

Mechanical behavior of materials

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Week-11

Lecture-56

Fracture & Theoretical Cohesive Strength of Materials

Course Title

Mechanical Behavior of Materials (Hindi)

Lecture-55
Deformation Mechanics Map and Superplasticity

Namaskar phir se swagat karta hoon aapka is course mein Mechanical Behavior of Materials jo ki hum Hindi mein padhenge. Last part mein humne creep deformation ke baare mein jaana tha. Is part mein hum ek generalized equation jaanenge creep ka aur usi ke upar hum uske saath padhai karenge deformation mechanism maps ki aur super plasticity ke baare mein. To ek generalized form of creep equation hum kuch is tarah se likh sakte hain. Yahan par humne dekha ki mein strain rate ko likh sakta hoon temperature dependence ke saath, stress dependence ke saath aur microstructure dependence ke saath. Ek generalized form jo ki mere material ke parameters...



Generalised form of a Creep equation

$$\dot{\epsilon} = \frac{ADGb}{kT} \left(\frac{\sigma}{G}\right)^n \left(\frac{b}{d}\right)^p \quad \text{Mukherjee-Bird-Dorn Equation}$$

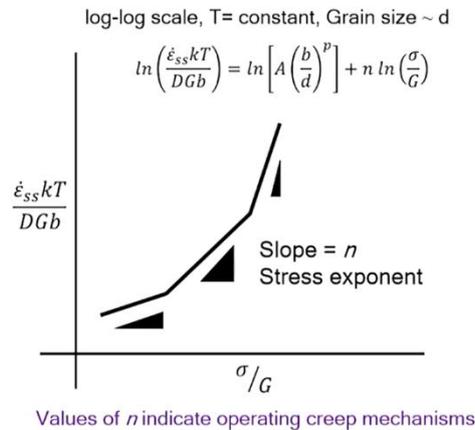
Where,

- A - Constant, Dorn constant (-)
- D - Diffusivity of a material (m²/s)
- b - Burgers vector (nm)
- σ - Applied stress (MPa)
- G - Shear modulus (GPa)
- d - Grain Size (μ m)
- n - Stress exponent (-)
- p - Inverse Grain size exponent (-)
- k - Boltzman constant (J/K)
- T - Temperature (K)

$$D = D_0 \exp\left(-\frac{Q}{kT}\right)$$

D₀- Pre-exponential factor (m²/s)

Q- Activation energy (kJ/mol)



This equation applied to all *Creep Mechanisms*

A. Mukherjee, J. Bird, J. Dorn, Trans. Am. Soc. Met. 62 (1969) 155

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ko bhi consider karta hai. Yahan pe ye jo saare term terminologies se kuch is tarah se mention ki hai yani ye jo D hai ye mera diffusivity hai material ka aur yahan pe G hai ye shear modulus hai. b mere Burgers vector hai material ka. Yahan pe bhi aap dekhenge ki humne strain rate likha tha aur yahan par maine jo stress hai applied stress hai isko normalize kiya hai mere shear modulus ke saath material ke shear modulus ke saath aur is normalized stress ko humne likha hai to the power n. Ye mera stress exponent tha. Strain rate inversely proportional hota hai grain size ke saath to is grain size ko bhi normalize kiya Burgers vector ke saath...

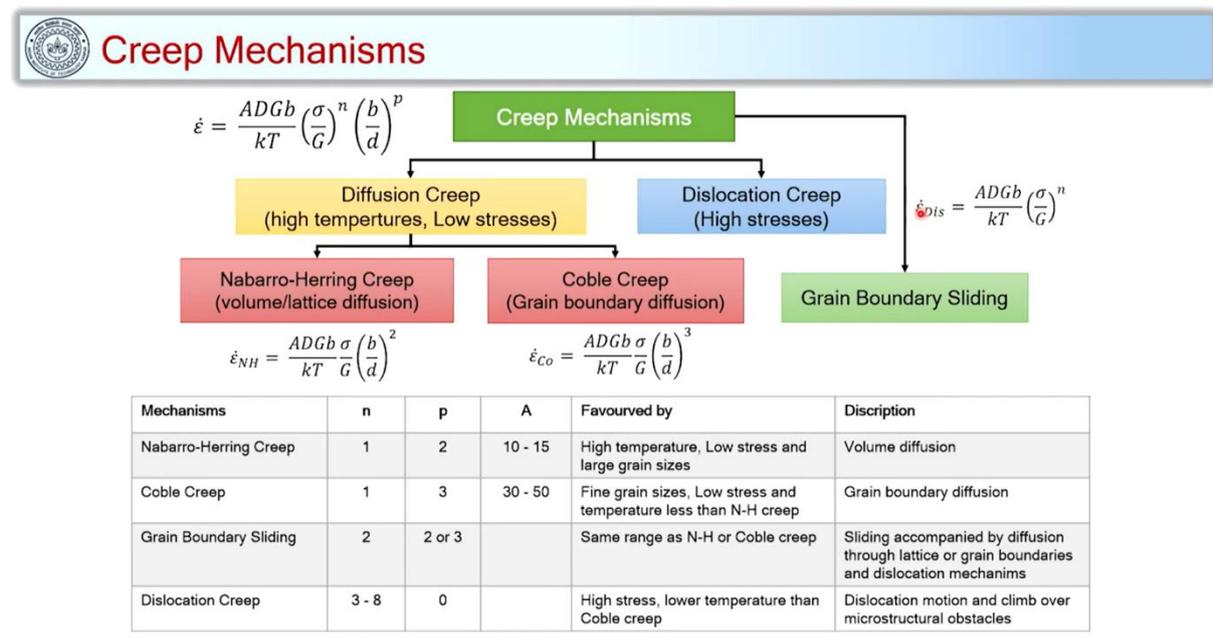
aur isko bhi likha hai kuch inverse grain size exponent aur material ki diffusivity parameters jo diffusion coefficient consider karke likh rahe hum. Aur yeh jo A hai yeh mera Dorn constant hai. Yeh is strain rate equation ko balance karta hai aur kT ye mera thermal energy hai aur mein D ko kuch is tarah se bhi likh sakta hoon $D = D_0 \exp(-Q / kT)$. To yeh ho gaya mera generalized form of creep equation aur yeh bhi jo equation hai wo empirical equation hai aur equation diya tha Mukherjee, Bird aur Dorn. To isliye isko kehte hain Mukherjee-Bird-Dorn equation. To ek equation ki kuch utility dekh sakte hain to yahan par maine kuch yeh...

equation ko is tarah se arrange kiya hai. To yani yeh jo strain rate hai is aur yeh jo term hai kuch is tarah se rearrange ki hai aur dono side par maine log leke kuch is tarah se likha hai. Abhi mein is equation ko agar mein log-log scale par plot karunga jab mein T constant maan

ke chal raha hoon aur grain size ek fixed grain size ke liye consider karke chal raha hoon to aap dekhenge ki mein kuch is tarah se plot likh sakta hoon. Agar mera grain size fixed hai grain size vary nahi ho raha hai aur T constant hai to aap dekh payenge ki yeh jo term hai isko mein stress ke saath normalized stress ke saath consider kar sakta hoon to aur mujhe yeh jo relation milega yeh kuch is tarah se agar mein...

iska relation normalized stress ke saath consider karunga to aapko yeh value milegi stress exponent ki hume kuch is tarah se values milegi n ki aur yeh jo n values hai yeh mujhe darshayegi ki kaun se mechanism operative hai. Agar kisi n ki value kuch hogi us n ki value se mein mechanism find out kar sakta hoon ki is strain rate ke jo stress lag raha hai ya is stress ke wajah se jo strain rate develop ho raha hai uske wajah se mujhe jo n ki value mil rahi hai usse mein kuch deformation mechanism ya creep mechanism ke baare mein baat kar sakta...

hoon is n ki value ke dwara. To n jo hai wo mera slope hai isko mein stress exponent kahunga aur n determine karega ki kaun se mere creep mechanism operative hai. Abhi humne yeh jo equation consider kiya hai yeh equation lagbhag all creep mechanism ke liye saare creep mechanism ke liye applied hai isliye isko generalized form of creep equation kehte hain. To yahan par maine humne kya kiya yeh jo strain rate hai isko consider kiya hai ek normalized stress ke dwara aur mere normalized grain size ke dwara. Abhi mein creep mechanism ki jab baat karunga to humne ek generalized creep equation dikhaya to mein jab creep mechanism ki baat kar raha hoon tab humne do creep mechanism...



majorly do creep mechanism study kiye thay ek diffusion creep aur dislocation creep. To diffusion creep generally hota hai high temperatures pe aur low stresses pe aur dislocation creep mujhe milta hai generally high stresses pe aur jab mein diffusion creep ki baat karunga to mere paas do mechanism hai yani diffusion creep hone ke liye do pathways hai agar wo lattice se ho raha hai ya volume se ho raha hai to hum usko Nabarro-Herring creep kehte hain agar wo grain boundary ke dwara ho raha hai diffusion to hum usko Coble creep kehte hain. Teesra mechanism bhi humne dekha tha ki jo grain boundary sliding hai wo in dono ka interplay hoke hume grain boundary...

sliding milta hai. Agar mein generalized creep equation is tarah consider karunga aur humne kaha tha ki n ki value mujhe kuch creep mechanism ke baare mein jaankari deti hai to yahan par kuch mechanism maine yahan pe likhe hain. Yeh jo bhi mechanism humne yahan pe likhe Nabarro-Herring creep, Coble creep, grain boundary sliding aur dislocation creep aur yahan pe n ki value, p ki value aur ye Dorn constant aur kuch conditions aur descriptions yahan pe maine likhe huye hain. To agar mere paas material mein Nabarro-Herring creep ho raha hai ya Coble creep ho raha hai to aap dekhenge ki n ki value yahan pe 1 hai aur p ki value Nabarro-Herring creep mein p ki value 2 hoti hai aur Coble creep mein...

p ki value 3 hoti hai. p mera inverse grain size exponent hai. A ki values kuch is tarah se mention kiye 10^{10} to 10^{15} aur 30 to 50 yeh ek general Dorn constant yahan pe likhe aap jis material pe aap study karenge aapko literature mein uske Dorn constant ki value dhoondni padegi ya dekhni padegi. Agar jab mein Nabarro-Herring creep aap dekhenge to yeh Nabarro-Herring creep hota hai lattice diffusion ke dwara ya volume diffusion ke dwara isliye generally high temperature pe hoga aur low stresses pe aur large grain size pe dominate karta hai Nabarro-Herring creep. Coble creep hume milta hai grain boundary diffusion ke dwara to jab grain boundary diffusion kab dominate karega jab...

mere material ke grain sizes fine rahenge aur similar conditions hume milti hai stresses ki jaise low stress aur aur temperatures bhi same rahenge less than mere Nabarro-Herring creep yani Nabarro-Herring creep ke liye hume high temperature ki zaroorat hai par Nabarro-Herring creep ke liye jo temperature hai usse kam agar temperature hai aur low stresses pe aur fine grain hai to mujhe Coble creep milega. Dislocation creep mein aap dekhenge ki p ki value yahan par shunya hai aur n ki value yahan par 3 se 8 hai. 3 se 8 ke beech mein n ki value ho sakti hai yeh hume milta hai high stresses pe lower temperatures pe yani lower temperature kaun sa Coble creep...

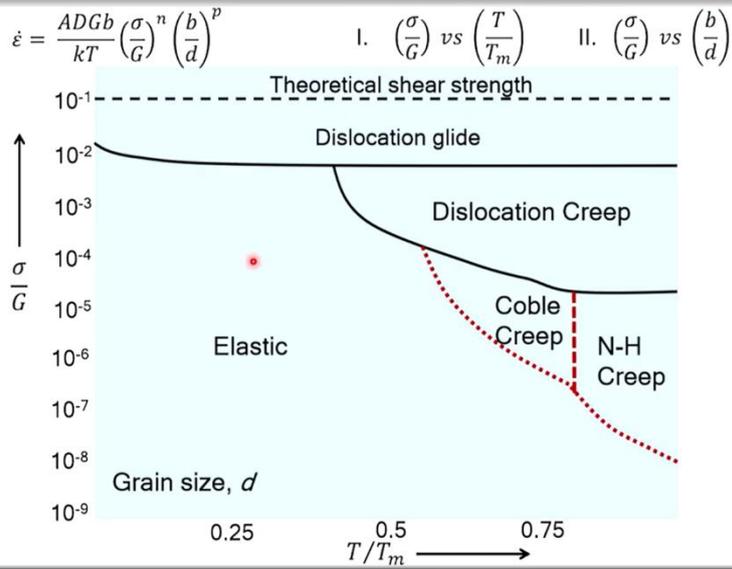
se jo temperature ho raha hai uske neeche jo temperature hai wahan par hume dislocation creep milta hai aur dislocation creep jo hota hai wo humne dekha hai ki climb, glide aur cross slip ya dislocation motion ke dwara hota hai jab mein grain boundary sliding ki baat karunga to yahan pe n ki value 2 hoti hai aur p ki value hai yahan 2 ya 3 ho sakti hai aur yeh jo range hai stress-temperature ka ye same range hota hai mere Nabarro-Herring creep aur Coble creep ke dwara aur hume yeh jo grain boundary sliding milta hai hume milta hai yeh sliding of grain boundaries yani grain boundary slide karte ek doosre ke upar aur yeh accompany hota...

hai diffusion aur dislocation mechanism ke dwara. To abhi humne yeh jo n ki value aur p ki value consider ki hai to agar yeh Nabarro-Herring creep ke baare mein likhunga jab strain rate likhunga to mein kuch is tarah se relation likh sakta hoon yahan par aap dekhenge jo Nabarro-Herring creep mein jo stress exponent hai uski value $n=1$ hai to aap dekhenge ki yeh jo strain rate hai agar mera grain size mein constant rakhta hoon to yahan pe iska variation strain rate ka variation mujhe linear milega stress ke saath aur mein Coble creep ki jab baat karunga to yahan pe p ki value 3 hai aur stress exponent ki value 1 hai to yahan pe bhi strain rate ka variation stress ke saath...

mujhe linear milega par yahan pe aap dekhenge ki Nabarro-Herring creep mein yeh jo inverse grain size exponent hai yeh 2 hai aur Coble creep mein yahan pe 3 hai to aap dekh payenge ki Coble creep mera bahut sensitive hai grain size se as compared to mere Nabarro-Herring creep yahan pe 3 hai isliye aap dekhenge ki jaise mein grain size refine karta hoon to yeh strain rate zyada affected hoga as compared to mere Nabarro-Herring creep ke aur dislocation creep ki jab mein baat karunga yahan pe p ki value shunya hai to ab mein keh sakta hoon ki jo strain rate hai yeh independent hai mere grain size ka to yahan par n ki value ya stress hi...



Deformation Mechanism Maps



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dominate karega grain size koi role play nahi karega mere strain rate par jab mein dislocation creep mein hoon ya mein high stresses par jab creep ho raha hai tab to yahan par yeh jo strain rate ki baat kar raha hoon mostly steady state region ke strain rate ki mein baat kar raha hoon. To yeh ho gaye mere creep mechanism aaiye dekhte hain is creep mechanism ko hum kisi maps ke dwara kaise plot kar sakte hain to yeh jo creep mechanism se hum plot karte hain kisi map ke dwara inko kehte hain deformation mechanism maps. To mere paas ye simple relation hai generalized relation agar mein map plot karta hoon tab mein kuch parameters constant rakhta hoon is case mein...

agar mein map plot karne ki koshish karunga to yahan par mein grain size constant consider kar raha hoon aur mein σ/G yani normalized stress versus homologous temperature (T/T_m) ke dwara mein map plot kar sakta hoon ya mein normalized stress versus normalized grain size (d/b) ke dwara mein map plot kar sakta hoon ye do type ke map mein plot karunga yahan pe mein temperature ko constant rakh raha hoon. To aaiye dekhte hain yeh map dekhte hain to yahan par maine σ/G normalized stress is tarah plot kiya y-axis pe aur yeh maine plot kiya hai yahan pe temperature...

stresses zyada hain very high stresses par mein hoon to mujhe yahan pe yani yeh jo value hai agar $\sigma/G \approx 10^{-2}$ hai to mujhe dislocation glide milta hai yani iske above mujhe dislocation glide milega. Agar mein isse agar zyada stresses jaunga to aap dekhenge ki yeh

mera yeh jo line hai ye mera theoretical shear strength ki value yahan pe dikh rahi hai humne σ/G nikala tha theoretical shear strength ye bahut high value ho yahan par mera material aise hi deform karega. Yahan par 10^{-2} mein mujhe dislocation glide milegi. Abhi hum dekhte hain jaise kuch values yahan par mein agar stress mera decrease kar...

raha hai aur yeh temperature lines maine kuch is tarah se mark kiye yahan par to yahan par aap dekhenge ki agar mein high temperature par hoon kuch is region mein hoon ya high stresses par hoon to yahan par mujhe dislocation creep milega. Aap dekhenge ki aap mein high stresses par hoon yeh high values of stresses hai aur yeh jo temperature hai aap dekhenge ki yeh high temperature hai lagbhag yahan se mein dekh paa raha hoon high temperature humne define kiya tha $0.4 T_m$ se upar jo hai mein high temperature ke ismein ginta hoon. To aap dekhenge ki high stresses aur yahan par is temperature ke upar mujhe dislocation creep milti hai. Abhi mein stresses bahut ghataunga yani bahut kam stresses pe agar mein baat kar...

raha hoon low stress values pe baat karunga to mujhe aur high temperatures pe baat karunga kuch is tarah se high temperature ye mera high temperature regime hai aap dekh paa rahe honge ki 0.5 ke upar mera high temperature regime yahan pe is tarah se aur high temperature aur low stresses pe mujhe diffusion creep milta hai. Abhi hum dekhenge ki yahan pe is region mein mujhe Coble creep milega aur Coble creep hume grain boundary diffusion ke dwara milta hai aur high temperature aur bahut low stresses par mujhe Nabarro-Herring creep milta hai is region mein mera volume diffusion dominate karta hai. To yeh ho gaye mere different mechanism creep mechanism jo ki mein is plot ke dwara...

dikha sakta hoon. To agar mujhe stress ki condition pata hai aur temperature ki condition pata hai to mein find out kar sakta hoon ki kaun se creep mechanism operative ho sakte hain mere material ke deformation mein aur yeh region jo hai yahan pe mera elastic deformation hota hai aur ye humne dekha tha map mere jahan pe mein grain size constant hai yani is constant grain size ke liye mein kuch map is tarah se find out kar sakta hoon. Agar grain size change ho raha hai to mujhe ye map phir se dhoondna padega banana padega. To usi prakar se is type ke map mein consider kar sakta hoon inko hum kehte hain Mohamed aur Langdon maps. To ye ho gaye mere kuch deformation mechanism...

maps. Abhi hum kuch aage badhte hain aur creep ke baare mein aur jaante hain. To jab mein creep ki baat karunga to humne dekha tha creep deformation mein time bahut important hai

yani time ke saath hamara deformation ho raha hai to hume jab hum koi bhi application mein material agar dalenge to mujhe creep life ko predict karna padega yani yeh material kitne samay ke baad creep failure ho sakta hai iska prediction mujhe dena padega. Usi prediction mein hum ye parameter consider karenge jisko Larson-Miller parameter kehte hain. To yeh jo Larson-Miller parameter hai to yeh jaan-ne se pehle jaante hain ki ek Sherby aur Dorn ne ek temperature compensated time parameter θ ko...

 **Creep Life prediction: Larson-Miller parameter**

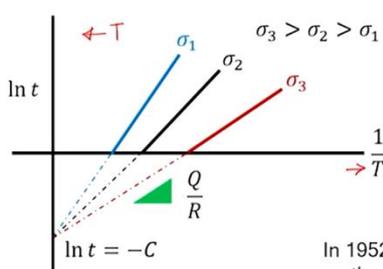
Sherby-Dorn temperature compensated time parameter (θ)

$$\theta = t \exp\left(-\frac{Q}{RT}\right)$$

t : time to rupture

$$\ln t = \ln \theta + \frac{Q}{RT}$$

θ and $\frac{Q}{R}$ are function of stress only



Stress-rupture data

$$\ln t = \ln \theta + \frac{Q}{RT}$$

$$\ln t + C = \frac{b}{T} \quad b = \frac{Q}{R}$$

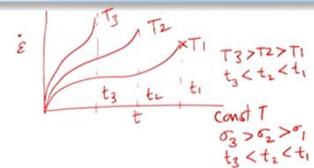
$$T(\ln t + C) = b = f(\sigma) = P_1$$

$$T(\ln t_r + C) = P_1$$

In 1952, Larson and Miller proposed a method that correlates

- the temperature T (in kelvins)
- with the time to failure/rupture, t_r (h)
- at a constant engineering stress, σ (MPa)

C : Larson-Miller parameter = assumed to be 46



define kiya hai kuch is tarah se define kiya hai us parameter ko mein θ is tarah se define karta hoon yahan pe yeh time hai aur yeh time hai compensated by temperature yahan pe yeh jo term introduce kiya gaya hai ismein $\exp(-Q / RT)$ ye consider karega ki yeh time ek compensate kar raha hai mere temperature ko aur yeh jo time hai yeh time to rupture hai ya time to creep rupture hai to yeh parameter is tarah se Sherby aur Dorn ne liye likha tha. Abhi hum dekhte hain ki is agar parameter ko mein is tarah se rearrange kar sakta hoon $\ln(t) = \ln(\theta) + Q / RT$ maine sirf log liya hai dono side pe aur is terms ko is tarah se rearrange kiya agar mein kuch assumptions maan ke chalta hoon jaise ki...

θ aur Q / R yeh jo ratio hai yeh mera yeh mere sirf stress ke function hai yani ek doosre ke upar dependent nahi hai yeh dono sirf stress ke function hai to aap kuch is tarah se isko plot kar sakte hain jaise mein $\ln(t)$ y-axis par plot karunga aur $1/T$ x-axis par agar plot kar raha hoon to mujhe linear relation milna chahiye aur yeh jo linear relation mujhe kuch is tarah se milega. To

yahan pe mein different stresses ke dwara maine ye $\ln(t)$ small t yani time ka time to rupture isko maine plot kiya hai versus $1/T$. To isko samajhne se pehle hum ye consider kar sakte hain jaise humne dekha tha ki agar mein creep curve kuch is tarah se nikaalu ek temperature T_1 pe hai agar mein...

temperature badha raha hoon T_2 aur yahan pe T_3 ye mera strain rate hai aur yahan pe mera time hai to aap dekhenge ki temperature ke liye ye time yahan pe rupture time hai aur ye time T_2 hai ye ek rupture time hai aur temperature T_3 ke liye ye rupture time hai. To aapne hum dekhte hain ki agar $T_3 > T_2 > T_1$ hai yani temperature ki baat kar raha hoon to aap dekh payenge ki ye small t_3 (time to rupture) will be smaller than time t_2 and time t_1 kuch is tarah se hume relation milega. To aap dekh paa rahe honge ki jaise-jaise mein temperature badha raha hoon waise waise rupture time mera ghatega to yehi relation yahan par hum plot kar rahe jaise jaise mein temperature badha raha hoon yahan par likh sakte...

hain hum kuch is tarah se $1/T$ is tarah se badh raha hai is direction mein. To yahan par aap dekhenge ki temperature is direction mein badhna chahiye to temperature mera is direction mein badh raha hai to aap dekhenge ki jaise jaise mera temperature badh raha hai to time to rupture mera decrease ho raha hai yahan pe. To ek particular stress pe humne ek plot kiya jaise σ_3 pe humne plot kiya ek aur jaise σ ye yahan pe ye relation hum likh sakte hain to yahan par σ_3 higher hai to σ_3 ke liye mujhe lower t yani time agar σ_3 zyada hai to time kam lagega to aap dekh paa rahe honge ki yeh ek yani ye θ aur Q/R ye mere...

function of stress hain aur time bhi iske dwara change honge yahan par humne yeh bhi relation yahan dikh sakte hain agar mein ek constant temperature par baat karunga aur stresses change karunga $\sigma_3 > \sigma_2 > \sigma_1$ to mein ismein bhi agar time nikaalne ki baat karunga to time jo lagega wo ek yeh relation follow karega. To yeh is tarah se mein plot likh sakta hoon $\ln(t)$ versus $1/T$ ka. Abhi yeh jo plot hai agar ye sirf function of stress hai to mein agar isko extrapolate karta hoon to yeh jaakar kuch is tarah se intercept hoga kyunki ye sirf function of stress hai to aap dekhenge ki jab $1/T$ shunya hone yani $1/T \rightarrow 0$ to aap dekhenge ki...

constant value mujhe milegi aur iska jo slope rahega yeh mujhe milega Q/R aur ye jo Q/R hai yeh jo slope hai yeh bhi kya hoga ye mere stress ka function hoga. Abhi dekhte ki yeh jo

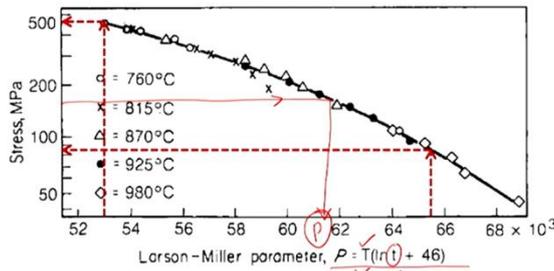
intercept mein hume mila hai yeh isko mein kuch is tarah se likh sakta hoon $\ln(t) = -C$. To mein yeh intercept ek constant maan ke chal raha hoon $-C$. Abhi mein agar yeh relation phir se consider karta hoon to is point pe mein is $\ln(t)$ ko C consider kar sakta hoon kyunki intercept hi hai to mein kuch is tarah relation rearrange kar sakta hoon $\ln(t) + C = B/T$ jahan pe B mera Q/R hai aur mein is temperature ko is side le...

aaunga to mein kuch is tarah se relation likh sakunga yahan par ye jo B hai humne likha hai ki Q/R aur aap dekhenge ki yeh Q/R mere function of stress ka hi function hai aur isko mein maan ke chal raha hoon ek constant P_1 . To mein kuch is tarah se is relation ko rearrange kar sakta hoon aur t_r ko jab yeh rupture time hai isko mein agar consider kar raha hoon to mein relation ko is tarah se modify karke likh sakta hoon yahan par jo C hai jo humne likha hai yehi hamara Larson-Miller parameter hai aur yeh most of the material ke liye 20 assume kiya jata hai to ye experimentally observed values hai jo ki Larson-Miller ne hume di thi aur yeh jo Miller parameter jo hai...

yeh propose kiya tha Larson aur Miller ne aur yahan par kuch points yahan par maine mention kiye ki jo temperature hai wo mera Kelvin mein hai aur time to failure ya rupture jo hai t_r jo hai wo hours mein hota hai aur yeh jo hai yeh constant engineering stress ke liye valid hai ya σ yeh mera MPa mein hai. To yeh jo Larson-Miller parameter jo hume mila hai ya jo ye identity mein hume mili hai iski hum abhi utility dekhte hain ki hum kis tarah se life creep life ko predict kar sakte hain. To ek simple example yahan pe maine liya hai. Determine the stress required for failure of Astroloy in 10^5 hours at temperatures of 650 aur 870 °C. To hume is do temperature par hume stress kitna lag raha hai failure ke...



Larson-Miller parameter



L-M Parameter for Astroloy
(Ni-based superalloy)

Example Determine the stress required for failure of Astroloy in 100,000 h at temperatures of 650 and 870°C, i.e., 923 and 1143 K.

Using Eq. (13-27) we determine values of the Larson-Miller parameter.

$$\text{At } 650^{\circ}\text{C}, \quad P = 923(\ln 10^5 + 46) = 923(11.5 + 46) = 53.1 \times 10^3$$

$$\text{At } 870^{\circ}\text{C}, \quad P = 1143(\ln 10^5 + 46) = 1143(11.5 + 46) = 65.7 \times 10^3$$

From the master plot for Astroloy (Fig. 13-20) we find the stresses corresponding to the values of the parameters.

$$\text{At } 650^{\circ}\text{C}, \quad P = 53.1 \times 10^3 \quad \text{and} \quad \sigma = 500 \text{ MPa}$$

$$\text{At } 870^{\circ}\text{C}, \quad P = 65.7 \times 10^3 \quad \text{and} \quad \sigma = 85 \text{ MPa}$$

There are time-temperature parameters

- Orr-Sherby-Dorn
- Manson-Haferd
- White-LeMay

GE Dieter: Mechanical Metallurgy

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liye yeh dhoondna hai is alloy ke liye. Astroloy ek nickel-base superalloy aur yeh jo map diya hai yeh mera Larson-Miller parameter map hai jo hume is Astroloy ke liye mila hai practically. Abhi hum dekhte hain ki yeh jo temperatures hai pehle to hume isko Kelvin mein convert karna hai 923 yani 650 ko mein convert karunga 273 add karke to mujhe 923 K milega aur 870 mujhe 1143 K milenge. Abhi hum ye hamare paas temperature hai aur hamare paas time hai to hum ek yeh parameter nikaal sakte hain humne dekha ki yeh parameter mein kuch is tarah se yahan pe C ki value maine 20 consider ki hai ye mera temperature hai parameter ye time hours mein hai 10^5 hours hai to...

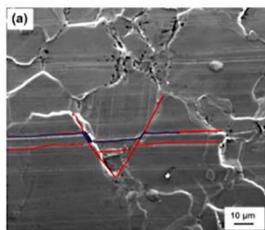
ye parameter 650 ke liye mujhe mil raha hai 23.1×10^3 aur yeh jo at 870 °C mujhe Larson-Miller parameter 28.6×10^3 mila. Abhi yeh parameters mujhe mile abhi hume stress nikaalna hai ki kis is stress pe yeh fail hoga is condition pe to maan lete hain 650 pe to hume jo pehle mila tha 23.1 to mein yahan pe uh yeh parameter consider kiya 23.1 is line pe gaya yahan pe jo iske corresponding stress hai wo mujhe mil raha hai lagbhag 500 MPa aur abhi hum dekhte hain ki mere paas jab 28.6 jo value mujhe mili hai ya 1143 K pe ya 870 °C pe to yeh hai 28.6 to yahan par kahin par mein Larson-Miller parameter mark...

karunga aage jaunga aur dekhunga ki iske corresponding mujhe stress kitna mil raha hai lagbhag ki jo ki aa raha hai mera 85 MPa. Abhi hum dekh sakte hain ki agar mere paas time diya hai ki service life di hai kitna itne time tak mera material chalna chahiye yani yahan pe Astroloy ki baat kar rahe aur is temperature par agar mein operate karna chahta hoon to kitna

maximum possible stress mein apply kar sakta hoon. To yahan par hum is tarah se stresses ki value nikaal sakte hain. Aap agar aapko stress diya hai aur aapko time nikaalna hai to aap kuch is tarah se nikaal sakte hain temperature nikaalna hai kuch is tarah se nikaal sakte hain. To aap stress agar mein yahan pe aaya...

aur stress ki value pata hai to mein stress ki value se ek parameter nikaal sakta hoon yahan par mujhe parameter ki value yahan par mil gayi aur mujhe time pata hai to mein temperature nikaal sakta hoon agar temperature pata hai to mein time nikaal sakta hoon. To yeh ho gayi utility mere Larson-Miller parameter ki. To yeh hamare ye jo Miller parameter jo mujhe mila tha wo mujhe Sherby aur Dorn ke temperature compensated time se mila tha to kuch aur parameters yahan pe aur literature mein aapko mil sakte hain jo ki time-temperature parameters kahe jaate hain jaise ki aur Sherby-Dorn, Manson-Haford aur Wyatt-Lemke. To yeh bhi kuch popular parameters hai hum janrally Larson-Miller parameter istemal karte hain...

 **GBS and Superplasticity**



Relationship between flow stress and strain rate at constant strain and temperature

$$\sigma = C (\dot{\epsilon})^m \Big|_{\epsilon, T}$$

$$\ln \sigma = \ln c + m \ln \dot{\epsilon}$$

$$m = \left(\frac{\partial \ln \sigma}{\partial \ln \dot{\epsilon}} \right)_{\epsilon, T} \quad m = \frac{\log(\sigma_2/\sigma_1)}{\log(\dot{\epsilon}_2/\dot{\epsilon}_1)}$$

m is strain rate sensitivity

$\dot{\epsilon} \propto \sigma^n$
 $\sigma \propto (\dot{\epsilon})^{1/n} \rightarrow m$
 strain rate jump test
 $\dot{\epsilon}_1 \rightarrow \dot{\epsilon}_2$
 $\sigma_1 \rightarrow \sigma_2$
 • $\dot{\epsilon}$ - regime
 σ - regime

- High strain rate sensitivity is a characteristic of a superplastic materials
- Elongations between 100 and 1000 percent
- Superplastic materials have grain sizes of the order of 1 μm

steels, aluminum aur titanium alloys ke liye ya superalloys ke liye. Baaki kuch material ke liye ye bhi parameters developed hain aap iske baare mein padh sakte hain books mein jaise ki Mechanical Metallurgy aur yeh jo example humne liya tha yeh bhi Mechanical Metallurgy book se aaya tha jo ki George Dieter se mila hai. Abhi hum aage badhte hain aur abhi hum super plasticity aur grain boundary sliding ke baare mein padhte hain. To grain boundary sliding humne dekha tha ki boundaries ek doosre ke upar slide karte hain to yahan par ek

microstructure maine dikhaya hai to aap dekhenge ki yeh jo boundary hai yahan pe yeh jo boundary ek doosre ke upar slide ho rahi hai to yeh kaise...

pata karenge ki kuch markers yahan par maine mark kiye kuch is tarah se yahan pe kuch markers aapko dikh rahe honge aur agar aap dekhoge ki is markers pe kuch offset aaya hua hai yeh jo offset hai yahan pe to yeh jo offset se hum pata kar sakte ki do grain ek doosre ke upar slide huye ya glide ho rahe hain slide ho rahe hain ek doosre ke upar. To isko hum grain boundary sliding kehte hain. Initially jab hum yeh jo markers lagate ye jo marker straight line hone chahiye thay initial condition mein wo straight line thay. Jab material deform ho gaya ya yahan pe grain boundary sliding jab hui to marker ke shift ke dwara hum kitni grain boundary sliding...

hui hai yeh quantify kar sakte hain. To ye jo ho gaya yeh mere microstructure se ek evidence ho gaya grain boundary sliding ka. Abhi hum dekhte hain jab grain boundary sliding ki baat karte tab hume ek relation lena padega flow stress ka aur strain rate ke saath. Agar hum yeh condition consider karte flow stress aur strain rate ki ek constant strain pe aur temperature ke saath agar yeh relation samajhte hain to hum super plasticity ya grain boundary sliding samajh sakte is parameter ke dwara jo ki meri strain rate sensitivity hai. Isko hum is tarah se bhi likh sakte hain humne dekha tha creep mein ki strain rate mera function hai σ^n ...

se bhi likh sakta hoon ki stress ko mein strain rate ke dwara bhi likh sakta hoon kuch is tarah se aur yeh jo parameter hai isko mein transfer kar sakta hoon ek aur parameter mein jo ki mera strain rate sensitivity (m) hai. Yeh equation ko mein agar log lunga aapko yeh equation mein tab likh sakta hoon jahan par mein mere paas strain aur temperature constant hai to mein is equation ko is tarah se modify kar sakta hoon. Agar mein m ki value yahan par strain rate sensitivity ki value agar mein nikaalna chahunga to mein kuch mathematically kuch is tarah se nikaal sakta hoon $\partial(\ln \sigma) / \partial(\ln \dot{\epsilon})$ ya mathematically experimentally mein kuch...

is tarah se nikaal sakta hoon yahan par aap dekh paa rahe honge ki mein strain rate sensitivity ki value nikaal raha hoon yahan pe $\log(\sigma_2/\sigma_1) / \log(\dot{\epsilon}_2/\dot{\epsilon}_1)$. To jab mein strain rate 1 se strain rate 2 mein ja raha hoon to mujhe kitna stress lag raha hai deformation ke liye yeh hum nikaalte hain to isko hum kehte hain strain rate jump test. To strain rate jump test se hum nikaal sakte hain ki kitna kitni meri strain rate sensitivity ho sakti hai mere material ki. To ye hui strain rate

sensitivity ki value. Strain rate sensitivity ki value is tarah se hum nikaal sakte hain. To jab mein super...

plasticity ki baat karunga grain boundary sliding ki jab baat karunga tab mujhe high strain rate sensitivity chahiye jo ki mujhe ek super plastic behavior deti hai. Jab mein super plasticity ki baat karunga to elongation jo mere material ke hone chahiye wo 100 to 1000 % hone chahiye aur super plasticity mujhe kisi grain size jo bhi mera grain size kuch is order pe hona chahiye $1 \mu\text{m}$ ki tarah yani hume super plasticity kuch grain size regime mein hi milti hai aur kisi strain rate sensitivity regime mein milti hai yani mein yahan pe likh sakta hoon ki strain rate ek particular regime hona chahiye aur grain size ka bhi ek particular regime hona...

chahiye yani hume kisi bhi strain rate sensitivity strain rate pe ya kisi bhi grain size par hume super plastic behavior material ka dikhta nahi hai ek particular regime hota hai usi mein hume strain rate aur grain size ka ek regime hota hai usi pe hume super plastic behavior milta hai. To ek introduction ho gaya hamare strain rate sensitivity ko abhi jaante hain ki super plasticity kis tarah se ho sakti hai milti hai. To jab mein super plasticity ki baat kar raha hoon to yahan pe hume samajhna padega ki competition hota hai hamesha geometric softening aur strain hardening ke beech mein jo ki necking ko decide karta hai. Agar...

 **Superplasticity and necking**

Competition between Geometrical softening and strain hardening $\frac{d\sigma}{d\varepsilon} = \sigma$

$d\sigma/d\varepsilon > \sigma$ In tensile deformation, No necking

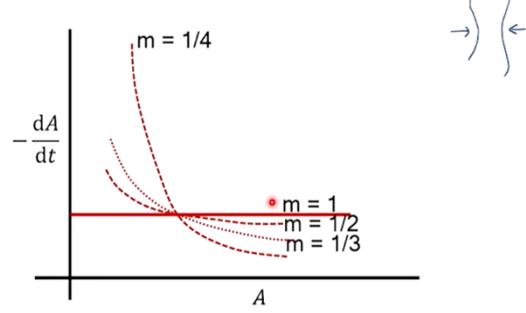
$\sigma = C(\dot{\varepsilon})^m \Big|_{\varepsilon, T}$ $\frac{P}{A} = \sigma = C(\dot{\varepsilon})^m$ Axial Force, P with cross-sectional area A

$\dot{\varepsilon} = \left(\frac{P}{C}\right)^{1/m} \left(\frac{1}{A}\right)^{1/m}$

$\dot{\varepsilon} = \frac{1}{L} \frac{dL}{dt} = -\frac{1}{A} \frac{dA}{dt}$

$-\frac{dA}{dt} = A\dot{\varepsilon}$

$-\frac{dA}{dt} = \left(\frac{P}{C}\right)^{1/m} \left(\frac{1}{A^{(1-m)/m}}\right)$



strain hardening dominate karega to material neck nahi hoga ya mein is tarah se bol sakta hoon jab mein hum tensile deformation ki baat karte hain to mera humne necking ka condition is

tarah se likha tha jo $d\sigma/d\varepsilon$ agar yeh $> \sigma$ hai to mujhe koi necking nahi milti hai. To hum is tarah se keh sakte hain jab necking jab hota hai to $d\sigma/d\varepsilon$ humne consider kiya necking ke baad yeh σ hona chahiye tab jaake ab mujhe necking milti hai is condition mein hume yeh is condition mein hume koi necking nahi milegi. To aap dekh paa rahe honge ki yeh competition hota hai geometric softening aur...

strain hardening ka jo hume necking milti hai agar necking agar mein avoid kar paa raha hoon to mein material ko elongate kar sakta hoon zyada degree tak. To jab mein strain rate sensitivity ki baat kar raha hoon to $\sigma = C \varepsilon^m$ ye meri strain rate sensitivity hai aur ek constant strain aur temperature ke saath mein baat kar raha hoon to agar mein stress ko kuch is tarah se likhunga $P/A = \sigma = C \varepsilon^m$ jahan pe P mera force hai aur ye A mera cross section area hai mere material ka. Abhi mein kuch is tarah se relation likh sakta...

hoon strain rate agar mein yahan pe is tarah se rearrange karunga is equation ko yeh dono equation consider karke to yahan par maine force stress ko P likha hai aur C yahan pe aa jayega neechे to mein kuch is tarah se rearrange kar sakta hoon. Abhi mein strain rate ($\dot{\varepsilon}$) ko is tarah se likh sakta hoon $\dot{\varepsilon} = (1/L) dL/dt$ yani yeh jo term hai ye mera strain rate ho gaya aur mein is relation ko agar necking nahi ho rahi hai to mein isko convert kar sakta hoon area change mein bhi yani kis tarah se mera rate of change of area ho raha hai is tarah se bhi mein likh...

sakta hoon. To yeh equation agar mein consider karunga to mein yeh jo rate of change of area hai cross section area ki baat kar raha hoon mein to mein isko $A \times \dot{\varepsilon}$ likh sakta hoon yeh agar term mein rakhunga is equation mein to mujhe yeh kuch is tarah se identity aayegi. Abhi hum dekhte hain ki yeh jo rate of change of cross section area hai yeh kis tarah se vary hota hai mere area ke saath aur strain rate sensitivity ke value ke saath to agar hum yeh is tarah se plot karenge kyunki mere paas yeh ek term hai aur yeh ek term hai to mujhe mein in dono ka relation nikaal sakta...

hoon agar mein different value of m yahan par rakhunga tab to mujhe jab m ki value kam hoti hai chhoti hoti hai to ya yahan par $1/4$ consider kar rahe hain to hum hume kuch is tarah se area ka change mila rate of change of area mil raha hai area ke saath is tarah se agar m ki value jaise jaise mein badha raha hoon to mujhe kuch is tarah se values variation mil raha hai m ki value is tarah se badh rahi hai yahan par $m = 0.5$ ho gaya hai aur yahan par $m = 1$ ho gaya hai. To aapko yahan pe yeh pata chalega ki jaise jaise mera area ghat raha hai aur m ki value kam hai waise waise yeh jo change hai rate of change of area yeh drastically...

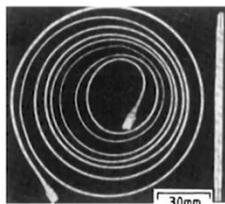
is rate se nahi ghat raha hai aur jab $m = 1$ hai to yeh jo rate of change of area hai wo more or less independent hai mere cross section area se. Iska matlab kya hua jaise ki humne dekha tha ki cross jab necking jab hota hai tab cross section area ghat-ta hai kuch locally is tarah se to agar area jahan pe ghat raha hai yani yahan pe low area pe agar mein baat karunga tab jaise mere strain rate sensitivity kam hai tab yeh jo decrease hoga wo drastically hoga as compared to mere strain rate sensitivity 1 hai wahan pe yeh jo area change hai wo necking wahan na milte huye kam milegi. Iska matlab yeh hai ki jab meri m ki value kam hai tab yeh jo area change ho raha hai yeh drastically change ho raha hai aur agar $m = 1$ hai to dekhenge ki yeh...

jo rate of change of area hai wo independent ho jayega mere cross section area se aur material yahan pe neck nahi karega aur yahan pe hume continuous elongation mil sakta hai ya tensile deformation mein. To yehi hume hamare super plasticity ka origin ho sakta hai yehi uh to jo material mujhe high strain rate sensitivity dikhathe wo material mujhe super plastic behavior dikhathe. To jab mein super plasticity ki baat kar raha hoon tab kuch applications yahan pe dekhte to humne dekha tha ki super plasticity ya tensile deformation mein hume kuch elongation milna chahiye jo ki 100 % se zyada hona chahiye...

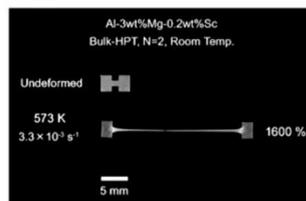


Superplasticity

Superplasticity is the ability of certain materials to undergo extraordinary tensile deformation (usually more than 100 %) without fracturing. Materials that have demonstrated superplasticity include aluminum, titanium, nickel, steels, and even some ceramics. This large tensile elongation can be used effectively to form net-shape, complex structures.



Tensile elongation of 1950% achieved in a Bi-Sn alloy



Superplasticity in an Al-Mg-Sc alloy processed by HPT



Superformed 5083 Aluminum Alloy

Pearson et al., J. Inst. Metals 1934, 54, 111-124.
Horita et al., Scripta Mater. 2008, 58, 1029-1032.

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without fracturing aur necking. To yahan par aap dekh paa rahe honge ki kuch kuch alloys hai yeh classic example hai aap dekhenge ki yeh initially bahut chhoti sample thi aur yeh elongate hoke kuch is tarah se hui hai yahan par hum dekhenge ki yahan par yeh material fracture bhi nahi hua hai. Similarly ek aluminum alloy hai yahan par un-deformed state mein aapko dikhaya

aur yahan par aap dekhenge ki yeh itna elongate hone ke baad almost 1600 % elongation hone ke baad hi fracture hua hai. Iska application is tarah se ki hum dekh sakte hain ki yeh super formed alloy hai 5083 aluminum alloy yeh kiya hua hai aap dekhenge ki ek hi sheet mein...

Designing for Creep resistance

$$\dot{\epsilon} \propto \frac{1}{d^p}$$

- High melting point
- Larger grain sizes
- Solid solution strengthening
- Disperse fine precipitates

- Nickel based superalloys
- Aircraft Turbine engine blades
 - 250 MPa 850 °C

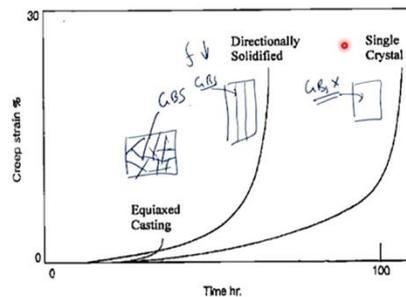
| | |
|----|-------|
| Ni | :Bal. |
| Co | :10 |
| Cr | :19 |
| Al | :06 |
| Mo | :05 |
| W | :10 |

Cr: Improves oxidation resistance, Cr₂O₃ layer

Nickel based superalloys

γ - Nickel Matrix
 γ' - Ni₃Al
 γ - γ' microstructure

Intermetallics
 Or ordered precipitates



humne isko is tarah se deform kiya hai ki hume ek hi sheet ke dwara ek complex complicated shape ka hume structure mila hai. To yeh super plasticity ka advantage hai. To yeh super plasticity behavior mere material processing ko bhi bachata hai to mujhe yahan pe machining karne ki zaroorat nahi hai ya kuch extra dies rakhne ki zaroorat nahi hai ya material loss yahan par mein ghata sakta hoon. To yeh ho gaya mera super plastic plasticity ka advantage. Jab abhi humne super plasticity ke baare mein padha to abhi hum kuch criteria dekhte hain ki jisse hum creep resistance ko badha sakte hain. To jab hum creep resistance ko badhane ki baat karte tab...

mujhe generally chahiye high melting point kyunki humne dekha hai ki creep depend karta hai mere melting point ke upar jitna mera melting point zyada utna mein us material ko high temperature par sustain kar survive karwa sakta hoon to isliye mujhe melting point high chahiye. Hume larger grain sizes chahiye kyunki humne dekha tha ki strain rate jo hai wo $\dot{\epsilon} \propto 1/d^p$ hota hai to hum dekhenge ki jitna mera grain size zyada utna mera creep resistance aur creep rate kam to isliye hum dekhenge ki creep resistance badhta hai jaise-jaise grain size badhta hai ye mein baat kar raha hoon jab diffusion mechanism ki baat kar raha hoon. Hum...

dekhenge ki agar mein solid solution strengthening kar raha hoon tab mujhe jo dislocation motions hai mein isko rok sakta hoon ya impede kar sakta hoon. Agar mere paas precipitates hai fine precipitates hai jo mein coherent precipitates rakhta hoon microstructure mein tab bhi mujhe mein dislocation ke motion ko rok sakta hoon aur jo dislocation creep mechanism hai isko mein avoid kar sakta hoon jab mein precipitates uh mere microstructure mein rehte hain. Kuch example lete hain jaise nickel-base superalloys mein yeh jo alloy hota hai wo istemal hota hai mere aircraft turbine engine blades ke liye aur ye blades operate hote hain high stresses aur high temperatures pe yani 250 MPa at 850 °C...

To aap dekhenge ki nickel-base superalloys ka composition kuch is tarah se hota hai yahan pe cobalt rehta hai chromium rehta hai aluminum rehta hai molybdenum rehta hai tungsten rehta hai tungsten ek high melting point alloy ya isko refractory element bhi kehte hain to is yeh mere material mein isliye add kiya jata hai ki mera material high temperature par sustain kar paye. Chromium is tarah se add kiya jata hai kyunki chromium hume oxidation resistance deta hai kyunki ek protective Cr_2O_3 layer form karta hai superalloy pe to hume oxidation resistance bhi important hai jab mein high temperature ki baat kar raha hoon ya creep temperature ki baat kar raha hoon. To is nickel-base...

superalloys mein important thing yeh hai ki yahan pe mujhe jo matrix hai wo nickel matrix hai aur yeh jo γ' (gamma prime) jo structure hai wo Ni_3Al structure hai yeh ordered structure hai. To yeh intermetallic ya ordered precipitates hain nickel-base superalloy mein yeh jo precipitate aap dekh paa rahe hain yeh mera γ' hai yeh Ni_3Al hai aur yeh jo dark region mil raha hai yahan par mujhe yeh mera nickel matrix hai. To humne dekha tha ki ye jo Ni_3Al hai ordered phase hai ya intermetallic hai to yahan pe dislocation movements aasani se nahi hote hain to hum dekhenge ki jaise-jaise mein is kind of precipitates ko introduce kar raha hoon aur gamma matrix bhi humne kuch is tarah se solid...

solution strength kiya hai to hume yeh mein material high temperature pe istemal kar sakta hoon jo ki yani hum dekh sakte hain ki 850 °C is high stresses pe bhi mein is superalloy ko istemal kar sakta hoon. To kuch strategies humne yahan pe point out kiye aur yeh kuch uske micro-structural evidences hain aur jab mein diffusion creep ki jab baat kar raha hoon to maine bataya tha ki larger grain sizes ki hum baat kar rahe thay to yahan pe ek map ya figure maine di hai yahan pe creep strain plot kiya hai aur yahan pe time plot kiya hai hours mein aap dekh paa rahe honge ki agar mein different processing techniques agar mein istemal karke kuch...

microstructure trend kar raha hoon jaise equiaxed casting jaise mujhe yahan pe equiaxed grains milenge aur kuch yahan par directional solidification agar mein consider kar raha hoon aur yahan par mere paas kuch single crystal yahan par mile hain to aap dekh paa rahe honge ki is kesse mein jab mere paas equiaxed casting hai to yahan par yeh material jaldi fail ho raha hai yani kam samay mein fail ho raha hai aur single crystal yahan par hum dekhenge to yeh zyada time le raha hai fail hone mein. To yahan pe humne kya kiya single crystal mein mere jo high angle grain boundaries hai un saare high angle grain boundaries ko maine eliminate kar diya hai aur is elimination ki wajah se...

mera diffusion creep kam ho gaya material mein aur yeh zyada creep resistance dikhayega. Directional solidification mein mujhe columnar grains milte hain aur is columnar grains ki wajah se mujhe uh grain boundaries jo hai wo ek particular direction mein hi milegi aur uske wajah se diffusion jo rate hai wo ek kam ho jayega jaise hum yahan par is tarah se samajh sakte hain agar mere paas kuch equiaxed grains hai is tarah se multiple grains hai to yahan par mujhe mere paas bahut saari boundaries hongy grain boundaries yahan par zyada hogi. Yahan par hum directional solidification mein hum dekhenge ki kuch is tarah se columnar grain hai ek to yeh saari jo grain boundaries hai to humne...

grain boundaries ko replace kar diya maine fraction of grain boundary yahan pe ghat gayi hai aur single crystal mein mere paas high angle grain boundaries nahi rahegi sirf ek single rahega to grain boundary fraction yahan par lagbhag nil rehta hai. To yahan par aap dekhenge ki agar mein diffusion creep ko kam kar raha hoon kam karna chahta hoon to mujhe grain boundaries ko eliminate kar-na padega aur yeh practical example hai ki processing mere material mein bahut important role play karti hai jab mein creep resistance ki baat kar raha hoon. To yeh ho gayi kuch strategy jo ki creep resistance ko badhati hai. To abhi tak humne yani is part mein humne creep ke baare mein generalized creep equation...

ke baare mein padha super plasticity ke baare mein padha aur yeh jo important topic hai creep deformation of material ka isko mein yahin par samapt karta hoon. Creep ko jaan-ne ke liye bahut saari cheezein hain bahut specific topics hain par ek sankshipt roop mein maine creep ko aapke saamne present kiya hai. Next part mein hum aur ek deformation mode ko jaanenge jisko hum kehte hain fatigue. Abhi ke liye rukta hoon dhanaywad.