Mechanical behavior of materials

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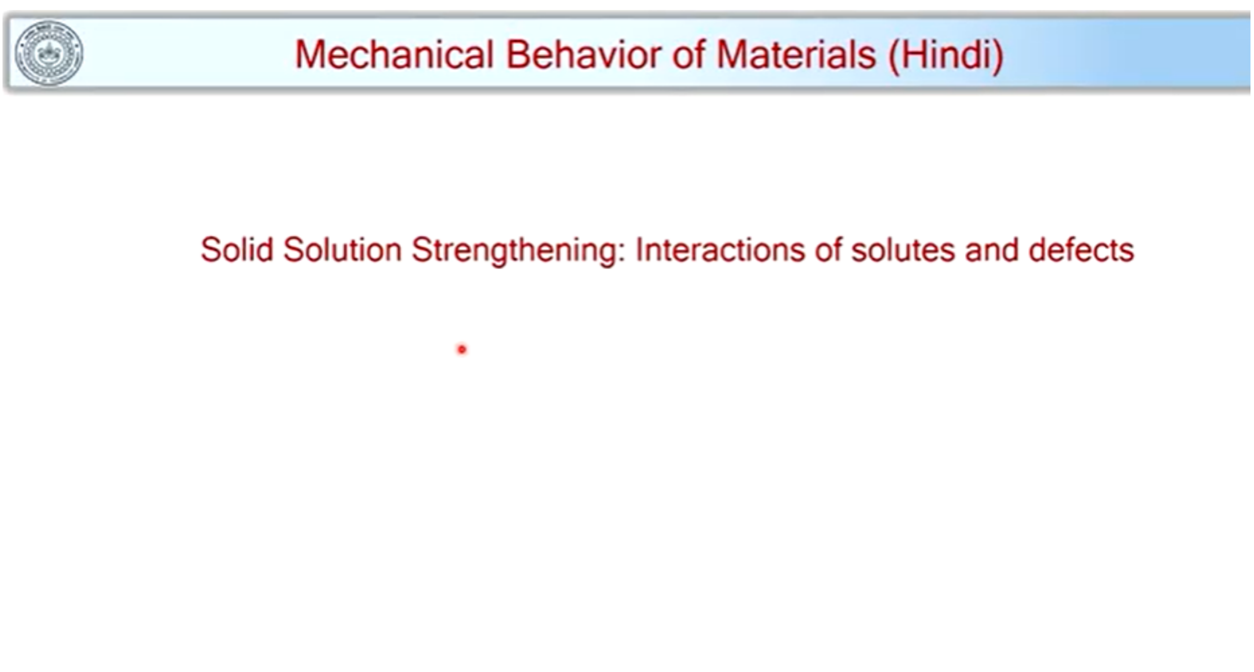
Week-9

Lecture-45

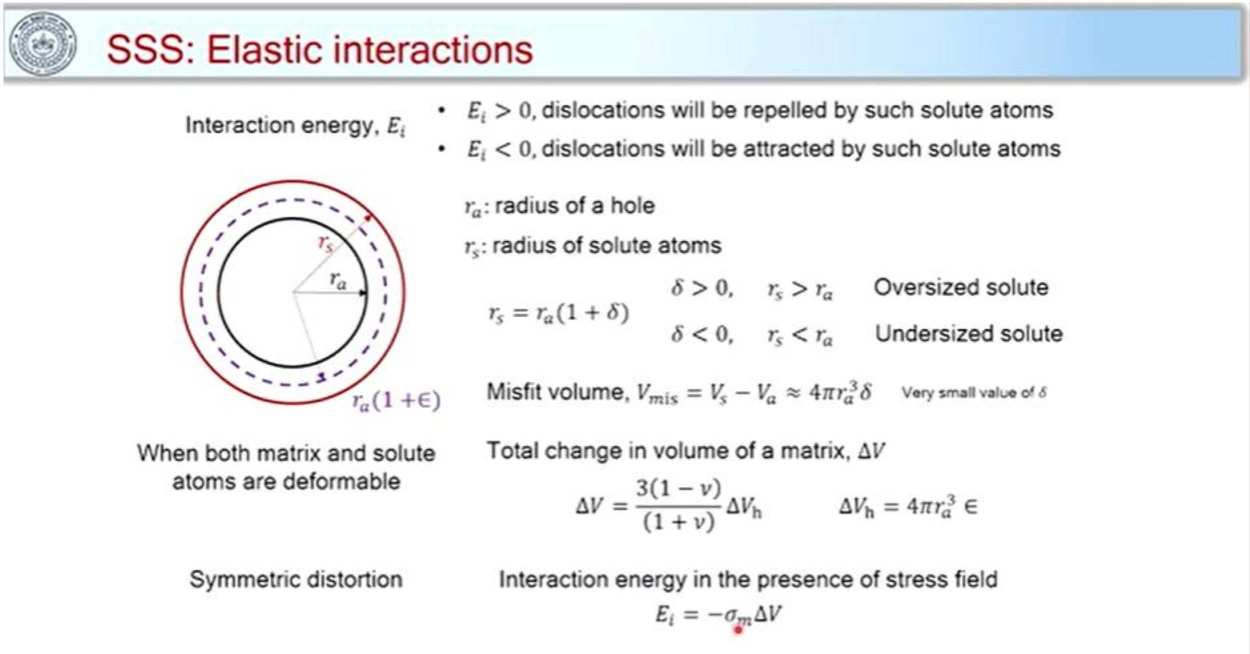
Solid Solution Strengthening: Interactions of solutes and defects



Last part mein humne dekha tha ki solid solution strengthening kis tarah se hoti hai aur usmein humne elastic interaction ke baare mein dekha tha is part mein hum jaanenge ki jab hum solid solution strengthening ki baat karenge to interaction energy kya hoti hai aur ye interactions defects ke saath kis tarah hote hain to iske liye hum ek model dekhte hain jahan par hum baat karenge ki interaction energy ke to hum interaction energy main usko E_I yahan pe likh raha hoon agar ye interaction energy jyada hai to yeh interaction energy kya hai yeh interaction energy hai mere solute atoms ke saath defects ke saath defects aur solute atoms ke saath to hum dekhenge ki ye interaction energy agar positive hai to hum dekhenge ki dislocation repel honge mere solute atom se agar yeh elastic energy negative hai to iska matlab yeh hai ki mere jo dislocation se woh attracted honge yaani khinche jayenge mere solute atoms ki taraf yeh yahan par is tarah se hum interaction energy ke baare mein baat kar sakte hain agar mujhe values pata hai interaction energy to main bata sakta hoon ki kaun sa solute atom is location ko attract karega ya nahi karega.

To abhi hum dekhte hain ek model to yahan par main consider kar raha hoon ek hole ko yaani hum baat karenge ki mere solvent mein ek radius rahegi ek hole rahega jahan par mera solvent atom ja sakta hai to yeh R_h isko main naam de raha hoon is yeh hai mera radius of hole yeh kuch nahi hai ek void hai yeh lattice par bhi ho sakta hai ya lattice points par bhi ho sakta hai ya ye ek interstitial void bhi ho sakta hai to iska ek radius main maan ke chal raha hoon aur wo hai R_h aur agar main maan ke chalta hoon ki mere solute atoms ka jo radius hai wo R_s hai kuch is tarah se ek R_s karke radius hai to abhi main in dono ke beech mein ek relation likh sakta hoon kuch is tarah se main likh sakta hoon $R_s = R_h(1+\delta)$ yaani ye jo δ factor hai wo decide karega ki mera solute atom kis tarah se hai to agar δ bada hai yaani zero se agar bada hai to aap dekhenge ki to is tarah se hum solute ko distinguish kehte hain abhi hum dekhenge ki agar main mera solute atom is hole ko occupy karne ki koshish karta hai to ek misfit volume yahan par taiyaar hoga yaani in dono ke beech mein agar $R_s = R_h$ nahi hai to aap dekhenge ek misfit volume taiyaar hoga aur us misfit volume ko main likh sakta hoon V_m yaani volume of solute minus volume of hole aur isko main kuch is tarah se simplify karke likh sakta hoon $4\pi r^3 \cdot \delta$ jab δ ki value yahan pe bahut-bahut chhoti hai yaani dono ke beech mein jo difference hai wo bahut kam hai to yahan pe ek main misfit volume is tarah se likh sakta hoon.

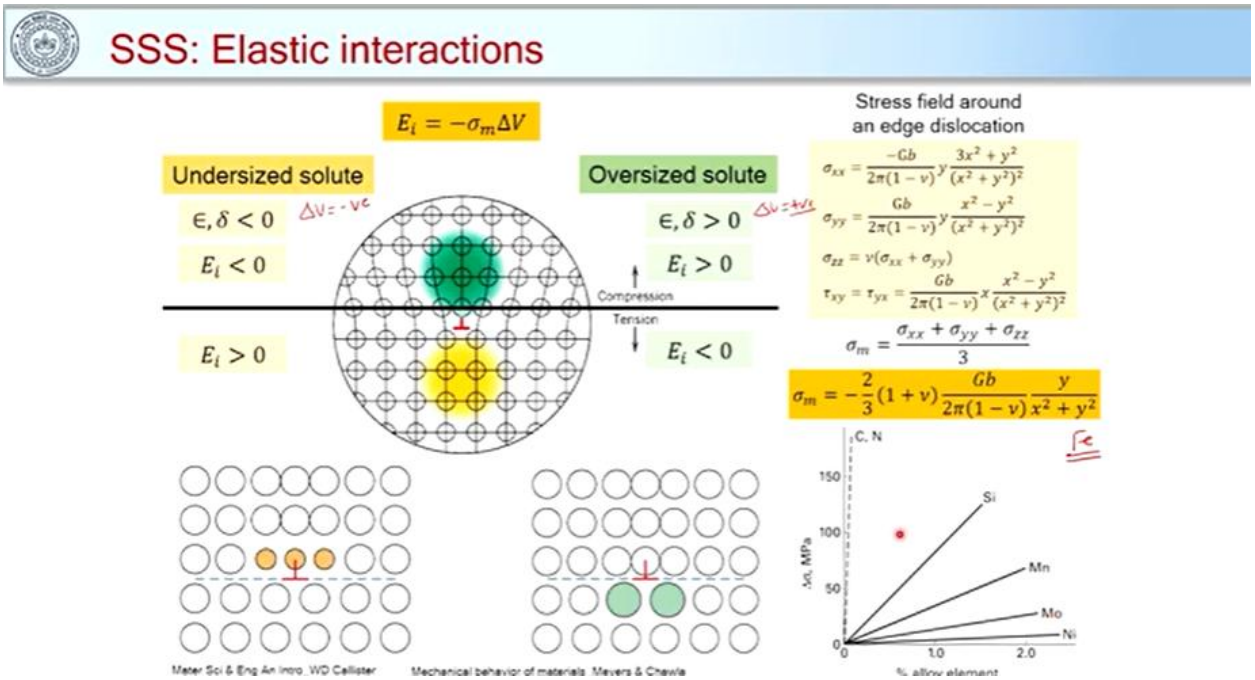
Abhi hum dekhte hain ki jab elastic interactions ki baat hoti hai tab agar yeh solute atom aur yeh radius of hole equal nahi hai tab yeh dono ek dusre ke saath interact karenge aur ek dusre ko elastically deform karne ki koshish karenge aur yaani jab hum baat kar rahe is model ki to hum dono ko yaani matrix aur solute atoms ko deformable maan ke chal rahe hain jab aap deformable maan ke chal rahe hain tab kya hoga tab ek equilibrium configuration aayega yeh equilibrium configuration is tarah se aayega agar mera yeh solute atom hai yeh deform hoke yahan par aayega aur mera hole kuch is tarah se main keh sakta hoon elastically deform hoke kuch is tarah se badhega to ek equilibrium position aayegi in dono ke beech mein aur usko main likh sakta hoon R yaani is is radius ko main likh sakta hoon equilibrium position ko $R(1+\epsilon)$ ab ye ϵ equal to δ hoga jab jab yahan par koi volume change nahi hoga to total change in volume of matrix main isko δV is tarah se likh sakta hoon δV ko main yeh formula ki tarah likh sakta hoon yahan par hum dekhenge ki jo δV hai yeh maine derive kiya yahan pe yeh directly aap kisi physical metallurgy ya standard text books mein aapko yeh formula mil jayega yahan pe hum iska derivation nahi dekh rahe yahan pe hum dekh rahe hain ki agar dono matrix aur solute deformable hai to mujhe jo volume change milega kuch is tarah se milega aur main δV_m ko is tarah se likh sakta hoon yahan par yeh jo hai ye ϵ hai yahan pe to ye hum jab symmetric distortion ki baat karte hain yahan pe to main ek interaction energy is volume change ke dwara likh sakta hoon to yeh volume change interaction energy ke saath kis tarah related hai ye interaction energy hoti hai mere presence of stress field ke dwara to ye interaction energy ko main likh sakta hoon $-\sigma_m \cdot \delta V$ jahan pe δV jo hai wo mera total change in volume mein hai jab mere paas symmetric distortion hai aur matrix aur solute dono deformable hai to abhi hum dekhenge ki ye meri elastic strain energy hai aur yeh jo σ_m hai yeh mera hydrostatic stress hai kyunki hamare paas to ek symmetric distortion mil raha hai yahan pe ye jo dotted line hai ye bata rahi hai ki symmetric distortion hai to is distortion ko main hydrostatic stress express kar sakta hoon isko likh sakta hoon σ_m se.



To abhi hum dekhenge ki yeh jo elastic interactions hai ye humne elastic energy jo yahan par likhi interaction energy likhi hai $-\sigma_m \cdot \delta V$ abhi kuch example lete hain aur isse is interaction ko samajhte hain to maan lete ki mere paas ek edge dislocation hai ab jab hum edge dislocation ki baat karte to mere paas kuch stress field hai humne bahut baar dekhe equation mere paas $\sigma_{xx}\sigma_{yy}\sigma_{zz}$ hai τ_{xy} aur τ_{yx} hai kuch is tarah se unki values bhi humne dekhi abhi hum isse mean stress nikaal sakte hain mean stress kya hoga $(\sigma_{xx} + \sigma_{yy} + \sigma_{zz})/3$ to normal stresses ka jo summation hoga unka average jo hoga wo mera σ_m rahega to main σ_m ki value nikaal sakta hoon agar mujhe yeh teenon values pata hai to wo value kuch is tarah se aate $-\frac{2}{3}(1+\nu)\frac{Gb}{2\pi(1-\nu)}\frac{y}{x^2+y^2}$ kuch is tarah se aayegi abhi hum ye jo equation hai ye istemal karenge mere σ_m ko nikaalne ke liye to main abhi positive edge dislocation consider kar raha hoon yeh mera positive edge dislocation hai to yeh mera slip plane hai to humne dekha tha ki ek jab positive edge dislocation ki baat karte to slip plane ke upar hoti hai meri mean stress ki value jo hoti hai wo compressive nature ki hoti hai aur slip plane ke niche jo value hoti hai mean value average value jo hoti hai wo tensile nature ki hoti hai to aap dekh paa rahe honge ki ye mera positive y hai aur yahan pe negative y hai to yahan pe main σ_m ki value likh sakta hoon ki positive y pe taraf jo rahegi wo meri compressive nature rahegi aur negative y pe meri tensile nature ki rahegi.

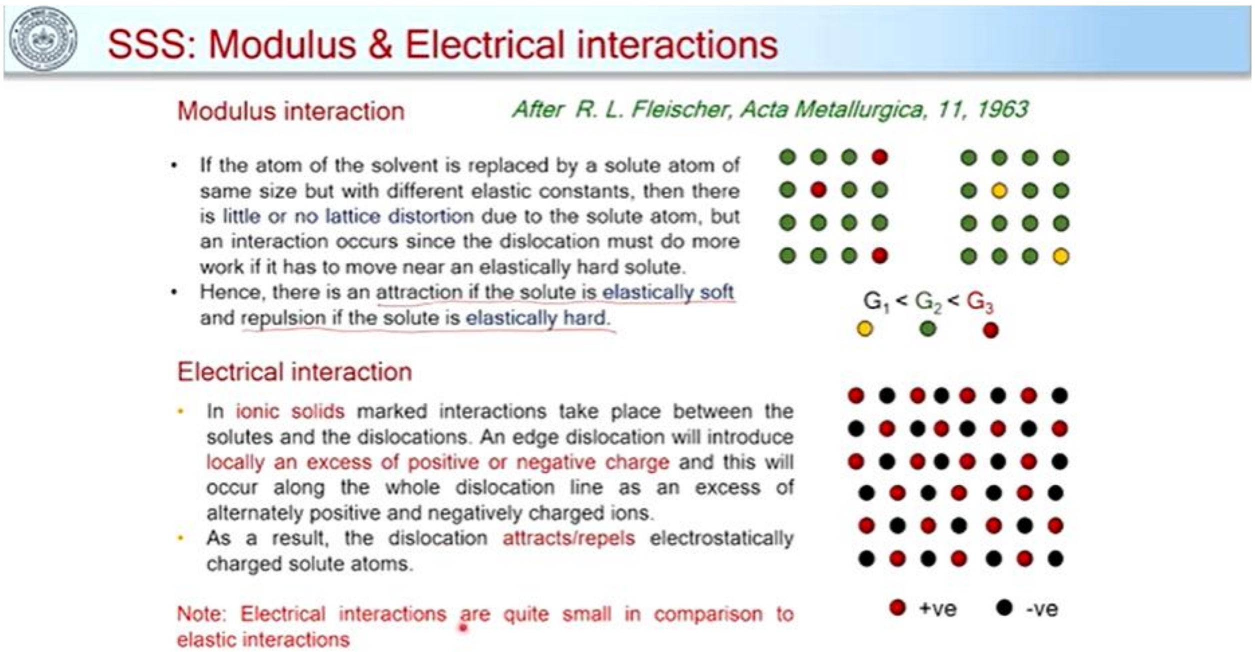
Abhi hum dekhte hain ki mere paas kuch solute atoms hai abhi hum interactions ki baat kar rahe hain solute atom aur dislocation ki to mere paas to stress field hogi dislocation ki ye humne padha tha abhi hum interaction energy nikaalne ki koshish karenge jab mere paas kuch solute atoms hai to mere paas oversize solute atom hai oversize solute atom yaani kya hoga mere paas jo ϵ aur δ hai wo greater than zero rahega abhi hum dekhenge ki agar yeh greater than zero hai to aap dekhenge ki δV ki value bhi positive hogi abhi interaction energy ki value kya hogi yahan pe hum dekhenge to is case mein agar yeh positive hai aur σ_m yahan par negative hai to interaction energy ki value is side yaani slip plane ke upar above ye aayegi greater than zero δV yahan pe positive hai aur σ_m compressive hai negative hai to negative negative banke ye positive aa jayega to yahan pe interaction energy ki value badhi aayegi greater than zero aayegi agar main niche hoon slip plane ke niche hoon to aap dekhenge ki interaction energy ki value kya aani chahiye σ_m ki value yahan pe positive hai aur positive into negative yeh hoga negative to aap dekhenge yahan par jo value aayegi interaction energy ki value wo less than zero aayegi ya negative aayegi to oversize solute ke liye mere paas kuch interaction energy ki value slip plane ke above positive aati hai niche jo hai wo negative aati hai abhi hum dekhenge ki undersize solute ke liye kya hoga to undersize solute ki jab hum baat karenge to ϵ aur δ ye less than zero rahega agar yeh less than zero hai to δV ki value negative rahegi yahan par likh lete yahan par δV ki value negative rahegi yahan par δV ki value positive rahegi oversize ke liye to abhi hum dekhenge ki agar δV ki value yahan par negative hai to hum dekhenge yeh jo term hai wo positive ho jayegi negative into negative δV ye positive ho jayegi par ab jab σ_m ki value compressive hai yaani negative hai to δE ki value ye aa jayegi less than zero ya negative to yahan pe δI ki value aayegi negative is case mein yaani slip plane ke niche jahan par mere paas tensile hai δE ki value aayegi positive to humne dekha ki dislocations ya solute atoms ki interaction energy agar negative hai to dislocation attract honge agar wo positive hai to dislocations repel honge to agar hum dekhenge to yahan pe dislocation hamare solute atoms ke size ke saath hum dekh sakte hain ki kis tarah se interact karenge to hum dekh paa rahe honge ki yahan pe is case mein yahan pe undersize solute atom hai mere paas yahan pe jo interaction energy hai slip plane ke above negative hai to ye jo saare solute atoms hain wo slip plane ke above aake is tarah se occupy karenge aur dislocation ke saath is tarah se interact karenge ye jo undersize solute atoms hai wo slip plane ke niche nahi jayenge wo above hi rahenge agar main oversize solute atom ki baat karunga to oversize solute atom yahan pe hum dekhenge yeh jo slip plane hai iske niche oversize solute atom ki interaction energy negative hai to ye oversize solute atom mere slip plane ke niche jayenge na ki above aayenge to aap dekh rahe honge ki ye jo solute atoms hai wo apne size ke hisaab se distortion taiyaar karenge aur interaction energy kuch is tarah se aayegi aur us interaction energy ke dwara hum likh sakte ki solute atoms kaun si side ko prefer karenge ya slip plane ke above jayenge ya below jayenge woh hum baat kar sakte hain is elastic interaction ke dwara yeh ho gayi meri solute aur dislocations ki interaction.

Abhi hum kuch values dekhte hain yaani kitna rise hua jab main kuch percentage of alloy atom daalta hoon to mera strength kitna badhta hai to hum interstitial atoms ki jab baat karenge yeh hum baat kar rahe hain steels ke andar to main agar carbon aur nitrogen daal raha hoon steels ke andar to aap dekh paa rahe honge steel ke andar yaani main bol raha hoon iron ke andar to mera solvent jo hai wo iron hai to agar mere paas carbon aur nitrogen hai jo ki interstitial atoms hai wo main small amount mein bhi daalunga to mujhe strength jyada milegi uske baad dekhte hain ki yeh jo saare elements hai silicon manganese molybdenum aur nickel ye jo saare solute atoms jo hai wo iron ke saath substitutional solid solution form karte aur aap dekh rahe honge ki silicon jyada strength badhata hai as compared to nickel moly aur manganese to is tarah se hum dekh sakte hain ki mere solute atoms daalne se strength meri badh sakti hai aur woh badhti hai mere elastic interactions ke dwara defects ke saath.

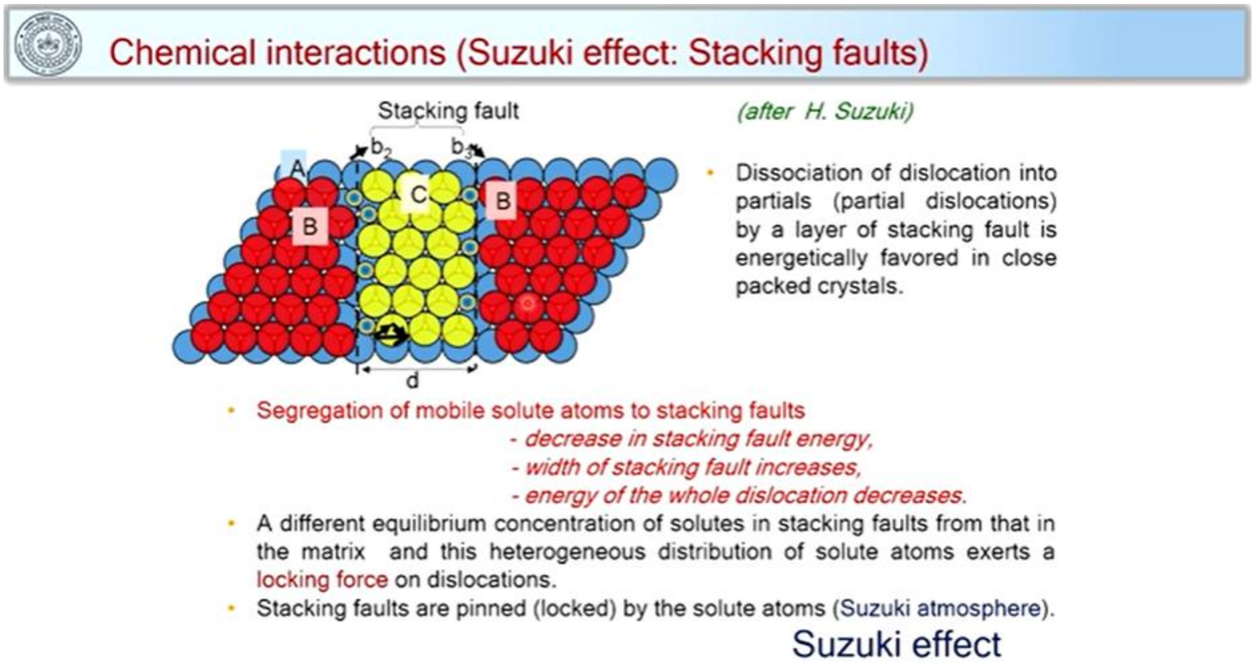


Abhi hum elastic interaction dekh liye abhi hum do interaction aur dekhte hain jis jo ki humne baat ki thi modulus aur electrical interaction yeh modulus interaction sabse pehle propose kiya tha fleischer ne aur hum isko kuch is tarah se samajhte hain to agar mere paas yeh green color ke jo atoms hai yahan par main isko solvent maan ke chal raha hoon aur red aur yellow jo hai color ke atoms inko main solute maan ke chal raha hoon aur yeh jo red solute hai yeh red solute ki jo elastic modulus hai ya shear modulus hai wo badi hai as compared to mere solvent atoms ke saath aur ye jo yellow color ke atoms se inki elastic modulus hai kam hai mere solvent atoms ke saath to modulus interaction ya fleischer is tarah se baat karte to hum dekhte hain ki jismein agar solvent solute atom ki elastic modulus badi hai yaani wo elastically hard hai wo mere dislocation ko repel karenge aur yahan par hum dekhenge jo elastically soft hai yaani is case mein yellow jahan par meri shear modulus kam hai yahan par hum dekhenge ki jo dislocation se woh elastically soft solute ke taraf attract hote hain to yeh ho gaya mera modulus interaction yahan par hum dekh rahe honge ki yeh jo maine atoms is tarah se liye yahan par kuch little distortion hai solute atoms ke dwara to yaani in dono ke size difference jo hai solute aur solvent atoms mein jyada nahi hai to par hum yeh point yahan par mark kar sakte hain ki attraction jo hai dislocations ka woh attractive rahega agar elastically soft solute hai aur repulsive rahega jab mera solute elastically hard hai yeh ho gaya mera modulus interaction.

Abhi hum electrical interaction ki baat karte hain jab electrical interaction ki hum baat karenge tab hum dekhte hain ki agar mere paas kuch is tarah se lattice hai solvent ka aur ionic solids se main maan leta hoon to mere paas kuch cations hai aur anions hai to mere paas kuch cations hai aur anions hai aur yahan par kuch dislocation hai kuch is tarah se to yeh jo dislocation hai yahan par aap dekh rahe honge ki mere paas number of cations aur anions yeh equal nahi hai yahan par to yahan par jo dislocation region hoga wahan par ek charge imbalance taiyaar hoga to yahan par ionic solids mein agar defects hai line defects se to mere paas ek charge imbalance hoga aur iski wajah se wo kuch solute atoms ko attract karenge electrostatically ya repel karenge to jis tarah se solute atom ka charge hoga agar yahan par hum dekhenge ki mere paas positive charge bada hai is case mein to agar negative ion hai yahan pe wo aasaani se attract hoga agar positive ion aayega to wo repel karega kyunki yahan pe jo charge imbalance hai wo positive hai to to yeh hote mere electrical interaction yeh hota hai electrostatically attraction aur repulsion dislocation aur solute atoms ke beech mein abhi hum jyada mahatva dete hain yaani electrical interaction ki hum baat karenge yeh small hote hain elastic interaction ki tulna mein to isliye sabse jyada strengthening hum jab consider karte tab elastic interaction ko jyada mahatva dete hain.



Abhi hum kuch aur cheez dekhenge jahan par humne baat ki thi ki chemical interaction to humne kuch stacking fault ke baare mein dekha tha to ek planar defect hai abhi hum dekhenge ki yahan pe jo regions hai yeh jo regions hai wo highly energy regions hogi aur iske wajah se kya hoga kuch solute atoms yahan pe segregate honge yahan pe segregate ho jayenge yaani yahan par aapko bahut saare solute atoms milenge mujhe unka concentration jyada rahega aur agar yeh concentration jyada hai to aap dekhenge ki chemical interaction hoga aur yeh jo faulted region hai yahan pe yeh yahan pe energy jyada thi maine isliye bola ki yahan pe solute atoms segregate ho jayenge to inki jo energy hai wo kam ho jayegi aur yeh jo solute atoms hai is stacking fault ko stabilize karne ki koshish karenge to yahan pe hum dekhte hain ki segregation hote hain mere mobile solute atoms ke stacking fault ke upar aur yeh kya karte hain mere stacking fault energy ko decrease karte hain aur hum dekh sakte hain ki width of stacking fault badhega tab ye stacking fault stable ho jayega aur energy saare dono dislocations ki decrease hogi iske wajah se hum dekhenge ki ek locking force taiyaar ho jayega mere dislocations ke upar agar yeh stable ho gaya yahan pe to yeh dislocation move nahi karega ek locking force hoga aur iske wajah se meri strength badhegi material ki agar mere ye solute atoms lock kare dislocations ko to strength badhegi aur isko hum kehte hain suzuki effect suzuki effect kya hai specially yeh stacking faults ke baare mein baat karte hain stacking faults jab pinned ho jaate hain ya locked ho jaate hain mere solute atoms ki wajah se isko yeh jo atmosphere hai yahan par yaani increased concentration hai solute atoms ka inko hum kehte hain suzuki atmosphere aur is effect ko kehte hain hum suzuki effect to yeh chaar interactions humne yahan par dekhe elastic interactions modulus interaction electrical interaction aur chemical interactions.



To is part mein humne solid solution strengthening ke baare mein jaana hai aur jab hum solid solution strength ke baare mein jaante hain tab humne humne interaction energy ke baare mein baat ki interaction energy ke baad humne solid solution strengthening mein solute interactions defect ke saath kaise hota hai yaani elastic interactions kya hote hai yeh dekhein iske baad humne dekha hai modulus interactions iske baad humne dekha hai chemical interactions aur electrical interaction in sab mein se elastic interaction jo hota hai woh sabse jyada strengthening deta hai isliye hum isko jyada mahatva dete hain abhi ke liye yahin par rukta hoon next part mein hum jaanenge ki in segregation ke wajah se ya solute atoms ke wajah se humein kaun si strengthening milti hai steels mein dhanyavad