

Mechanical behavior of materials

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Week-11

Lecture-59

Fracture & Theoretical Cohesive Strength of Materials

Course Title

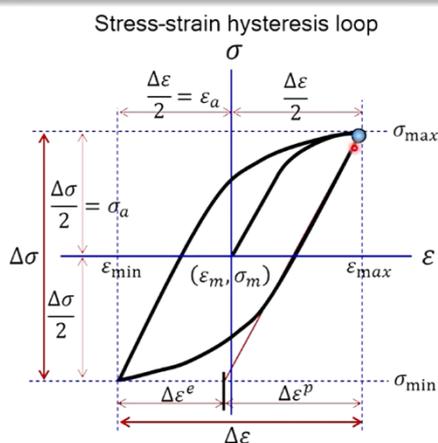
Mechanical Behavior of Materials (Hindi)

Lecture-58 Cyclic stress-strain curve and Strain life curve

Namaskar aapka swagat karta hoon is course mein Mechanical Behavior of Materials jo ki hum Hindi mein padhenge. Last part tak humne fatigue ke baare mein padha aur fatigue ke kuch stages ke baare mein padha. Is part mein hum cyclic stress strain curve aur strain life cycle ya curve kis tarah se define karte hain yeh padhenge. To jab main fatigue padhta hoon tab sabse pehli cheez mind pe aayegi ki cyclic stress strain curve yaani jab tak hum stress strain curve padhte the wahan pe humne static load apply karte the. Cyclic loads kabhi apply nahi kiye. To humein pehle sabse pehle cyclic stress



Cyclic stress-strain curve



- If the loading process is reversed & the specimen unloaded after yielding, the stress-strain relationship will follow a line parallel to the loading direction
- Bauschinger effect (not related to fatigue)
 - The directionality of strain hardening
 - YS in tension increased and YS in compression decreased
- Assuming the material exhibits symmetry along both tension and compression, we get a hysteresis in the stress strain response under loading.

Strain-controlled cyclic loading

- Reversed bending between fixed displacements
- Thermal cycling
- Plasticity near the root of notch experiences strain-controlled conditions

One fatigue cycle = 2 Strain reversals

strain curve samajhna padega. To uske liye kuch is tarah se samjhenge. Yaani jab main stress strain curve ki baat kar raha hoon tab main y axis pe stress plot karunga aur x axis pe strain plot karunga. Aur main kuch is tarah se cycle doonga yaani is tarah se stress measure karunga is strain ke saath ki yeh jo strain hai vo cyclic nature ka strain hai. Aaiye isko samajhte hain. To jab jab main agar strain badha raha hoon mere material ka to mujhe stress badha raha padega. Yeh humne dekha tha ki yeh hamara stress behavior hai. To kuch pehle mujhe elastic part is tarah se milega aur kuch is tarah se plastic part milega ya plastic deformation yahan pe milega.

Generrally humein monotonic curve ya monotonic stress strain curve se yeh information milti hai. Abhi hum dekhenge ki hum main jab strain ko cyclic nature mein change karta hoon to stress kis tarah se change hota hai. To ye ho gaya mera yahan tak main pahunch gaya. Abhi ye strain main fix kar raha hoon mere material pe aur abhi main reverse mein jaunga. Yaani abhi maine ye tensile strain apply kiya tha yahan pe. Abhi main strain ko reverse karunga ya ulte direction mein jaunga to kuch is tarah se mujhe milega. Yaani ye maine positive strain apply kiya. Ab main negative strain kuch is tarah se is direction tak aaunga. To kis tarah se yeh

stress change hoga. To, yeh stress kuch is tarah se mera change hoga. Aap dekh pa rahe hain ki main yahan par tha aur ye strain maine yahan pe is direction mein negative strain apply kiya. To mujhe jo stress response mila hai kuch is tarah se mila hai. To aap dekhenge ki yahan pe kuch point maine likha hai ki jab maine loading reverse ki to yahan pe pehle stress decrease hua aur is point pe aap keh sakte hain ki stress zero hai. To mera specimen unload ho gaya. Ab main reverse direction mein ja raha hoon ya reverse loading kar raha hoon to stress strain relation kuch is tarah se mujhe milega aur ye jo jab main reverse direction mein jaunga tab initially aap dekhenge ki ye jo

part hai ye linear rahega is linear part se. To aap dekhenge ki stress and curve ya nature kuch is tarah se mujhe milega. Abhi aap dekh pa rahe honge ki yahan pe yielding main jab agar main is strain ko tension maan ke chal raha hoon to is direction mein yielding mujhe kuch is stress pe mil raha hai. Aap dekhenge ki generrally jab main reverse karta hoon strain ya reversal loading karta hoon to yielding kuch lower stresses pe milegi. Agar main yeh tension mein apply karta ya compression mein kuch is tarah se apply karta to yeh jo yield strength hai vo same aana chahiye tha. Par aap dekhenge ki jaise hi maine isko yahan pe

reverse kiya hai, yeh yield strength compression mein kam aa raha hai. Isko hum kehte hain Bauschinger effect. Aap dekhenge ki ye jo strain hardening ki directionality hai, yeh depend karegi kis direction pe main load kar raha hoon. To, aap dekhenge ki yield strain yahan pe is case mein mujhe tension mein zyada mil raha hai aur yield strength compression mein mujhe kam mil raha hai. To, yeh vice versa bhi ho sakta hai. Aur is effect ko hum kehte hain Bauschinger effect. Yeh fatigue se related nahi hai. Par yeh jo nature hai stress strain curve ka yeh samajhne mein Bauschinger effect ka bhi humein madad milta hai. To yeh ho gaya mera stress strain curve aur yahan tak maine aa gaya

negative strain tak. Abhi main phir se positive strain tak jaunga. To ek cycle meri complete hogi. Kuch is tarah se main phir se strain yahan par badhane ki koshish karunga aur mujhe kuch is tarah se ek loop milega stress strain loop ya abhi jaise maine direction meri reverse kar di to aap dekhenge ki ye jo pehla part hai ye linear rahega is part se aur phir yahan pe jaake yeh mujhe plastic part milega aur stress strain nature kuch is tarah se milaiga. To ek humein ek loop milta hai. To aapko yeh loop milega aur main agar yeh strain cycles is tarah se hi continue karunga to ek loop mujhe ye continuous loop is tarah se milte

rahega. Aur ismein kuch assumptions hum consider kar rahe hain. Ye ek ideal loop jab mujhe milta hai. Ye main consider kar raha hoon ki tension compression mein ek symmetry maintain ho rahi hai stress strain behavior ki. To isi liye mujhe ye kuch is tarah se milra hai. Hum aage bhi challenge ki ye loop kis tarah se change hota hai jab mere hardening behavior material ka hardening behavior change hota hai. To ye ek loop mujhe mila hai. To abhi hum kuch parameters dekh lete hain. To aap dekhenge ki ye stress axis hai. Aur is stress axis pe maine yahan pe do lines mark kar liye. Aur ye jo stress hai ye maximum stress hai mera. Aur yeh material experience karega minimum

stress. To isko hum likh lete hain σ_{max} aur σ_{min} . Aur humein pata hai ki σ_{max} aur σ_{min} ka difference $\Delta\sigma$ hum likhte hain. Jab main cyclic stress ki baat kar raha hoon ya cyclic nature of stress ki baat kar raha hoon. To ye $\Delta\sigma$ isko sigma range bhi humne kaha tha. Ye difference hai $\sigma_{max} - \sigma_{min}$. Abhi humne dekha hai ki yahan pe maine kuch do lines aur draw kar di. Yeh bata rahi hai meri strain range. Aap dekh pa rahe honge ki main is point se is strain tak positive strain apply kiya hai. Aur yahan se maine ek negative strain apply kiya hai. To main yahan pe bhi kuch is tarah se likh sakta hoon

stress ki tarah. Ek ϵ max aur ek ϵ min. Abhi main strain range bhi yahan par likh sakta hoon. $\Delta\epsilon$ yeh meri strain range ho gayi. Abhi hum dekhenge ki agar mujhe is strain range mein ab maine kaha tha yahan par ek linear part hai, ek plastic part hai. To hum yahan pe nikaalenge ki is strain range mein kitna percent elastic part hai aur kitna percent plastic strain hai. To uske liye hum kya karte hain? Uske liye bhi hum simple ek humne methodology consider ki thi ki jab main is draw line ko draw karke seedhe yahan pe is line pe jab intersect hoga vo jo remaining strain rahega

vo mera elastic strain rahega. To aap dekh pa rahe honge ki agar mere paas $\Delta\sigma$ hai aur mujhe Young's modulus pata hai to main strain nikaal sakta hoon ki elastic strain part kya ho sakta hai vo nikaal sakta hoon. Wahi methodology hum yahan pe dekhenge. To main ek line draw ki yahan pe seedhe aur ye ek yahan pe intersect karenge ye ye jo part hai yahan pe to hum kya consider kar rahe hain agar mera stress strain curve kuch is tarah se rehta agar is tarah se main consider kar raha hoon to yahan pe ek $\Delta\sigma$ hai ye poora aur iske according kitna elastic strain material mein ho sakta hai. To, hum dekhenge ki is methodology se mujhe pata chal sakta hai ki yeh

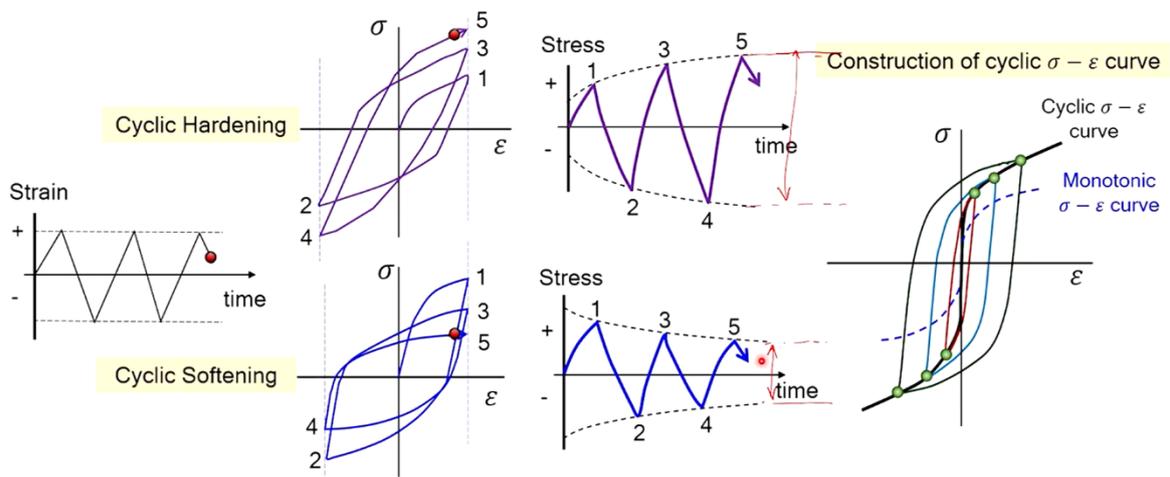
jo amount hai, yeh mera elastic strain part hai. To, remaining part agar hum $\Delta\epsilon$ agar consider karenge, to remaining part jo hoga vo mera $\Delta\epsilon$ p hoga jo ki plastic part hoga. Yeh hogi plastic strain range aur isko main kahunga elastic strain range kyunki yeh meri total strain range hai. Abhi hum dekhte hain ki agar mere paas $\Delta\sigma$ hai to yeh jo point hai is point ke around yeh jo curve hai ye symmetric hai to isliye main iske kuch coordinates mark kar loonga ϵ m aur σ m ye mean stress ya mean strain ki baat yahan pe main kar sakta hoon. To agar is point ko main ϵ mean yaani yahan pe main likh leta hoon ki

yahan pe ϵ mean yaani yeh mean hai. Minimum nahi hai. Aur σ m yeh bhi sigma mean hai. To ye point agar maine yahan pe mark kar liya to is point ke hisab se main dekh paunga ki ye jo part hai ye ho jayega $\Delta\sigma / 2$ ye bhi part $\Delta\sigma / 2$ abhi $\Delta\sigma / 2$ agar main dekhunga ye sigma mean se σ max ye ye kya hoga mera? Yeh mera hoga stress amplitude. To yeh bhi ek stress amplitude hoga. Usi tarah se main yeh point ko likh sakta hoon. Strain ke baare mein bhi likh sakta hoon. Ye jo part hoga ye hoga $\Delta\epsilon / 2$ aur ye jo $\Delta\epsilon / 2$ hoga ye hoga mera strain amplitude. To hum is analogy se ye

part bhi likh sakte hain strain ke baare mein. To ye ho gayi meri cyclic stress strain curve. Yahan pe aap dekh lenge ki mera cyclic stress strain curve kuch is tarah se aa raha hai. To ye

kahan pe important hai isko samajhte hain. Aur ye jo hysteresis loop mila hai isko main kehta hoon stress strain hysteresis loop. Aur ye kahan pe important hai? Ye important hoti hai us applications mein jahan par main dekhta hoon ki mere displacements fixed hain. To aap dekhenge ki yahan pe strain material jo cyclic strain ja raha hai vo ϵ_{max} se ϵ_{min} tak ja raha hai. Initially humne abhi tak padha tha ki stress fluctuate ho raha tha ek maximum value

 **Cyclic stress-strain curve: Hardening and Softening**



se minimum value tak. Abhi hum kya ka rahe hain? Hum consider kar rahe hain ki ϵ_{max} se ϵ_{min} tak ja rahe hain aur hum stress strain curve yahan pe consider kar rahe hain. To ye milta hai humein jab displacement fixed ho aur waisi condition kab aati hai jab mere paas thermal cycling ho materials ki ya aap dekhenge ki jab mere material mein kuch cracks hain ya notches present hain aur uske aage kuch plastic region hai vo plastic region hamesha ek strain controlled condition experience karega. To is conditions mein humein strain control cyclic loading milti hai. To yeh ho gaya hamara ek introduction cyclic stress strain curve ka aur iski hum abhi

utility dekhte hain. Aur yahan pe ek aur cheez yahan pe main mention karna chahta hoon jo ki hum aage chalke is part mein bhi istemal karenge ki ek one cycle fatigue ke ek one cycle mein do strain reversals hain. To aap dekh pa rahe honge ki yahan pe ek strain reversal ho gaya aur ek doosra strain reversal ho gaya. To ek strain cycle mein ye poore ek strain cycle mein mere paas do strain reversals milte hain. Abhi hum dekhte hain ki jab main kuch strain is tarah se change karta hoon. Ye meri strain cycle hai. Aap dekh pa rahe honge ki yahan pe main ek positive strain apply kar raha hoon. Negative strain apply kar

raha hoon. Aur meri ye strain cycle kuch is tarah se samay ke saath change ho rahi hai. To abhi hum dekhte hain ki material kis tarah se behave karta hai. To material uske liye hum phir se strain stress versus strain plot karenge. Ek maine ek examples diye yahan pe cyclic hardening aur cyclic softening. Yaani jaise-jaise main strain badha raha hoon ya strain cycle de raha hoon material ka. Waise-waise mera material harden ho raha hai, us material ko main ek cyclic hardening material kehta hoon. Aur agar stress ghat raha hai to main usko cyclic softening kehta hoon. To aaiye isko samajhte hain. To is case mein aap dekhenge ki main yahan se shuru kiya. Main strain

cycle diya. Yahan pe main aaya. Phir yahan se aap dekhenge ki meri stress badh rahi hai. Kuch is tarah se aur yahan par bhi teesre cycle mein chauthi cycle mein kuch is tarah se meri strain stress badh rahi hai. Is case mein aap dekhenge maine yahan se shuruat ki hai aur jab main jaise-jaise cycle karta hoon to yeh stress ghat raha hai per cycle ke saath. Jaise-jaise meri cycle badh rahi hai waise-waise ye jo stress hai vo ghat raha hai. To agar main ye strain amplitude fix kar doon yahan pe ya strain range fix kar doon in donon case mein to hum ye points kuch is tarah se mark kar sakte hain. Agar ye mera pehla point hai to yahan pe mujhe stress is tarah se mila hai. Doosre point

pe jab main yahan pe aaunga to stress mujhe kuch is tarah se mila. Teesre point pe stress is tarah se chauthi point pe yahan pe aur paanchve point pe yahan pe. To aap dekhenge ki is cycle ke saath mera stress jo hai vo badh raha hai. Do jo strain amplitude hai vo constant hai ya strain range jo hai vo constant hai. Is case mein hum dekhte hain softening ke case mein aap dekhenge ki ye jo stress hai each cycle ke saath ye ghat raha hai. Kuch is tarah se ye first tha. Ye second point phir ye third point fourth point aur fifth point. To is cycle ke saath yeh kuch is tarah se ghat raha hai. To isko is tarah se samajh sakte hain ki meri cycle is tarah se badh rahi hai.

Aap dekh pa rahe honge ki aap iski locations dekhiye is ball ki to aap dekh pa rahe honge ki mera stress ismein badh raha hai. Is case mein ghat raha hai. To jahan pe stress ghat raha hai usko main kehta hoon cyclic softening aur jahan pe stress badh raha hai usko main kehta hoon cyclic hardening. To main kuch is tarah se bhi likh sakta hoon ya dikha sakta hoon. Jaise stress aur time main plot karunga is cycle ke anusar. To yahan par main dekh pa raha hoon ki ye jo stress hai is cycle ke saath badh raha hai. Kuch is tarah se to aap dekh pa rahe honge ki stress ki jo value hai vo badh rahi hai cycle ke saath. Isliye isko cyclic hardening kehte hain. Yahan pe ghat rahi hai. Isko hum cyclic softening kehte

hain. To kuch samay ke baad jaise main number of cycles badhaunga. Yahan pe paanch cycles tak humne dikhaya. Jaise number of cycles jaise-jaise badhegi to ye value saturate ho jayegi ek constant value ke saath. Ye material bahut saare material hain. Softening ke case mein bhi ya hardening ke case mein bhi ye value ek level pe jaake saturate ho jati hai. Jaise main yahan pe mark kar sakta hoon. Jaise ye value yahan pe kuch is tarah se constant ho jayegi. Similarly yahan pe bhi ye value constant ho jayegi. Yaani ye jo difference hai ye saturate ho jayega. Ye constant ho jayega. To hum cyclic stress strain curve kuch is tarah se nikaal sakte hain.

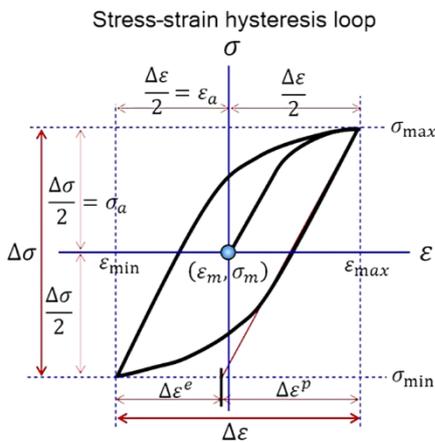
Jaise abhi main cyclic stress strain curve nikaalunga. Humne monotonic stress strain curve nikaala hai. Jaise yeh stress hai aur strain hai. Jaise-jaise main strain badha raha hoon to mera monotonic stress strain curve kuch is tarah se mujhe behavior deta hai. Jaise strain badh rahi hai to hum dekhte hain ki stress us hisab se badhta hai. But cyclic stress strain curve mein hum kya karte hain? Hum different strain range ke liye ya strain amplitude ke liye hum ye hysteresis loop nikaalte hain. Kuch is tarah se ye ye mera strain range ho gaya aur is range ke liye ya strain amplitude ho gaya. Is amplitude ke liye main ek hysteresis loop nikaala. Uske

baad maine strain range ya strain amplitude badhaya hai. To mujhe ye kuch is tarah se hysteresis loop mila. To over strain amplitude badhaya to aap dekhenge ki mujhe is tarah se ek hysteresis loop mila hai. To aap dekh pa rahe honge ki jaise-jaise main strain range ya strain amplitude badha raha hoon to waise-waise hysteresis loop badh raha hai. To abhi hum kya karte hain? Agar mujhe cyclic stress strain curve construct karna hai, to hum yeh jo saturated points hain yahan pe yeh mere saturated curves hain ye values hum yahan pe consider karte hain. To yahan pe ek point hai. Ye ek saturated point hai stress ka. Ye ek saturated point hai stress ka.

Isko hum connect karte hain. Kuch is tarah se ye points maine mark kar liye. Aur isko main connect karunga aur mujhe ek cyclic stress strain curve yahan pe milega. Ye information humein isliye zaroori hai kyunki ye fatigue jab application hum karte hain to ye stress strain curve hum istemal karte hain na ki monotonic stress strain curve. Agar maan lijiye ki agar material mein ek saturation point nahi pahunchta hai, to hum ek maximum value of stress yahan pe hum consider karte hain aur us points ko hum join karke yeh cyclic stress strain curve nikaalte hain. To, yeh ho gaya mera softening aur hardening behavior cycles ke saath. Abhi hum jaante hain ki kuch equations



Cyclic Hardening and Softening



$$\Delta \varepsilon = \Delta \varepsilon^e + \Delta \varepsilon^p$$

$$\Rightarrow \frac{\Delta \varepsilon}{2} = \frac{\Delta \varepsilon^e}{2} + \frac{\Delta \varepsilon^p}{2}$$

$$\frac{\Delta \varepsilon}{2} = \frac{\Delta \sigma}{2E} + \frac{1}{2} \left(\frac{\Delta \sigma}{K'} \right)^{1/n'}$$

$$\sigma = k \varepsilon^n \quad \Delta \varepsilon^e = \frac{\Delta \sigma}{E}$$

n : monotonic strain-hardening exponent

Similarly, we can write

$$\Delta \sigma = K' (\Delta \varepsilon^p)^{n'}$$

Where,
 n' : the cyclic strain-hardening exponent
 K' : the cyclic strength coefficient

$n' = 0.10 - 0.20$ for metals

For Monotonic

When, $n > 0.15$: Cyclic hardening, and when $n < 0.15$ cyclic softening

$$\frac{\sigma_{UTS}}{\sigma_{YS}} > 1.4 \Rightarrow \text{Cyclic hardening}$$

$$\frac{\sigma_{UTS}}{\sigma_{YS}} < 1.2 \Rightarrow \text{Cyclic softening}$$

hum yahan par likh lete hain jo ki humein help karegi fatigue life ko determine karne ke liye. To ye humne dekha tha ki mere paas ek stress hysteresis loop milta hai. Ye ek cycle ke liye humne likha hai yahan pe aur is relation se hum likh sakte hain ki ye jo $\Delta \varepsilon$ hai ye comprises hai do part ka ek elastic part aur ek plastic part. To main kuch is tarah se inko likh sakta hoon mathematically aur abhi main isko agar strain amplitude mein agar convert karna chahta hoon kyunki strain amplitude hi important parameter hai jo hamare fatigue life ko determine karta hai ya ye measure karne mein aasani deta hai. To isko main strain amplitude mein jab convert

karunga to isko mujhe do se divide karna padega. Kyunki humne dekha hai ki strain amplitude ye kya hai? $\Delta \varepsilon / 2$ similarly hum stress amplitude ko bhi jab dekhte hain to $\Delta \sigma / 2$ consider karte hain. To yahan pe main strain amplitude ko consider karunga. Agar main isko divide karunga to mere paas ek elastic strain amplitude aayega aur ek plastic strain amplitude aayega. Abhi hum monotonic stress strain curve ki baat karenge. Ye relation humne dekha tha $\sigma = K * \varepsilon^n$ jahan pe n jab humne introduce kiya tha ye mera strain hardening exponent tha. To abhi hum dekhenge ek

similar approach aur same analogy se hum cyclic stress strain curve kya define kar sakte hain kuch is tarah se to hum likh sakte hain ye $\Delta \sigma = K' * (\Delta \varepsilon^p)^{n'}$ to ye jo n' hai ye mera cyclic strain hardening exponent hai. Ye monotonic strain hardening exponent tha. Yeh mera cyclic strain hardening exponent hai. Aur yeh jo K' hai, yeh cyclic strength coefficient hai. To, aap dekh pa rahe honge ki similarity in donon ki kuch is tarah se hai. Yahan pe bhi sigma hai. Ye

sigma ka term hai. Ye ek strength coefficient hai. Yahan pe bhi ek strength coefficient tha. But ye monotonic strength coefficient hoga. Ye

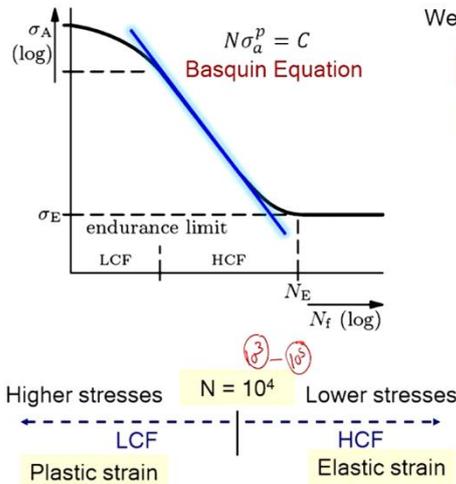
cyclic strength coefficient hoga. Aur yeh jo strain tha yeh plastic strain tha. Aur yeh bhi hai. Yeh plastic part hai. Mere cyclic loading ki baat kar raha hoon. Aur yeh bhi ek exponent hai is strain ka plastic strain ka. To yahan se main is equation ko kuch is tarah se likh sakta hoon. Aur humne ye jo part nikaala hai is strain ko bhi elastic strain ko main kuch is tarah se likh paunga. Jaan lete hain ki ye jo n' hai ye 0.1 to 0.2 for metals ke liye vary hota hai. Abhi main is strain amplitude ko kuch is tarah se likh paunga. Yaani elastic strain amplitude ko main jaise ye $\Delta \epsilon_e$ hai. Isko main $\Delta \sigma / 2E$

likh sakta hoon. Yaani yahan pe aap dekhenge ki ye jo part hai $\Delta \epsilon^e$ isko main $\Delta \sigma / E$ likh sakta hoon. Agar mujhe Young's modulus material ka pata hai to. To ye part yahan pe maine replace kar diya. Aur yeh jo plastic part hai, yeh equation se maine ismein yahan pe likh liya hai. To, yeh ho gaya mera total strain amplitude jo ki elastic strain amplitude hai aur ek plastic strain amplitude ka part hai. Isko hum revisit karenge just do teen slides ke baad aur consider karenge jab main strain life likhunga mere material ke liye. To for monotonic material. To jab hum monotonic stress strain curve karte

hain usse bhi humein kuch idea mil jata hai ki material cyclic hardening hai ya cyclic softening hai. To ek empirical relations main yahan pe de raha hoon. Jaise n ki value yaani monotonic strain hardening exponent ki value greater than 0.15 hai to vo material cyclic hardening behavior dikhata hai aur generally agar n ki value less than 0.15 hai vo cyclic softening dikhata hai. Kuch aur parameters aap consider kar sakte hain. Jaise ratio consider kar sakte hain UTS ka material ke UTS ka ratio uske yield strength ke saath aur vo agar greater than 1.4 hai to vo cyclic hardening deta hai aur agar vo less than 1.2 hai vo cyclic softening deta



Fatigue Life Relationships



We need to know if there's a measurable plastic deformation occurring

If, plastic deformation $\epsilon - N$ diagram

If, elastic deformation $\sigma - N$ or S-N diagram

If we reformulate the Basquin Equation as follows

$$N\sigma_a^p = C$$

$$\Rightarrow \sigma_a = C^{1/p} N^{-1/p}$$

$$\sigma_a = \sigma_f' (2N_f)^{b_0}$$

$2N_f$ = number of load reversals to failure

Where,

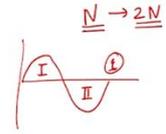
σ_a = stress amplitude

$\Delta\epsilon_e/2$ = strain amplitude (elastic)

σ_f' = fatigue strength coefficient

b = fatigue strength exponent (values: -0.05 to -0.12)

$$\sigma_a = \sigma_f' (2N_f)^{-x}$$



hai. In donon ke beech mein agar values hain to material ko aapko test karke dekhna padega ki woh cyclic hardening ya softening deta hai. Yeh empirical relations hain. Agar aapko cyclic strain curve nikaalna hai to aapko practically nikaal ke dekhna padega. Ye just ek empirical relations hai mere monotonic values se. To ye ho gaya cyclic hardening aur softening. Abhi aage badhte hain aur hamari fatigue life relations ko hum abhi consider karte hain. To yahan pe main ek cycle S N curve yahan pe maine plot kiya hai. Yahan pe stress hai y axis pe aur x axis pe cycles hain. To yahan pe humne isko convert ya isko humne likha tha lo

cycle fatigue aur high cycle fatigue. Aur ye jo value hai yahan pe material is cycle ke baad ya is stress ke neeche infinite number of cycles endure kar sakti hai. Usko humne likha tha endurance limit. Ye humne initial classes mein jab fatigue hum padh rahe the tab humne dekha tha. To humne kuch distinguish kiye the. Jaise n ki value agar number of cycles 10^4 hai. Uske neeche hai, to usko main kehta hoon lo cycle fatigue. Kuch books mein aap dekhenge ki n ki value 10^5 bhi likhi rehti hai ya kuch books mein 10^3 likhi rehti hai ya 10^5 tak. To ye typical range hai. Main 10^4 yahan pe consider kar raha hoon.

Agar 10^4 ke neeche hai to main isko hum kehte hain low cycle fatigue aur yahan pe hum dekhenge ki higher stresses dominate karte hain. Agar main low cycle fatigue regime mein hoon. Agar aap dekhenge ki yahan pe main ek line draw kar raha hoon to ye jo stresses hain ye material experience kar raha hai. Ye high stresses hain as compared to high cycle fatigue mein aap dekhenge ki ye jo stresses hain ye lower stresses hain. To aap dekhenge ki agar higher

stresses hain to material mein plastic strain dominate karta hai. Agar lower stresses hain to material mein elastic strain dominate karta hai. Abhi hum isko aur achhe se samjhenge.

To agar mujhe material ki life ke baare mein kuch idea dekhni hai to mujhe is material mein jo plastic deformation occurring hai usko dhoondna padega. Uske liye hum kuch methodology dekhte hain. Agar plastic deformation mein plastic deformation hai material mein to main preference doonga strain versus number of cycles ke diagram ko. Agar elastic deformation dominate karta hai tab hum stress SN diagram ya stress versus number of cycles diagram ko preference denge. To yahan pe maine SN diagram yahan pe dikhayi hai. Agar plastic deformation ho raha hai to aap dekhenge ki yeh jo strain versus N diagram isko hum consider karenge. Isko hum plot karenge kuch understanding ke saath.

To jab humne stress versus number of cycles ki diagram jab dekhi thi tab humne ek iska ek empirical relation consider kiya tha. Yahan par yeh jo part hai isko maine jab consider kiya tha isko hum explain kar sakte hain Basquin equation ke saath aur Basquin equation ko humne is tarah se likha tha. $(\sigma a)^p = C$ Abhi main is Basquin equation ko kuch is tarah se reformulate kar sakta hoon aur main yeh stress amplitude kuch is tarah se nikaal sakta hoon. To, yahan par aap dekhenge ki maine is power ko aise consider kiya. To, mujhe $C^{(1/p)} * n^{(-1/p)}$ is equation ko just reformulate humne kiya hai.

Abhi isko main kuch is tarah se phir se likh sakta hoon. Ye stress amplitude hai. Aur ye $C^{(1/p)}$ ko main ek $\sigma' f$ likh sakta hoon. Aur ye jo n hai isko main $2N f$ likh raha hoon. Aur ye jo $-1/p$ hai isko main b consider kar raha hoon. To yahan pe ye jo $\sigma' f$ hai ye mera fatigue strength coefficient hai. Aur ye jo $2N f$ yahan pe humne consider kiya. Ye number of load reversals to failure hai. Yaani humne yahan pe consider kiya tha agar mere paas kuch cycle hai kuch is tarah se to ek cycle hai to ek cycle mein mere do reversals honge. Stress reversals ya strain reversals honge.

To agar mere paas n number of cycles hain ya n number of cycles material sustain kar raha hai to wahan par main consider kar sakta hoon ki twice n mere load reversals ya strain reversals to failure main yahan pe consider kar sakta hoon. To, isliye maine isko twice NF likha hai. To, ab yeh jo b hai, yeh mera fatigue strength exponent hai. Aap dekhenge ki iski value yahan pe

maine $-1/p$ ko likh hai. Isko maine positive convert kiya hai. To, iski jo b ki value hai vo negative hogi. aur values hain typically -0.05 to -0.12 . Agar yahan pe is equation ko kisi-kisi kitab mein kuch is tarah se bhi likha rehta hai. $\sigma_a = \sigma'_f * (2N_f)^{-b}$

Isko main x consider karunga to aap dekhenge ki ye x ki value yahan pe phir positive ho jayegi to aapko ye samajhna hai ki ye equation kis tarah se aaya hai. To ye equation main yahan par consider karunga. $\sigma_a = \sigma'_f * (2N_f)^{-b}$ Abhi ye equation mein agar main yahan pe consider karta hoon to maan lete agar complete elastic strain hai mere paas kyunki humne high cycle fatigue pe consider kiya tha. Basquin equation bhi hum high cycle fatigue pe consider kar rahe the. Agar poor elastic strain hai to main elastic strain ke liye kuch is tarah se likh sakta hoon. Ye $\sigma_a = \Delta \epsilon / 2$ ye mera stress amplitude hai.

Strain controlled fatigue: Elastic strain and Plastic strain

$\sigma_a = \sigma'_f (2N_f)^b$

If all strain is elastic

$\sigma_a = \frac{\Delta \sigma}{2} = \frac{\Delta \epsilon^e E}{2}$

$\epsilon_a^e = \frac{\Delta \epsilon^e}{2} = \frac{\sigma_a}{E} = \frac{\sigma'_f (2N_f)^b}{E}$

$\epsilon_a^e = \left(\frac{\sigma'_f}{E} \right) (2N_f)^b$

Contribution in HCF

Where,

$\frac{\Delta \epsilon^e}{2}$ = elastic strain amplitude

$\frac{\Delta \epsilon^p}{2}$ = plastic strain amplitude,

ϵ'_f = fatigue ductility coefficient (regression intercept)

C = fatigue ductility exponent (regression slope)

$2N_f$ = number of strain reversals (one cycle is two strain reversals)

$\epsilon_a^p = \frac{\Delta \epsilon^p}{2}$

$\epsilon_a^p = (\epsilon'_f) (2N_f)^C$

Coffin-Manson relation

Contribution in LCF

For low-cycle fatigue applications, using the test data, a plot of the plastic strain range ($\Delta \epsilon_p$) is plotted as a function of number of cycles to failure.

Mechanical Metallurgy: GE Dieter

Ye humne dekha tha cyclic stress strain curve se. Isko main is $\Delta \sigma$ ko main kuch is tarah se likh sakta hoon. $\Delta \epsilon^e * E$ Yaani elastic strain part aur multiply by Young's modulus. To $\Delta \sigma$ ko kuch is tarah se likh sakta hoon. Abhi yeh jo part hai $\Delta \epsilon^e / 2$ yeh kya hoga? Yeh strain amplitude hoga aur is strain amplitude ko main is equation se kuch is tarah se nikaal sakta hoon. σ_a / E stress amplitude / E aur stress amplitude ki value main kuch is tarah se is equation se yahan pe likh sakta hoon. To agar main ye value yahan pe put karunga to mujhe ye identity milegi aur main kuch terms rearrange karunga to mere paas ek strain amplitude aayega.

Elastic strain amplitude aayega kuch is tarah se. Aur ye jo elastic strain amplitude hai, ye contribute karega mere high cycle fatigue mein. Usi tarah se hum abhi dekhte hain ki plastic strain kahan pe contribute karta hai. To humne consider kiya tha ki low cycle fatigue mein plastic strain contribute karta hai. To hum kuch is tarah se likh sakte hain ki ye mera plastic strain amplitude hai. Isko main aisa likh sakta hoon $\Delta \epsilon_p / 2$ aur same analogy main yahan pe consider karunga aur is equation ko likhunga. To main kuch is tarah se likh raha hoon yahan pe. Yeh mera plastic strain amplitude hai.

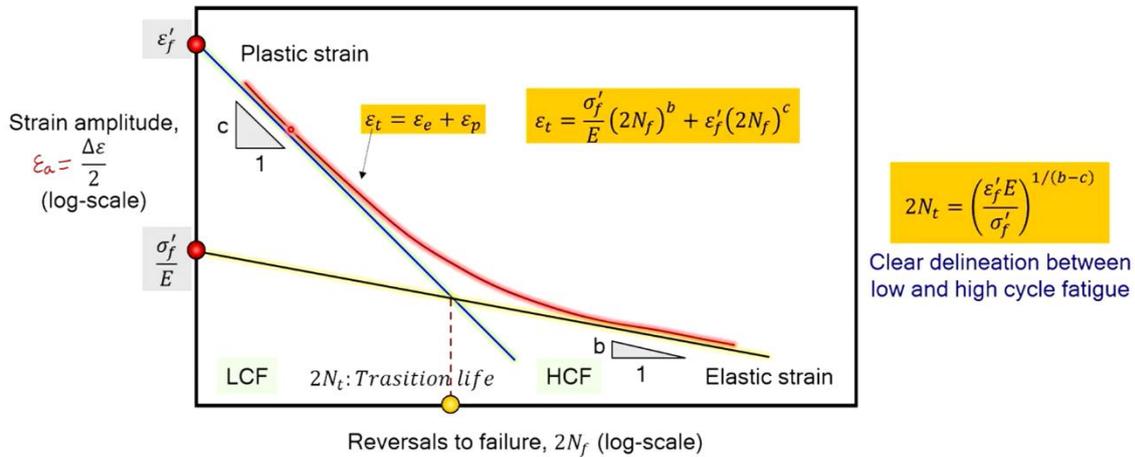
Isko ye jo part hai isko main yahan par sirf likh raha hoon. $\epsilon'_f * (2N_f)^c$ aur ye jo c ki value bhi hai ye bhi meri negative hogi. jaise b ki value negative hai, waise bhi c ki value yahan par negative hai. Aap dekhenge ki yeh jo part hai, yeh mera jo part hai, yeh nothing but mera strain part hai. Kyunki iska is isko hum consider karenge. Iska unit dimensionless hoga. Aur ye jo identity hai, ye mujhe strain value degi. Isliye yahan pe humne ek fatigue ductility coefficient ye introduce yahan pe kiya hai. Aur yahan pe ye jo c hai ye fatigue ductility exponent hai aur $\Delta \epsilon_e$ hai ye elastic strain amplitude hai.

aur ye plastic strain amplitude hai. To hamare paas donon strain amplitudes yahan pe humein mil gaye hain. Aur humne dekha hai ye jo equation hai isko Coffin-Manson relation bhi kehte hain. Aur ye jo plastic strain hai ye contribute karega mere low cycle fatigue mein. To aap dekhenge ki achha relation yahan pe ye relation follow hota hai mostly steels ke liye most of the materials ke liye. Aur iska jo iska jo slope hai ye humein c ki value dega. To ye ho gaya plastic strain range versus cycles to failure aur ek ek neat linear relation yahan pe humein mil raha hai jab hum log-log scales plot kar rahe hain.



Strain life curve

Now one can combine the Coffin-Manson equation (plastic strain amplitude) and the modified Basquin's equation (elastic strain amplitude) to get the total strain amplitude. $\Delta\varepsilon = \Delta\varepsilon^e + \Delta\varepsilon^p$



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To abhi hamare paas do strain amplitudes aa gaye hain. Abhi hum total strain nikaalenge kuch is tarah se. Agar mujhe total strain nikaalna hai, isko main kahunga strain life curve. To main donon equation ko add kar doonga Coffin-Manson equation aur Basquin equation. Yeh humne dekha tha jab humne cyclic stress strain curve padha tha to humne total strain ko kuch is tarah se likha tha. Aap agar peechhe jaake dekhenge to aapko ye relation milega. To is identity ke basis pe main ek total strain equation likh sakta hoon ya total strain amplitude likh sakta hoon. Kuch is tarah se usko main likhunga strain amplitude.

Vo hoga $\Delta\varepsilon / 2$ isko yahan pe is tarah se bhi likh sakte hain. Ye mera total strain amplitude ho gaya. Aur ye ho gaya n reversals to failures ye $2N_f$ aur ye donon log-log scale mein. To agar main total strain amplitude kuch is tarah se likhunga. Yahan pe ε_t likha hai. Ye nothing but ε a bhi consider kar sakte ho. Ye ho gaya elastic part aur ye ho gaya plastic part. Agar main in donon ko add karunga to kuch is tarah se humein relation milega. Agar main plot karne ki koshish karunga to mujhe kuch is tarah se ye total strain amplitude mujhe milega. Ye total strain amplitude milega.

Abhi humein agar contributions nikaalne plastic strain aur elastic strain ke to main kya karta hoon? Ye jo portion hai yahan pe yahan pe kuch tangents draw karunga. Kuch is tarah se. To mujhe yeh jo contribution mil jayega yeh mujhe milega plastic strain ka contribution mere strain amplitude mein agar aap dekhenge ki yahan pe ye jo slope hai ye slope ki value c milegi mujhe. Agar ye plastic strain part main consider kar raha hoon to slope ki value mujhe c milegi.

Aur aap dekhenge ki ye negative slope hai to c ki value yahan pe negative rahegi. Aur aap dekhenge ki ye jo intercept hai ye mera $\epsilon' f$ hai.

To ye intercept bhi hum yahan se nikaal sakte hain. Similarly hum elastic strain ka contribution kuch is tarah se nikaal sakte hain. To agar main ye tangent draw karunga to ye mujhe elastic strain ka contribution nikalega. Agar iska slope hum dekhenge to iska slope aayega b abhi value b ki value bhi negative rahegi. Aur yahan pe agar hum intercept dekhenge to intercept mujhe $\sigma' f / E$ milega. Abhi aap dekhenge ki yeh plastic strain aur elastic strain jab main inhein lines draw ki hai to ye ek yahan pe ek intersect kar rahi hai. Ye mujhe ek point degi. Is point ko is intersect ke corresponding jo cycle hai

number of cycles yeh mujhe batayegi ki transition life kya hai? To aap dekh pa rahe honge ki maine plastic strain ka contribution nikaala hai aur maine elastic strains ka contribution nikaala hai mere total strain amplitude mein. To main ek clearly bata paunga ki plastic strain aur elastic strain kab dominate kar sakta hai. To yeh transition life ye jo transition point hai isko main kahunga transition life. Aur is transition life ke dwara main material ki life cycle ya fatigue cycle ko bhi divide kar sakta hoon. Jaise ye low cycle fatigue ho gayi aur ye high cycle fatigue ho gayi.

Aap dekh pa rahe honge ki low cycle fatigue mein mera plastic strain yahan pe aap dominate kar raha hai elastic strain ke upar. Agar high cycle fatigue mein aap dekhenge to yahan pe elastic strain dominate kar raha hai mere plastic strain ke upar. To transition life hum kuch is tarah se nikaal sakte hain. Yahan pe is point pe ye donon values equal ho jayengi. To usse hum ek transition life nikaal sakte hain. $2N f$ isko is tarah se agar hum solve karenge to humein ye transition life is tarah se milegi. Aur yeh hai clear delineation. Yaani clearly demarcate kar sakta hoon ki kab meri low cycle fatigue se high cycle fatigue mein

transition hogi. Kis cycles pe ya kis reversal pe. To yeh ho gayi meri total strain life curve kisi bhi material ke liye. Aur is tarah se main elastic strain aur plastic strain ke contribution se ek total strain amplitude nikaal sakta hoon. Aur us total strain amplitude se main material ki poori life through its reversal cycle mark kar sakta hoon. To yeh ek advantage hai mere jab main strain ko istemal karke fatigue ko explain karne ki koshish karta hoon. To is part mein humne do teen cheezein dekhi jaise ki humne cyclic stress strain curve dekha. Humne uski tulna ki ki vah monotonic stress strain ke curve ke saath kaise alag

hai aur humne cyclic hardening aur cyclic softening ke baare mein baat ki. Aur humne phir elastic strain amplitude aur plastic strain amplitude in donon ko mila ke ek total strain amplitude aur ek equation likha hai. Us equation ke dwara humne material ki strain life cycle aur strain life curve yahan pe humne padhai ki. Aur is strain life curve ke dwara main material ki low cycle fatigue aur high cycle fatigue kis cycle pe change ho sakti hai yeh humne dekha. To abhi ke liye yahan par hi rukta hoon. Next part mein humne hum fatigue ke baare mein aur padhenge aur fatigue kis tarah se fatigue resistance material ka improve ho sakta hai

yeh bhi padhenge. Abhi ke liye rukta hoon. Dhanyawad.