Mechanical behavior of materials

Dr Niraj Mohan Chawake

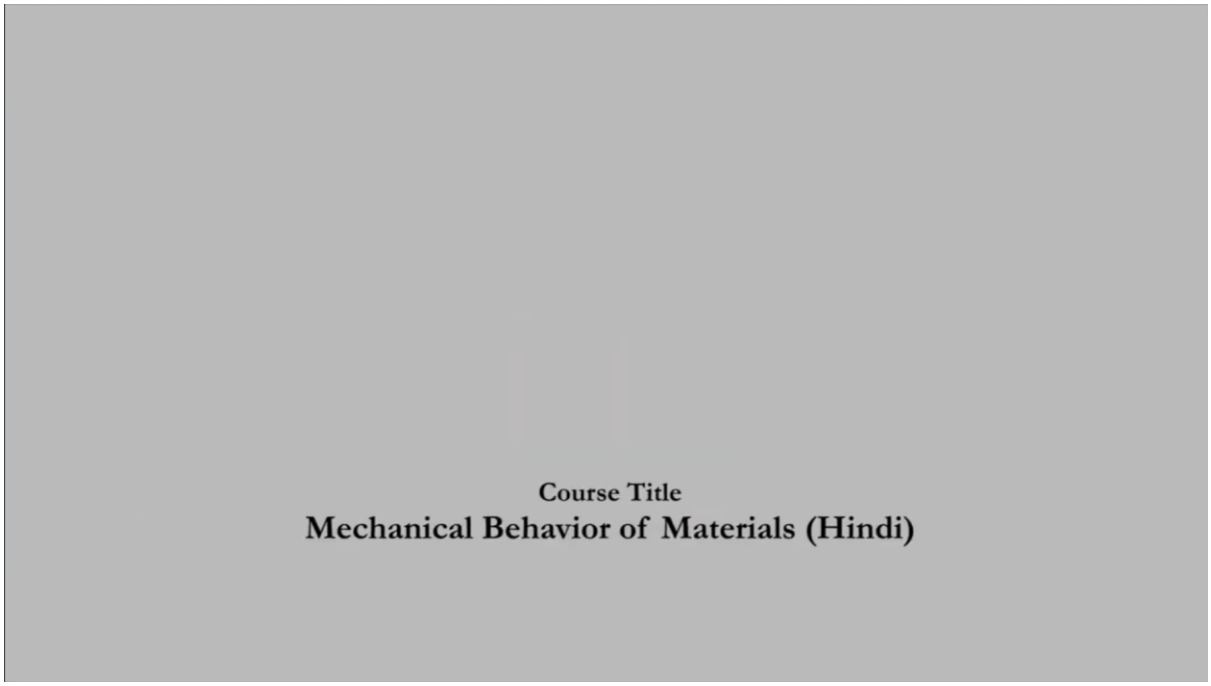
Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

Week-10

Lecture-54

Fracture & Theoretical Cohesive Strength of Materials

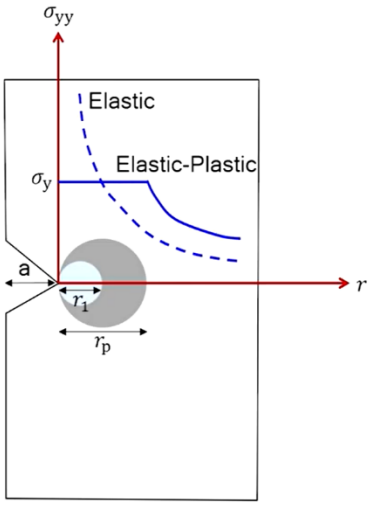


Lecture-53

Fracture Mechanics - LEFM vs EPFM and J- Integral

Phir se swagat karta hoon aapka Mechanical Behavior of Materials is course mein jo ki hum Hindi mein padhenge. Last part tak humne dekha ki fracture kis tarah se hota hai aur crack ka kya mahatva hai aur humne dekha tha ki do tarah se fracture hote hain: ek jab crack ke saamne koi elastic field hi rehti hai aur crack ke saamne jab koi plastic zone taiyar hota hai. To is tarah se humne dekha ki material elastically deform hota hai, elastically fracture ho sakta hai ya wahan par koi plastic zone hokar fracture ho sakta hai. To usi ko hum dekhenge LEFM aur EPFM ki tarah aur jab hum EP...

Stress ahead of a crap tip

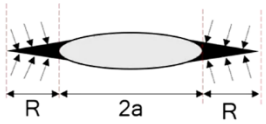


Irwin's Model

$a_{eff} = a + r_p$ $\quad r_p = 2r_1$

- Fictional crack length
- Longer but takes care of a stress
- r_p, iteratively identified

Dugdale Model



$a_{eff} = 2a + 2R$
$= 2(a+R)$

$$R = \frac{\pi^2\sigma^2 a}{8\sigma_{ys}^2} = \frac{\pi K^2}{8\sigma_{ys}^2}$$

FM ki baat karenge tab hum is part mein J-Integral bhi padhenge. To sabse pehle jaante hain ki crack ke saamne jo stress field hoti hai kis tarah se hoti hai. To yeh mera material hai aur ek kuch surface crack hai aur uski length maine mark kar li hai kuch 'a' is tarah se. Aur jab hum stress field ki baat karte hain crack... crack tip ke aage to hum kuch coordinates mark kar lenge isko mein 'r' keh raha hoon is x-direction ko aur yahan pe is y-direction pe mein mark karunga $\sigma_{\gamma\gamma}$ (Sigma yy). To yahan par ek hi stress dekh rahe hain hum yahan par $\sigma_{\gamma\gamma}$. Agar yeh samjhenge to hum baaki ke do stress field bhi acche se samajh payenge. To yahan par jab mein stress field ki baat...

karunga jab material elastic behavior ki tarah yaani brittle behavior dikhata hai to jo stress field hogi crack tip ke aage kuch is tarah se decrease hogi jaise-jaise mein crack se door jaunga waise-waise stress yahan pe decrease hoga. Humne kaha tha ki crack tip ke aage kuch stress concentration hota hai ya high triaxial state of stress hota hai. To kuch is tarah se yeh stress vary hota hai mein jaise-jaise crack tip se door ja raha hoon. Aur jab material plastically deform karta hai tab humne dekha ki ek plastic zone taiyar hota hai kuch is tarah se. Is plastic zone ka diameter mein kuch...

mark kar raha hoon yahan pe yeh r_p keh raha hoon ise is diameter ko. Agar material mera plastically deform ho raha hai yahan pe to jo stress rahega yahan pe aap dekh pa rahe honge ki agar yahan par plastically deform ho raha hai to yeh stress jo hoga woh yield stress (σ_γ) ke barabar hona chahiye. To mein kuch is tarah se mark kar raha hoon meri stress field yahan pe ek stress constant rahega jo ki yield strength ke barabar rahega mere material ke aur yeh jo behavior hai jis material mein dikhate hain isko hum kehte hain Elastic-Plastic Behavior. Abhi hum dekhenge ki yeh jo elastic-plastic behavior hai to mein kuch is tarah se mark ka sakta hoon ek...

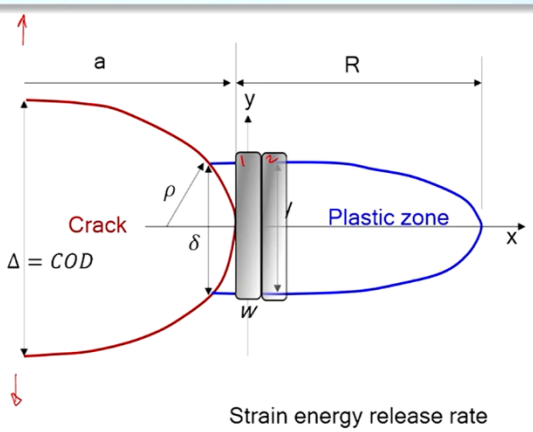
effective length yaani Irwin ne ek model diya tha is total length ko yaani agar mein is tarah se consider karunga $a_e$fp yaani ek total effective crack length. Yeh kya hai? Yeh meri crack length hai 'a' plus r□. r□ hai mere plastic zone ka diameter. To agar hum in dono ko add kar dunga yeh ho jayegi meri effective crack length. Yeh Irwin ne ise consider kiya hai. Abhi yeh jo plastic zone ki diameter hai kuch is tarah se hum nikaal sakte hain. Yahan par ek maine diameter mark kar li r_1 . Yeh r_1 is tarah se yahan par aap dekh pa rahe honge yeh jo elastic-plastic stress hai jab elastic stress ko intersect karta hai crack tip ke aage ya barabar hota hai yahan par mein keh sakta hoon jis distance par...

barabar hota hai woh jo diameter rahegi us circle ke jo diameter rahegi usko mein r_1 keh raha hoon aur yeh jo r□ hai yeh twice of r_1 consider ki yaani is r_1 ke diameter se jo r_1 mila hai uske double hum consider karte hain yeh plastic zone ki diameter. To yeh jo crack length hai $a_e$fp crack length Irwin ne jo consider ki yeh fictional crack length hai kyunki hamari actual crack to 'a' hai par yeh agar mein consider karunga to mein yeh stress field ko consider karke mere calculations kar sakta hoon. Yaani fictional crack length isliye consider ki hai kyunki yeh is plastic zone ke stress field ko consider kar leta hai ya take care kar leta hai...

aur yeh jo r_p hai humein jo milta hai woh iteratively identify kiya jata hai yaani iterative calculation se ya bahut saare attempt karne ke baad isko determine kiya jata hai ki yeh plastic zone ki diameter kya ho sakti hai. Yeh ho gaya Irwin ka model. Abhi hum dekhte hain isi model ko Dugdale ne is tarah se consider kiya. Agar mein... mere paas ek internal crack length hai maan lete hain uski length 2a hai aur ek plastic zone hai to is plastic zone ko mein is tarah se consider kar sakta hoon. Yeh jo shaded region hai black mein yeh meri plastic zone ka region hai aur isko mein consider kar sakta hoon total effective crack length. Yeh jo region consider kiya hai plastic zone isko hum kehte hain yahan pe kuch...

compressive stresses act kar rahe hain. Iske dimension mark kar liye 'r' aur 'r'. Aur yeh jo compressive stresses act kar rahe hain is crack length pe yeh is crack ke propagation mein baadha pahunchayenge ya isko crack propagation nahi hone denge. To ek kuch compressive zone mark kar liya yahan pe Dugdale ne. To yahan pe effective crack length kya hogi? To mein $a_e$fp is tarah se likh sakta hoon 2a + 2r. To yeh hogi meri effective crack length twice of (a + r). Aur 'r' jo zone hai yahan par ek yeh bhi fictitious zone hai jahan par meri crack jo hai is tip pe ek compressive force consider kiya gaya. Yeh model se kuch 'r' jo hai yeh zone iska dimension hum nikaal sakte hain kuch...

Crack tip opening displacement



Mode I

ρ: root radius of a crack

$\Delta = Crack\ opening\ dislplacement$

δ :Crack tip opening displacement

Tensile sample: l × w

Fracture 1 → 2 Unstable

Fracture 1 → X 2 Stable

Strain energy release rate

$^{\circ}G = \sigma_{ys}\delta$

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calculations karke iska value aata hai $\pi K^2 / 8\sigma_{ys}^2$. Where σ_{ys} jo hai yeh mera yield strength hai material ka. Yeh humein kuch strain energy release rate nikaalne mein madad karegi. To yeh Dugdale ka model kisi bhi standard book mein aapko mil jayega. To is introduction ke saath aage badhte hain aur kuch terminology samajhte hain jaise Crack Tip Opening Displacement. Maan lete hain mere paas kuch is tarah se crack hai aur hum consider karte hain plastic zone hai mere crack tip ke aage. Yeh Dugdale ka modified model bhi consider kar sakte hain. Abhi hum consider karte hain iske dimensions 'a' aur...

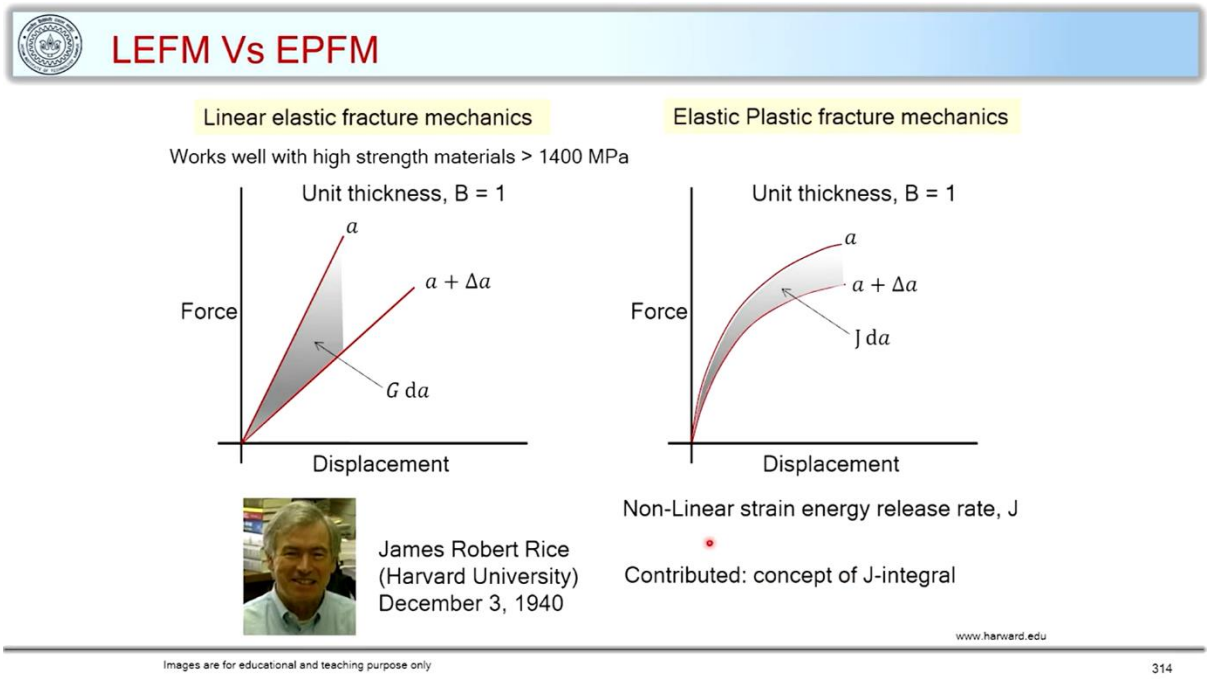
'r'. Abhi kuch consider karte hain is crack ko hum Mode I mein open karenge yaani Mode I yaani jab mein ek tensile force yahan pe apply kar raha hoon. Yeh humne dekha tha ki Mode I kisko kehte hain. To jab mein ek tensile force apply karta hoon to kuch is tarah se mein mark kar raha hoon mere coordinates 'x' aur 'y'. Aur yeh jo radius hai isko mein kehta hoon root radius of a crack yaani yeh mere crack ki crack tip ki ek root radius hai jisko 'ρ (rho)' ke naam se maine likha hai. Yeh jo distance hai Δ (Delta) isko mein kehta hoon COD (Crack Opening Displacement). Yeh displacement jo hoga yeh isko mein kahunga Crack Opening Displacement. Yaani jab mein Mode I mein is crack ko open karne ki koshish...

karunga yaani ek tensile force apply karunga tab yeh jab crack badhegi aage badhne ki koshish karegi tab yeh jo distance hai yeh badhega isliye isko kehte hain Crack Opening Displacement. Abhi aur ek term istemal karte hain hum jo ki yeh hai small 'δ (delta)'. Isko kehte hain CTOD (Crack Tip Opening Displacement). Yaani yeh jo maine delta consider kiya hai yeh mere crack

tip ke paas hai. Yahan... yeh mere crack ki tip hai isliye yeh jo opening displacement yahan pe hoga isko mein kehta hoon Crack Tip Opening Displacement. Abhi jab is model ko hum consider karte hain tab yeh maan ke chalte hain ki is plastic zone mein kuch tensile samples hain. Yeh isko aapko assume karna hai ya isko...

hypothetically ek is tarah se consider kar sakte hain ki kuch tensile sample ki series hai is plastic zone mein. To meri crack kab propagate hogi? Jab yeh agar tensile sample fracture ho jayega kisi bhi stress mein... humne stress field ka variation dekha tha abhi pichli slide mein. Us stress ke andar agar yeh tensile sample agar fracture ho raha hai to agar yeh jab sample fracture hoga to iske next wala jo sample hoga kuch is tarah se iski length mein mark kar raha hoon 'l' aur 'w'. Aur ek doosra tensile sample ek series mein kuch is tarah se jude huye tensile samples ko mein consider kar sakta hoon mere understanding ke liye ya is model ke development ke liye. Jab yeh tensile sample...

fracture hoga aur iski wajah se yeh bhi sample agar fracture hota hai to is type ke crack propagation ko hum kehte hain unstable crack propagation. Yaani mein mark kar leta hoon yahan pe agar yeh mera sample one hai aur sample two hai aur maine kaha ki sample one se agar sample one agar fracture ho raha hai aur yeh fracture propagate hota hai sample two mein to is type of crack propagation ko hum kehte hain unstable crack propagation. Agar mera maan lete hain sample one ho raha hai aur sample two mein yeh fracture propagate nahi ho raha hai ya... to isko hum kehte hain stable crack propagation. To yeh concept se hum kuch is tarah se likh payenge jab yeh fracture badhta hai to mein kuch strain energy release...



rate ki baat karunga jisko humne 'G' ka naam diya tha. Isko mein identify kar sakta hoon σ_{ys} aur δ ke product se. σ_{ys} mera yield strength hai material ka aur δ mera Crack Tip Opening Displacement hai. To agar mein yeh crack tip opening displacement agar measure karta hoon aur mujhe yield strength pata hai material ka to mein strain energy release rate ko quantify kar sakta hoon ya measure kar sakta hoon. Aaiye abhi jaante hain ki jab mein do material ki baat kar raha hoon yaani jo material brittle fail hote hain aur jo material jab crack ke saamne plastic zone taiyar karte hain to do tarah ke humein fracture mechanics milte hain. Pehle ko naam dete hain hum LEFM (Linear Elastic Fracture Mechanics) aur...

doosre ko naam dete hain hum EPFM (Elastic Plastic Fracture Mechanics). To iske baare mein aur jaante hain. Yeh jo Linear Elastic Fracture Mechanics humne kaha hai ki ek brittle material ke liye acche se istemal kar sakte hain jaise ki jo material jinki strength bhi zyada hai, high strength material yaani jinki strength zyada hai 1400 MPa se bhi unke liye bhi hum comfortably LEFM istemal kar sakte hain. To inke baare mein jab jaanenge LEFM kya hai to jaise maine force aur displacement ki baat ki thi jab mere material mein kuch crack hai aur maan lete hain mere jo material ka hai thickness yeh unit thickness hai yaani B = 1...

mein maan ke chal raha hoon aur ek crack hai to uske liye mujhe kuch force lagega is tarah se aur yeh jo force hai aap dekh pa rahe honge yeh linearly vary ho raha hai jaise-jaise displacement mein badhaane ki kuch koshish kar raha hoon waise-waise force yeh linearly vary ho raha hai. Maan lete hain ki kuch is crack ko mein extend karunga a + Δa ya da se to kuch is

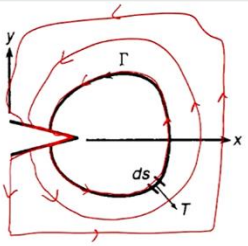
tarah se a + Δa. To aap dekh pa rahe honge ki jaise crack badhti hai to yeh force ghatega humne dekha tha. To yahan par yeh bhi jo force hai yeh linearly vary kar raha hai. To yeh jo energy hai yahan par jo strain energy mil rahi hai humein releasing strain energy isko humne G da consider kiya tha. Yeh mere LEFM ka...

basis hai. Is tarah se jab mein EPFM ke baare mein padh raha hoon tab hum force displacement kuch is tarah se plot karte hain aur jo yeh jo force hai woh mein consider kar raha hoon ek unit thickness mere material ki hai kuch is tarah se aur ek crack hai usmein 'a' aur usko jab yeh jab crack hai aur force aur displacement ka relation mein consider kar raha hoon tab yeh jo relation hai yeh linear nahi hai. Yeh kuch is tarah se vary kar raha hai. Maan lete hain mere paas kuch ek crack hai a + Δa kuch is tarah se ismein bhi aapko force kam lagega par yeh jo force aur displacement ka relation hai yeh linear nahi hai. To yeh jo yahan par strain energy release rate aayegi yeh non-linear hogi. Isko...

mein kehta hoon J da. To non-linear strain energy release rate ko mein 'J' kehta hoon. Yeh jo J hai yeh James Robert Rice ke naam ke jo initial pehla naam hai is J ke upar diya gaya hai kyunki unhone bahut kaam kiya hai hamare is J-Integral concept ko develop karne ke liye. Yaani J-Integral yaani hamare non-linear strain energy release rate ko quantify karne mein inka kaafi bada yogdaan hai aur yeh jo G hai yeh hamare Griffith ke naam se jaana jata hai. To humne yahan pe do models dekhe LEFM aur EPFM aur humne dekha ki force displacement agar linearly vary ho raha hai yeh mujhe brittle material mein milta hai to mein usko G kehta...

J-Integral

Non linear strain energy release rate J.



Path independent-line integral

2D approach: thickness B=1

$J = -\frac{dU_0}{da}$ Release of potential energy per unit crack extension

$$J = \int_{\Gamma} \left(\omega \, dy - T \frac{\partial u}{\partial x} ds \right)$$

W	: strain energy per unit volume due to loading
Γ	: the path of the integral which encloses the crack
T	: outward traction vector acting on the contour around the crack
u	: the displacement vector
ds	: an increment of the contour path
$T\frac{\partial u}{\partial x}ds$	: the rate of work input from the stress field into the area enclosed

$J = \frac{K_I^2}{E'}$ $E' = E$ Plane stress

$E' = E/(1-\nu^2)$ Plane strain

Relation between J and CTOD

$J = \sigma_{ys}\delta$

J obtained under Elastic plastic condition is numerically equal to G obtained under elastic condition

Mechanical Metallurgy: GE Dieter

hoon jo linear strain energy release rate ko. Aur jab mere paas non-linear variation hai tab mein us... jab energy release rate hogi yaane jab 'a' se 'a + Δa' propagate kar raha hai crack tab us strain energy release rate ko mein non-linear strain energy release rate kehta hoon usko mein J se denote karta hoon ya likhta hoon. Abhi hum J-Integral ke baare mein padhenge ki isko hum quantify kaise kar sakte hain. To maan lete hain ki mere paas ek crack hai aur maine kuch dimensions ya mere coordinates is tarah se mark kar liye 'x' aur 'y'. Abhi mein kya kar raha hoon yahan par mein ek path determine kar raha hoon yaani is tarah se maine kuch path yahan par determine kar liya...

yeh is tarah se aap dekh pa rahe honge mein is tarah se move kar raha hoon is path mein aur is path ko mein hamesha close karunga. Path hamesha mera closed rahega mujhe kyunki non-linear strain energy release rate nikaalna hai jo ki J ki value hai. Isko bhi likh lete hain mujhe non-linear strain energy release rate nikaalna hai yaane mujhe J nikaalna hai, J ki value nikaalni hai. To kuch methodology dekhte hain yahan pe. Yeh approach mein abhi 2D se consider kar raha hoon kyunki humne x aur y nikaali aur mein yahan pe thickness B=1 maan ke chal raha hoon. Mein 2D ke liye consider karunga to 3D ke liye bhi aap aasani se samajh payenge isko. To yahan pe J...

ko mein is tarah se likh sakta hoon -dU/da. Yaani yeh jo hai J ko yaani non-linear strain energy release rate ko mein is tarah se bhi consider kar sakta hoon ki ek potential energy release hai meri ek crack per unit extension crack yaani mere crack agar ek unit badh rahi hai to kitna potential energy release ho raha hai isko mein kehta hoon non-linear strain energy release rate. Mein use mathematically kuch is tarah se likh sakta hoon. Yeh similar approach humne linear strain energy release rate ya G determine karne ke liye liya tha. To J ko mein is tarah se consider kar raha hoon. Yeh jo path maine define kiya hai yeh path yaani Γ (Gamma), yeh capital Gamma mein is path ke upar...

mein kuch integral nikaal ke mein is tarah se determine kar sakta hoon. To aaiye terminology dekhte hain. To yahan pe yeh jo ω (Omega) hai yeh jo hai yeh strain energy per unit volume due to loading yaani mein agar load kar raha hoon is crack ko ya material ko to yahan pe kitni strain energy per unit volume hogi yeh hum Omega se quantify karte hain. Γ (Capital Gamma) yeh mera path hai yaani yeh jo is path pe jahan par mein yeh J nikaalne ki koshish kar raha hoon aur yeh hamesha is crack ko hamesha enclose karegi yaani aap dekhenge maine bola tha ki crack ko hamesha yeh path enclose karni chahiye. 't' jo hai, 't' jo hai mera traction vector hai kyunki jab mein force apply karunga yahan pe kuch...

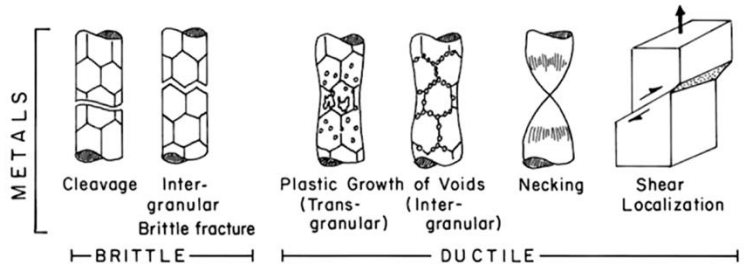
strain energy taiyar hogi woh release bhi hogi uske wajah se ek work done hoga uske wajah se ek traction mein consider kar sakta hoon is path pe. To yeh traction mera outward side pe act kar raha hai kuch is tarah se aur yeh ds hai yeh mera small counter path hai. Agar mein is path par yeh traction consider karunga aur mein is poore path yaani mein integral lunga to mere paas total value aa jayegi J ki. Aur yeh jo hai yeh terminology yeh hai mera rate of work input from the stress field into the area enclosed yaani jo area enclosed hai ismein jo work input hoga kyunki humne bola ki jab hum force lagate hain tab kuch strain energy wahan pe hogi crack extend hogi to wahan pe...

kuch work done bhi hoga to yeh jo balance hai isko hum J se quantify kar sakte hain. To abhi humne dekha yeh... yeh jo iska formulation hai aap Mechanical Metallurgy Dieter mein aap detail se padh sakte hain yahan pe hum sankshipt mein dekh rahe hain. To agar mein isko solve karunga to mere paas kuch J ki value kuch is tarah se aayegi K_I^2 / E'. Aur yeh jo value hai E', yahan par $E' = E$ yaani modulus hai mere material ka Young's modulus jab plane stress condition hai aur $E' = E / (1 - \nu^2)$ hai jab mere paas plane strain condition hai. Yeh bhi humne dekha tha ki plane stress aur plane strain condition thickness ke upar depend karti hai. To mein J kuch is tarah se nikaal sakta hoon. Abhi...

hum dekhenge ki yeh jo J hai mein kuch agar mein isko crack tip opening displacement ke saath relate karunga to mein dekhunga ki yeh J ki value mein $\sigma_{ys} \times \delta$ likh sakta hoon. Abhi hum J-Integral ka mahatva jab jaanenge tab yeh dekhte hain ki jab maine bola tha ki path independent hai to mein agar koi bhi path agar consider kar raha hoon is tarah se agar mein naya path leta hoon kuch is tarah se to bhi meri jo J ki value rahegi woh same rahegi. Mein path is tarah se bhi consider kar sakta hoon par aapko hamesha yaad rakhna hai ki is path mein yeh jo crack hai hamesha enclosed honi...

Fracture terminologies

	Brittle	Ductile
Crystallographic mode	Cleavage	Shear
Appearance of fracture	Granular/bright	Fibrous/dull
Path	Intergranular	Transgranular/Intragranular



Mechanical behavior of Materials: Meyers and Chawla

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chahiye. To mein consider kar sakta hoon agar mera path independent hai to mein sample ke dimensions ke saath bhi consider karke J ki value jab nikaalunga tab mujhe jo J ki value doosre path mein bhi milegi woh same rahegi isliye isko path independent line integral kehte hain. To abhi hamare paas kuch relation aaya J ka crack tip opening displacement ke saath: $\sigma_{ys} \times \delta$ aur humne pichli slide mein dekha ki G ki value bhi hum kuch is tarah se likh sakte hain. To ek important conclusion hum yahan par likh sakte hain ki jo J ki value humein milti hai elastic-plastic condition mein woh humein woh numerically mathematically equal rahegi G ki value ke saath jo humein elastic condition...

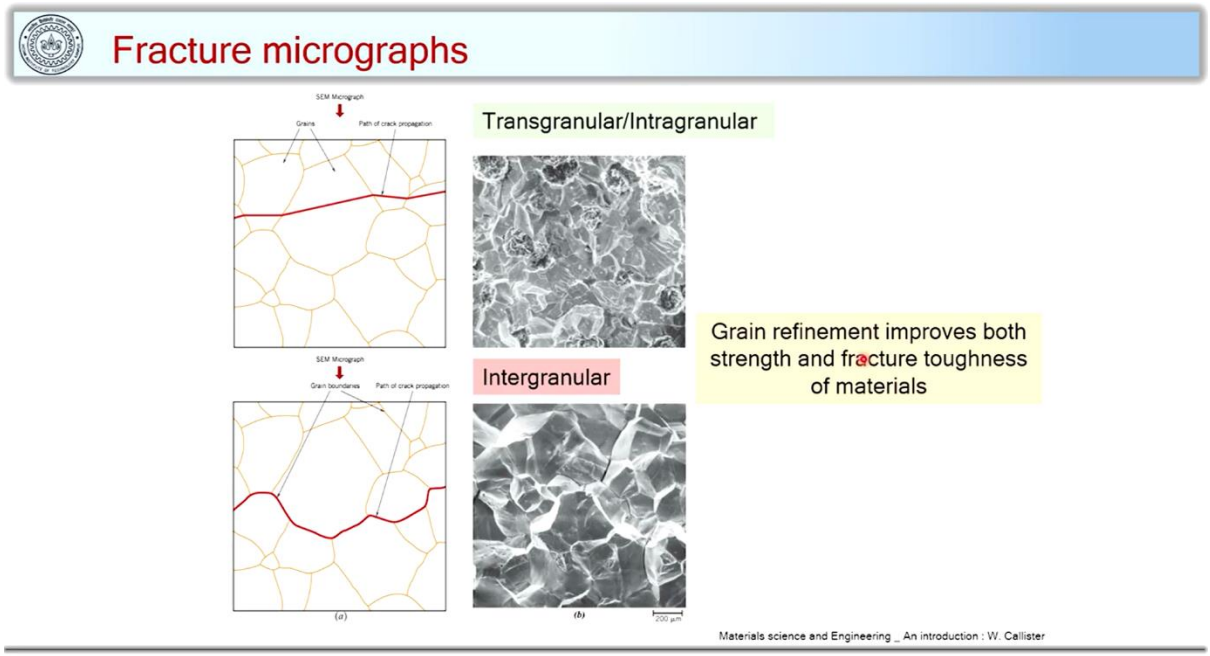
mein milti hai. Yeh ek important conclusion hai hamare J-Integral aur pichle waale slide se yaani jo J ki value kya hai non-linear strain energy release rate hai yeh humein kab milti hai jab hum elastic-plastic condition consider karte hain aur woh numerically equal hai exactly numerical equal rahegi hamare G ki value se. G meri linear strain energy release rate hai jab mein elastic condition consider karta hoon. To yeh ho gaya sankshipt mein J-Integral ka mahatva. Abhi hum aage badhte hain aur kuch terminology dekhte hain jab mein fracture ko padhta hoon. To fracture jab mein padh raha hoon tab humne abhi tak dekha tha ki isko mein brittle fracture aur...

ductile fracture ke naam se is tarah se denote kar raha hoon. To isko aur kuch naam diye jaate hain jab mein kuch crystallographic mode ki baat karunga ya fracture ke appearance ke saath baat karunga ya path ke saath yaani meri crack kis direction mein ja rahi hai kis path kis path

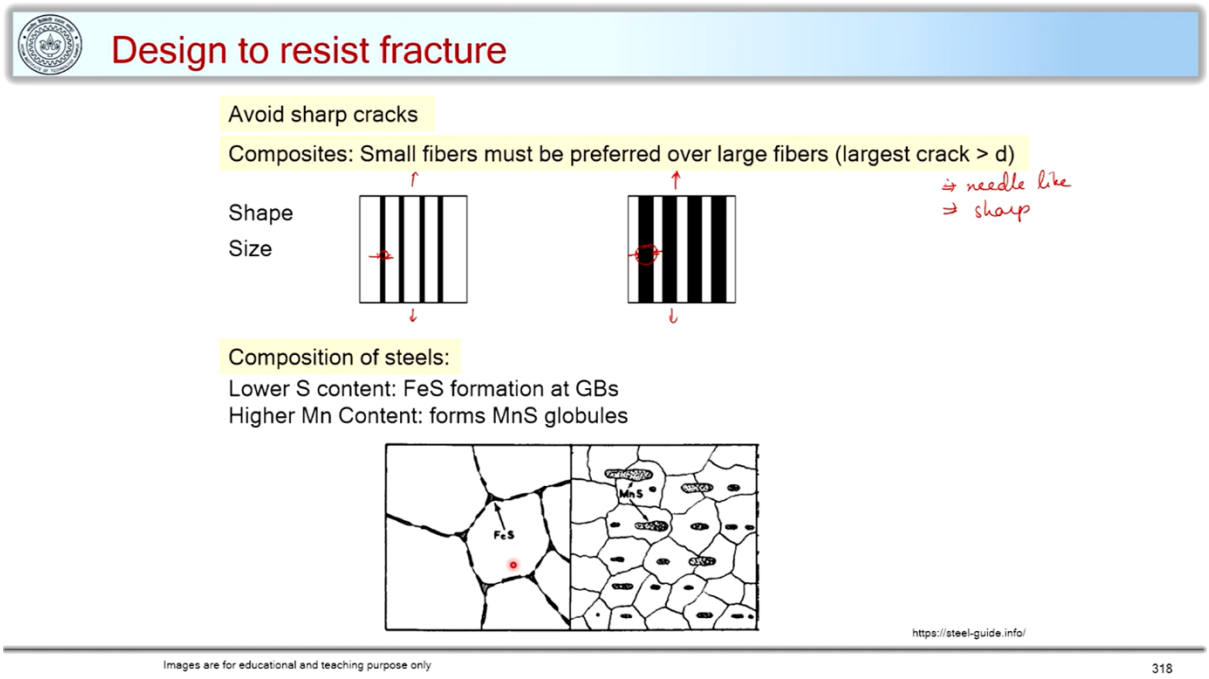
ko le rahi hai us path ke upar bhi mein kuch terminology istemal karta hoon jab mein fracture ki baat karta hoon material ki. To jab mein crystallographic mode ki baat karunga tab jab brittle fracture hoga isko literature mein cleavage bhi kehte hain aur ductile jo fracture hai usko hum kehte hain shear fracture. Yaani aap jab shear failure bologe ya shear fracture bologe tab mein ductile fracture ki baat kar raha hoon par...

mein crystal kisi crystallographic mode ki baat kar raha hoon yeh aapko dhayan mein rakhna hai. Ab mein jab appearance ki baat karunga tab hum dekhte hain ki brittle fracture mujhe granular ya bright dikhta hai halanki jo ductile fracture hai woh mujhe hamesha fibrous ya dull dikhta hai. To yeh ho gaya fracture ke appearance ke baare mein. Phir hum dekhenge fracture path yaani fracture meri crack kis path se guzar rahi hai. Agar fracture intergranular ho raha hai yaani grain boundaries ke through ja raha hai to woh brittle nature dikhata hai material ka aur transgranular ya intragranular fracture ho raha hai woh ductile material hamesha dikhate hain. To yeh ho gaya path ke baare mein. Abhi hum isko thoda sa aur samajhte hain acche se jaise yahan pe hum dekhenge ki yahan pe kuch brittle fracture ke schematics nikaale aur ductile fracture ke schematics yahan pe...

nikaale. Aap dekh rahe honge ki agar mein crystallographic mode ki jab baat karunga yahan par humne dikhaya ki kuch particular plane par agar fracture ho raha hai woh mera cleavage fracture ko generate karta hai aur woh generally brittle material mein mujhe milta hai yaani woh us fracture ko mein brittle kahunga aur agar kuch shear ho raha hai aap dekh pa rahe honge ki yahan pe shear nature yahan pe taiyar ho raha hai to jab mein kisi planes ki jab baat karunga ya crystal mode ki baat karunga tab mein kehta hoon ki usko mein cleavage ya shear fracture se denote karunga jab mein brittle aur ductile fracture ki baat kar raha hoon. Yahan par hum dekh sakte hain ki yeh path bhi hum dekhte hain next slide...



mein. To yahan par aap dekh pa rahe honge ki yeh jo crack hai kuch is tarah se propagate hui hai yaani yeh grain ke through propagate ho rahi hai. Yeh jo crack hai yeh aap dekh pa rahe honge yeh grain boundary ke through propagate ho rahi hai. To is fracture ko mein kehta hoon yeh hai mera transgranular ya intragranular kyunki do grains ke through propagate ho rahi hai isliye isko trans ya intragranular kehte hain aur is fracture ko hum kehte hain intergranular. Aap dekh pa rahe honge ki transgranular mein mera surface kuch is tarah se dikhta hai aur intergranular mein mera surface kuch is tarah se dikhta hai aur agar mera material intergranular failure ho raha hai tab agar aap dekh pa rahe honge ki...



grain boundaries ke through crack propagate ho rahi hai. Agar mein grain ko refine karunga to aapko do cheez yahan par mil sakti hain ki mein grain ki strength bhi badha sakta hoon yaani material ki strength bhi badha sakta hoon aur mein fracture toughness bhi badha sakta hoon material ka. To grain refinement ek aisi technique hai jahan par mein strength aur fracture toughness material ka dono ek saath badha sakta hoon. Yeh ek lauti aisi technique hai jahan par mein dono cheez haasil kar sakta hoon. To abhi hum dekhte hain yeh jo fracture terminology humne baat ki abhi kuch dekhte hain kuch design parameters dekhte hain jisse hum fracture ya material ki jo fracture strength hai ya fracture toughness...

hai usko hum badha sakte hain. To sabse pehle humein sharp cracks avoid karne hain mere material mein. Humne dekha tha ki sharp crack ke aage ek stress field hoti hai high stress concentration hota hai uske wajah se material jaldi fail ho jata hai to isliye humein sharp cracks ko avoid karna hai. To jab mein composites ko develop kar raha hoon tab mein small fibers ka istemal karunga as compared to mere large fibers. Isko thoda sa samajhte hain to aapko samajh mein aa jayega ki mein sharp cracks ki jab baat kar raha hoon to maan lete hain ki mein kuch composite is tarah se develop kar raha hoon aur yeh jo small fiber aap dekh pa rahe hain iski diameter small hai is composite mein iski...

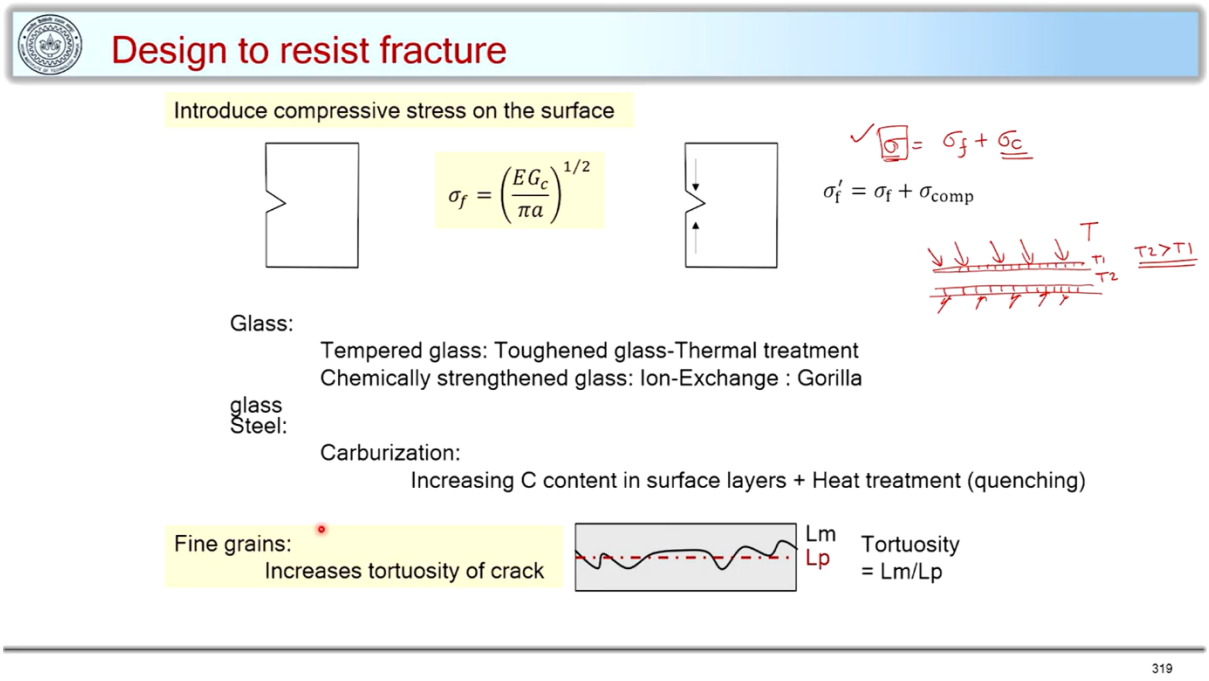
diameter thodi badi hai tab yahan par jab material delaminate hoga maan lete hain ki kis... mein agar isko force apply kar raha hoon to aur material samajh lete hain yahan par delaminate hua hai to jo crack length yahan par taiyar hogi woh badi hogi as compared to is crack length se.

To aap dekhenge ki yahan par agar delaminate ho gaya yaani matrix aur reinforcement ka adhesion toot gaya ya inmein jo continuity hai woh toot gayi to yahan par crack taiyar hogi aur crack ki dimension kuch is tarah se hogi. To jitne bade fiber honge utni badi crack length hogi aur agar mere paas badi crack length hai to mera material jaldi fail hoga ya brittle way se fail hoga. To humein yeh...

isliye avoid karna hai. To largest crack meri jo dimension hogi woh kya hogi is diameter se badi hogi ya exactly equal hogi. To humein bigger fibers ya large fibers ko avoid karna hai. To humne yahan par dekha... aur size to size ke baare mein humne baat ki to shape bhi yahan par jo fibers hain unmein jo fibers hain woh sharp nahi hone chahiye. To fibers ke shape ki jab baat kar raha hoon to woh needle like shapes nahi hone chahiye ya sharp fibers nahi hone chahiye kyunki stress concentration taiyar kar sakte hain aur isse mera material jaldi fail ho jayega. Jab mein composition of steel ki baat karunga yahan pe kuch ek acchi case study...

consider karte hain jaise humne dekha hai ki jab steel ke jab mein design karunga fracture toughness ke liye to mein usmein jo sulfur content hai uska kam karne ki koshish karunga kyunki sulfur jo steel mein hota hai woh FeS taiyar karta hai grain boundaries par. Aur jab mein fracture toughness badhaane ki baat karunga tab mein steels mein hamesha manganese add karne ki koshish karunga kyunki yeh manganese jo hoga woh sulfur ke saath react karega aur MnS globule taiyar karega. To jab FeS taiyar hota hai agar material mein yaani steel mein agar sulfur zyada hai to FeS se mere grain boundaries pe kuch is tarah se taiyar hota hai aur yeh jo FeS ka structure hota hai yeh boundaries pe kuch needle type ya...

sharp edges iske hote hain is precipitate ke aur iske wajah se stress concentration zyada badhti hai aur material jaldi fail hota hai. Agar hum yahan par dekhenge agar maine manganese dala hai mere steel mein to yeh manganese sulfur ke saath react karke kuch is tarah se globules taiyar karega aur yeh grain boundaries pe nahi rahega kuch is tarah se rahega grain mein rahega ya is tarah se uska nature rahega. To yahan pe aap dekhenge ki yeh jo MnS globules hain precipitates taiyar huye yeh kuch stress concentration ko ghatayenge ya badhayenge nahi at least badhayenge nahi. To yahan pe yeh jo material hai woh zyada fracture toughness dikhayega as compared to is material mein jahan...



par manganese kam hai. To yeh classical example tha jab humne steels ki baat ki thi Titanic ke case mein. To Titanic ke case mein sulfur content bahut zyada tha iske wajah se wahan pe yeh precipitates grain boundaries pe taiyar huye aur material catastrophically fail hua hai. To yeh ho gaya jab mein steels ki design ki baat karta hoon. Aaiye kuch aur cheez dekhte hain jab mein fracture ko resist karta hoon tab hum dekh sakte hain ki agar fracture mein agar mein kuch compressive stresses daal dunga surface pe tab kya hota hai. Maan lete hain ki mere paas kuch is tarah se crack hai aur humne dekha tha ki agar fracture stress mujhe kuch is tarah se milega yeh kuch crack length 'a' hai surface par...

is tarah se. Agar mein kuch compressive stresses daal dunga surface par to fracture stress kuch badhega kuch is tarah se. To yeh fracture stress mera add up ho jayega compressive stresses ke saath. Agar kuch compressive stresses hain to mere crack propagation ke liye mujhe high amount of stress ko dena padega tab jaake mera fracture hoga ya ek crack propagate hogi. To compressive stresses mere surface pe hain to fracture toughness material ka badhta hai. To yahan pe haan is tarah se maine mark kiya ki agar yeh mera σf' hai to yeh compressive stress hai aur yeh σf jab koi compressive stress nahi rahega material pe...

ya surface pe tab yeh mera σf hai jo ki is equation se mujhe milta hai. To compressive stresses hamesha mere fracture toughness ko badhayenge. To aapko yeh bhi dhayan rakhna hai agar tensile stresses hain surface par to fracture toughness ko ghatayenge crack ko open karne mein madad karenge. Yahan par aap dekh pa rahe honge ki agar compressive stresses hain to ek

crack ko close karne mein madad kar rahe hain. To humne Dugdale ya Irwin ke model mein bhi yahan par consider kiya tha yeh compressive stresses hain to crack ko woh close karne ki koshish karte hain. Yahan par humne wahan par humne dekha tha ki wahan par plastic zone hai jis jo compressive stresses is crack par consider kar sakte hain. To aapko dekhna hai ki...

surface par tensile stresses na hon ya surface pe compressive stresses zyada hon jo mere fracture resistance ko badhayenge. Jab mein compressive stresses ki baat karta hoon to kuch example yahan pe consider karna chahta hoon jaise ki glass ka. To hum hum dekhte hain ki tempered glass ya toughened glass jo hum normally hamare mobiles par istemal karte hain ya latest technologies mein hum istemal karte hain ki chemical strengthened glass jahan par ion exchange ke istemal karte hain jisko hum Gorilla Glass bhi kehte hain. To yeh bhi hum istemal karte hain tempered glass aur Gorilla Glass. To tempered glass mein jaise mere paas kuch glass material hai glass sheet hai isko maine heat...

kar diya kisi high temperature par aur isko turant nikaal ke agar mein uske upar kuch cool air pass karunga iske surface par to aap dekh payenge ki yeh jo cool air ke wajah se yahan par surface par jaldi yahan par temperature ghat jayega aur yahan pe contract hoga temperature ghatne se as compared to inside material yaani inside temperature yahan par agar mein isko t1 aur isko t2 consider karunga to t2 hamesha zyada hoga kyunki woh inside hai. To aap dekh pa rahe honge ki surface par contraction ke wajah se kuch stresses taiyar honge aur woh compressive nature ke honge aur isko hi hum kehte hain toughened glass.

Yeh Gorilla Glass ke baare mein aap padh sakte hain ki yeh chemical strengthened glass hote hain aur jab mein steels ki baat karunga tab mein carbon add karta hoon aur isko carbonization kehte hain. Jab mein carbon add karta hoon surface par to woh surface par jaake ek compressive stresses yahan pe taiyar karenge. To agar mein in dono ka combination karoon jaise carbonization heat treatment aur isko quench kar doon to surface pe hamesha compressive stresses taiyar honge aur mein material ya steels ki is case mein fracture toughness ko badha sakta hoon. Jab mein fracture ki baat kar raha hoon tab aur ek cheez hum dekhte hain ki maine kaha tha ki fine grains ko agar mein maine material ke...

grains ko agar mein fine kar raha hoon to mein fracture toughness ko badha sakta hoon yeh humne dekha tha. Aur iske hi case mein ek term hamesha istemal ki jati hai literature mein isko kehte hain tortuosity of crack. To actually jab mein fine grain bana raha hoon to humne kaha tha ki agar intergranular fracture hai to grain boundaries ke through agar fracture propagate ho

raha hai aur intergranular hai tab crack ko zyada length travel karna padega. Isko is tarah se samajhte hain ki agar mera material hai aur material kuch is tarah se ja raha hai yaani crack is tarah se propagate ho rahi hai to yeh meri crack ki length hai Lm aur iski projected length bhi mein consider kar sakta hoon agar crack is end se is end...

mein ja rahi hai to is crack ki mein projected length kuch is tarah se consider karunga Lp. Aur hum dekhenge ki tortuosity kuch is tarah se define hoti hai. Mein tortuosity ko is tarah se define Lm / Lp yaani jo total length of crack hai upon projected length Lp. To yeh agar Lm agar zyada hai to aap dekh pa rahe honge ki tortuosity of crack zyada hogi aur yeh fine grains mein jitna hum grains ko fine karenge utni yeh jo length hai crack propagation ki jo distance usko cover karna padega ya yahan is end se is end mein woh bada rahega as compared to uske projected length...

se. To isko hum kehte hain tortuosity of crack aur fine grain ki wajah se humein strength bhi milti hai aur fracture toughness bhi milti hai. To is part mein humne do teen cheezein seekhi jaise LEFM, EPFM aur humne kuch terminology dekhi hai ki jo fracture ko define karti hai aur humne kuch strategies dekhi jisse hum fracture toughness ko badha sakte hain material ke. Last ke kuch parts mein humne fracture ke baare mein padha tha is course ke liye hum fracture ko yahin par rokte hain agle course se hum kuch aur plastic deformation mechanism ke baare mein padhenge. Abhi ke liye rukta hoon. Dhanyavaad.