Mechanical behavior of materials

Dr. Niraj Mohan Chawake

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

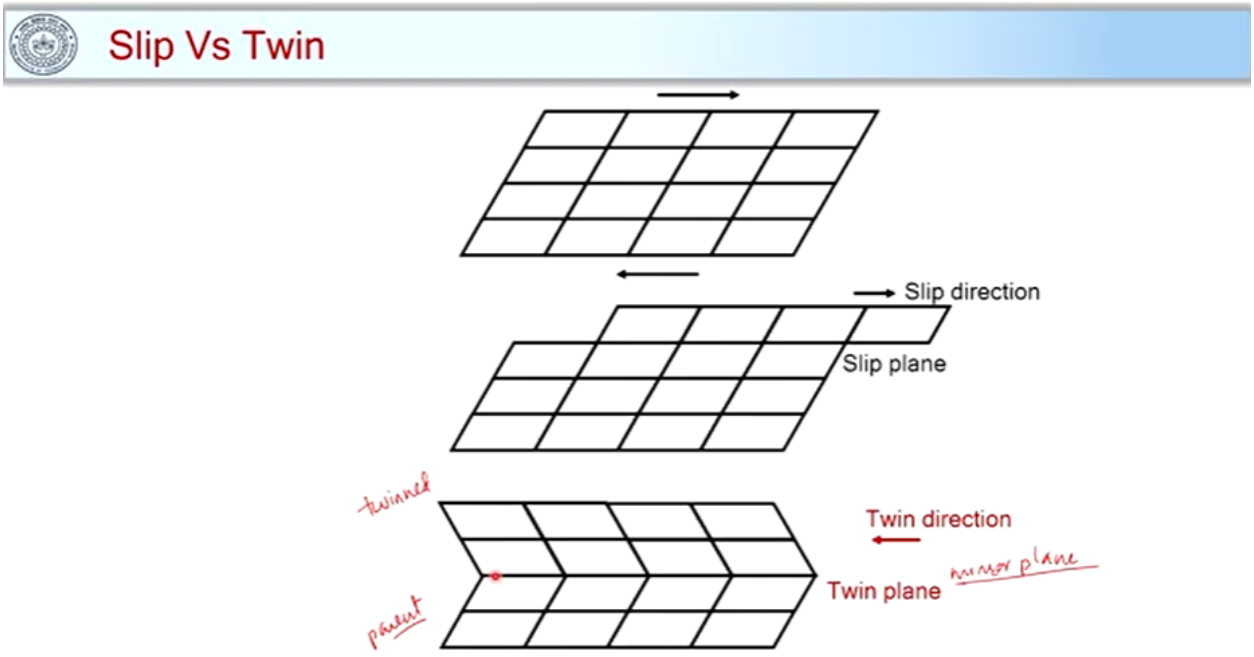
Week-9

Lecture-50

Twinning in crystalline Materials

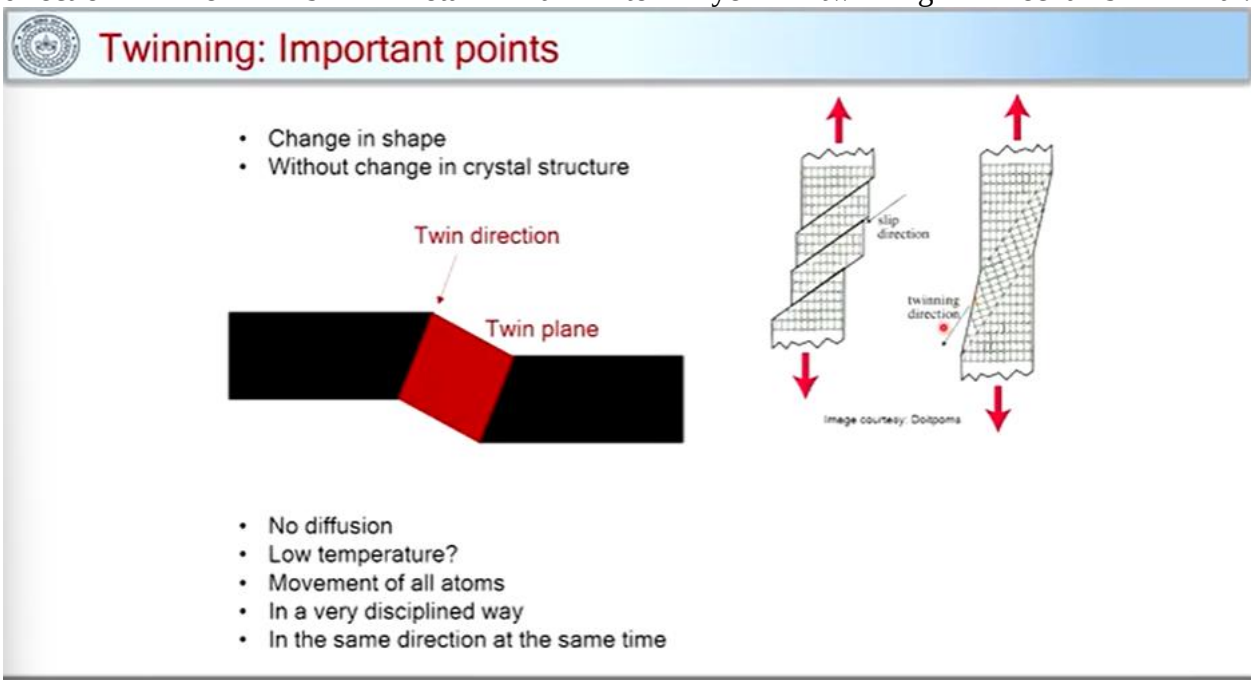
Namaskar aapka swagat karta hoon mechanical behavior of materials is course mein jo ki hum hindi mein padhenge last part tak humne dekhe the ki strengthening mechanisms kya hai materials mein is part mein hum dekhenge ek important plastic deformation mechanism jo humne initial classes mein iska introduction kiya tha jab maine slip ki baat ki thi slip aur twinning to is class mein hum twinning ke baare mein padhenge twinning ek bahut hi important plastic deformation mechanism hai materials mein crystalline materials mein to jab main twin ki baat karunga to sabse pehle slip se hum isko samjhenge to hum jab plastic deformation ki baat karte hain to maan lete hain mere paas kuch is tarah se crystal hai aur main ispe kuch shear stress apply karunga aur humne dekha ki plastic deformation ki jab baat karenge tab shape change hota hai mere crystal ka aur humne baat ki thi ki slip aur twin ye shape change karte hain mere crystals ka to agar main yahan pe is crystal ko deform kar raha hoon to jab main slip ki baat karunga to maine kaha tha ki slip ek particular plane pe hota hai aur ek particular direction pe hota hai to wo jo plane hota hai usko hum slip plane kehte hain aur jo direction hoti hai usko hum slip direction kehte hain to agar main

plastic deformation ki baat karunga to slip kuch is tarah se hota hai twin bhi kuch is tarah se hi hum samjhenge twin bhi ek particular plane par hota hai jisko hum twin plane kehte hain aur ek particular direction par hota hai twin direction par in dono mein kuch antar hai aaiye jaante hain schematic se to yahan pe agar main slip karunga to dekhte hain slip kuch is tarah se hoga yeh crystal deform ho gaya aur ek particular slip plane pe mujhe glide mila ya slip mila aur yeh particular direction par mujhe mila hai to mujhe ek shape change mila hai isko main slip kehta hoon twin mein aap dekhenge ki shape change to milega par ek particular mechanism yahan pe hoga jaante hain ki twin kis tarah se hota hai to maan lete hain yeh mera twin plane hai aur yeh meri twin direction hai yaani twinning mujhe kuch is direction pe milegi to aapne dekha ki yahan par twin jo hua kuch is tarah se yeh mera initial crystal structure hai aur yeh mera final crystal structure hai jahan pe mujhe twinning mili to twin hua is plane pe aur is direction ke along twinning hua hai aap dekh paa rahe honge ki ismein mujhe shape change mila hai par ek particular information yahan pe aap dekh sakte hain ki yeh jo crystal hai yahan pe aur yeh jo crystal hai aur yeh main plane agar consider karunga to yeh jo crystal hai jo twinned crystal hai aur yeh jo mera parent crystal hai isko hum likh dete hain ki ye mera twinned crystal hai aur ye mera parent crystal hai to parent crystal aur twin crystal mein ek orientation relation hai yahan par aap dekhenge ki orientation hi sirf yahan par change hua hai crystals ka is plane ke above yaani twin plane ke above to aap dekh paa rahe honge ki ye point aur ye point yaani parent mein ye point aur twin crystal mein ye point ye ek ye jo plane hai ye aap dekh paa rahe honge ye dono ek dusre se ek dusre ka mirror reflection hai to ek mirror symmetry yahan par aapko dikhegi is plane ke dauran to is plane ko bhi hum kuch is tarah se kehte hain is plane ko bhi hum kisi text book mein mirror plane bhi consider karte hain to aapke paas ek mirror plane bhi yahan pe dikhega jahan pe ek orientation relationship milega mujhe twin crystal aur parent crystal.



To yeh ho gaya mera basic difference slip aur twin mein abhi hum dekhenge ki yeh twin kis tarah se hota hai yeh mechanisms kya hai iske micromechanics kya hai to twinning jab main baat

karunga to kuch important points yahan pe hum note kar lete hain to humne dekha yahan pe change in shape milta hai mujhe crystal ka aur yahan pe koi bhi crystal structure change nahi milega sirf mujhe ek orientation change milta hai to yahan pe hum dekh paa rahe honge ye mera parent crystal hai aur ye mera ek parent crystal hai aur yahan pe twinning hui hai beech mein aur twinning kuch particular direction mein hui hai wo jo direction hai usko twin direction kehte hain aur jis plane pe yaani yeh jo plane hai yahan pe hui hai twinning us plane ko hum kehte hain twin plane yeh humne dekha yahan pe to yahan par koi crystal structure change mujhe mil nahi raha hai aur kuch points yahan pe hum dekhenge ki yahan pe koi diffusion nahi ho raha hai yaani agar aap dekhenge ki ye saare atoms yahan pe is direction mein ek hi saath move hue hain is is twin part mein yahan pe koi diffusion nahi hua hai yahan pe hum dekhenge ki ye jo twinning hoti hai low temperature pe hoti hai yeh hum dekhenge ki low temperature pe kyun twinning honi chahiye yahan par hum dekhenge ki movement of atoms aap dekhenge ki sudden jo crystal change mila hai woh movement of atoms sudden hua hai ek saath hua hai aur ek direction mein hua hai ek disciplined way se yaani ek particular way se hi hua hai ek saath hua hai ek direction mein ek disciplined way se yahan pe atoms ki movement hui hai jisse mujhe ek orientation change mujhe mil raha hai aur yeh hua hai ek hi direction aur ek hi time pe to yeh ek important points hain twinning ke to yeh points hum saare cover karenge is part mein to agar main slip aur twin ki baat kar kar raha hoon to ye image sabse pehle humne introduce ki thi jab maine slip ki baat ki thi aur humne kaha tha ki twinning hum consider karenge baad mein to aap dekh paa rahe honge ki mere paas slip plane hai aur slip direction hai yahan pe aap dekh paa rahe honge ki crystal structure koi change nahi ho raha hai yahan pe aur yahan pe mujhe shape change mil raha hai similarly jab twinning hoti hai material mein to hum dekhenge ki yahan pe koi crystal structure yahan pe change nahi ho raha hai yahan pe sirf orientation hai crystal ka yeh change ho raha hai aur ek particular plane aur particular direction mein bhi hota hai to yeh twinning mechanism hai.



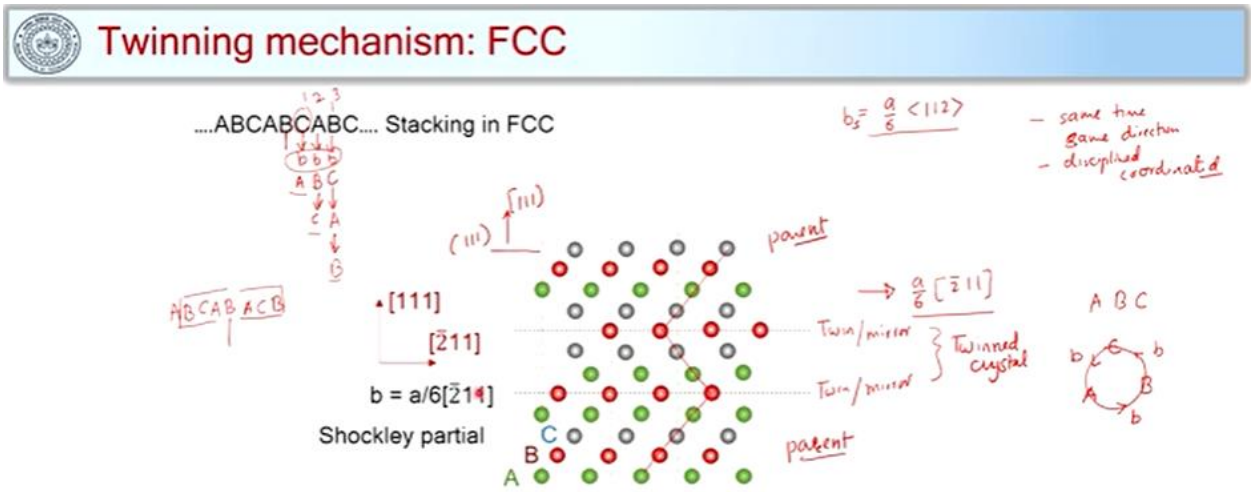
Abhi hum twinning jab baat karenge to sabse pehle hum consider karenge fcc to fcc mein mujhe sequence yaani (111) plane ka jo sequence hai wo $ABCABC$ stacking sequence hai twinning fcc crystal se aasaani se samjhi ja sakti hai isliye ye udaharan hum fcc crystal ka yahan pe consider kar rahe hain aur jab hum deformation ki baat karte hain to twinning ek important plastic

deformation mechanism hai fcc materials mein bcc materials mein aur hcp materials mein to jab humein micromechanics ki baat karni hai ki kis tarah se twinning hoti hai is crystalline materials mein to sabse pehle hum consider karenge sirf fcc material ka jahan pe mujhe $ABCABC$ stacking milti hai aur ye stacking kaun se planes ki hoti hai aap humne padha tha jab humne stacking fault padhe the fcc materials mein to ye $ABCABC$ stacking hoti hai mere (111) plane ki to yahan pe humne (111) plane consider kiye aur (111) plane kahan pe hai yahan pe maine kuch directions mark kiye ye [111] direction hai kuch is tarah se aur ye a $[2\bar{1}1]$ direction hai specific direction hai aap dekh paa rahe honge ki agar ye [111] direction hai cubic materials mein to ye jo planes hain jo is tarah se planes maine mark kiye hain ye saare planes mere (111) planes hain to isko hum is tarah se mark kar lenge ye jo planes hain jahan pe ye [111] direction hai meri perpendicular to ye jo planes honge ye saare mere (111) planes honge aur inka stacking maine kuch is tarah se mark kiya hai a b c aap dekh paa rahe honge ki maine a ko ek color diya hai b ko dusra color diya hai aur c ko teesra ek color diya hai aur hum jab baat karenge ki fcc mein to hum baat karenge shockley partials ki shockley partials humne padha tha ki yeh hota hai $a/6[2\bar{1}1]$ yaani humne dekha tha ki shockley partials kuch is type ke hote hain unka unka burgers vector kuch is type type ka hota hai $\langle 112 \rangle$ type ke to yeh mere shockley partials hain to abhi dekhenge ki yeh jo direction hai yeh $[12\bar{1}]$ hai to aap dekh paa rahe honge ye jo dotted planes maine mark kiye ye jo planes hain green wale ye jo plane hai ye mere $(2\bar{1}1)$ planes honge aur ye jo plane hai red wale yahan pe dotted lines jo red mark ki hai yahan pe ye saare planes mere (111) planes honge aaiye jaante hain ki agar twinning hona chahiye to material mein to kis tarah se hota hai to yahan pe aap focus karenge yeh jo do planes maine mark kiye red wale lines se in do planes ke beech mein hum twinning mechanism padhenge to yahan pe twinning jab hota hai to twinning ke liye humein chahiye ki atomic movements ek hi direction mein isko likh lete hain humne kuch peeche pichle slide mein points likhe the same time same direction aur isko kehte hain disciplined aur coordinated movements yaani coordinated movements hone chahiye atoms ke abhi hum slowly dekhte hain is atomic movements ko to main kya karunga ye jo layers hai yahan pe is plane ke upar ye mera twin plane isko maine maan ke chal raha hoon to main kya karunga is atoms hai ye do planes ke beech mein in atoms ki movements karunga kaise movements karunga main by shockley partial movement karunga yaani main in planes ko $a/6[2\bar{1}1]$ direction mein aur is magnitude se displace karunga kuch is tarah se aap dekh paa rahe honge ki yeh jo atom hai aur yeh atom hai yeh jo distance hai yeh mera burgers vector hoga ye mera b hoga aur ye jo distance hai yahan pe in do planes ke beech mein ye ho jayega $a/6[2\bar{1}1]$ abhi hum slowly isko displace karenge in saare atoms ko.

To aaiye chalte hain is saare teen planes ko pehle main ek baar displace karunga to kuch is tarah se aap dekh paa rahe honge ki maine teen planes ko yeh teen planes ko by $a/6[2\bar{1}1]$ direction mein displace kiya ye meri direction hai is direction mein maine displace kiya hai is magnitude se main har baar displace karunga is magnitude se to aap dekh paa rahe honge ki jaise maine yeh movement kiya hai yeh jo layer hai yeh mere green layer se match ho gayi aur yeh jo layer hai yeh mere red layer se match ho gayi aur yeh jo red layer hai yeh mere grey layer se match ho gayi hai to aaiye inka pehle color change kar lete hain to pehle maine teen layers ko movement kiya hai aur humne ek is tarah se movements ki hai abhi hum kya karenge sirf ye do layers ki movement karenge ye red aur ye grey layer ki kuch is tarah se isi magnitude mein agar main unki movement karta hoon to aap dekh paa rahe honge ki sirf yeh do layer move hui aur abhi aap dekhenge ki ye jo grey layer hai aur ye red layer hai ek dusre ko match ho rahi hai aur yeh jo grey layer hai aur yeh green layer hai yeh match ho rahi hai to main isko change kar dunga is layer ko green layer ke

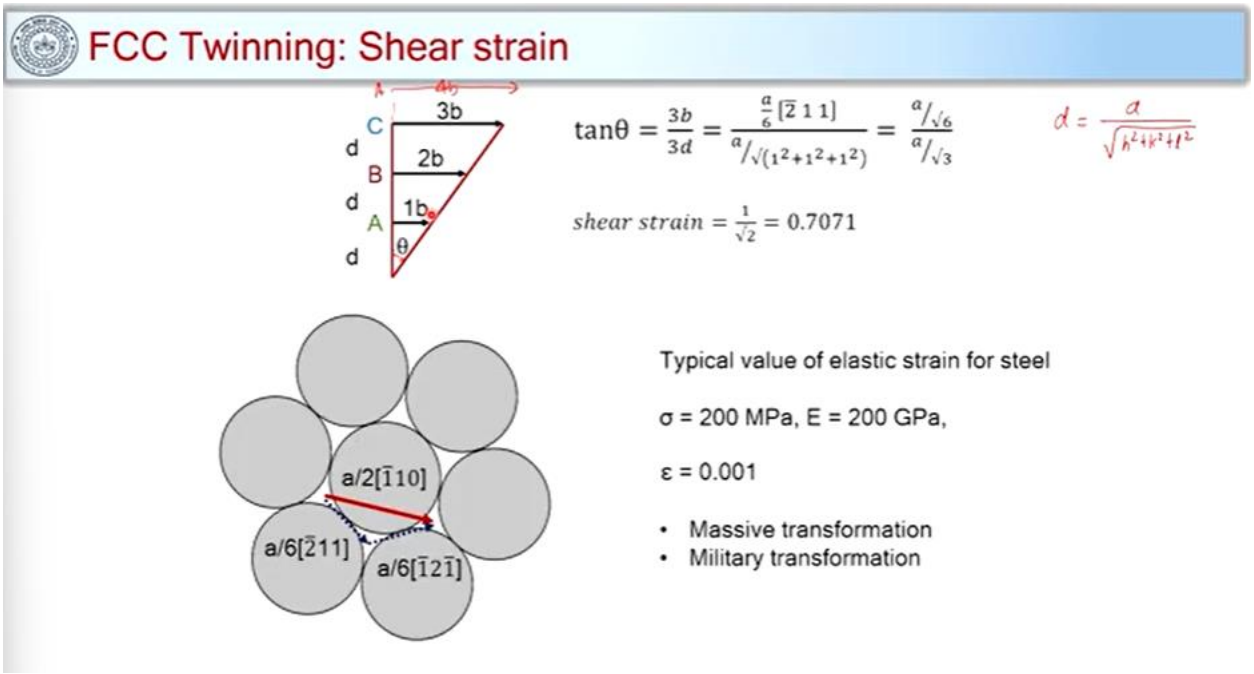
saath green layer yaani aap samajh sakte ho ki ye a layer ho gayi hai abhi aur yeh jo layer hai yahan pe red layer hai yeh meri c layer ho gayi hai to kuch is tarah se main unko change kar raha hoon to maine inko change kar diya is direction mein abhi main kya karunga sirf ye jo layer hai green layer hai isko displace karunga kaun se magnitude se is magnitude se to mere paas kya hoga mere paas kis tarah se displacement aayenge to kuch is tarah se displacement aayenge aur aap dekh paa rahe honge ki yeh jo displacements hai mujhe ye green atoms ko kuch is tarah se match kar gaye mere red layer ke saath to aaiye iska bhi color change hum karte hain to ye ho jayega mera b layer to aap dekh paa rahe honge yahan pe humne kuch atomic displacements kiye the ek hi direction mein kiye same direction mein abhi ek disciplined way se kiye aur coordinated movements se kiye to aap dekh paa rahe honge ki yahan par agar main atomic arrangements consider karu to main kuch is tarah se draw karunga aap isko thoda focus kariye is tarah se aur kuch is tarah se to aap dekh paa rahe honge ye jo planes hai ye do planes yahan pe jahan pe maine atomic movements ki thi ye mere twin planes ho gaye right yeh mere twin planes hain yeh mera twin plane hai ya inko mirror planes bhi keh sakte hain aap dekh paa rahe honge isko hum thodi der mein dekhenge ki ye kis tarah se mirror ki tarah kaam karte hain agar main ye plane ko twin plane maan raha hoon ya mirror plane maan raha hoon to aap dekh rahe honge ki atomic jo arrangements hai yahan pe jo atom hai yahan pe grey atom aur ek grey atom yahan pe ek iski ek mirror image yahan pe aap dekh paa rahe honge green atom ka green atom ke saath red atom ka red atom ke saath similarly ismein aap dekh paa rahe honge green atom aur green atom match ho rahe hain aur grey atom aur grey atom ek saath match ho rahe hain to aap dekh paa rahe honge ki yahan pe ye jo region hai yahan pe twinned ho gaya to ye mera twinned crystal ho gaya isko main twinned crystal keh sakta hoon aur yeh jo hai yeh mere parent crystal hai yahan pe koi displacements nahi hui thi yeh mere parent crystal ho jayenge dono to is tarah se twinning mili humein fcc ke case mein to humne kya kiya yahan par isko is stacking ke dwara hum samajh sakte hain to yahan pe sabse pehle ye meri $ABCAB$ layer thi aur b layer ko main mirror plane maan raha hoon to yahan pe likh lete hain yeh mera mirror plane hai aur sabse pehle maine kya kiya tha in teen layers ko maine move kiya tha kis direction ke dwara b direction to yeh ho gayi jab main move karunga b magnitude se b magnitude se main teeno layer ko move karunga to yeh ho jayegi meri a layer yeh ho jayegi meri c layer aur ye ho jayegi meri b layer aap dekh dekhenge agar is video ko peeche karke to aapko kuch is tarah se phir maine yeh do layers ko move kiya tha kiske dwara is magnitude ke dwara to aapko milega yeh yeh a layer thi a layer to aisi hi rahegi yahan par sorry agar aap dekhenge to yeh mil jayegi aapko b layer aur ye ek dusre se match ho gayi thi 1 minute isko hum is tarah se samajh sakte hain jab agar main a layer se c layer ko move kar raha hoon b magnitude dwara to mujhe milegi a layer a ko move kar raha hoon to mujhe milegi b layer aur phir se move karunga to mujhe mil jayegi c layer aur phir se main isko move karunga to mujhe milegi ye c layer b ko aur c ko move karunga to mujhe milegi b layer aur phir phir se main isko move karunga to mujhe milegi a layer to yahan par maine teen movements ki thi c layer ki sirf ek baar movement ki thi a layer ki do baar movement ki thi aur b layer ki teen baar movement ki thi to mere paas kuch stacking is tarah se aayegi $ABCAB$ jo mera mirror plane hai phir ye stacking aayegi $ACAAC$ aur yahan pe sorry yeh a layer hogi movement hoke aur ye jo hai ye b layer hogi to kuch is tarah se mere paas agar aap dekhenge ye crystal to ye twinned crystal yahan pe aapko milega kuch is tarah se to hum kuch is tarah se a b c layer ko hum consider karenge aap is tarah se samajh sakte hain agar main isko ek triangle mein consider karu to main b magnitude se move karunga to mujhe a layer pe pahunchunga a layer ko b magnitude se move karunga to main b layer pe pahunchunga aur b magnitude se move karunga to main c layer pe pahunchunga kuch is tarah se cyclic dwara to aap

dekh paa rahe honge ki mujhe ek twin crystal yahan pe milega aur aap is stacking ke dwara bhi samajh sakte hain.



Abhi yeh ho gaya mere twinning mechanism fcc crystal mein aur humne dekha ki ye kis kis tarah humein ye movements milte hain to abhi hum dekhenge ki ismein shear kitna develop hota hai to humne kya kiya ki humne jo a b c layer ko kis tarah se movement kiya tha ek b a layer ko maine move kiya tha ek b se b layer ko maine kiya do baar aur c layer ko maine kiya tha teen baar to ek coordinated movement hai aur yeh jab humne dikhaya tha humne jab animation dekha tha to ye humne ek ek yaani ek ek ke baar dekha tha par ye jo movements hote hain wo materials mein ek saath hote hain yaani jab a layer ek baar move ho raha hai to b layer mera do baar move hoga burgers magnitude ke dwara aur c layer mera teen baar move hoga aur yahan pe agar phir se a layer hota aur twin twinning is tarah se badh rahi hogi to ye jo layer hai ye $4b$ se move hota to ye kuch is tarah se coordinated movement hogi aur ye ek samay pe hogi yaani humne to sequentially dekha tha par yeh sequentially nahi simultaneously ek saath hoti hai is movements yeh movements to humne dekha tha kuch is tarah se aur ye movements hoti hai meri is position se so yaani main b layer se yahan pe main ye agar ye main a layer consider karunga to b layer c layer pe jayega aur c layer mera a layer pe aayega to is tarah se mere movements honge shockley partial dwara to agar hum twinning consider karenge to twinning ko kuch is tarah se hum samajh sakte hain agar main $tan\theta$ shear strain ki value nikaalne ki koshish karunga is diagram dwara to humein pata hai ye a b c mere (111) planes hain aur inke beech ka distance ye interplanar distance hoga to yahan pe hum teen layer hi consider kar rahe hain a b c aur hum dekhenge ki kitna displaced hua hai pura ye to agar main θ ki value nikaalne ki koshish karunga yahan pe ye θ ki value agar main nikaalne ki koshish karunga to ab dekhenge $tan\theta$ ko main kuch is tarah se likh sakta hoon $3b/3d$ aur $3b$ kya hai yahan pe hum humein pata hai burgers vector kya ho sakta hai $a/6[2\bar{1}1]$ 3 3 cancel ho jayenge burgers vector rahega b/d ratio mujhe nikaalna hai aur d main nikaal sakta hoon agar mujhe lattice parameter pata hai $a/\sqrt{1^2+1^2+1^2}$ yaani hum hum is tarah se d spacing mein humne ye formula dekha tha cubic materials mein $h^2+k^2+l^2$ yahan pe hkl 1 hai to aapke paas ye d ki value kuch is tarah se aayegi aur hum isko calculate karenge to shear strain mujhe milega

$1/\sqrt{2}$ jo ki milta hai 0.7071 abhi humne shear strain calculate kiya twinning ke dwara to abhi hum elastic deformation mein kitna shear strain aur ki elastic deformation mein kitna strain develop hota hai ye pehle dekhenge to let's say hamare paas kuch steel ki value hai aur sigma jo agar main yield strength ki baat karunga to maan lete hain ki ye sigma mera 200 mpa aur elastic modulus mera 200 gpa agar main elastic strain ki baat karunga to elastic strain ki value aati hai 0.001 to ye meri elastic strain ki value aayi ah steel mein aur agar hum main twinning ki baat karunga to mere paas kuch is tarah se value mil rahi hai to aap dekh rahe honge ki yeh jo value hai yeh kaafi jyada hai twinning mein as compared to elastic strain values isliye twinning ko bhi hum kehte hain massive transformation kyunki yahan pe jo deformation hai wo bahut jyada hai as compared to meri elastic deformation hum dekh sakte hain ki twinning mein bahut jyada strain accommodate ho sakta hai ek twinning jab hoti hai material mein tab as compared to mere elastic deformation to isliye hum isko massive transformation ya massive deformation bhi keh sakte hain isko military transformation isliye bhi kehte hain jab hum dekhenge ki mera a layer $1b$ se mu move ho raha hai aur b layer mera $2b$ se move ho raha hai aur c layer mera $3b$ se move ho raha hai to aap dekh paa rahe honge ki ye jo hai ek military ki tarah yaani ek coordinated way se iska movement ho raha hai to isliye isko military transformation bhi kehte hain aur yeh jo displacements ho rahe hain mere a b c layer ke jab twinning ki baat kar raha hoon aapko hamesha dhyaan rakhna hai ki yeh ek saath ho rahe hain ek samay pe ho rahe hain aur ek direction mein ho rahe hain humne animation mein ek ek baar dikhaya tha wo hum samajhne ke liye kar rahe the par yahan pe aap dekhenge jab twin hota hai wo ek saath ek samay pe ek direction pe hota hai.

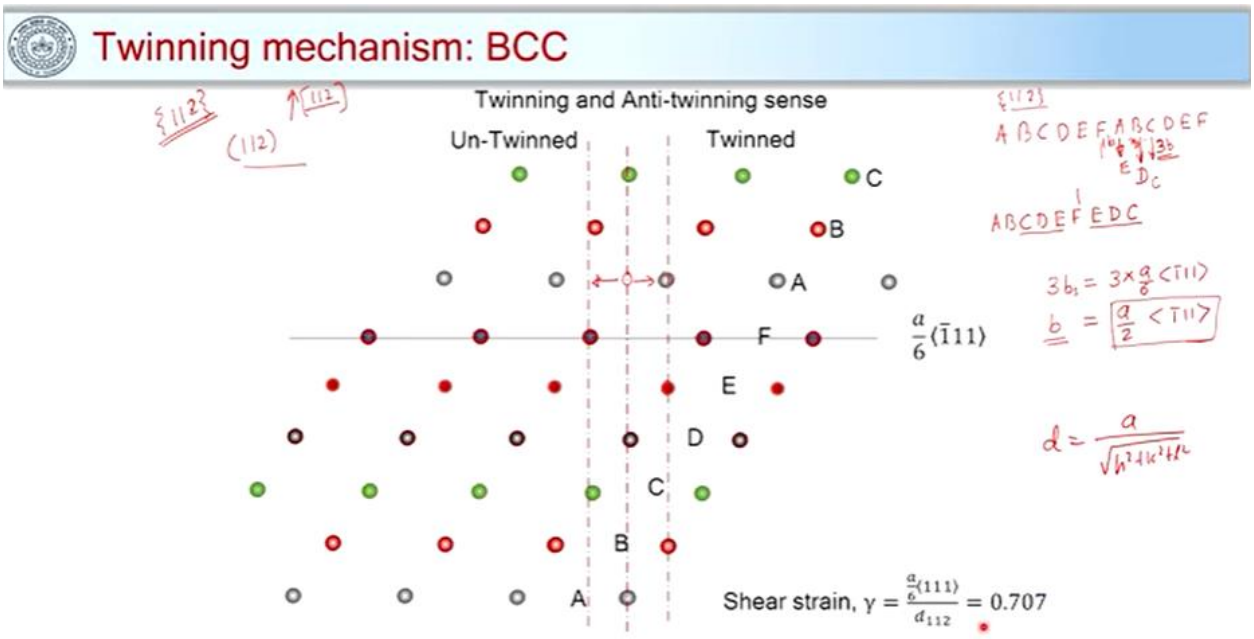


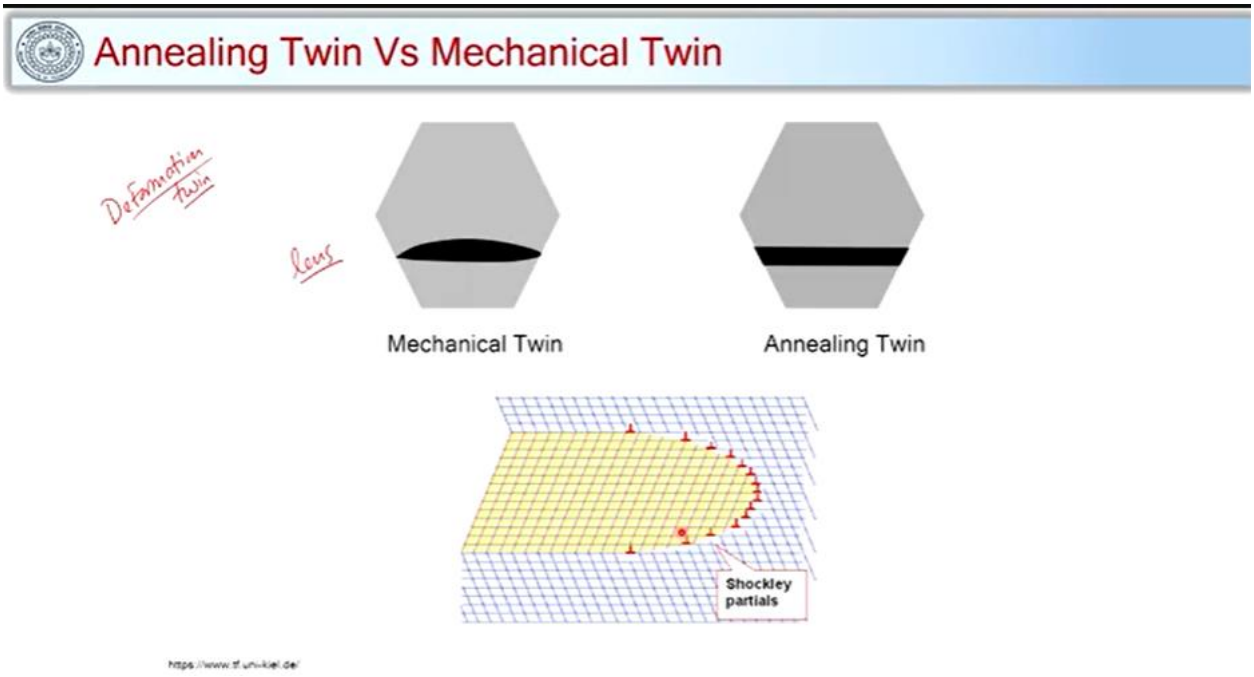
Abhi hum bcc ki jab baat karenge tab bcc mein humne stacking faults dekhe the bcc mein to aap yaad kar payenge ki bcc mein stacking fault kis direction mein hote hain aur kis plane mein hote hain humne agar aap yaad karenge to bcc mein stacking fault hamare (112) planes pe mujhe milte hain mujhe (110) planes pe stacking faults nahi milte to jis plane par stacking faults milenge us plane par twinning humein milta hai bcc ke case mein to ye jo planes maine dikhaye hain yahan pe ye mere (112) planes hain yaani aap dekh paa rahe honge ki ye jo direction hai ye meri [112] direction hogi aur ye jo planes hain saare ye (112) planes honge aur jab stacking fault maine create

kiya tha to wo is displacement dwara main create kar sakta hoon $a/6[1\bar{1}1]$ to ye jo planes agar main nikaalunga kuch is tarah se ye jo planes hain ye mere $(1\bar{1}1)$ plane hain to main kuch is tarah se reference planes mark kar raha hoon yahan pe is tarah se samjhenge twinning bcc mein to ye maine teen reference planes maine mark kar liye abhi main kya karunga humne dekha tha ki stacking fault agar mujhe taiyaar karna hai bcc mein to mujhe ek stacking fault nahi milta hai to mujhe ek layer of stacking faults move karne layer layer of bcc mein layer of a two planes ko move karna padega ki agar mujhe stacking fault chahiye to to aap dekh paa rahe honge ki main kuch layers ko yahan pe move karunga kyunki wahi stable hote hain ek layer stacking fault nahi hota hai stable bcc mein to isliye main kuch layers ko yahan pe move karunga kuch is tarah se maan lete hain main is position se is position se move karunga ye teen layers ko a b c aur yeh mera mirror plane yaani twin plane yeh maan ke chal raha hoon to main kuch is tarah se move karunga to aap dekh paa rahe honge ki yeh ek dusre ke upar aa jayenge aur humne dekha tha ki yahan par yeh high energy configuration ho jayega to twinning jab hogi tab aap dekh paa rahe honge ki agar main opposite direction mein move karta hoon to aap dekh paa rahe honge ki ye ek favorable configuration hoga main is position pe tha to main is direction pe aaya to yahan pe ek high energy configuration hoga par main opposite direction mein move hua to mere paas kuch is tarah se ah ek favorable configuration mila abhi maine ye ek layer ko is tarah se move kiya abhi main iske upar ki saari layer yaani b ko main kuch is tarah se move karunga main hum isko is tarah se samajh sakte hain a b c d e f hamare paas cheh layers hoti hai a b c d e f (112) ki stacking pe aur yeh jo (112) ki stacking hai mujhe bcc structure deti hai agar main yahan pe f layer ko twin plane maan ke chal raha hoon to main a layer ko jab move karunga tab tab a layer ko jab maine move kiya is direction mein tab aap dekh paa rahe honge ki wo jo ho jayega wo mera wo e layer yahan pe ho jayegi kuch is tarah se aap dekh paa rahe honge ki yeh jo meri e layer hai yahan pe to e layer yahan pe ho jayegi usi tarah se main is b layer ko move karunga b aur c ko move karunga agar main in planes ko consider kar raha hoon is isko main do baar move karta hoon yaani in dono planes ko phir se move karunga to b ko main $2b$ ke dwara move karunga $2b$ aur c ko main $3b$ ke dwara move karunga to yahan pe mujhe milega ye d plane ho jayega main do baar move karunga aur yahan pe agar main move karunga to ye c plane rahega kyunki $3b$ se agar main move karunga $3b$ kya hai mera yeh mujhe mere paas b pata hai displacement kitna hai $3 \times a/6[1\bar{1}1]$ to aap dekh hi rahe honge ki ye ho jayega $a/2[1\bar{1}1]$ to teen b se agar main move karunga to aapke paas yeh mera burgers vector ho jayega yeh humne dekha tha ki burgers vector ka magnitude hai yeh to yeh mera burgers vector ho jayega yeh agar burgers vector hai to jis plane agar main ek plane ko burgers vector se move kar raha hoon to mere paas wahi plane aa jayega to aap dekh paa rahe honge ki agar main is plane mein agar stacking fault agar create karna chahta hoon to aap dekh paa rahe honge yahan pe f mera ye reference plane tha aur yeh plane e ho gaya yeh d ho gaya aur yeh c ho gaya to aap dekh paa rahe honge yahan pe aur yahan pe ek twin structure taiyaar hua hai to is tarah se aap twinning kar sakte hain bcc aur fcc materials mein.

To abhi hum dekhenge ki humne ek direction pe move kiya jab shear stress apply kiya tha to yahan pe ek high energy configuration taiyaar hua tha aur is is direction ko hum kehte hain untwinning direction ya yahan pe hum dekh sakte hain ki untwinning a ho raha tha mere material mein is direction mein jab maine move kiya to yahan par twinning mujhe mil raha tha hum yahan par the is position par aur is direction mein move hai aur is direction mein move to humein ek untwinning sense milega aur ek twinning sense milega to mujhe ek twinning aur anti-twinning sense milta hai bcc mein to aapko yeh yaad rakhna hai ki fcc mein koi twinning aur anti twinning sense nahi hota hai but aap bcc mein ek twinning aur anti twinning sense ki baat kar sakte hain jab yaani wo shear stress ke direction pe to yahan pe humne dekha tha ki is direction mein move hua hai to ek

untwinning ho raha tha aur is direction mein move ho raha hai to ek twinning mujhe sense mil raha hai to is isiliye bcc materials kuch anisotropic behavior dikhate hain shear stress ke saath bhi to yeh ho gaya mera twinning in bcc yahan par bhi hum shear strain ki jab baat karenge to humne dekha agar main shear strain calculate karne ki koshish karunga to humein yeh jo mil raha hai ye mera displacement hai $a/6[1\bar{1}1]$ aur hum agar ye do planes ka distance hum calculate karenge to humne dekha tha ki ye jo planes hain saare ye (112) planes hai to main ye jo interplanar distance hai wo (112) plane ka consider karunga aur ye d_{112} calculate karunga to mere paas jo value aayegi ye aati hai 0.707 yeh fcc material ke liye hi ke barabar hai equivalent hai to aap d ki value is tarah se nikaal sakte hain humne pichle slide mein bhi dekha hai $h^2 + k^2 + l^2$ to ye ho gaya mera shear strain aur yahan pe bhi hum dekh paa rahe hain to yeh jo shear strain ki value hai woh kaafi jyada hai aur isiliye hum is transformation ko massive transformation bhi kehte hain.

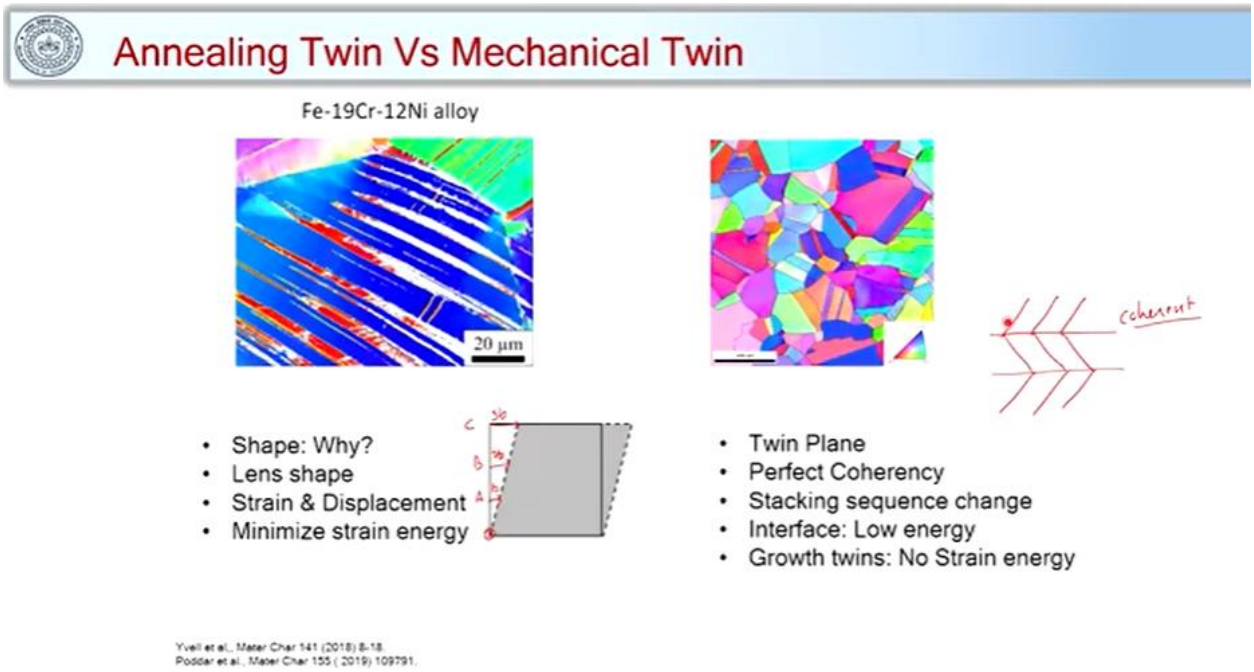




Abhi hum dekhte hain do prakar ke twin hote hain material mein ek annealing twin aur ek mechanical twin to yahan par humne dekha tha ki twin jo hai woh ek mirror plane ki tarah twin plane jo hai woh mirror plane ki tarah kaam karta hai par mujhe hum jab baat karenge mechanical twin ki isko hum deformation twin bhi kehte hain isko hum deformation twin bhi likh sakte hain to mechanical twin mera kuch is tarah se dikhta hai material mein aur annealing twin agar main dekhunga to kuch is tarah se dikhta hai to yahan par yeh ek lens shape hai isko bhi likh lete hain ek lens shape ki tarah mujhe mechanical twin milta hai is microstructure feature ko dekh ke aap bata sakte hain ki material mein mechanical twin ho raha hai ya annealing twin hai annealing twin humein milta hai kyunki yeh ek ek boundary hai ek coherent boundary mujhe low energy coherent boundary mili hai high high angle boundary hai yeh bhi aur yeh jo boundary hai yeh annealing ke samay humein prapt ho sakti hai mechanical twin ki jab main baat karunga to mera mechanical twin kuch is tarah se milega agar main dislocation ke movements ki baat karunga yaani shockley partials ki movement ki baat karunga ah (111) planes pe fcc mein to kuch is tarah se mujhe shockley partials ki arrangement milegi aur isliye mujhe yeh jo mechanical twin hai iska shape is tarah se hota hai lens shape ki tarah abhi yeh jo ho gaya annealing twin aur mechanical twin humne dekha inmein kya difference hai ye samajh sakte hain actual micrograph se yahan pe yeh alloy mein humne dikhaya ki hamare paas yeh kuch mechanical twin hai yahan pe aap dekh rahe honge ki yahan pe ek lench shape structure humein mil raha hai aur yahan pe kuch annealing twins hai to aap dekh paa rahe honge ki annealing twins kuch is tarah se dikhte hain ye ebsd ah maps hai aur yahan pe aapko kuch is tarah se annealing twins humein mil rahe hain aur in dono ka shape aap aasaani se dekh sakte hain ki yahan par lens shape hai aur yahan par jo boundaries hai twin boundaries hai wo straight hai to humein ye shape kyun milta hai lens shape kyun milta hai to humne dekha ki agar mere paas kuch is tarah se crystal hai wo shear hota hai to humne dekha yahan pe maan lete hain ye to humne dekha a layer b displace hua b layer mera $2b$ se displace hua aur c layer mera $3b$ se displace hua to yahan pe hum dekhenge ki ye jo point pe hai to yahan par displacement shunya hai aur agar main twin structure ki baat karunga yahan pe kuch is direction mein bhi baat karunga to yahan pe displacement mere shunya hai aap dekh paa rahe honge ki ye jo hai ye jo boundary hai yahan pe yahan pe aap dekh paa rahe honge ki ye jo main shear

deformation se jo strain aur displacement ki wajah se mujhe jo structure mila hai wo mujhe lens structure ki tarah a ye mechanical twin milega yeh isliye milta hai kyunki mujhe yahan par jo strain energy hai yahan pe minimize karni hoti hai.

Abhi hum dekhenge ki is case mein annealing twin mein mere paas twin plane hai aur yahan pe aap dekhenge ki yahan pe perfect coherency hai sirf stacking sequence change hoga agar main twin ki baat kar raha hoon annealing twin ki to aap dekh paa rahe honge ki yeh jo hai yahan pe exactly kuch is tarah se perfect coherency milegi yaani koi mismatch yahan pe milega nahi aur yeh jo boundaries hai kuch is tarah se milegi aur ye jo region hai sirf low energy regions se hai yahan pe sirf orientation change ho raha hai yahan pe koi strain develop nahi ho raha hai to ya in twins ko annealing twins ko growth twins bhi kehte hain aur ye jo interfaces hai ye mere low energy interfaces hai mostly hum ek coherent hote hain to ye coherent twins bhi kehlate hain to yahan pe koi strain energy hoti nahi hai isliye humein jo shape milta hai inka kuch is tarah se milta hai yeh sirf mere atomic displacements hue hain jo ki jo interface bana hai jo isliye bana hai kyunki ye jo region hai ye jo boundary hai wo low energy boundary hai humne iski bhi baat ki thi jab humne grain boundaries ki baat ki thi ki kuch high angle grain boundaries mein low energy milti hai to twin boundary ek unmein se hi grain boundary hai jo low energy humein deti hai abhi main deformation twinning ki baat karunga kyunki hum is course mein twinning ki jab baat kar rahe hain to yeh plastic deformation ki tarah baat kare ka baat kar raha hoon to yahan pe kuch ek plot main yahan pe nikaalunga stress versus temperature ka aur hum dekhenge kuch is tarah se jo twinning stress hai jo maine baat kiya ki agar material mein twin hona hai.



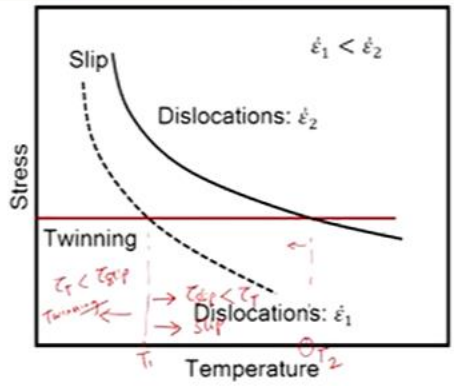
To mujhe wo kuch is tarah se milega humne dekha tha ki twinning jo milta hai kuch stacking faults form karne se milta hai to yahan pe aap dekh dekhenge ki jo twin stress hai shear stress jo mujhe lagega wo kis pe dependent hai wo depend hai mere stacking fault energy pe to jitni stacking fault energy a jyada utna mujhe twinning yahan pe milega aur yahan par main ab dekhenge ki yahan par G/b_s yaani ye shear modulus hai aur yeh mera shockley partial hai jab main twinning ki baat kar raha hoon aur ye K jo hai wo proportionality constant hai jab main twinning ki baat kar raha hoon to aap is case mein dekhenge ki is equation mein koi temperature ka term nahi hai to main

maan ke chal sakta hoon ki jo twinning stress hai wo more or less constant hai mere temperature ke saath yeh abhi maan ke chal rahe hain jyada variation nahi milta hai mujhe twinning stress ka temperature ke saath abhi hum slip stress ki baat karenge ya slip ke liye jo stress lagega woh agar main baat karunga to woh temperature ke saath kuch is tarah se vary hota hai aur yahan pe hum dekhenge ki jab plastic deformation hota hai tab slip aur twinning ye do mechanisms major mechanisms hain jahan pe strain accommodation ho sakta hai to agar aap dekhenge yeh temperature agar main critical temperature ki baat kar raha hoon ye temperature pe isko mark kar lete hain ye jo temperature hai iske above aap dekh paa rahe honge iske above slip stress yahan pe main slip stress baat karunga slip stress se chhota hai mere twin stress se to yahan pe mujhe is temperature ke above mujhe slip mechanism milega par is temperature ke niche aap dekh paa rahe honge ki twinning stress kam hai mere slip stress se to aapko yahan par twinning milega yaani material prefer karega ki twinning se plastic strain accommodate ho to ek temperature ke niche humein twinning milti hai aur ek temperature ke above humein slip slip milti hai ye jo temperature hai ye kaafi low hota hai materials ke liye to humein generally twinning ek temperature dependent phenomena hai halanki is equation mein koi temperature term nahi hai aur humein twinning isliye milti hai kyunki yahan pe is temperature ke niche slip difficult ho jaati hai kyunki slip stress mera jyada hai to isliye humein twinning milti hai to slip aur twinning ek a competitive mechanisms hai ek dusre ke saath agar slip difficult hai tab mujhe twinning milti hai to agar hum dekhenge iska slip ka nature yaani main keh sakta hoon ki slip stress mere agar strain rate pe bhi dependent hai isko is tarah se samajh sakte hain humne hum aage padhenge iske baare mein let se humne strain rate ke saath humne comparison kiya tha strain rate mujhe is tarah se milta hai to agar mera strain rate badh raha hai to mera mobile dislocation density badhna chahiye is tarah se samjhunga agar V constant hai to aur mera mobile dislocation density agar badh raha hai to shear stress bhi badhna chahiye humne dekha tha ki tau proportional hai mere dislocation density ke dwara to hum ye keh sakte hain ki strain rate agar badh raha hai yahan pe to stress slip ke liye jo lagega wo badhna chahiye to yahan pe yahi explain kiya hai agar main higher strain rate pe hoon yaani humne dekha hai strain rate one hai yahan pe aur strain rate two hai to strain rate two badha hai strain rate one se to slip stress yahan pe is tarah se badhega aur aap dekh paa rahe honge ki agar mera strain rate badhta hai to ye jo twin aur slip jo behavior hai yaani plastic deformation mechanism se yeh change ho sakte hain mere temperature ke saath to aap yahan pe is condition mein aap dekh sakte hain ki agar main high strength rate pe deform kar raha hoon to twinning mujhe is higher temperature pe mil sakti hai T_2 pe mujhe twinning mil sakti hai T_2 ke niche mujhe twinning mil sakti hai to humne dekha ki twinning mera strain rate dependent hai aur ye also dependent hai mere temperature ke saath to kyun kyunki slip difficult ho jaati hai temperature aur strain rate ke saath to humein twinning milti hai to aaiye dekhte hain ki kuch materials mein aap dekhenge ki mere materials mein stacking fault energies ki main jab baat karunga to mere paas kuch aluminium hai aur yahan pe stacking fault energy jyada hai aur yeh jo silver hai yahan pe stacking fault energy kam hai to aap dekh paa rahe honge ki aluminium mein stacking fault energy jyada hai to twin stress jyada hoga to aluminium mein mujhe twinning kam milega kyunki twin stress jyada hai yahan pe aur silver mein twin stress kam stacking fault energy kam hai to is case mein silver ya gold mein mujhe twinning milti hai to generally hum dekhte hain ki twinning tendency badh jaati hai jab stacking fault energy less than or equal to 20 millijoule per meter square hoti hai generally is energy ke niche mujhe twinning milti hai.

To kuch points yahan pe likh sakte hain hum ki jo twin stress hai wo aur twinning hai wo kis point kis-kis conditions pe dependent hota hai wo stacking fault energy pe dependent hota hai humne

dekha wo strain rate pe dependent hota hai woh temperature pe dependent hota hai aur woh kuch grain size ke upar bhi dependent hota hai yeh hum grain size ka part next slide mein dekhte hain.

Deformation Twinning



$$\tau_T = k\left(\frac{\gamma_{SF}}{Gb_s}\right)$$

where,
k = proportionality constant,
γ_{SF} = Stacking fault energy (mJ m^{-2})

Metals	Ag	Au	Si	Cu	Ni	Mg	Al
SFE (mJ m^{-2})	25	75	45	80	120	125	200

- Stacking Fault Energy
- Strain rate
- Temperature
- Grain Size

To hum jab twinning ki baat karenge twin plane aur twin direction ki baat karenge to humne dekha ki fcc mein mere paas yeh plane hai (111) plane aur [112] direction hai bcc mein mere paas (112) plane hai aur [111] direction hai aur hcp mein $(10\bar{1}2)$ plane hai aur $[10\bar{1}1]$ direction se twin directions aur main consider karu slip ki baat to aap dekh paa rahe honge ki fcc mein jo twin plane hai yahan par fcc mein aur slip plane hai dono same hai yahan par aur yeh jo direction hai slip direction main yahan pe [110] ki baat kar raha hoon par aap slip ko is tarah se bhi samajh sakte hain main dono partials mein convert kar sakta hoon is [110] ko a ye [112] direction bhi ho sakti hai to humein jo fcc aur fcc mein slip aur twin jo milta hai wo similar planes aur similar direction mein milti hai usi tarah se main bcc agar consider karunga to mujhe stacking fault sirf (112) plane pe milti hai to yahan pe aap dekh paa rahe honge ki yeh jo (112) plane hai yahi mera twin plane hai aur [111] direction meri twin direction hai yahan pe $\langle 111 \rangle$ direction hai yeh meri slip direction hai hexagonal mein wo depend karega yahan pe aap dekh paa rahe honge ki twinning jo dependent hogi ye meri c/a ratio pe dependent hogi to yahan par hum slip plane aur slip direction twin plane aur twin direction ki tulna kar rahe hain.

Twinning plane and direction

Twin plane and twin direction

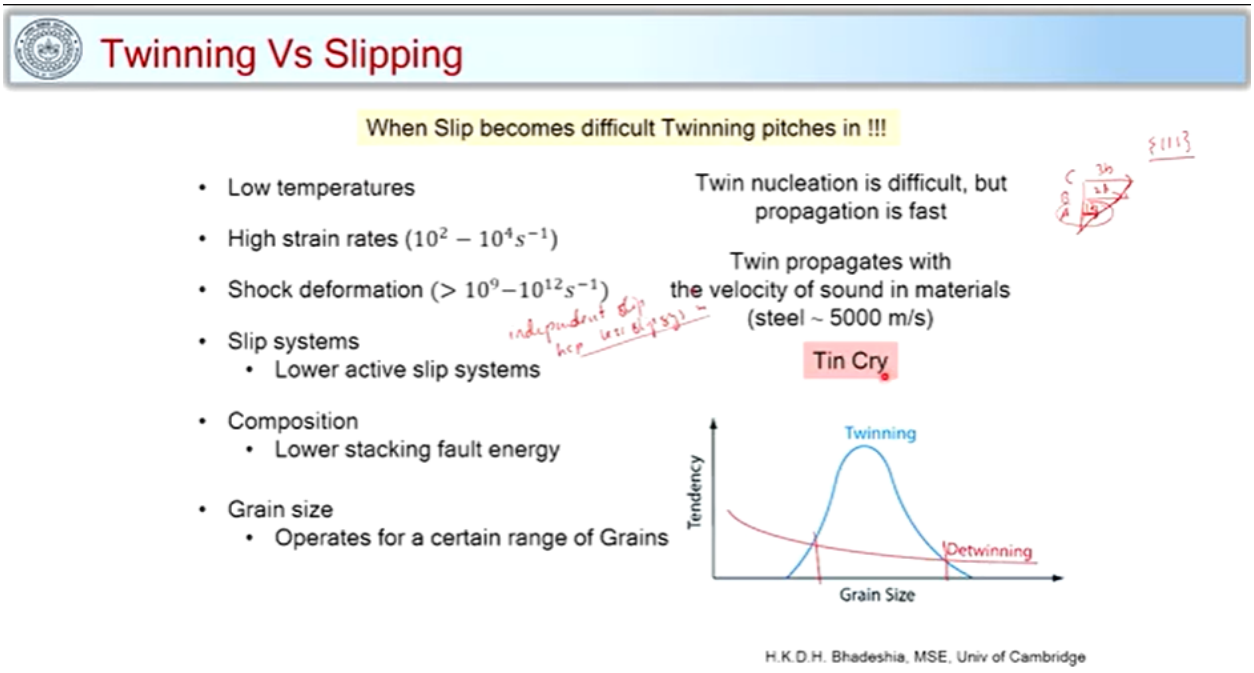
Structure	Plane	Direction	Metals
hcp	$\{10\bar{1}2\}$	$\langle 10\bar{1}\bar{1}\rangle$	Zn, Cd, Be, Mg
bcc	{1 1 2}	⟨111⟩	Fe, β-brass, W, Ta, Nb, V, Cr, Mo
fcc	(1 1 1)	⟨112⟩	Cu, Ag, Au, Ag-Au, Cu-Al

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}	⟨1120⟩	3
Ti, Mg, Zr	{1010}	⟨1120⟩	3
Ti, Mg	{1011}	⟨1120⟩	6

Mater Sci & Eng An Intro WD Callister

Abhi jab main slip aur twinning ki baat karunga tab ek statement maine bola tha ki twinning kab hogi twinning tab hogi jab slip deformation difficult ho jayegi mere materials mein to aaiye isko samajhte hain ki slip kab-kab difficult ho sakti hai slip difficult ho jaati hai low temperature pe kyunki dislocation ka glide hona difficult ho jayega low temperature pe to isliye mere material mein aap dekh paa rahe honge ki plastic deformation agar accommodate hona hona hoga to wo twinning se hoga dusra high strain rates se humne dekha tha ki high strain rates jab main baat karunga 10^2 to 10^4 per second jo rates hai is rate se agar main deform kar raha hoon mere material ko to aap dekhenge ki aapko twinning milegi kyunki yahan pe slip difficult ho jaati hai ye humne abhi do slide pehle humne dekha tha shock deformation agar hum dekh paa rahe ho ki agar shock deformation ki baat karunga 10^9 ya 10^{12} per second pe agar main deform kar raha hoon mere material ko strain rate itna high hai tab aapko milega twinning milegi is case mein to aapko aluminium mein bhi twinning milti hai jismein stacking fault energy bhi jyada hai is conditions mein slip systems ki jab main baat karunga to mere paas lower active slip systems hain to humne dekha tha ki ah jab humne von mises criteria baat ki thi independent slip systems ki tab humne ne bataya tha ki bcc aur fcc mein paanch se jyada independent slip systems hoti hai aur hcp mein kam slip systems hoti hai less slip systems to hcc mein humein deformation jo milti hai wo twinning ke dwara milti hai dusra hum dekh sakte hain ki agar lower stacking fault energy hai to yahan par humein twinning milegi aur main stacking fault energy change kar sakta hoon mere material ki agar main kuch alloying elements daal raha hoon jo mere materials ki stacking fault energy kam karenge tab mujhe twinning yahan pe mil sakti hai grain size to humne baat ki thi ki grain size ek particular range pe humein twinning milti hai to yahan pe aap dekhenge ki grain size is grain size ke beech mein ek schematic maine dikhaya hai ki yahan par de-twinning ki tendency hai aur twinning ki tendency hai to aap dekh paa rahe honge ki is particular range mein hi mujhe ya is range mein yahan pe aap dekh paa rahe honge is range mein mujhe twinning milegi to ek particular range of grain size pe hi mujhe twinning milti hai a yeh part hum yahan pe cover nahi kar rahe hain par aapke jaankari ke liye aap isko yaad rakh sakte hain ki grain size pe bhi twinning depend karegi yaani kuch range par humein kuch range ke grain size par humein twinning milti hai.

A ek aur cheez hum yahan pe discuss kar sakte hain jahan pe humne dekha ki twin nucleation ye sabse difficult hai par propagation ye fast hai jaise humne bataya tha ki jab humein twin chahiye to ek hi samay pe coordinated moments chahiye humein to jaise a b aur c ki main jab baat karunga fcc ke case mein to nucleation kuch is yahan pe hoga jahan pe mere a plane jo (111) plane hai is pe mujhe twin ko nucleate karna hai ye jo process hai ye difficult hoti hai to isliye ye kaha jaata hai ki twin nucleation difficult hai par jaise yeh nucleate hogi yeh propagation yahan pe is direction mein aasaan hai yaani fast hai aur twin kis tarah se propagate hote hain yeh aap dekh sakte hain ki twin is tarah se propagate hote hain yahan pe kuch maine likha hai twin propagate with the velocity of sound in materials jaise main steel mein dekhta hoon ki steel mein veloc velocity of sound kya hai 5000 meters per second to aap dekh paa rahe honge ki twin is velocity se propagate ho sakte hain material mein yaani nucleation difficult hai par propagation fast hai mere twinning ka jab twin deformation hota hai materials mein aap iske baare mein aur padh sakte hain jaise ek important concept hai tin cry jo ki tin mein dekha jaata hai jab hum dekhenge tin ek particular low temperature pe hum deform karte hain to ek sound aata hai usse usko hum tin cry kehte hain ek cracking sound aata hai usko hum tin cry kehte hain iske baare mein aap dekh sakte hain kuch work hai professor bashiya ke unke kuch videos bhi hai tin cry ke baare mein to aap dekh sakte hain ki twinning kitna important role play karta hai materials ke deformation mein to is part mein humne dekha ki twinning ek important mechanism hai deformation ka aur twinning kab hoga jab mera slip difficult hota hai materials mein to yeh ek important deformation mechanism pitch in karega jab kuch deformation conditions slip ko difficult banati hai tabhi mujhe twinning milta hai material mein aur twinning jab hota hai.



To strain accommodation wo bahut jyada hota hai isliye usko massive transformation bhi kehte hain aur isko military transformation bhi kehte hain abhi ke liye yahin rukta hoon dhanyavad