

Mechanical behavior of materials

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Week-12

Lecture-60

Fracture & Theoretical Cohesive Strength of Materials

Course Title

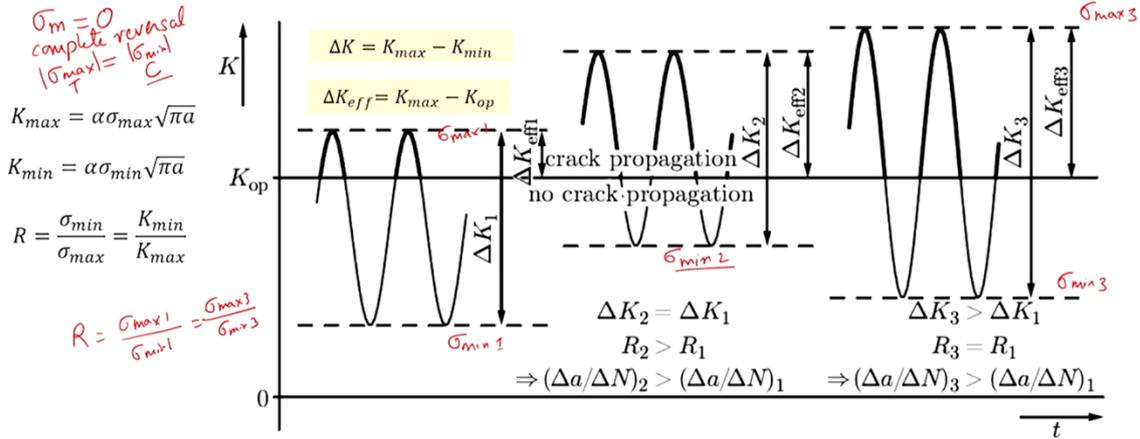
Mechanical Behavior of Materials (Hindi)

Lecture-59
Effect of Mean Stress and Stress Amplitude

Namaskar aapka swagat karta hoon Mechanical Behavior of Material jiske jisko hum Hindi mein padhenge. Last part tak humne dekha ki jo mean stress ki value hoti hai fatigue cycle mein jo mean stress ki value hoti hai vo humne shunya maan ke chali thi yaani maximum stress aur jo minimum stress hai unka magnitude same tha. Par jab hum practical fatigue cycle ki baat karte hain to kuch process parameter hum consider karte hain jaise maximum stress aur minimum stress. To abhi maine jaise bataya ki jo σ mean (sigma mean) ki value hai voh hum shunya maan ke chalte chalte the normal, yeh completely reversed cycle thi, complete reversal yahan par hum keh sakte hain aur iska



Fatigue Cycles and process parameters



- ΔK_{op} is usually unknown, thus its dependence on ΔK and R is used
- ΔK_{eff} increases with ΔK and with the R ratio

matlab hai ki $\sigma_{max} = \sigma_{min}$ rahega magnitude mein, par sign aur direction jo rahega woh alag rahega. Yeh agar tension mein hai to yeh compression mein. To humne do parameters introduce kiye the K_{max} aur K_{min} agar mere paas maximum stress hai uske corresponding stress intensity factor mere material mein kuch crack available hai to. To isko humne likha tha K_{max} aur minimum stress ke corresponding humne likha tha K_{min} . To humne stress ratio R ki value humne define ki thi ratio kya tha σ_{min} ka σ_{max} ke saath. Agar hum yeh do relation agar dekhenge to hum R ki value ko K_{min} / K_{max} yeh bhi likh sakte.

hain. To abhi hum kuch cycles dekhte hain aur jaante hain ki yeh K_{max} aur K_{min} ya R ratio ka kya effect ho sakta hai. To yahan par humne kuch plot kiye yaani yahan par time ke saath kuch cycles yahan par teen cycle yahan par maine dikhayi hai aur is axis par yahan par hum σ (sigma) dikhate hain par yahan par dikhayenge corresponding stress intensity factor. Kyunki stress intensity factor hi vo factor rahega jo crack ko open karega. Yeh humne dekha tha jab hum Paris law ke baare mein discuss kar rahe the. Abhi hum dekhte hain ki ye $K_{operational}$ mere material ke liye kuch is tarah se yeh constant hai aur abhi hum teen cycles dekhenge. Yeh pehli cycle yeh doosri cycle aur teesri cycle.

Abhi kuch parameters yahan par hum define kar lete jaise ki ΔK (delta K). Agar main ΔK ki baat karunga to yeh kya hoga $K_{max} - K_{min}$. Yaani K_{max} kya hai ye stress intensity factor hai corresponding to σ_{max} aur K_{min} hai corresponding to σ_{min} . Abhi hum dekhte hain ki $\Delta K_{effective}$ isko kaise define karte hain. Isko define karte hain $K_{max} - K_{operational}$. To yeh

jo K operational hai ye humne define kiya hai K operational lagbhag yeh hai yaani hum kahenge ki iske upar agar stress intensity factor jaati hai value tabhi woh crack open hogi. Agar iske neeche hai to woh crack open nahi hogi ya hum keh sakte hain ki iske upar hi crack propagate hone mein madad karti hai.

To humne kaha tha ki yeh jo part hai yahan pe is cycle mein yeh jo dark karke yahan par highlight hai yeh jo part hai yahi mere crack ko open karne ya propagate karne mein madad karegi isliye humne isko naam de diya ΔK effective aur yeh value milti hai $K_{max} - K_{operational}$ se. Ab ye ΔK ki value yahan pe hum dekhenge is cycle ke liye first cycle ke liye isko hum difference maanenge $K_{max} - K_{min}$. To ye total jo value hai yeh hogi meri ΔK jo difference hoga yeh hoga ΔK . Abhi hum dekhte hain ki iske corresponding σ_{mean} ki value shunya hai aur yahan par ek stress ratio hoga R ki value jo main baat kar raha hoon woh hoga K_{max} / K_{min} .

Abhi hum dekhte hain doosri cycle yahan par hum consider karte hain ye jo doosri cycle hai. To hum dekhte hain ki yeh cycle kuch is tarah se highlighted hai to hum dekhenge ki yeh jo part hai K operational ke upar jo cycle ka part hai wahi mera madad karegi ki jo crack propagation mein neeche wala part crack propagation mein madad nahi karengi. To ismein ΔK ki value kya hogi ismein ΔK ki value kuch is tarah se hogi is arrow se mark ki aur ΔK effective hoga $K_{max} - K_{operational}$ to ye Δ effective ho jayegi. Similarly third cycle hum dekhte hain to yahan par bhi hum dekhenge yeh jo part hai yahi part mera madad karega crack propagation mein aur yeh jo

part hai yeh crack propagation mein madad nahi karega. Yahan par ΔK ki value yeh ho gayi ΔK_3 isko maine mark kiya hai aur ΔK effective kuch is tarah se mark kiya $K_{max} - K_{operational}$. Abhi hum dekhte hain second case mein kuch comparison karte hain yahan par humne likha hai ki ΔK_2 yaani yeh jo difference hai yeh equal hai mere ΔK_1 ke saath yaani donon ka difference jo hai woh same hai to yaani $\Delta K_2 = \Delta K_1$. Yahan pe hum dekhte hain ki cycle thodi above chali gayi hai to hum keh sakte hain ki R2 ki value yahan pe yaani R2 ki value greater than hogi R1 se to hum keh sakte hain ki σ_{mean} yahan pe badh raha hai.

yahan pe yahan pe likh lete hain $\sigma_{mean 1}$ for first cycle aur $\sigma_{mean 2}$ jo hai second cycle woh badh raha. To aap dekhenge ki agar σ_{mean} ki value badh rahi hai to aap dekhenge ki yeh jo ratio hai woh badhega ya positive hoga to R2 ki value greater than R1 hogi. Abhi hum dekhte hain ki yahan par ΔK ki value same hai par $R_2 > R_1$ hai to hum yeh keh sakte hain ki crack

propagation yahan pe doosre case mein zyada hogi as compared to mere pehle case mein. Kyunki aap dekh pa rahe honge ki iske yeh jo part hai cycle ka woh zyada above hai is crack propagation ya operational stress intensity factor ke upar.

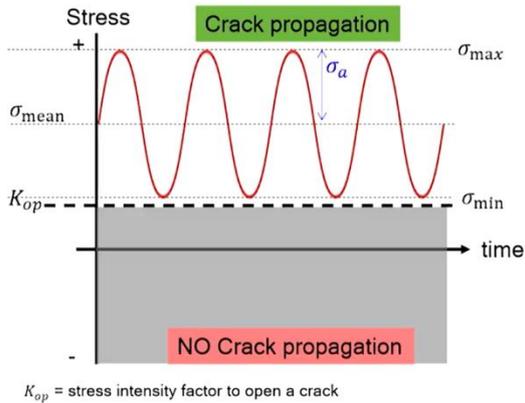
part hai woh zyada madad karega meri crack propagation mein isliye hum yeh keh sakte hain. To main keh sakta hoon ki agar mera R2 badh raha hai to crack propagation mein aasani hogi yaani main keh sakta hoon ki R ratio agar badh raha hai to crack propagation mein aasani hogi. Teesra case agar consider karte hain to yahan pe ΔK_3 ki value ΔK_1 se badi hai. Agar ye dekhenge yeh jo value hai ΔK_3 aap dekh pa rahe honge physically bhi ΔK_1 se badi hai. Par hum dekhenge ki ye jo ratio hai $R_3 = R_1$ yaani yahan pe yahan par likh lete hain ki ye jo ratio hai $\sigma_{\max 1} / \sigma_{\min 1} = \sigma_{\max 3} / \sigma_{\min 3}$. To hum yeh keh sakte hain ki R ki value in donon case mein same hai.

$\sigma_{\max 1} / \sigma_{\text{mean } 1} = \sigma_{\max 3} / \sigma_{\text{mean } 3}$. To yeh ratio same hai par ΔK ki value yahan par zyada hai badi hai ya hum keh sakte hain ki Δ effective ki value bhi yahan par badi hai. To hum yeh keh sakte hain ki donon ratio same hain par yeh jo value hai yeh zyada hai K3 mein to hum keh sakte hain ki yeh jo term hai yaani crack propagation jo hoga woh teen mein teesre cycle mein zyada hoga as compared to mere pehle cycle mein. Main yahan par kuch conclusion likh sakta hoon to main keh sakta hoon ki ΔK operational yeh jo term hai ye difficult hoti hai sometimes different cycle mein find out karne ke liye.

dependence hum aasani se likh sakte hain ΔK aur R ke upar. Agar mujhe ΔK pata hai ya R pata hai to main keh sakta hoon ki main ΔK operational ke baare mein kuch knowledge rakh sakta hoon. Aur ek cheez hum keh sakte hain ki ΔK effective badhta hai kab badhega woh jab mera ΔK bhi badhta hai aur mera R ratio badhta hai to mera ΔK effective higher hoga increase hoga mere agar mera ΔK , ΔK yaani ye jo difference hai ye agar badh raha hai ya R ratio badh raha hai yaani R ratio positive raha hai tab jaake yaani mera σ_{mean} badh raha hai to aap keh sakte hain ki jo ΔK effective hai woh badhega.



Effect of Mean Stress

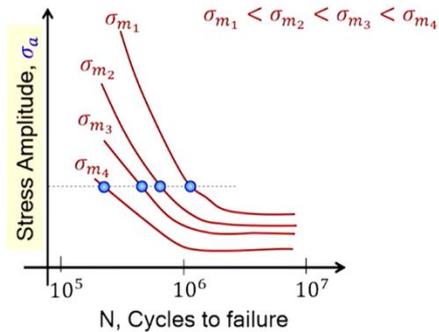


K_{op} = stress intensity factor to open a crack

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

- Fatigue life decreases with increase in mean stress (σ_{mean} or σ_m) for a given stress amplitude (σ_a)

When, $\sigma_m \neq 0$



As mean stress increases, fatigue life decreases for a given σ_a

implication kya hai agar ΔK effective badh raha hai to aap keh sakte hain ki material mein crack propagation aasani se hogi to yaani fatigue failure jaldi hoga. To ΔK effective agar badh raha hai to fatigue failure material mein jaldi hoga woh kam stress mein fail hoga ya kam cycles mein fail hoga to yeh iska implication yeh iska mahatva hai ΔK effective ka. Abhi kuch cycles dekhte hain jab hum process parameters ki baat kar rahe hain to effect of mean stress ki baat karte hain to maan lete hain mere paas kuch aise stress cycle hai aur yeh meri cycle hai yahan par aap dekhenge ki yahan par σ mean yahan par shunya hai kyunki cycle aap dekhenge ki completely reversible $\sigma_{max} = \sigma_{min}$.

to ye σ mean ki value yahan par shunya hai. Aur hum kehte hain ki ek operational stress hai yaani stress intensity factor jo mere crack ko open karne ke liye madad karega aur σ amplitude (σ_a) kuch is tarah se hum likhte hain $\sigma_{max} - \sigma_{mean}$ ye minimum mean jo value hai iska difference jo hoga woh mera stress amplitude hoga ya hum is tarah se bhi likh sakte hain $(\sigma_{max} - \sigma_{min}) / 2$. To ye stress amplitude is tarah se humne define kiya hai. Abhi hum keh sakte hain ki agar meri cycle kuch is tarah se hai K operational kuch is tarah se aur aap dekh sakte hain ki yeh part jo K operational ke upar hai yahi sirf crack propagation mein madad karega.

to isko bhi hum likh dete hain ki yahan par jo yeh neechे wala part hai woh madad nahi karega mere crack propagation mein aur upar wala part hi sirf madad karega. Abhi hum cycle is tarah se choose karte hain maan lete hain ki cycle mein mera σ_{max} main yahan par badha raha hoon aur σ_{min} bhi badha raha hoon par main jo stress amplitude hai woh constant rakh raha hoon

kuch is tarah se. Aap dekhenge ki maine jo stress amplitude hai woh constant rakha hai par cycle mein jo stress max hai σ_{max} hai woh badh gaya aur σ_{min} ki value bhi hai woh bhi badh gayi hai.

aur yeh jo mean value aa rahi hai σ_m ki value hai yeh bhi yahan par badh rahi hai. Abhi hum dekhte hain ki to aap dekhenge ki yeh jo part hai abhi jaise jaise mera σ_m badh raha hai waise waise jo cycle ka jo part hai jo mere crack open mein madad karega woh bhi badh raha hai. Abhi phir se agar main cycle ko kuch is tarah se consider karunga to aap dekhenge ki complete cycle mere crack propagation mein madad karegi yaani aap dekh rahe honge ki yahan pe ye σ_m ki jo value hai woh badh rahi hai aur main σ_a constant rakh raha hoon yahan pe σ_a change nahi ho raha hai.

to aap σ_m ki value badh rahi hai to aap keh sakte hain ki R ki value bhi badh rahi hai aap agar calculate karenge σ_m aur R ka relation to aap dekh paayenge ki jaise jaise σ_m badhta hai waise waise R ki value bhi badhti hai. To yeh observation ho gaya aur jaise jaise σ_m aur R ki value badhegi jab main stress amplitude constant rakh raha hoon waise waise stress jo complete cycle hai woh istemal hogi mere crack propagation mein to crack propagation mein aasani hogi aur fatigue life yahan pe decrease hogi kyunki jitne zyada se achhe se crack propagate aur aasani se crack propagate hoga utna mera fatigue life decrease hoga.

To main kuch is tarah se ek sentence likh sakta hoon ki fatigue life decrease hogi jaise jaise mera mean stress badh raha hai for a given stress amplitude yaani stress amplitude jab constant hai aur main mean stress ki value badha raha hoon to fatigue life decrease hogi. To main kuch is tarah se plot kar sakta hoon jab mera σ_m shunya nahi hai yaani reversible cycle nahi hai to main yahan par stress amplitude plot kar raha hoon yahan par stress amplitude main agar dekhunga stress amplitude yahan pe main plot karunga aur yahan par number of cycles to failure main plot karne wala hoon.

To maan lete hain kuch is tarah se points maine plot kiye yeh dash line dikha rahi hai ki constant stress amplitude ke liye yaani agar mera stress amplitude change nahi ho raha hai to aap dekhenge ki jaise jaise mera mean stress decrease hoga to yahan pe jo mean stress ki value hai woh highest rahegi as compared to jo mean stress hai yeh jo value hai iske corresponding jo number of cycles to failure hai woh decrease ho rahi hai. Agar main constant σ_a ke liye main agar plot karunga kuch is tarah se to mujhe kuch is tarah se S-N curve type milega stress amplitude versus number of cycles kuch is tarah se milenge ye constant mere σ_m ki value hai.

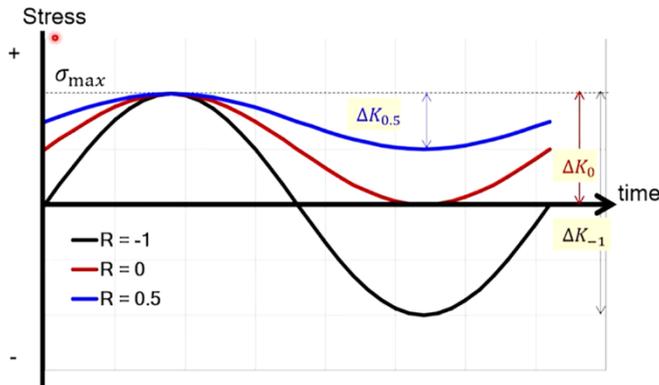


Effect of R ratio

Let σ_{max} be the maximum allowable stress: $\sigma_a + \sigma_m \leq \sigma_{max}$

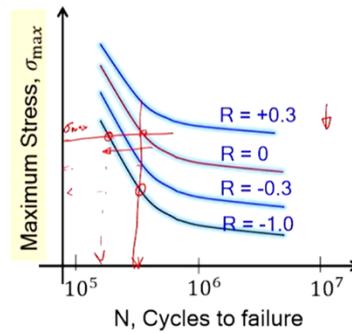
σ_a const
 $R \uparrow$

$$\Delta K_{eff} \propto \Delta K$$



$$\Delta K_{R=-1} > \Delta K_{R=0} > \Delta K_{R=0.5}$$

$$\Delta K_{eff|R=-1} > \Delta K_{eff|R=0} > \Delta K_{eff|R=0.5}$$



As ΔK increases, fatigue life decreases

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To aap dekh pa rahe honge ye jo σ_m hai ye less than σ_m hai less than σ_m hai aur less than σ_m hai to aap dekhenge jaise jaise mera mean stress ki value badhegi waise waise meri fatigue life yahan pe decrease hogi yaani number of cycles to failure yahan pe decrease honge. To yeh hum kuch is tarah se mean stress ka effect dekh sakte hain mere fatigue life pe. To ek sentence phir se hum likh lete hain yahan pe ki jaise jaise mean stress increase hota hai waise waise fatigue life decrease hogi for a given σ_a .

yaani agar σ_a change nahi ho raha ye σ_a yahan pe change nahi ho raha tha aur mean stress jaise jaise main badha raha hoon waise waise aap dekhenge ki ye fatigue life yahan pe decrease hogi to yeh relation ho gaya mera σ_a versus N jab mean stress shunya nahi hai. Abhi hum dekhte hain ki effect of R ratio to iske liye kuch cycles yahan par hum consider kar lete hain maan lete hain meri stress versus time kuch is tarah se humne plot kiya hai aur maan lete hain ki main σ_{max} fix karke chal raha hoon yaani maximum stress main yahan par fix kar loonga aur main sirf R ratio change karunga.

To agar mera maximum σ_{max} fix hai to jo ki mera allowable stress hai to main yeh relation aasani se likh sakta hoon $\sigma_a + \sigma_m \leq \sigma_{max}$. To maan lete hain kuch is tarah se mere paas cycles hain yahan par aap dekhenge ki R ki value yeh jo black cycle hai iske liye R ki value -1 hai yaani complete reversible hai aap dekhenge ki σ_{max} aur σ_{min} donon ka magnitude same hai yahan par ek tension mein ye compression mein. R ki value yahan par shunya hai

to aap dekhenge ki rate ke liye σ_m jo value hai woh zero hai yahan par aur R ki value 0.5 hai.

To aap dekhenge ki yeh jo blue curve hai yahan par σ_{min} ki value yahan par minimum jo value hai uski yahan par badh gayi hai aur is teeno cycles mein maine σ_{max} ko constant maan ke chala hai σ_{max} mein yahan par change nahi kar raha hoon fixed maine rakha hai sirf yahan par meri R ki value yahan par badh rahi hai. Ab hum dekhte hain ki is cycle ki wajah se yaani R ki jab value main badha raha hoon to fatigue life par kya asar hoga. To humne pehle slide mein dekha ki jo ΔK effective hai woh directly proportional to ΔK hai.

aur ΔK main kis tarah se find out karunga jo maximum stress hai aur jo minimum stress hai in donon ka difference zyada hai to ΔK ki value zyada hogi. To yahan in teen cycle ke hum ΔK nikaalte hain aur ΔK 0.5 ke liye kuch is tarah se hoga ye maximum stress hai ΔK 0.5 ke liye ye maximum stress hai ye minimum stress hai in donon ka difference mujhe ΔK dega. Similarly agar main $R = 0$ consider karunga to $\sigma_{max} - \sigma_{min}$ ye jab stress ratio zero hai to isliye ΔK ki value yahan pe is tarah se dikhayi. $R = -1$ hai to aapko yeh jo value hai yeh ΔK ki value milegi yahan par ΔK -1 ke liye.

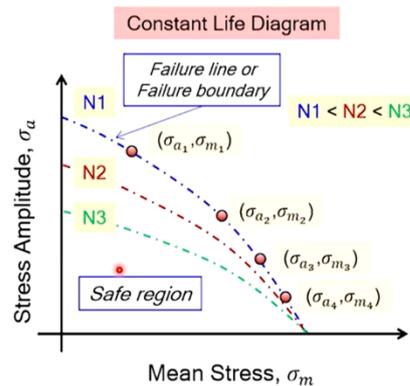
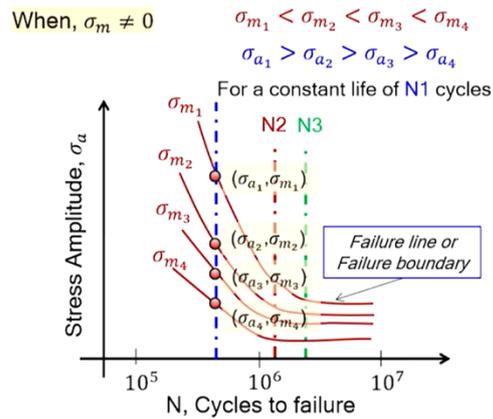
To aap dekh pa rahe honge ki jaise jaise mera R ratio badh raha hai waise waise ΔK ki value kam ho rahi hai to ya yeh main keh sakta hoon ki jab main σ_{max} ko fix karke rakha ho yahan par σ_{max} change nahi ho raha hai constant hai aur σ_{min} main badha raha hoon to waise waise R ki value badhegi to waise waise ΔK ki value yahan par ghategi. Main is tarah se likh sakta hoon ki $\Delta K(R = -1) > \Delta K(R = 0) > \Delta K(R = 0.5)$. To humne yeh relation yahan par dekha hai to main effective value ki bhi main is tarah se relation la sakta hoon.

to aap dekh paayenge ki jab $R = -1$ hai to ΔK effective zyada hai as compared to jab mera R positive ho raha hai ya badh raha hai to is kes mein crack propagation aasani se hogi yaani iska matlab yeh hoga ki agar crack propagation aasani se hogi to aapki fatigue life yahan pe decrease hogi. To main kuch is tarah se relation likh sakta hoon ki maximum stress main agar plot kar raha hoon yahan pe aap dekhenge Y axis pe maine maximum stress plot kiya aur X axis par maine number of cycles to failure maine plot kiye to mujhe kuch is tarah se yeh jo S-N curve is tarah se milenge.

To agar main R ki value plot karunga to main dekh paunga ki $R = -1$ ke liye mujhe stress versus number of cycles S-N curve is tarah se milega. To aap dekh pa rahe honge ki yeh jo $R = -1$ as

compared to $R = 0.3$ hai tab aap dekhenge ki ek same cycle ke liye yahan par mark kar sakte hain ek same cycle ke liye jaise meri cycle fixed hai to aap dekhenge ki yeh jo stress hai woh maximum allowable stress kam ho gaya hai as compared to R jaise jaise R mera badh raha hai. Ya main aur ek cheez likh sakta hoon jaise main constant σ_{max} ki baat karunga.

Constant Life Diagram: Effect of σ_a and σ_m



$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

to aap dekhenge ki yeh jo value hai ek constant σ_{max} maine agar fix karke rakha hai to jaise jaise R mera ghat raha hai R yahan par is direction mein ghat raha hai to number of cycles to failure yahan pe ghat rahe hain. To aap dekh pa rahe honge ki $R = 0.3$ aur $R = -1$ mein ye difference hai. To hum ek conclusion yahan pe likh sakta hoon ki jaise jaise mera ΔK increase hota hai waise waise meri fatigue life decrease hogi kyunki ΔK jab increase hoga to ΔK effective increase hoga. ΔK effective agar increase ho raha hai to material jaldi ya lower number of cycles par fail hoga.

to yeh ho gaya mere effect of R ratio is kes mein humne σ_{max} ko fix karke rakha hai yeh aapko yaad rakhna hai. To agar hum yahan par σ_a ko constant maan ke challenge aur R ki value badhayenge to fatigue par alag asar hoga yeh aapko yaad rakhna hai ki hum kya parameters ke saath play kar rahe hain. To abhi hum dekhte hain ki in donon ko hum kis tarah se ek constant life diagram ke saath represent kar sakte hain. Humne σ_a ka value dekha ki σ_a kis tarah se change nahi ho raha hai aur mera σ_m jab badh raha hai tab fatigue life decrease hoti hai.

ab hum donon ko kis tarah se present represent karenge to humein fatigue life material ki determine karne mein aasani hogi. To humne yeh cycle abhi likhi thi S-N curve humne is tarah se stress amplitude yahan pe plot kiya Y axis pe aur X axis par number of cycles plot kiya aur humne dekha ki jaise jaise yeh σ_m mean value badh rahi hai waise waise stress life ghat rahi hai. Abhi main kya karta hoon abhi constant number of cycles ke liye jaise N yeh maine kuch is tarah se maan liya is number of cycles ke liye main abhi kuch coordinates likhunga is is plot ke dwara jaise kuch is tarah se jaise maine ye N number of cycles N1.

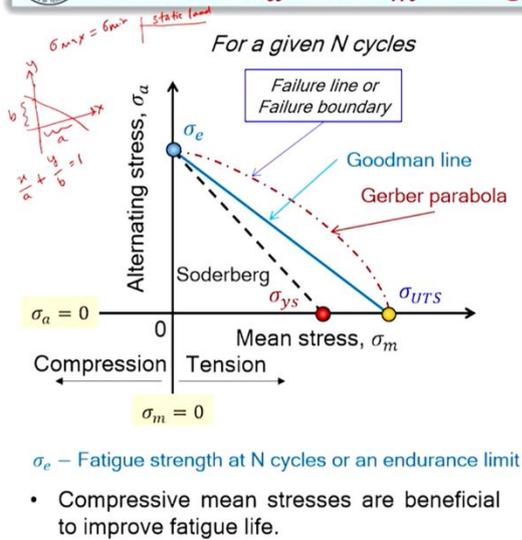
cycles ke liye maine likh liya σ_a , σ_m yeh iske coordinates maine kuch is tarah se likh liye. To yeh yeh corresponding mean stress aur amplitude yahan par hum plot kar rahe hain σ_m versus σ_a plot par. To aap dekhenge ki jaise jaise mera sigma mean increase ho raha hai waise waise stress amplitude decrease ho raha hai to main yeh relation likh sakta hoon yahan par yeh constant life N1 ke liye main yeh likh sakta hoon ki jaise jaise mera mean stress yahan par badh raha hai waise waise σ_a yahan par ghat raha hai decrease ho raha hai to main isko plot bhi kar sakta hoon.

Agar main stress amplitude plot karunga Y axis pe aur mean stress agar main plot karunga X axis pe to main kuch is tarah se plot kar sakta hoon yahan par aap dekh pa rahe honge ki jaise jaise mera σ_m badh raha hai waise waise σ_a yahan par ghat raha hai to yeh jo plot hai woh main kisi ek constant cycle ke liye likh raha hoon jaise N1 cycle ke liye. To main kuch N2 cycle ke liye bhi yahan par likh sakta hoon agar main N2 yahan par plot karunga to mujhe corresponding σ_a aur σ_m mil jayega to main kuch similarly main N3 cycle ke liye bhi likh likh paunga.

To aap dekh pa rahe honge ki jaise N1, N2 aur N3 mein kuch is tarah se relation hai to N1 jo hai lower number of cycles se N2 se aur N3 se. To aap dekh pa rahe honge ki jaise jaise meri number of cycles main badhate ja raha hoon waise waise sigma amplitude ghatega woh is plot se hi aapko milega. To yeh jo ho gaya isko hum kuch is tarah se samajh sakte hain ki yeh jo hai yeh meri constant life diagram hai. Agar main N1 cycle ki baat karunga to mujhe stress amplitude aur mean stress ke beech mein kuch is tarah se relation milega.



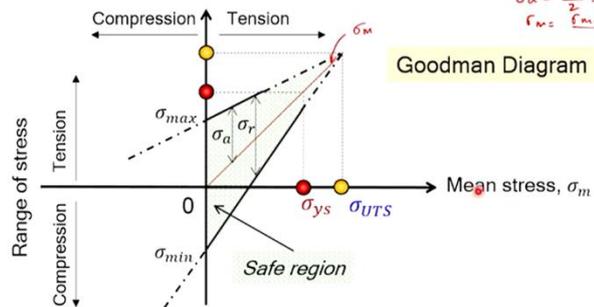
Effect of σ_a and σ_m : Fatigue failure criteria



Soderberg Line $\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_{ys}} = 1$ More conservative

Goodman Line $\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_{UTS}} = 1$ Mostly used

Gerber Parabola $\frac{\sigma_a}{\sigma_e} + \left(\frac{\sigma_m}{\sigma_{UTS}}\right)^2 = 1$ Test data of ductile materials fall closer to this



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Jab humne S-N curve ki baat ki hai tab humne kaha tha ki ye jo boundary hai yeh kya darshati hai yeh darshati hai failure line ya failure boundary. To agar hum dekhenge ki iske agar neeche stress hai agar yeh main point consider kar raha hoon σ_a aur σ_m for N_1 cycle to aap dekhenge ki agar mera stress isse kam hai ya number of cycle isse kam hai to material fail nahi hoga. To yeh region mein aapka material safe rahega is region mein material fatigue fail karega. Similarly yahan pe main keh sakta hoon ki ye jo line hai yeh bhi darsha rahi hai ek failure line ya failure boundary.

To yeh jo mera safe region ho jayega is line ke andar agar N_1 ki baat karunga to yeh poora area iske andar jo bhi values hain usmein mera material safe work karega iske upar agar jayega to yeh material fail hoga boundary darshati hai ki failure line kya hogi to N_2 ke liye ye boundary line ho jayegi aur N_3 ke liye ye boundary line ho jayegi. Isko hum kehte hain constant life diagram. To ye ho gaya mera stress amplitude aur mean stress ka effect fatigue life pe. To is diagram se aap aasani se samajh paayenge ki material kab fail hoga aur kis condition mein fail hoga.

Abhi hum phir se dekhte hain ki σ_a aur σ_m ki beech mein jo relation hai jo humne abhi plot kiya tha kuch is tarah se jaise maine alternating stress is Y axis par plot kiya aur mean stress kuch is tarah se plot kiya. Abhi hum in donon ke beech mein mathematical relation ki baat karenge isko hum kabhi kabhi kehte hain fatigue failure criteria. To yahan par maine baat ki yeh jo stress hai yeh origin hai to yahan par stress zero ho to aap dekhenge ki agar yeh zero hai

to mean stress ki jab main baat karunga σ_m ki baat karunga to yeh tension mein rahega aur yeh compression mein rahega.

Abhi main baat karta hoon yahan par aap dekh paayenge ki alternating stress is point par zero hai $\sigma_{\text{alternating}} = 0$ yaani yeh kya ho gaya yeh yahan par koi cycles nahi hai ya iska matlab kya hai σ_{max} yeh mathematically aur direction wise equal to σ_{min} ho jayega yaani aapke paas koi cycle nahi rahegi ek static load rahega ye time ke saath vary nahi karega to ye static load ho gaya. To ab hum dekhte hain ki ye σ_a agar shunya hai to Soderberg ne ye propose kiya tha ki material kab fail hoga material fail hoga jab material ka yield strength ki point pahunch jayegi.

Soderberg ne propose kiya ki agar mean stress ki value agar yield strength se agar zyada hai to material iske baad fail hoga. To ye ek limiting point yahan pe Soderberg ne mark karke rakha hai σ_m ki value jab shunya ho jayegi yaani completely reversible stress ki jab main baat kar raha hoon tab aap dekhenge jo alternating stress ki value hai woh Soderberg ne consider ki yeh ho jayegi meri fatigue strength ya endurance limit jab main N cycles ki baat kar raha hoon kyunki hum jo plot kar rahe typical N cycle ke liye hum baat kar rahe hain.

To yeh jo value ho jayegi σ_a ki iske upar jab endurance limit ke upar main jaunga tab material fail hoga iske neeche agar meri alternating stress ki value rahegi tab material safely work karega. To Soderberg ne ek linear relation diya hai kyunki humne σ_a aur σ_m ke beech mein relation laana hai to Soderberg ne consider kiya ki yeh jo boundary hai yeh meri boundary darshayegi ki mera safe region kaun sa hai. Yeh limit yahan pe define kiya hai Goodman ne. To Goodman ne Goodman line draw ki ya relation endurance limit ka ya fatigue strength ka UTS ke saath ek line draw ki.

aur bataya ki yeh line jo hai yeh mera iske neeche jo rahega woh mera safe region rahega aur iske upar jo rahega woh unsafe region rahega. Isko kehte hain Goodman line aur teesra criteria agar propose kiya hai to yeh in donon ka linear relation nahi bataya yeh bataya hai parabola ke saath to yeh jo propose ki yeh Gerber ne propose kiya hai to isko kehte hain yeh jo line hai isko kahenge Gerber parabola. To abhi hum dekhte hain ki yeh jo teeno surface hain ya lines hain ya boundaries hain yeh failure line batati hai failure boundary batati hai.

To teeno criteria hum dekhenge ki inka mathematical relation kya ho sakta hai to sabse pehle hum dekhte Soderberg line dekhte hain. To agar humein is line ka equation agar nikaalna hai

to aap dekhenge ki yahan par humein intercepts pata hain ki yahan par Y axis par intercept hai σ_e aur Soderberg jab consider karta hai to Soderberg relation consider karta hai σ_{ys} ka. To agar hum mean stress yaani X axis par agar intercept ki baat karenge to yeh jo distance hoga yeh σ_{ys} hoga aur aapko pata hai ki equation of line hum intercept method se kis tarah se nikaalte hain.

yahi hum fundamental apply karenge Soderberg line ka equation nikaalne ke liye to Y axis meri hai stress amplitude ya alternating stress to yeh σ_a hai aur yahan par intercept hoga mera σ_e to yeh ho jayega endurance limit plus hum likhenge X axis par yahan par σ_m aa jayega aur intercept hoga σ_{ys} kyunki Soderberg σ_{ys} consider karta hai aur yeh ho jayega equation mere Soderberg line ka equal to ek. Usi tarah se hum Goodman line likh sakte hain to Goodman line mein aap dekhenge ki ye Y intercept to constant hai yaani σ_e hai yahan pe aur yahan pe sirf Soderberg Goodman consider karte hain σ_{UTS} .

yaani ultimate tensile strength to yahan pe hum likhenge kuch is tarah se aur yeh ho jayegi Goodman line. Agar main parabola ka equation agar consider karunga is intercept method se to hum kuch is tarah se likh paayenge $\sigma_a / \sigma_e + (\sigma_m / \sigma_{UTS})^2 = 1$. Yeh jo ho jayega yeh yahan par square term aa jayega yeh darshayega mera parabola ka equation. To is tarah se hum failure criteria yahan pe likh sakte hain ya σ_a aur σ_m ka relation nikaal sakte hain material properties ke dwara.

To yeh jo pehla Soderberg line ya Soderberg criteria main consider karunga ye more conservative hai kyunki aap dekhenge ki σ_{ys} pe material fail nahi hota hai sirf yield hota hai par yeh jo region hai woh safe region yahan par ghat raha hai yahan par. To aap dekhenge ki yeh more conservative criteria hai. Goodman line jo hai woh mostly use karte hain mathematically ya analysis ke liye hum mostly istemal karte hain aur yeh jo Gerber parabola hai yeh criteria hum istemal karte hain mostly ductile material ke liye kyunki yeh achha fit deta hai.

to yeh teeno criteria ka apna apna ek mahatva hai aap koi bhi criteria istemal kar sakte hain agar aapko more conservative se istemal karna hai to aap Soderberg criteria kariye Goodman aasani se istemal karte hain bahut saare material ke liye istemal karte hain aur yeh achha fit deta hai aapke ductile material ke liye. To ye ho gaya alternating stress versus mean stress ke beech ka relation. Abhi hum dekhte hain is alternating stress ko main kuch alag tarah se

represent kar sakta hoon to yahan par maine kuch is tarah se mark kiya X axis maine mean stress constant rakha.

to iske upar yeh tension hai aur iske neeche value jo rahegi woh compression darshayegi. Same way yeh range of stress ke liye yahan par tension hai positive Y axis aur negative Y axis aapko compression darshayegi. To stress range yaani hum is tarah se likh sakte hain isko hum likh lete hain ek baar. Agar main σ amplitude ki baat karunga to main stress divided by do likh sakta hoon ya is tarah se stress range aap likh sakte $(\sigma_{\max} - \sigma_{\min}) / 2$. To abhi kuch points yahan par mark kar lete hain jaise σ_{ys} aur σ_{UTS} .

Abhi hum jaante hain ki agar main range of stress ko kis tarah se represent kar sakta hoon σ_{\max} aur σ_{\min} dwara. To main σ_{\max} aur σ_{\min} yahan par maine plot kiye to aap dekhenge ki yeh jo σ_{\max} ki value yahan pe maine solid line se yahan dikha li hai ye aap dekhenge ki maine ye σ_{ys} tak hi mark kiye iska matlab yeh hai ki jab hum fatigue test karte hain hum maximum value σ_y tak jaake deform karte hain isliye yahan pe yeh σ_{\max} aur σ_{\min} ki value maine σ_{ys} tak hi mark ki hai.

Abhi aap dekhenge yahan par sigma mean ki value ya σ_m ki value shunya hai to aap dekhenge yeh jo stress range hogi yeh completely reversible cycle hogi yaani yahan par R ki value is point par -1 hogi. Abhi hum dekhte hain ki agar main isko extend karunga to material hamesha σ_{UTS} par fail hoga to σ_{\max} ko maine is tarah se dotted line par dikhaya. Abhi main yeh jo plot kar raha hoon yeh mera sigma yeh meri σ_m ki value hogi jo red marked hai woh σ_m hoga mean stress aur yeh jo hogi σ_m ki value yahan par hum likh sakte hain σ_m kya hoga $(\sigma_{\max} + \sigma_{\min}) / 2$.

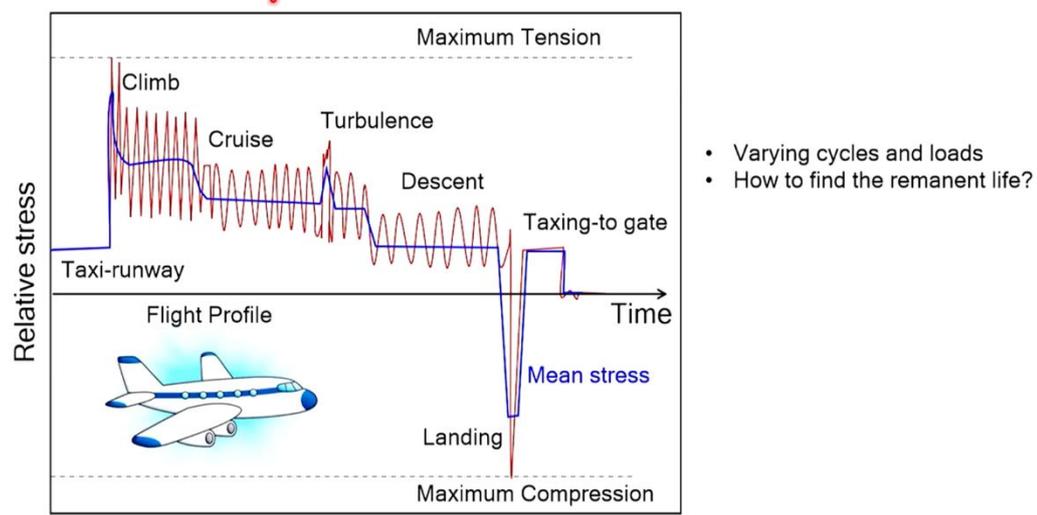
aur yeh hamesha is axis ke saath paitalis degree angle banayegi to aap dekhenge ki yeh X aur Y axis ke saath paitalis degree mein inclined rahegi. Abhi hum sigma range ki baat karenge to sigma range jab main baat karunga sigma range kya ho jayega $\sigma_{\max} - \sigma_{\min}$ to is sigma m ke liye yeh σ_R ho jayega sigma range ho jayegi. Yeh agar main baat karunga to yeh sigma amplitude hogi yaani agar aap difference dekhein $\sigma_{\max} - \sigma_{\min}$ yaani σ_a yeh ho jayega mera sigma amplitude.

To aap dekh pa rahe honge ki yeh jo region hai yahan par maine shaded kiya yeh dikhayega mera ki yeh region mein agar main operate karunga to yeh region hoga mera safe region hoga yeh main particular N number of cycles ke liye plot kar raha hoon. To aap dekhenge ki is agar

particular N number of cycles ke liye main consider karunga to ye jo region hoga yeh safe region hoga to aap keh sakte hain ki yeh jo sigma amplitude hai jaise jaise mera mean stress yaani σ_m badh raha hai to mera sigma amplitude jo main apply kar sakta hoon woh ghatega.

Is direction mein agar dekhunga to yahan par dekhenge ki yeh σ_m zero se neeche hai to yeh compressive stresses hain donon aur humein pata hai ki compressive mean stresses yeh beneficial hote hain mere fatigue life ko improve karne mein kyunki yeh jo stresses hain woh mere crack ko open nahi karenge to isliye yahan pe isko hum keh sakte hain ki compressive stresses help karenge to meri fatigue life yahan pe badhegi. Is diagram ko hum kehte hain Goodman diagram. To yeh relations abhi yahan par humne teen criteria dekhe.

Fatigue Lifetime Assessment



Abhi hum kuch consider karenge jab main fatigue life assessment ki baat karta hoon to janrally kya hota hai applications mein jaise ek example main yahan par aeroplane ka dena chahta hoon. To agar main flight profile dekhunga yaani yeh jo component hai aeroplane ke agar yeh stress kuch experience kar rahe hain to kis tarah se stress changes hote hain. To yahan pe maine relative stress plot kiya aur time yahan pe maine time scale yahan pe plot kiye. To aap dekhenge ki jaise jaise main aeroplane ka example consider kar raha hoon.

stress experience karega phir jab ek certain height pe pahunch jata hai to kuch is tarah se cruise time mein woh is tarah se stress experience karega beech mein hawa ka turbulence hota hai to kuch is tarah se stress experience karega ya jab descend karega jab utarne ki ya landing ki

taiyari karta hai tab kuch is tarah se stress experience karta hai aur jab land karta hai tab kuch compressive stress woh experience karta hai. To hum dekhenge ki kuch maximum tension is tarah se experience karte hain yeh aeroplane ke component ya maximum compression is tarah se experience karte.

Agar main mean stress ki baat karunga σ_m ki baat karunga to kuch is tarah se main dekh pa raha hoon. To yahan par aap dekhenge ki number of cycles yahan par alag hai mean stress ki value yahan par alag hai. To jab hum fatigue test karte laboratory mein to hum constant cycle par karte hain aur constant stress level par karte hain par actually practically aap dekhenge ki mean stress bhi change hota hai application ke dauran aur number of cycles yahan pe kaise apply ho rahi hai yeh bhi change hoti rehti hai.

Miner's Rule: Accumulative Damage during fatigue

Overstress cycle

Defect or Damage accumulation during each overstress cycle

$\frac{N_1}{N_{f1}}$	$\frac{N_2}{N_{f2}}$	$\frac{N_3}{N_{f3}}$	$\frac{N_4}{N_{f4}}$
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Linear Cumulative Damage, D

$$\frac{N_1}{N_{f1}} + \frac{N_2}{N_{f2}} + \frac{N_3}{N_{f3}} + \frac{N_4}{N_{f4}} = D$$

$$D = \sum_{i=1}^n \frac{N_i}{N_{fi}}$$

eg $D = \sum_{i=1}^4 \frac{N_i}{N_{fi}} = 0.8$

$D = 0.2$

$0.8 + \frac{N_5}{N_{f5}} = 1$

The component fails when the Total damage D equals one

Miner's Rule $D = \sum_{i=1}^n \frac{N_i}{N_{fi}} = 1$

Also called as Palmgren-Miner rule

Find out what is "coaxing"?

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To aap kaise determine karoge laboratory experiments ke dwara ki mere material ya mera component kisi application mein kitna life sustain ya kitna life survive kar paayenge To aap dekh pa rahe honge ki yahan pe do points maine likhe ki jab mere paas cycles change ho rahi hain ya loads change ho rahi hain to main material ki kitni life bachi hui hai ya material ya component kitne samay tak sustain kar paayega yeh kaise predict kar paunga To isko hum kehte hain fatigue lifetime assessment.

To iske liye kuch is tarah se consider karte iske liye hum ek concept istemal karte hain accumulative fatigue damage ki is tarah se. To kuch cycles is tarah se material is tarah se

experience kar raha hai ye stress cycle phir ye samay ke baad material kuch higher stresses experience kar raha hai aur cycles kuch is tarah se hain phir ye samay ke baad material kuch is tarah se stress experience kar raha hai and cycles kuch is tarah se hain ya ye samay ke baad material kuch is tarah se cycles experience kar raha hai.

To aap dekh pa rahe honge ki application ke dauran yeh stress aur cycles ke nature change ho raha hai to hum kaise determine karenge ki material kitne samay tak ya kitne cycle tak yeh stress experience kar paayega To iske liye hum yeh consider karte hain maan lete hain ki agar main laboratory test kar raha hoon is stress level pe aur is cycles ke liye to material fail hoga mere Nf_1 cycle ke baad. Yaani agar main continuously yahi cycle agar istemal kar raha hoon to Nf_1 cycle ke baad material fail hoga.

To main kuch is tarah se likh paunga ek damage ya defect accumulation each over stress cycle mein yaani ek particular over stress cycle mein kitna defect accumulation ho raha hai. To usko main simply is tarah se consider karta hoon ye kitne cycles usne experience kiye aur total number of cycles fail hone ke liye us over stress ke liye yeh ratio agar main consider karunga isko main kehta hoon kuch defect accumulation ho gaya is cycle mein. Doosra cycle mein kuch is tarah se N_2 / Nf_2 ho jayega teesre cycle mein material kuch N_3 cycle experience kiya hai.

but Nf_3 cycle chahiye thi usko fail hone ke liye is stress level pe. To yeh jo ho gaya defect accumulation ho gaya yeh material ko fail hone ke liye. Nf_4 ke liye aap dekhein ki jo N_4 cycles material ya component experience ki hai aur Nf_4 chahiye material ko fail hone ke liye to yeh jo ho gaye yeh mere defect accumulation. Aap is tarah se bhi samajh sakte hain ki jab $N_1 = Nf_1$ ho jayega to material isi cycle mein fail ho jayega N_2 agar Nf_2 ke barabar ho jayega to material isi cycle mein fail ho jayega.

To hum dekhte hain ki yeh jo damage accumulation hai main kuch linear add kar sakta hoon isko hum kehte hain linear cumulative damage accumulation. To yeh D main $N_1 / Nf_1 + N_2 / Nf_2 + N_3 / Nf_3 + N_4 / Nf_4$ ye main linear cumulative damage accumulation yahan pe maine likh liya hai. To main D n number of cycles ke liye kuch is tarah se likh sakta hoon summation from $I = 1$ to n n_i / Nf_i . To yeh main generalized way se likh sakta hoon. Abhi humne kaha hai ki component kab fail hoga jab $D = 1$ ho jayega.

Isko kehte hain Miners rule. To Miners ne yeh criteria diya tha linear cumulative damage accumulation ka agar $D = 1$ hai to material fail ho jayega. To main kuch is tarah se likh sakta

hoon isko hum kehte the Palmgren-Miner rule. To agar yeh maine consider kiya hai aur aap dekh pa rahe honge ki yahan pe agar maan lete hain ek example le lete hain yahan pe in charon cycle ka damage yeh D jo hai yaani main kuch is tarah se likhunga $\sum n_i/N_{fi}$ agar yeh value yahan pe maine maan li 0.8 hai to yahan pe material fail nahi hoga.

material fail hoga jab damage accumulation add ho jayega yaani 0.2 aur add hone ke baad material fail hoga kyunki in donon ka summation yahan par ek ho jayega. To aap is tarah se number of cycles to failure aap yahan par nikaal sakte hain. To aap kuch is tarah se nikaal sakte hain ki yeh jo failure damage hai kuch is tarah se aap nikaal sakte hain agar yahi example hum maan ke chal rahe 0.8 agar main maan ke chal raha hoon aur humne bola ki der ki N_{f5} ye failure cycles hai mera agar fifth cycle pe hai to kitne cycles lagegi n_5 aap kaise nikaaloge

to aap is tarah se nikaal sakte ho ki 0.8 pehle char cycle ki hogi aur n_5 / N_{f5} yeh ho jayegi agar ye add hoke ek ho rahi hai to aap n_5 yahan par nikaal sakte ho aapko N_{f5} pata hai is stress level pe kitni cycles lagegi fail hone ke liye to aap n_5 yaani kitni cycle material us stress level pe sustain kar paayega ye aap nikaal sakte ho aasani se isko kehte hain Miners rule. Abhi main aapko ek exercise dene wala hoon aapko ek method find out karni hai ek method hai Coaxing isko aapko find out karna hai ki coaxing kya hota hai.



Factors that influence fatigue life

- Alloy strength: Yield strength or ultimate tensile strength
- Fracture toughness: K_{IC}
- Mechanical design features that are stress concentrators
 - Inclusions and manufacturing defects (cracks, voids etc.,)
 - Surface defects, surface roughness or surface finish
- Residual Stresses
 - Compressive residual stresses will enhance the fatigue life
 - Tensile residual stresses will decrease the fatigue life

Yeh ho gaya mera Miners rule ye isse main cumulative damage nikaal sakta hoon aur remnant life bhi nikaal sakta hoon is rule se ye sabse aasaan rule mostly empirical rule hai to aapca

istemat karke material ki fatigue life kitni fatigue life baaki hai ye nikaal sakte. Abhi tak humne fatigue padha hai to abhi hum dekhte hain ki fatigue ko fatigue life improve karni hai to kya kya factors influence karte hain aur kya kya factors humein control karne padenge. To sabse pehle hai ki alloy strength to agar material ki alloy strength hum badha

rahe hain jaise yield strength badha rahe hain ultimate tensile strength hum badha rahe hain to material ki fatigue life yahan pe badhegi. Doosra factor hai fracture toughness. Hum dekhenge ki K1 se agar zyada hai to aap dekhenge ki jo crack propagation hai woh aasani se nahi hoga material tough hai to crack propagation aasani se nahi hoga. To humein material ki fracture toughness yahan par badhani hogi tab jaake hum fatigue life badha sakte hain. Teesra hai ki humein material ke andar stress concentrator jo sites hain isko decrease karna padega.

manufacturing defects jaise cracks aur voids ye humein avoid karne padenge agar humein fatigue life badhani hai to. To humne dekha tha ki yeh jo stress concentrators hain yeh cracks nucleate kar sakte hain aur ye cracks phir jaake fatigue cycles ke dauran propagate hokar fail ho sakti hai. Similarly humein surface defects kam karne hain jaise surface roughness aur surface finish. To agar compressive residual stresses hain surface pe to hum material ki fatigue life badha sakte hain agar tensile residual stresses hain to woh fatigue life drastically decrease karenge.

To yeh kuch points the hamare understanding jaise humne bahut saari understanding yahan par dekhi ki fatigue ke mechanism kya hain uske dwara humne samajh paaya ki agar yeh main material ke properties ke saath change kar sakta hoon ya play kar sakta hoon to main material ki fatigue life yahan pe badha sakta hoon. Is part mein hum fatigue pe jo discussion hai yahin par rokte hain agle part mein hum kuch mechanical testing dekhenge ya kuch mechanical behavior dekhenge material ka. Abhi ke liye rukta hoon. Dhanyawad.