Mechanical behavior of materials

Dr. Niraj Mohan Chawake

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

Week-1

Lecture-1

Introduction: Definitions and Units

Namaskar main Neeraj Mohan Chawake Assistant Professor hoon main Department of Material Science Engineering IIT Kanpur se. Main is course mein aapka swagat karta hoon jo ki Mechanical Behaviour of Material hai jo main Hindi mein padhaunga. To ye jo mere kuch contact details diye hain aapke liye, isse aap mujhe contact kar sakte hain. So is course mein jo contents hain woh mainly teen topics hain – Elasticity, Plasticity aur Plastic Deformation. Elasticity mein hum thoda stress aur strength ke baare mein jayenge. Hum yielding of material tak pahunchenge. Uske baad hum Plasticity mein dislocation aur microstructure aspects kya hote hain jo strength aur ductility ko affect karenge, iske baare mein hum thoda jaanenge. Uske baad plastic deformation mechanism kya hai aur phir material fail kaise hote hain, jo ki mostly hum

Instructor

Dr. Niraj Mohan Chawake

417, Faculty Building

Department of Materials Science and Engineering

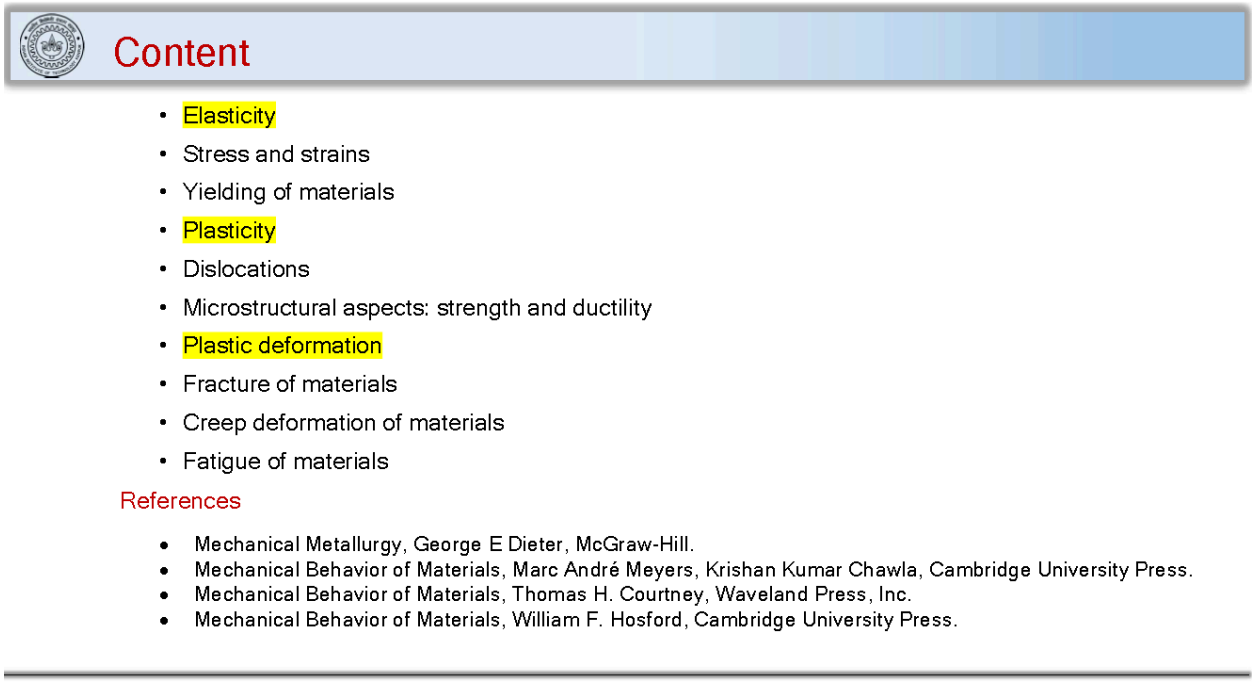
Indian Institute of Technology Kanpur

Kanpur-208016, Uttar Pradesh, INDIA.

Email: nchawake@iitk.ac.in

Phone: +91 512 259 2181 (O)

fracture of material ke baare mein baat karenge, creep ke baare mein baat karenge aur fatigue of material ke baare mein.



So ye jo content hai, ye mostly in chaar text books se banaya gaya hai – jo ki *Mechanical Metallurgy* George E Dieter, ye ek famous book hai jo mechanical metallurgists padhte hi padhte hain. Uske baad *Mechanical Behaviour of Materials* Meyers aur Chawla ka ek jo book hai, ye bahut hi accha book hai jahan par problems achhe se solve kiye gaye hain. Phir ek *Mechanical Behaviour of Materials* by Thomas H. Courtney, ye book conceptual zyada hai. So agar concepts kuch samajhne hain to aap Thomas H. Courtney ko refer kariye. Aur *Mechanical Behaviour of Materials* jo William Hosford hai, isme bhi bahut saare numericals diye hain jo aap istemal kar sakte hain.

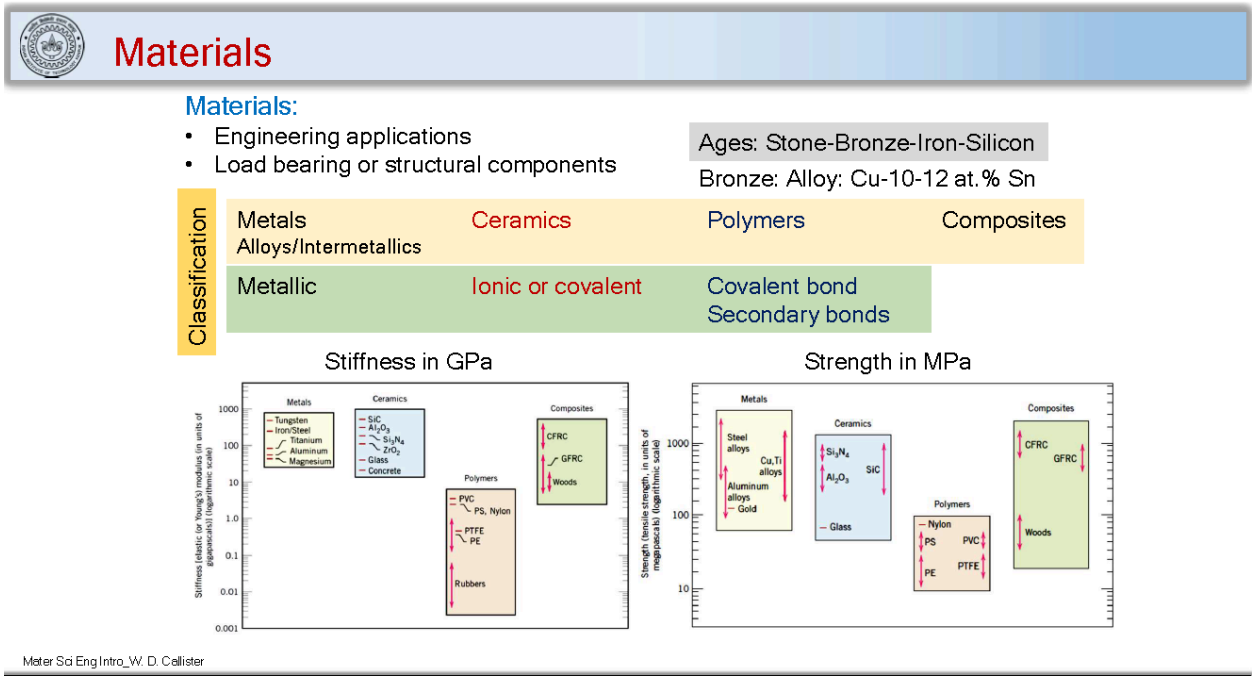
Important Information

- Most of the diagrams and schematic images are sourced from various references in the literature and online. The sources are cited, or the relevant information is provided at the bottom of the slide where the content is used.
- These external figures and images are intended solely for educational and teaching purposes.

Baaki ek important information main aapko dena chahta hoon – jo is course content jo hai, woh bahut saare literature sources se banaya gaya hai, jo references online available hain ya text book mein available hain, apart from jo maine abhi jo text books aapko mention kiye. Agar ye sources main slides ke neeche mention karunga to ye cited hain. Aur ek aur information batana chahta hoon ki ye jo saare jo external figures ya images jo maine liye hain, ye sirf educational aur teaching purpose ke liye.

To chaliye shuruat karte hain hamare course ke liye. To sabse pehle hamare course ka naam hai *Mechanical Behaviour of Materials*. To ye jo material hum istemal karne wale hain, ye hum saare istemal karne wale hain structural applications ke. To structural applications kya hoti hain? To ye kuch pictures maine lagaye hue hain yahan pe. Jaise ye pehla picture aap dekhiye, ye picture hai blast furnace ji Tata Steel ka. To yahan par aap dekhiye bahut saare structural members, yani ek long structure tayyar kiya hai jo steel members se banaya hua hai. Ye aap doosra image dekh rahe hain, ye image hai turbine blades ka, aur high pressure par kaam karna hai to ye turbine blades bante hain superalloy se. Third picture aap dekhenge ki rockets ka hai, to ye rocket nozzles hain, inko bhi high temperature par kaam karna hai, inko structure ko support bhi karna hai. Chautha picture aap dekhenge ki ye bridge hai, aur is bridge mein jo cables lage hue hain, to ye cables ko is complete civil structure ko support karna hai. By the way ye structural jo cables hain, ye hamara Signature Bridge Delhi se hai. Aur ye jo paanchwa picture hai, ye hamare nuclear reactor ka hai, ye body hai nuclear reactor ke bahari body ka. To aapko pata hai nuclear reactor jo hote hain, unme temperatures 1000–3000°C tak jaate hain, aur yahan par plasma banta hai. To aap jaan sakte hain ki in materials ko us plasma ko rakhna hai apne paas aur ye us condition mein deform na ho. To ye importance hai structural materials ka in structural applications mein. Is introduction ke saath main aage badhta hoon. Is course mein humne baat ki hai ki material ke baare mein. To material kya hote hain? To sabse pehle hum is course mein

engineering jo applications hain woh structural components ke liye istemal karne wale. To hum unhi materials ke baare mein baat karenge jo load bearing yani jo load ko carry karte hain, unhi materials ke baare mein hum baat karenge.



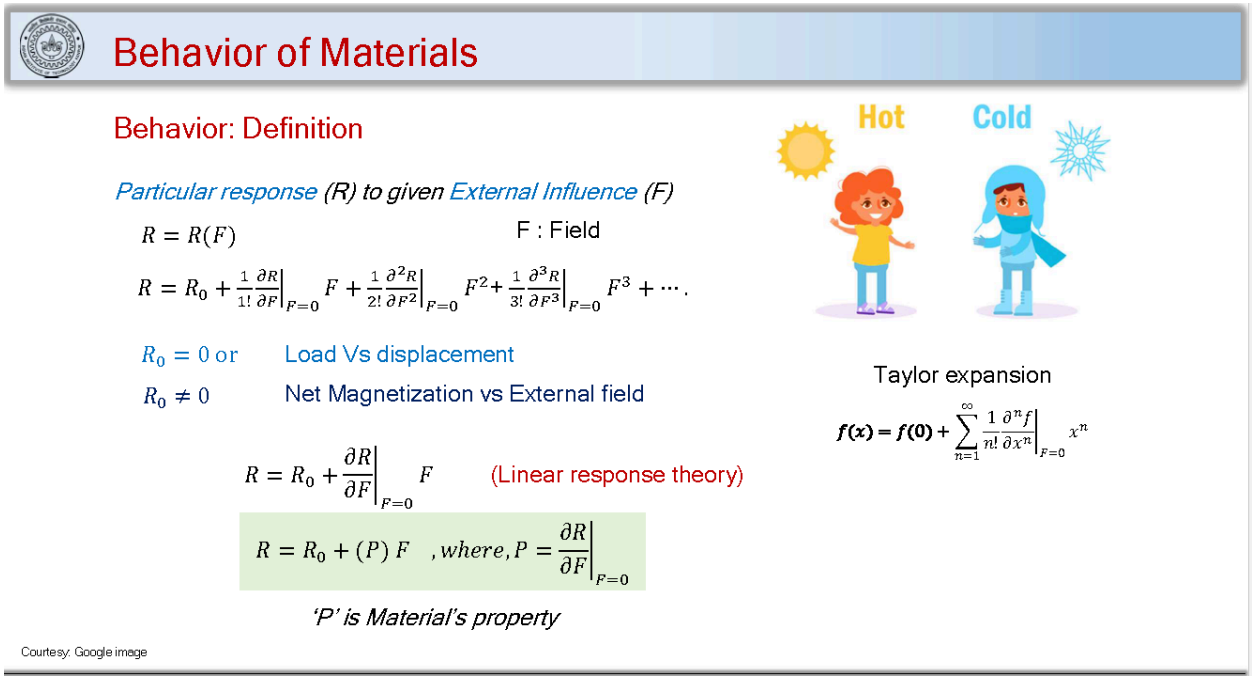
To material ka importance main batana chahta hoon ki jo kaal ya ages hain unka bhi naam humne material par rakha rakha hai. Jaise ki Stone Age, Bronze Age, Iron Age aur Silicon Age (ya semiconductor age). Ye saare ages ya jo kaal hain hum ye material ke naam par hi baat karte hain. To jaise Bronze hum baat karenge, to Bronze ek alloy hai copper aur tin ka.

To materials ko hum classify karte hain generally chaar types mein:

1. Metals – isme hum alloys aur intermetallics ko bhi todenge
2. Ceramics
3. Polymers
4. Composites – jo in teeno mein se kisi ek ka combination hota hai, jaise metal-ceramic, ceramic-polymer, polymer-metal.

Ye jo classification ya vargikaran maine kiya hai ye vargikaran bonding jo bonding present hai in material mein unke wajah se kiya hai. Jaise metals mein hum dekhenge ki ye metallic bonds

rehte hain, ceramics mein hum dekhenge ki ionic aur covalent bonds rehte hain aur polymers me covalent and secondary bonds rehte hain. Ye jo teeno bonds hain – metallic, ionic aur covalent – inko hum primary bonds kehte hain and secondary bonds jaise hydrogen bonds aur van der Waals bonds hote hain. To yeh jo bonds hote hain, yeh in material ko — jaise metals mein metallic jo bonding hai — yeh kuch properties deti hai. To properties jaise hum baat karenge is class mein to stiffness aur strength, jaise hum dekhenge ki metallic bonds aur ionic aur covalent bonds metals aur ceramics ko higher stiffness dete hain, zyada stiffness dete hain. Jaise par agar hum polymers ki baat karenge to covalent yahan pe present hote hain aur secondary bonds present hote hain jo thode weak hote hain primary bonds se. To aap dekhenge ki polymers ka stiffness, ceramics ke tulna mein kam rehta hai. Aur composites mein jo stiffness dono ka mixture karke hum composites mein stiffness kar sakte hain. Strength ka bhi waise hi hai — jaise metallic bonds, ionic bonds aur covalent to yeh strong bonds hote hain, to hume metals mein strength is tarah se milta hai ya is range mein milta hai. Polymers mein strength kam rahta hai metals aur ceramics ki tulna mein, aur composites mein hum in dono ka mixture karke ek strength prapt kar sakte hain.



To jab humne material ki baare mein baat ki hai, to hum iske behaviour ke baare mein bhi baat karenge, kyunki course ka naam Mechanical Behaviour of Material hai to hum pehle behaviour

kya hai yeh jaante hain. To iske liye main ek udaharan dena chahta hoon, jaise ki hum dekhte hain ki hamara weather ya vaataavaran badalta hai, waise hum apne mein badlaav laate hain. Jaise garm weather mein hum thoda light kapde pehente hain ya thand mein hum woollen clothes pehente hain. To hamara jo behaviour hai, woh baahri vaataavaran se juda hua hai. To kisi kisi ko agar thand zyada lagti hai to woh ek vyakti ke roop ke anusaar uska behaviour change hota hai. Usi tarah material ka behaviour bhi baahri vaataavaran se avalambit rehta hai. To usko hum kaise likh sakte hain ki yeh jo vaataavaran ka prabhav hai material pe, usko hum material ke response se jaante hain. To is tarah se jaise humne bataya ki hot aur cold weather hai to hamara usme response kya hai, pratisad kya hai. To yeh pratisad hi material ka baahri vaataavaran se hum jaanne ki koshish karte hain. Isko hi hum behaviour kehte hain. Abhi isko mathematical bhasha mein is tarah se likha jaayega — ek jo response hai material ka, yeh baahri field ya baahri external influence ka kya function hai. To yeh mera response hai aur yeh mera function hai external field se. To isko hum agar expand karte hain Taylor expansion se, to hum yeh dekhenge ki yeh jo response hai, main usko likh sakta hoon R_0 aur yeh maine isko expand kiya as a Taylor expansion jo aapne padha hoga 12vi kaksha vagherah mein to hum isko is formula se expand karenge. Abhi yeh jo R_0 hai, yeh mera behaviour hai material ka. Yeh mera behaviour hai material ka jab koi field na ho — jo baahar ki koi field na ho — tab hum isko kahenge yeh jo response hai usko R_0 kahenge. To yeh R_0 kabhi zero ho sakta hai, kabhi nahin ho sakta hai. Jaise is case mein load versus displacement ki jab hum baat karenge tab yeh R_0 zero hota hai. Jaise hum koi material par load lagaye to usme kuch displacement milenge, par agar load nahin hai to usme koi displacement nahin honge, aur us R_0 ko hum zero kahenge. Doosra udaharan dena chahta hoon — jaise magnetization. Magnetization yaani kuch material mein magnetization agar field nahin hai phir bhi uplabdh ho sakta hai ya reh sakta hai. Us case mein yeh jo R_0 hai yeh zero nahin rahega. To is expression ko thoda simplify kar sakte hain — usko hum linear response theory keh sakte hain. Isko linear response theory isliye kaha gaya hai kyunki yeh jo higher orders hain yahan pe, humne inko neglect kar diya hai aur humne yeh only first response aur first order hi yahan pe rakha hai. To yeh mera response hai material ka, yeh jo mera material ka response hai jab field zero hogi ya koi field nahin rahegi, isko hum samajhte hain jaise hum is equation ko agar is tarah se likhen jab rahega tab hume milega. To ye mera R_0 hai — ye mera material ka response hai jab meri field zero hai. Aur ye jo mera pehla term hai to isko hum kahenge jab main koi field apply karta hoon to ye mera response hai jab koi field apply ki jaati

hai. To ye response ko bhi hum thoda samajhte hain — hum ye keh sakte hain ki ye mera response mein kya change hai with respect to change in my external field. To ye baahari jo field change ho rahi hai uske wajah se mera response mein kya change aa raha hai isko hum is term mein likhte hain. To hum isko is tarah se bhi likh sakte hain:— nothing but aapka change in response with respect to change in external field. To ye jo P hai ye meri material property hai — yaani ye P har material ke liye alag-alag hoti hai.

What is the meaning of Mechanical?

- Response of Materials to forces or loads
- Materials experience stresses (σ) undergoing deformation (ε)

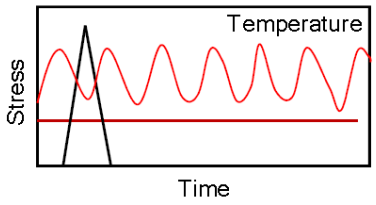
$$R = R_0 + (P)\,F \quad ,where, P = \left.\frac{\partial R}{\partial F}\right|_{F=0}$$

e.g., Stress = (Elastic modulus) × (Strain) *** Hooke's Law

$$\sigma = E\,\varepsilon$$

E = Elastic modulus (Material's property)

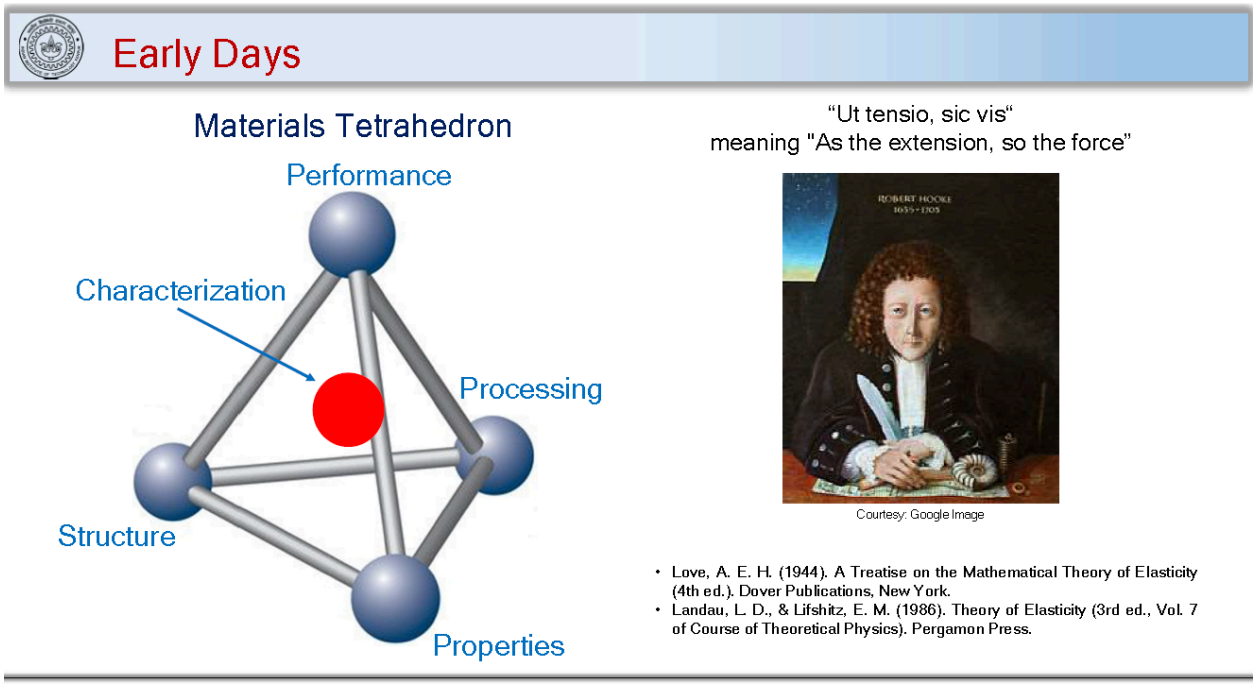
Stress
-Static, Dynamic, time varying
-Temperature



*** Present purpose: Stress = Force/Area and Strain = ΔL/L

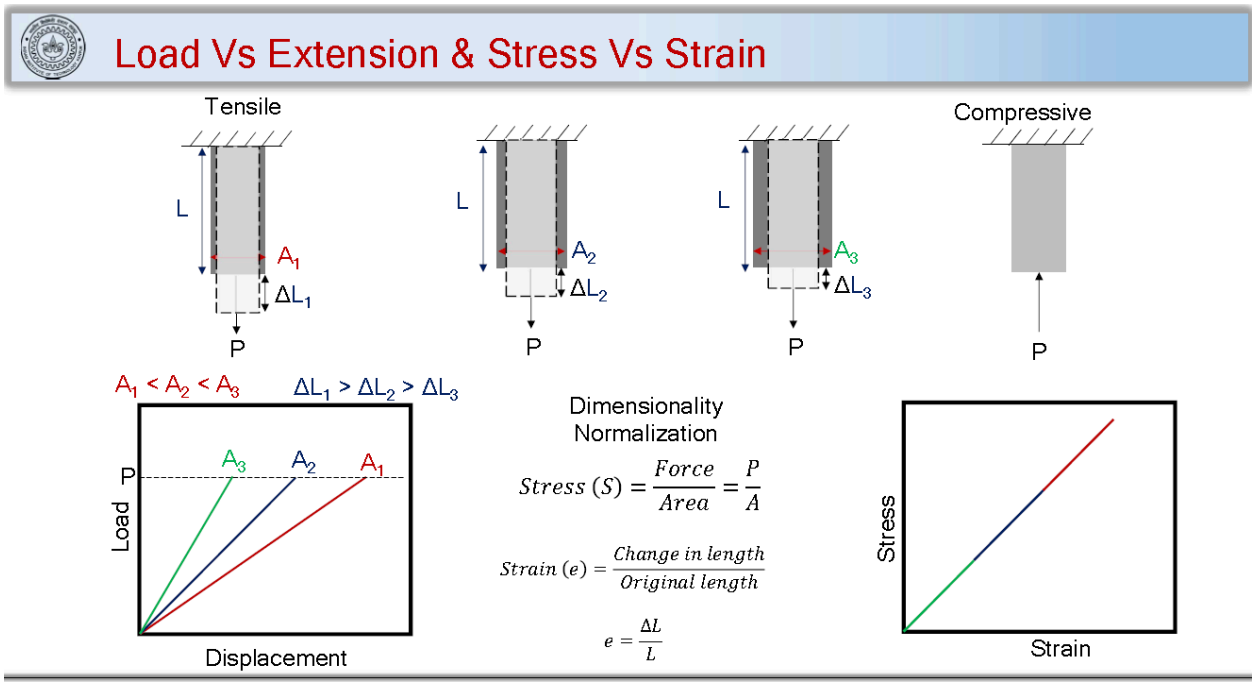
To abhi humne ek cheez jaan li ki hamara behaviour kya hai material ka. Abhi hum jaanenge ki *mechanical* kya hai — ye word *mechanical* ka meaning kya hai. To isko hum jaanenge: jab *mechanical* shabd istemal karte hain uska arth hota hai ki koi forces ya koi load material par apply ho rahe hain aur un forces ya load mein material response de raha hai. To isi ko hum kahenge ki stresses experience karte hain material jab hum usko deform karna chahte hain. To hum isi equation ko phir se istemal karenge: P jo hai material property hai.To isko hm simple vhasa , agar me is equation ka udaharad dena chahta hun jaise . To abhi ke liye is course ke liye hum yahi jaanenge k stress hai force/area aur strain hai dimensional change or change in (length)/(original length) abhi k liye is course k liye hum itna hi janenge par iska thoda aur deeper meaning hai jo hum aage course mein padhenge. To hum isko is equation mein bhi likh sakte hain. To ye jo elastic modulus hai ye mere material ki property hai. Agar aap dekhenge koi

textbook ko to ye elastic modulus ko hum is tarah se bhi likhte hain: *change in stress / change in strain* — to ye nothing but hamare material ki property ho gayi. To ab stresses kya kya hote hain? To stresses hum is tarah se dekhenge: stresses ko hum time ke saath kaise badal rahe hain us tarah se hum classify karenge. To ye jo stress hai jo time ke saath badal nahi raha hai — ye continuous ek hi stress hai — isko hum kahte hain *static stress*. Isko hum static stress kahenge. Doosra stress hai jo ek short duration time mein sudden change ho raha hai is stress mein Badh raha hai aur sudden kam ho raha hai isko hum kahenge *dynamic stress*.Teesra stress hota hai jo time ke saath ghat raha hai, badh raha hai, ghat raha hai, badh raha hai aur ghat raha hai — to isko hum kehte hain *cyclic stress*. To hum is course mein in teeno stresses ka kya prabhav hai material par aur material ka kya response hai, kya behaviour hai — yahi hum jaanne ki koshish karenge. Aur ek cheez hoti hai — jo hum temperature ke saath ye stress kaise affect karega material ke behaviour par — ye bhi jaanne ki koshish karenge. To stresses humne jaane hain: *static*, *dynamic* aur *time-varying*; aur temperature ka kya prabhav rahega stresses par hum ye jaanne ki koshish karenge is course mein. To thoda history mein batana chahta hoon — to ye picture hai Robert Hook ka. Unhone likha hai *Ut tension, sic vis* to iska matlab hai ki jaisa extension hai usi tarah se hume force apply karna padega. To humne abhi Hook's Law padha hai. Jaise phir se main likhna chahta hoon — to stress strain se proportional hai. To ye hamara material ka property hai. To yahi Hooks ne bataya ki extension aur force mein relation hai. Ye kuch books hain jo aap padh sakte hain Theory of Elasticity ke liye jo samajhna chahte hain achhe se. Ye ek bahut achhe references hain — to ek book hai Love ka aur ek Landau ka. Inko aap zarur refer kariyega agar aap Theory of Elasticity achhe se samajhna chahte hain. To ab is course mein hum ye baat karenge ki material ke hisaab se is stress-strain ka kya relation hai. To jab hum material ki property jaan-na chahte hain tab material tetrahedron ki baat karte hain. *Tetrahedron* yaane yahaan par chaar faces hain aur in chaar faces mein chaar vertices mein chaar-chaar hum gun likhte hain padarth ke — jaise *structure, properties, processing* aur *performance*. Aur inko hum chaaro ko samajhte hain characterization ke through. To is course mein ye jo characterization ki baat kar rahe hain — to ye characterization hoga hamara *mechanical characterization*, kyunki hum *mechanical behaviour of materials* ko padh rahe hain. To jaise hum ye jaan sakte hain ki structure property ko govern karega, property processing par avalambit rahegi, aur ye teeno milkar hamare material ka performance govern karenge.



To abhi humne Hook's Law padha, to usme load aur extension ki baat aayi, aur stress aur strain humne Hook's Law mein padha hai jo modern Hook's Law hai. To pehle load aur extension samajhte hain. Samajhiye ki ye hamara member hai, yahaan par ye isko pakad ke rakha hai is end par, aur isko hum ek force apply karte hain, usko naam dete hai P. To ye jo force hai isko hum tensile force kehte hain kyunki yahaan par humne jab pakad ke rakha hai to yahaan par reaction jo tayar hogi to is direction mein hogi, to isliye hum isko tensile force kehte hain. Usi tarah se agar hum ye member hai yahaan par hi hai aur hum force ulti de dete hain to isko hum kehte hain compressive stress, kyunki isme jo reaction tayar hogi vo is disha mein tayar hogi. To abhi hum focus karte hain is member ko jo humne tensile load kiya hai. Maan lete hain iska length L hai aur iska cross-section A hai. Maan lo ye cylinder hai — cylindrical cross-section ho sakta hai ya square cross-section. Aur jab hum ye load apply karenge tab isme ek elongation mein change hoga — to iska length change hogi aur ye badh ke yahaan par aayegi. Aur jo change hai, is change ko hum kehte hain $\Delta L1$. Maan lo ek another member hai same length ka aur hum usko tensile force same force apply karte hain, aur uska cross-section thoda bada hai, to jab isme jo elongation aayegi usko maan lete hain $\Delta L2$. Aur let's say teesra member hai hamare paas jiski lambai L hai par cross-section bada hai aur same force apply karte hain to usme jo elongation aati hai usko maan lete hain $\Delta L3$. Jab hum plot karenge load vs displacement to load to hamara constant hai. Yahaan par hum pehle case mein dekhenge ki hamara cross-section area

chhota hai tab length mein elongation zyada milegi, isme jo elongation hai zyada milegi, isme usse kam milegi, aur isme A3 jiska cross-section hai usme in dono se kam milegi. To hume ye data milega load vs displacement ka — to A1 mein displacement zyada rahega, A2 jo hai usme displacement A1 se kam rahega, aur A3 mein displacement A2 aur A1 se kam rahega. To hum ye likh sakte hain: jaise-jaise area badh raha hai waise-waise elongation ghatega. To isme hm material ka behavior nahin jaan sakte. Agar hme material ka behavior janna hai to hame jaise jaise dimension change ho raha hai hame waise waise hame load vs displacement plot krna padega to ham isse material ka behavior nahi bata sakte agar A4 area jo in teeno se bhinn hai vo aata hai to hume phir se load–displacement karna padega. To uske liye ek solution bataya hai jo hum baat karenge — jisse dimension ko normalize karte hain. Iska matlab kya hai? Jaise main is force ko iske area se divide kar dunga (bhaag dunga). Kyunki maine jaana hai ki jaise area badh raha hai waise elongation kam ho rahi hai, to main is force ko area se bhaag dunga to mujhe ek quantity milegi jisko main stress ke naam se jaanunga. Usko main stress se define karta hoon. Waise hi hum strain ko define karenge jo change in length — yaani jo ye change tha length ka — usko hum iski original length (jo pehli wali length thi) usse bhaag karenge usko kahenge strain. To mere paas do term ho gaye stress aur strain abhi main kya karta hoon k yeh jo same data hai isko main dimension normalization jab karoonga stress strain plot karoonga to main stress aur strain ko plot karta hoon tab agar main yeh data saara dekhoonga to yeh saara data ek line pe aayega to yeh jo ek line pe aa raha hai to yeh mujhe material ka behavior bata raha hai to yeh yaani mujhe agar doosra sample mil jaye to main bata paaunga ki mujhe kitna stress chahiye strain paane ke liye ya kitna strain agar mujhe apply karna hai to kitna stress chahiye to yeh ek hi plot se main bata paaunga to yeh stress strain jo behavior hai isse main material ka behavior bata paaunga.



To hum pehle iske units jaan lete hain jo humne stress ke baare mein baat ki to hum jab s jab bolenge hum isko engineering stress se likhenge aur jab e likhenge to is course mein hum engineering strain ke baare mein baat karenge to hamara engineering stress hai applied force upon initial cross section area aur engineering strain hai hamara change in length upon original length to inke kuch units hum dekhenge to hum yeh jo units yahan par is course mein istemal karenge vo saare SI units mein hum follow karenge to SI units mein load aur force ka unit hota hai Newton displacement ka unit hota hai meter aur area ka unit hota hai meter square aur stress ka unit hoga hamara Newton upon area to yaani Newton per meter square books mein aap dekhenge ki yeh Newton per millimeter square bhi likha jaata hai to aur strain ko hum likhenge change in length upon original length to yeh meter upon meter hoga to yeh jo unit hoga strain ka vo dimensionless to isko koi unit nahi hoga strain ka to stress ko hum likhenge 1 upon Newton per meter square isko one Pascal bhi kehte hain aur 1 upon 1 Newton per millimeter square ko hum kehte hain 1 MegaPascal to yeh kuch conversion units hai jo hum dekhenge na kPa yaani 1 kilo Pascal equal to 10 to power 3 Pascal 1 Mega Pascal equal to 10 to the power 6 Pascal aur 1 Giga Pascal equal 10 to the power 9 Pascal to yeh conversion aapko pata hone chahiye yeh text books mein kaafi istemal hote hain to is case mein agar hum dekhenge to engineering stress ka unit hota hai MPa aur engineering strain ka unit nahi hota hai dimensionless quantity hai to humne Hooke's law jab baat ki to hum Hooke's law ke baare mein jab baat karte hain to humne

likha tha stress equal to some material constant hum isko Young's modulus maanenge aur yeh strain hai to stress ka unit hota hai MPa aur strain ka unit dimensionless hamare yeh jo material constant Young's modulus hum jab baat karenge iska unit kya aana chahiye iska unit aana chahiye MPa left hand side equal to right hand side aana chahiye to iska unit aana chahiye MPa par Young's modulus ka unit humesha likhte hain GPa mein kyunki iski value zyada hoti hai to humne GPa jaana hai yeh 10 to power 9 Pascal hota hai isse hum yahan par rukte hain baaki hum testing hum next class mein padhenge.

Dhanyavaad