenge ki crystal structure change ho raha hai yahan par aap dekhenge yeh initial crystal structure cubic tha yahan par ye rhombus ho gaya aur third case mein yahan par dekhenge ki koi crystal structure hi nahi hai ya jo atoms deform ho rahe hai wahan par koi ek crystalline order ya crystalline structure nahi hai isko main kehta hoon Amorphous State.

To jab 100 saal pehle jab plastic deformation pe research ho raha tha tab yeh ek question tha scientist ke saamne ki plastic deformation mein kya hota hai.

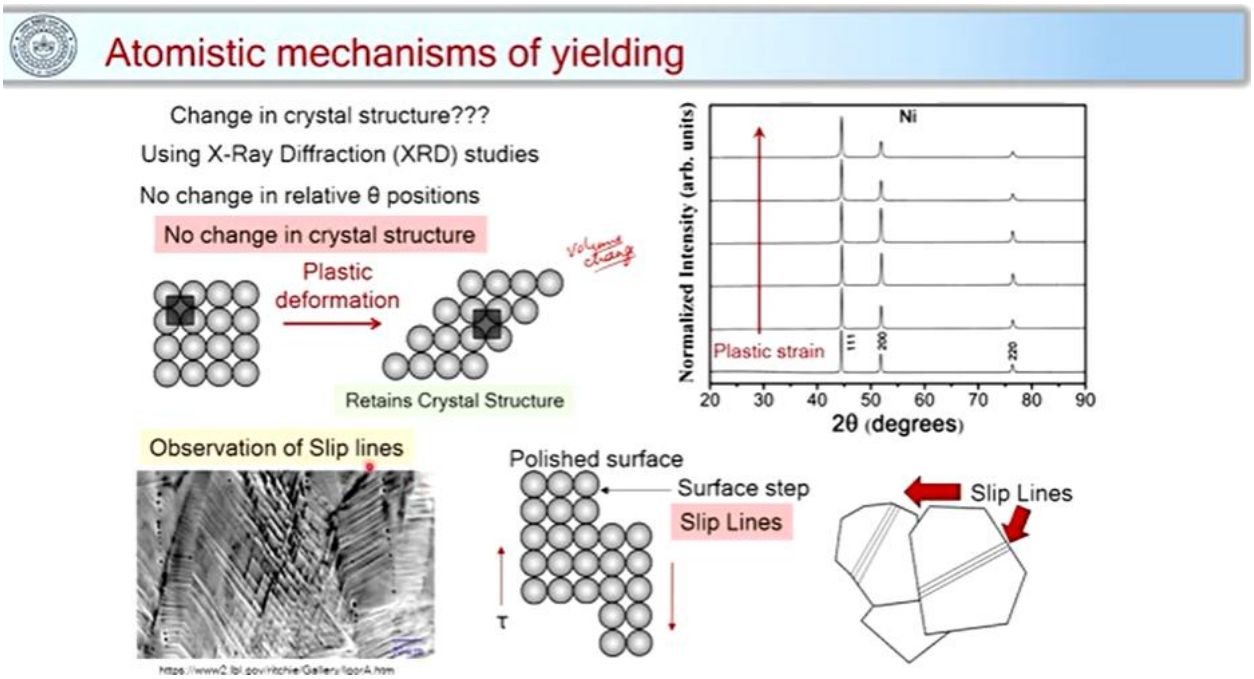


To uske liye hamare paas humein dekhna hai ki crystal structure change hota hai ki nahi hota hai plastic deformation to uske liye hum XRD techniques istemaal karte hain. To agar mere paas X-ray Diffraction Techniques hai to main X-ray Diffraction se baat kar paunga ki crystal structure change hota hai ki nahi hota hai. Ek example dena chahta hoon yahan par yahan par Nickel ka example diya hai aur yahan par aap dekhenge ki yeh jo XRD pattern hai yahan par plastic strain yani mera material Nickel jo hai wo deform main kar raha hoon plastic strain yahan par increase ho raha hai aur aap dekhenge ki agar maine XRD pattern liya to aap dekhenge ki jo theta position hai yahan par agar {111} peak ke theta position se {200} peak ke theta position se ya {220} ke theta position se yeh change nahi ho rahe yeh ek hi theta position par hai. To iska matlab kya hai wahan jahan par agar theta position change nahi ho rahe agar hum Bragg's Law apply karenge to hum janenge ki yahan par crystal structure mera change nahi ho raha hai yani yeh jo peaks hai wo ek hi theta position par to yeh maine XRD studies different material par ki hai aur aur isse yeh mujhe prapt hua hai ki crystal structure change nahi hota plastic deformation to mera ek scenario hi possible hai yahan par yeh mera crystal structure hai yahan par shape change ho raha hai par crystal structure change nahi ho raha hai to ya mera crystal structure retain ho raha hai.

To ek baat aur janenge yahan par plastic deformation jab baat karenge to plastic deformation mein volume change nahi hota hai yeh humne dekha tha. To ye ek cheez aapko yaad rakhna hai yahan par shape change ho raha hai volume change nahi ho raha hai aur crystal structure bhi same reh raha hai wo retain hota hai plastic deformation mein.

Aur kuch cheezein experimentally observe ki thi scientist ne jab plastic deformation ki baat karte hain to yeh isko hum kehte hain **Slip Lines**. Iske baare mein janenge ye word ke baare mein bhi janenge slip ke baare mein. To slip lines kya hoti hai agar mere paas ek material hai polished tha ye yani mirror finish tha aur agar maine isko deform kiya to mere paas kuch is tarah se lines banti hai surface pe isko main kehta hoon slip lines. To isko samajhte hain agar ye mere paas crystal structure hai aise aur yeh maan lete hain mera surface hai material ka to ye polished surface hai yani aap polished surface yani mirror polish yani aap isme apna chehra bhi dekh sakte hain aisa polished surface hai but jab hum isko shear stress apply karte yani deform karte to kya hoga yahan

par ek process hogi material deform hoga plastically yani uska shape change hoga. To is tarah se kuch agar shear stress mein deformation ho raha hai mere material ka to yahan par yeh surface par aap dekhenge ek step taiyar hua isko main kahunga ye isko yeh surface step kahunga agar aap upar se dekh rahe hain to aapko ek step yahan par dikhai degi yeh ek ek height pe hai aur yeh ek height pe isko hum kehte hain surface step. To yeh surface step mujhe practically observe huye microscope mein isko bhi slip lines kehte hain is surface step ko aur yeh slip lines iska schematic maine is tarah se liya hai magar mere paas different grains hai isko bhi hum janenge ki grains kya hote hain aur yeh grains mein mujhe milenge ye slip lines yani kuch surface steps taiyar honge jab main material ko deform karunga aur ye jo deformation hai ye mera permanent deformation hai yani agar main ye stress ko reverse karoon yani ye stress ko release kar doon to ye deformation wapas nahi hoga yani shape change permanent rahega yahan pe. To yeh ho gaya mera Slip.



To jante ki Slip hota kya hai actually. To humne dekha hai ki agar hum slip dekhenge to yahan par hoga microscopic shape change without any crystal change yahi humne dekha abhi practically jo hum observation dekhe the do cheezein. To yahan par shape change ho raha hai par crystal structure change nahi ho raha hai. To do mechanism proposed hai hum deformation mein jante hain ek hai Slip aur dusra hai Twinning.

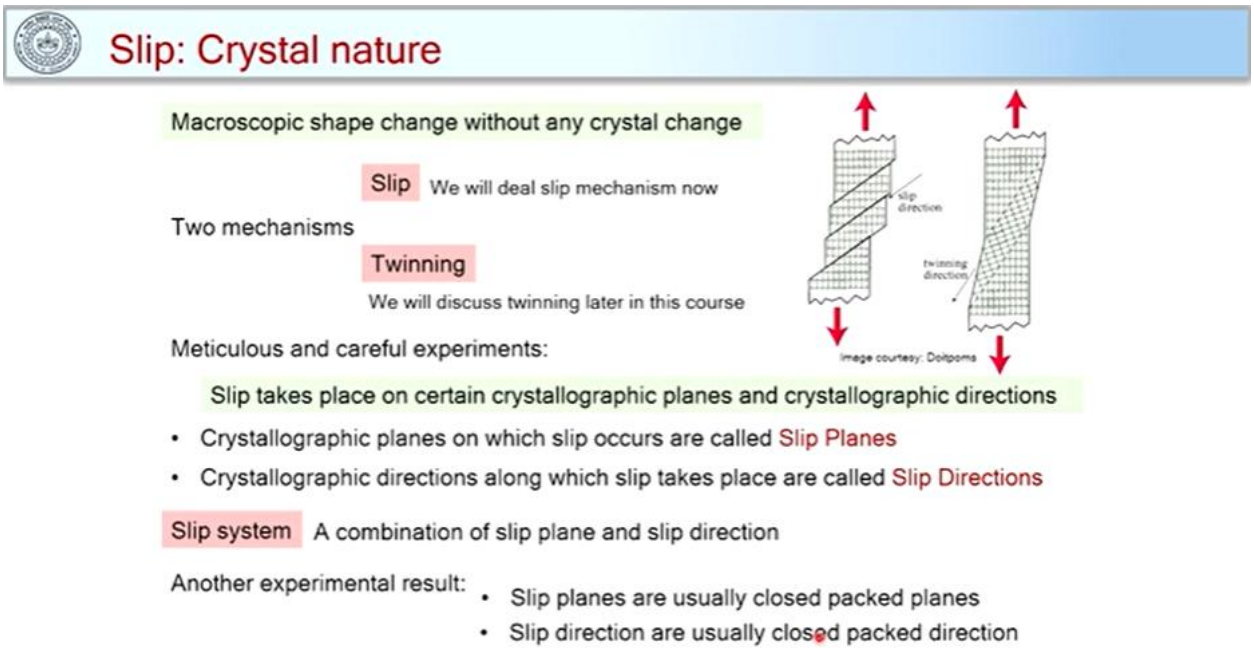
Aaiye jante hain ki Slip hota kya hai. Agar mere paas ek crystal hai aur main usko deform kar raha hoon to aap dekhenge ki yeh jo crystal hai ek particular direction par aur ek particular plane par deform ho raha hai. Agar main usko tensile deform kar raha hoon to aap dekhenge ki yahan par shape change ho raha hai. To yeh jo shape change ho raha hai aap dekhenge yeh atomistically ho raha hai yahan par to maine bada karke dikhaya par yeh aapko dikhega atomistically aur agar aap surface dekhenge agar ye tensile sample ka to aapko yahan par ye steps dikhengi. Is process ko jab material is tarah se deform hota hai to isko hum kehte hain Slip.

Dusra ek mechanism hai jisko hum Twinning kehte hain abhi hum usko abhi hum usko deal nahi karenge hum usko aage dekhenge hamari course mein ki Twinning hota kya hai. Yahan par bhi aap dekhenge ki material ka jo shape hai microscopic shape hai wo change ho raha hai plastically

deform ho raha hai par ye jo mechanism hai wo orientation change ke karan ho raha hai ye hum baad mein dekhenge is course mein.

To abhi jante hain ki Slip hota kya hai. Slip yane agar dekhenge Hindi mein iska anuvaad karenge to Slip ka matlab hota hai phisalna. To yahan par aap dekhenge jo atom rows hai wo phisal rahe hain ek dusre ke upar yeh iska matlab hai. To agar hum yeh jo experiments hai ye ek kuch agar hum experiments dekhenge iske careful observations dekhenge to yeh dekhenge ki slip jo ho rahi hai ek particular plane par ho rahi hai. Particular plane yani main agar jab crystals ki baat karunga ek particular Crystallographic Planes pe ho rahi hai aur ek particular Crystallographic Direction ke along ho rahi hai. Aap dekhenge yahan pe ab slip jo ho raha hai is schematic mein dikhaya hai ki yeh jo planes hai ispe slip ho raha hai yani ispe atoms phisal rahe hain aur ek particular direction mein phisal rahe hain. To us yani main dekhunga ki slip mein Crystallographic Planes aur Crystallographic Direction ka ek mahatva hai. To ye jo Crystallographic Planes hai isko main kehta hoon **Slip Planes** yani jahan par yeh jo planes phisal rahe ek dusre ke upar isko main kehta hoon Slip Planes aur jis direction mein phisal rahe usko main kehta hoon **Slip Direction** aur yeh dono cheezein mila ke main ek system ko define karta hoon aur usko kehta hoon main **Slip System**. Slip System yani kya hoga combination of Slip Plane and Slip Direction in dono ka combination jo hoga wo mera Slip System hoga.

To ek aur experimental result hai yahan par hum dekhenge jo Slip Plane hai Slip Plane mein jab crystals ki baat karunga to jo Slip Planes hai yeh mere Close Packed Planes hote hain generally aur Slip Direction bhi hoti hai yeh meri Close Packed Direction hoti hai. Aap kisi bhi Physical Metallurgy jo text book hai isme aap iske baare mein padh sakte hain ki Close Packed Planes kya hote hain kisi bhi crystal structure mein aur Close Packed Directions kya hoti hai. Yahan par main ek chhota sa introduction dena chahta hoon yahan par. To kuch crystal structure hum dekhenge aur unke Close Packed Planes aur Close Packed Directions dekhenge.



Maan lete hain sabse simple hai mera Face Centered Cubic. To yahan pe dekhenge ki mere paas Face Centered Cubic crystal structure yani kya hota hai yahan pe mere paas aath atoms hai jo

corners pe hai aur jo chhe atoms hai wo chhe face centers pe hai isliye isko hum kehte hain Face Centered Cubic. Aur ek jo plane maine mark kiya yahan pe ye plane mera crystallographic (111) plane hai. Agar aap Miller Indices nikalenge is plane ki to yeh Miller Indices aayegi meri (111) plane ki. To FCC mein Close Packed Planes jo hoti hai wo {111} planes hoti hai. To yahan par aap dekhenge ki yeh jo aisa bracket hai is ye bracket dikha raha hai ek particular (111) plane specific (111) plane. Jab main curly brackets nikalta hoon yeh dikhata hai meri Family of {111} Planes. To jo bhi saare {111} planes hai mere Close Packed Planes hai FCC mein.

Abhi hum jante hain ki Close Packed Directions kya hoti hai. To uske pehle janenge ki ye kitne plane hote hain. To mere paas yeh {111} plane hai to inko hum kehte hain Octahedral Planes. Agar main is main agar aath unit cells agar nikalun FCC join kar lunga aise to mere paas yeh aath FCC planes FCC ke {111} planes milenge par aap dekhenge ki isme se jo chaar planes hai wo dusre chaar plane se parallel hai. To hum crystallographically unique plane ki baat karenge to hamare paas chaar {111} plane hote hain. To is tarah se hum janenge agar main dekhunga yeh plane main mark kar raha hoon yahan pe yeh agar plane dekhunga is tarah se yeh ek plane hai aur yeh ek plane hai ye ek dusre ke opposite hai yani parallel hai aur yeh crystallographically same plane hai. To agar main consider karunga to unique plane ki baat karunga to mere paas sirf chaar planes honge jo main top chaar planes hai top chaar {111} planes hai bottom chaar ke parallel rahenge ya unique yani sam samaan rahenge. To mere paas unique chaar planes hi hai. To chaar {111} plane ho gaye.

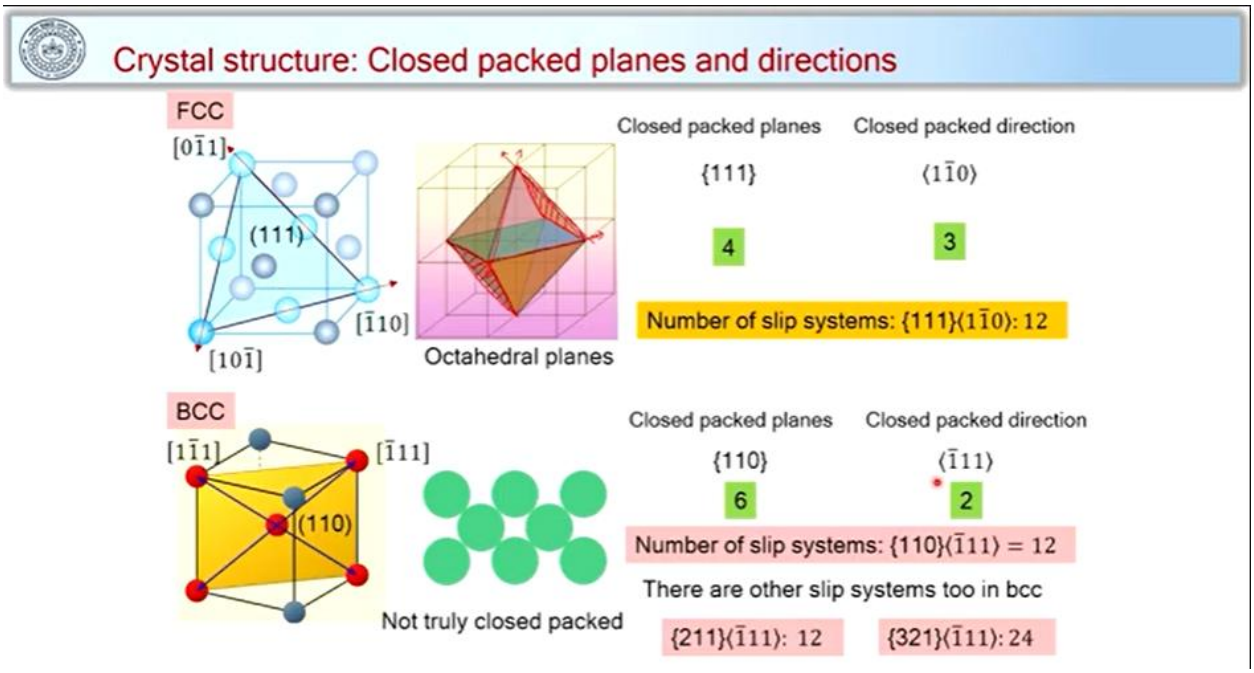
Abhi Close Packed Direction hum dekhenge. Close Packed Direction kahan pe hoti hai? To agar hum dekhenge ki Close Packed Direction (111) plane mein ye let's say is plane mein to yeh ek Close Packed Direction hogi yeh $[\bar{1}10]$ is tarah se Close Packed Directions hogi aur dusri do aur Close Packed Direction se is (111) plane mein yeh hai $[0\bar{1}1]$ aur $[10\bar{1}]$. Agar hum direction jab dikhate hain to direction yeh square brackets mein dikhate mere paas $[\bar{1}10]$ jo direction hai yahan par ek specific direction dikhai hai. Agar mere paas is tarah se bracket se $\langle\rangle$ to yeh Family of Direction dikhati hai. To yahan par mere ek plane mein teen Close Packed Direction hai.

Ek aur cheez yahan par main important cheez batana chahta hoon ki ye jo direction hai ye isi plane mein honi chahiye. To slip isi plane mein main is baar is schematic mein mark karta hoon ye agar mera ek (111) plane hai to yeh jo direction hai teen directions is (111) plane mein ye is teen $\langle 110\rangle$ ye jo teen direction hai wo isi plane mein honi chahiye yani wo direction is plane par lie karti hai. To slip hota hai is plane par par is direction ke along jo ki isi plane mein lie karti hai. To mere paas teen directions hai jo is (111) plane mein lie kar rahi hai. To mere paas slip systems kitni ho gayi? Agar main dekhunga agar chaar slip system se aur aur teen direction se ek plane mein to 4×3 mujhe milega 12. To mere paas slip system main is tarah se likhta hoon mere paas plane hai yeh Family of Planes hai {111} ki aur yeh $\langle 110\rangle$ ye direction hai. To yeh hogi meri Slip System aur kitne slip systems hone chahiye paas 4×3 yani 12 slip systems hone chahiye.

Abhi hum dekhte hain Body Centered Cubic. Body Centered Cubic structure kaise hota hai yahan pe eight jo atoms hote hain yeh corners pe hote hain aur ek atom jo hota hai wo body centered hota hai ya is cube ke center pe hota hai body ke center pe. To ye ho gaya mera Body Centered Cubic. Isme Close Packed Planes kaun se hote hain? To most Close Packed Planes hote hain {110}. To aap yahan par dekhenge ye jo yellow color mein mark hai ye mera ek specific (110) plane hai aur ye jo hai ye meri family of {110} plane hai. To aise kitne planes hote hain BCC mein Close Packed Planes ya yahan pe pehle mark kar lete hain Close Packed Directions kitne hote hain. Close Packed Directions isme aap dekhenge ki ye jo body diagonal hai $[\bar{1}11]$ ya $[\bar{1}11]$ is plane mein ye meri

Close Packed Direction se jo body diagonals se hai cube ke ye meri Close Packed Direction se raha aur aap dekhenge ki ye jo directions hai do directions maine ye specific directions mark kiye yeh is plane par lie karti hai yani (110) pe lie karti hai. To agar main direction dekhunga ⟨111⟩ ye yeh mere paas chhe planes ho jayenge agar main dekhunga {110} to main is tarah se chhe planes nikal sakta hoon is crystal structure mein aur directions hogi mere paas do to 6×2 ye mere paas 12 slip systems ho jayegi is Close Packed Planes aur Close Packed Directions mein. To mere paas slip system jo hai yeh {110}⟨111⟩ yeh slip system hogi aur yeh ho jayegi meri 12 kul mila ke 12 slip system.

Aur ek cheez yahan pe dhyan rakhne wali hai ye jo plane hai {110} ye iska packing is tarah se hai to yeh yahan pe hum keh sakte hain ki yeh jo plane hai yeh mera truly Close Packed Planes nahi hai. To kabhi kabhi kisi conditions mein ye mere paas dusre slip systems bhi hote hain BCC mein. To yeh jo dusre slip systems hai iske baare mein bhi jante hain. To mere paas kuch alag dusre slip system hai yahan par aap dekhenge {211} plane hai aur yeh jo direction hai ⟨111⟩ ye yahi meri Close Packed Directions hai to yeh mere paas mila ke 12 slip systems se aur kuch aur dusra plane hai yeh hai {321} to {321} family wale plane bhi mere slip plane ki tarah act karte aur yeh jo direction hai yeh meri ⟨111⟩ hi hai aur yeh mila ke 24 slip system taiyar karte. To mere paas kul mila ke 12, 12 aur 24 yani 48 slip system. Yeh isliye kyunki yahan par jo planes hai kisi koi bhi plane hai {110}, {211} ya {321} yeh mere close yani truly Close Packed Planes nahi hai. FCC mein jo {111} plane hai yeh mera Close Packed Plane hai par aap dekhenge ki BCC mein yeh cheez yaad rakhne wali hai yeh jo direction hai ⟨111⟩ type wali yeh Close Packed Direction hai.



Abhi jante hain HCP Crystal Structure ke baare mein. To HCP Crystal Structure is tarah se main draw kiya hoon aur aap dekhenge yeh jo plane hai top plane ya bottom plane isko main kehta hoon Basal Plane yeh (0001) type plane hai aur isme agar aap dekhenge ki yeh mera Close Packed Plane hai aur aise kitne plane hai yahan pe yeh sirf aur Close Packed Direction jo hai wo is tarah se yeh jo direction dikh rahi hai aapko yeh ⟨11$\bar{2}$0⟩ type directions hai. To yahan par mere paas sirf ye ek hi plane hai agar ye plane main consider kar raha hoon to ye jo planes hai ye saare

crystallographically same hai. To mere paas ek hi plane available hai (0001) type ka aur yeh jo directions hai is plane mein mere paas teen different type ke directions hai ye agar main yahan pe teen directions maine dikhai hai $[11\bar{2}0]$, $[11\bar{2}0]$ type aur ye $[11\bar{2}0]$ type to ye teeno alag alag directions hai ye mere paas teen directions ho gayi aur jo slip system hogi wah main is tarah se likh paunga $\{0001\}$ aur $\langle 11\bar{2}0\rangle$ yeh jo direction hai aur in dono ka product mila ke mere paas ho jayegi kul mila ke teen slip systems HCP case mein.

Aur yahan pe jante hain ki maine teen crystal structure yahan par study kiye FCC, BCC aur Hexagonal ye isliye kiye hai kyunki jo bhi hum Periodic Table table agar uthakar dekhenge to 90% jo Metals aur Alloys hai unmein yahi crystal structure paya jata hai Face Centered Cubic, Body Centered Cubic ya Hexagonal Close Packed. To isliye ye teen crystal structure yahan par discuss kiye. To hum dekhenge ki koi metals hai yahan pe FCC metals hai to Copper, Aluminium, Nickel, Silver, Gold ye jo hai yeh mere Face Centered Cubic material se. To yahan pe humne dekha tha ki ye mere paas $\{111\}$ plane hai aur $\langle 110\rangle$ direction hai to mere paas kul mila ke 12 slip systems hai FCC mein.

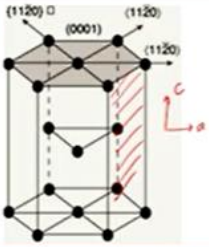
BCC mein aap dekhenge ki mere paas $\{110\}$ hai aur $\langle 111\rangle$ direction hai ye mila ke 12 ho gayi. Agar aap dekhenge ki alpha Iron $\{211\}$ ye kisi high temperature pe ye slip system active hoti hai aur yeh meri slip direction hai yeh bhi kul mila ke 12 hoti hai aur aur ek plane hai $\{321\}$ ye bhi kisi temperature aur strain state mein slip plane active hota hai aur mere paas ye $\langle 111\rangle$ direction hai ye kul mila ke 24 slip system ho jati hai. To aap dekhenge ki BCC mein jo slip direction hai wo common hai $\langle 111\rangle$ yeh meri kyunki Close Packed Direction hai.

Hexagonal Close Packed mein aap dekhenge ki maine humne yeh slip system discuss ki thi $\{0001\}$ aur $\langle 11\bar{2}0\rangle$ ye teen slip system hai par Hexagonal Close Packed mein kuch planes jaise $\{10\bar{1}0\}$ isko main is tarah se bhi likh sakta hoon yeh isko hum kehte hain Prismatic Plane yeh Prismatic Plane hai aur yeh type jo plane hai yeh mere Pyramidal hai ye mere Pyramidal plane hai. To Prismatic plane jo hote hai wo parallel to mere agar ye main Z axis maan raha hoon yahan par ya C axis maan raha hoon isko main kehta hoon Prismatic Planes. Agar hum dekhenge yeh jo plane hai yeh planes hai jaise ye planes hai yeh mere Prismatic Planes hai kyunki parallel to mere C axis hai agar yeh mera A axis hai HCP mein aur ye C axis hai to yeh planes jo hai yeh parallel hai C axis ko unko main Prismatic kehta hoon aur jo intersect karte hain C axis ko unko main kehta hoon Pyramidal Planes. To ye depend karti hai slip systems mere c/a ratio ke upar. To jaise c/a ratio change hota hai us tarah se mere slip system change hoti hai par majorly agar HCP crystal structure dekhenge to mere paas yeh slip system available rehti hai.

To is part mein humne dekha ki jo slip hai wo ek Close Packed Planes par hoti hai aur jo slip hoti hai Close Direction par hoti hai. To humne jaana hai ki agar mere paas koi crystal hai theek hai is tarah se main mark kar raha hoon yeh mere Slip Planes hai yeh Slip Planes jo hongi major yeh hongi mere Close Packed Planes aur yeh jo ye jis direction mein slip honge wo hogi meri Close Packed Direction aur aap janenge ki ye jo direction hai Slip Plane jo hai ya jo direction hai yeh meri Slip Plane par lie honi chahiye yani wo usi Slip Plane mein agar main Slip Plane aise consider kar raha hoon to wo direction us plane mein lie hoti hai. To aap dekhenge ki agar main Slip Plane aur Slip Direction ka dot product lunga to shunya aana chahiye agar main Slip Plane ko G maan ke chal raha hoon aur Slip Direction ko B maan ke chal raha ho to ye shunya aana chahiye. To yeh aap dekhiyega isko hum aur aage acche se detail mein dekhenge.

Crystal structure: Closed packed planes and directions

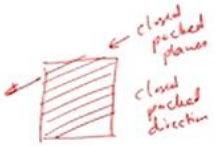
HCP



Closed packed planes: {0001} — 1

Closed packed direction: ⟨11$\bar{2}$0⟩ — 3

Number of slip systems: {0001}⟨11$\bar{2}$0⟩: 3



Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	{111}	⟨110⟩	12
	Body-Centered Cubic		
α-Fe, W, Mo	{110}	⟨111⟩	12
α-Fe,W	{211}	⟨111⟩	12
α-Fe, K	{321}	⟨111⟩	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	{0001}	⟨11$\bar{2}$0⟩	3
Ti, Mg, Zr	{10$\bar{1}$0} prismatic	⟨11$\bar{2}$0⟩	3
Ti, Mg	{10$\bar{1}$1} pyramidal	⟨11$\bar{2}$0⟩	6

Slip occurs on Closed packed planes

And along Closed packed directions

Is part mein mein humne dekha tha ki jo slip hota hai plastic deformation ka pehla mechanism jo slip hota hai yani jo planes ka phisalna hota hai isko hi hum slip kehte hain ye ek particular planes pe hota hai aur ek particular direction pe hota hai. Next class mein iske baare mein aur detail mein janenge abhi ke liye yahan par hi rukta hoon dhanyavad.