Mechanical behavior of materials

Dr. Niraj Mohan Chawake

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

Week-1

Lecture-2

Engineering Stress Strain Curve and Measures of Strength

Units

S = Engineering Stress = $\frac{Applied\ force}{Initial\ cross\ section\ area}$

e = Engineering Strain = $\frac{Change\ in\ length}{original\ length}$

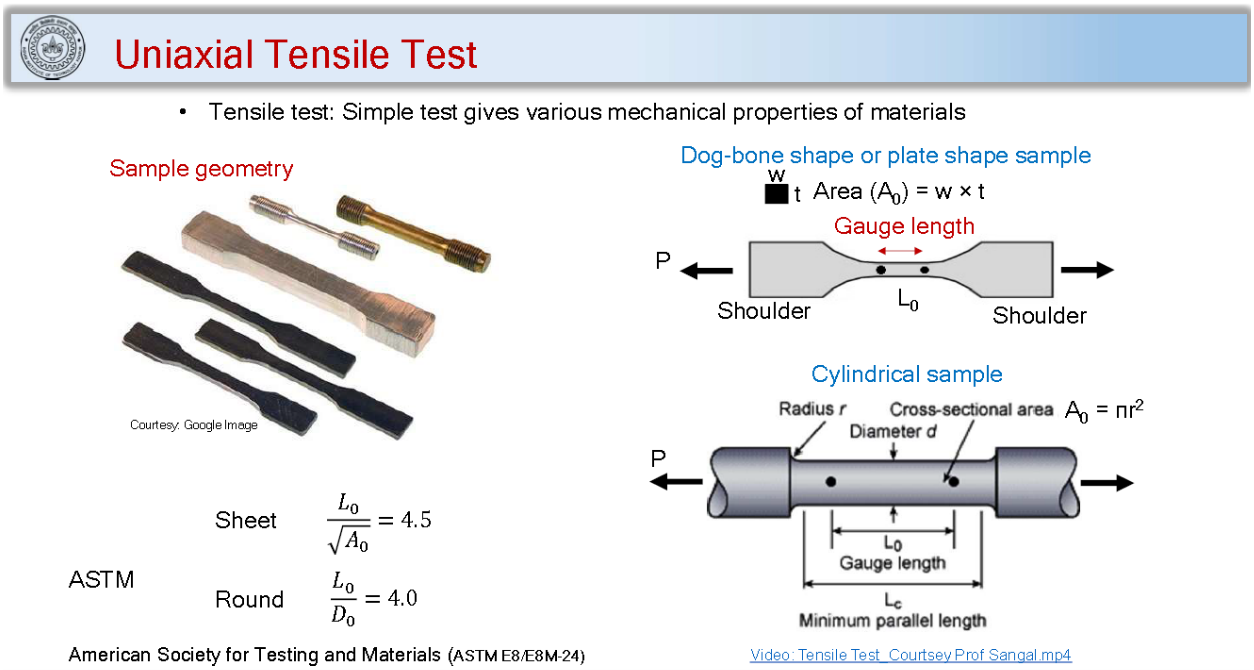
- Load or force : N
- Displacement: m
- Area: m^2
- Stress = Force/Area = N/m^2
- Strain = $\Delta L/L$ = m/m = Dimensionless

Stress = 1 N/m^2 = 1 Pa i.e., Pascal

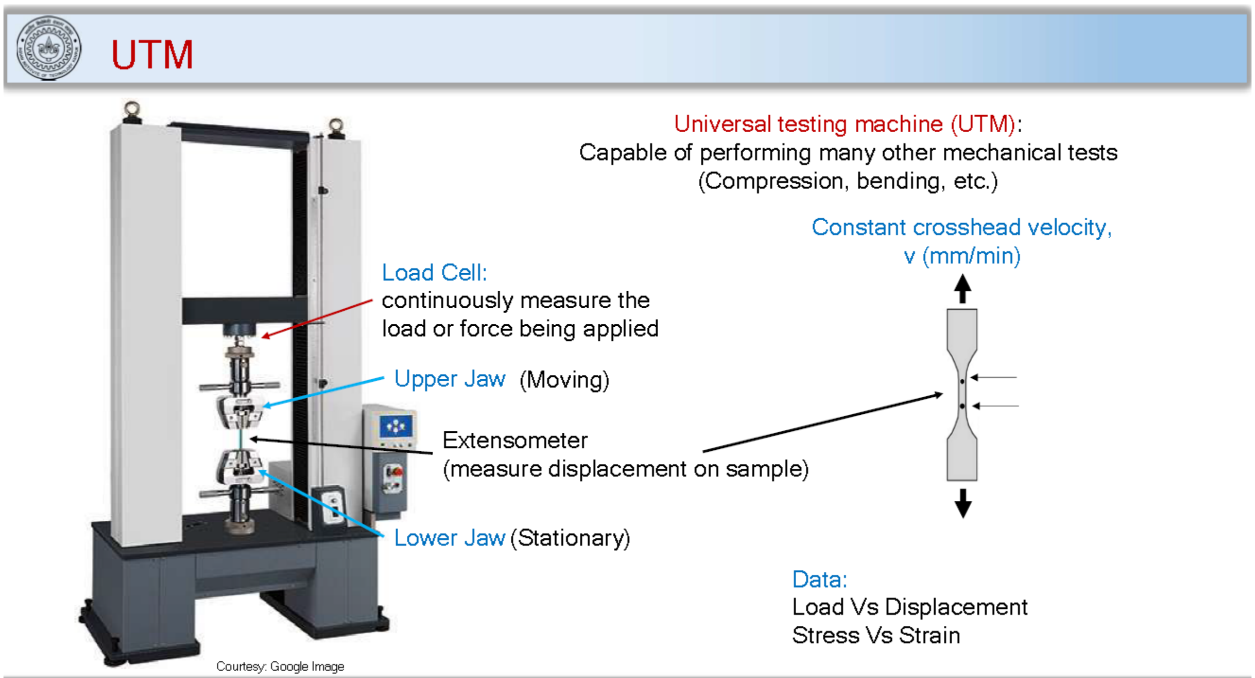
Stress = 1 N/mm^2 = 1 MPa

1 kPa = 10^3 Pa
1 MPa = 10^6 Pa
1 GPa = 10^9 Pa

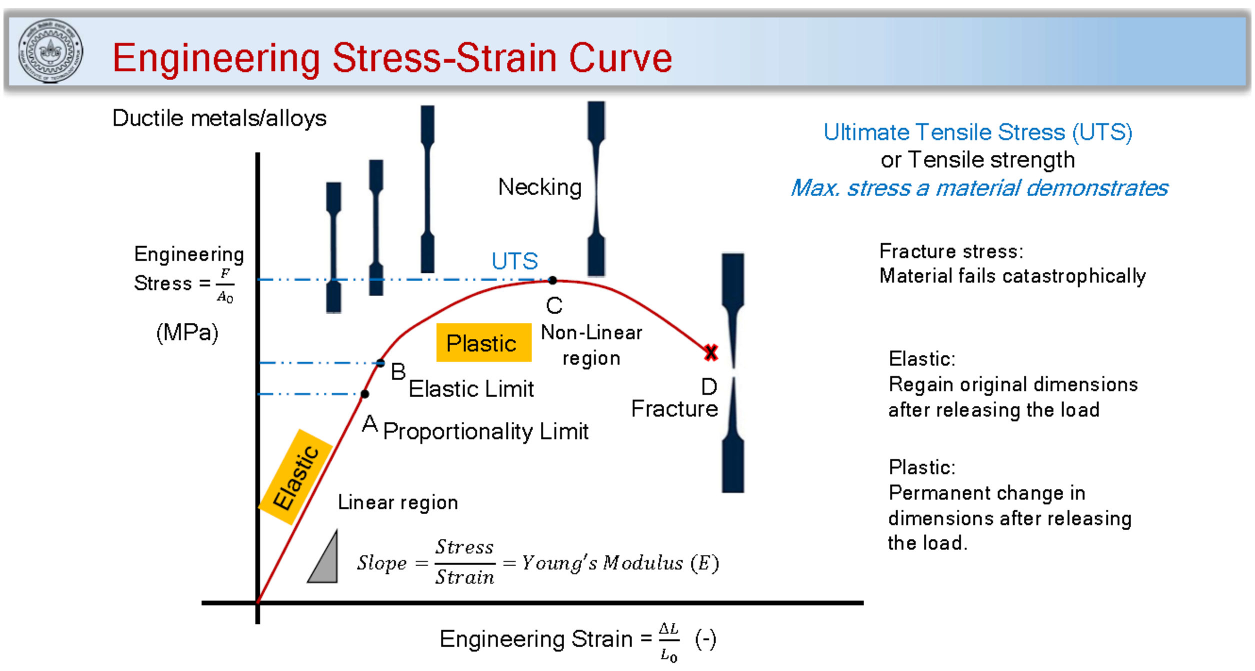
Namaskar main phir se swagat karta hoon is course mein jiska naam Mechanical Behavior of Material hai jo ki main Hindi mein padhaunga. Humne last video mein dekha hum Engineering Stress aur Engineering Strain define kiye the. So humne Engineering Stress aise define kiya tha Applied Force / Initial Cross Section Area aur Engineering Strain ko humne define kiya tha Change in Length / Original Length. To hume jab Engineering Stress aur Engineering Strain nikalna hai to uske liye hume Initial Cross Section Area chahiye aur Original Length chahiye aur hum major kya karenge ki material kitna force le raha hai aur usmein kitne change aa rahe hain to yeh hum kaise nikalte hain yeh is part mein hum aaj dekhenge.



To iske liye hum istemal karte hain Uni-axial Tensile Test. Aise jo Tensile Test hai ekdam saral test hai, simple test hai aur yeh itna important test hai ki isse hum bahut saari mechanical properties nikal sakte hain jo hum discuss karenge is course mein kya-kya mechanical properties yeh simple saral test se nikaali ja sakti hain. So dekhte hain ki Tensile Test kya hota hai. To iske liye hume chahiye ki kaunse sample hum istemal karenge. To koi bhi material hai hamare paas to usse hum is tarah se sample nikalenge is geometry wale sample nikalenge. To yeh kuch sheet samples hain, yeh kuch thin-thick samples hain, mote samples hain, yeh kuch cylindrical samples hain. To iski geometry is tarah se hoti hai. To is geometry ko hum kehte hain dog-bone shape aur plate-shape sample. Dog-bone isliye kehte hain ki ya yeh dog ka jo bone hota hai hum dekhte hain movies mein vagairah us tarah se iska geometry hai, isliye usko dog-bone shape kehte hain. Aur is tareeke se kya hota hai hum discuss karenge. Ya kuch plate-shape sample jo flat sample hai, us ya koi sheet se hum sample nikal rahe hain to hum us sheet samples ko is tarah se le sakte hain. To iska cross-section dekhte hain is samples ka to yeh ek dog-bone shape sample hai to is part ko hum kehte hain shoulder, yeh humare shoulder ho gaye. Aur is part par is sample par humne do points mark kiye yahan par. To is do points se jo resha jaati hai aur jo axis hai sample ka, is direction mein hum force ko apply karenge. Is direction mein force ko apply karte hain isliye hum isko uni-axial tensile test kehte hain. To ek cheez aur samjhana chahta hoon jaise hum yeh sample agar hum hai to hamara agar hum coordinate axis dekhen to hum yeh x, y aur z maan ke chalenge. To hum force jo apply kar rahe hain vo kisi ek direction mein apply kar rahe hain. To isliye hum isko uni-axial tensile test kehte hain to now abhi yeh jo points hain do points, in do points ke beech ke length ko hum kehte hain gauge length. Yeh points isliye important hain kyunki iske across jo length hai iska jo cross-section area hai vo uniform hai aur vo sabse chhota cross-section area hai sample ki saari tulna se. So yaani iska matlab yeh jo cross-section hai yahan par, yeh maine mark kiya, yahan par iski yeh width hai aur iski thickness hai. To iska cross-section area hoga jo maine $A_0 = w \times t$. To yeh jo A_0 hai yeh agar koi bhi sample ka koi bhi hissa agar hum dekhen—yeh part, yeh part—in saare hisso mein se yeh jo part hai gauge length ka area yeh sabse chhota rahega. Yeh kyon chhota rahega? Kyunki humne last part mein dekha tha, humne stress aur strain ke baare mein dekha tha. To humne stress define kiya tha—yeh hamara Hooke’s law ho gaya—and stress humne define kiya tha Force upon Area. To hamara area agar chhota hai to stress zyada hai. Agar stress zyada hoga to hamara sample isi length mein break hona chahiye agar yeh uni-axial tensile test hai to. To isiliye hum chahte hain ki hamara area sabse kam rahe aur hamara sample in dono points ke beech mein hi break ho. Jo ki hum agar koi different material se istemal kar rahe hain to humein uska comparison karne ke liye aasani ho. To hum chahte hain hamara sample isi length mein break ho isliye area sabse chhota hai. So isliye gauge length ka importance sabse mahatvapurn hai uni-axial tensile test mein. Kuch cylindrical samples hain jo yahan par bhi show kiye. To cylindrical samples mein bhi waise hi hai. Yahan par humne dikhaya ki humne ek axis ke around ek force apply kiya hai, isliye hum isko uni-axial test kehte hain. Iski humne diameter di hai D. Aur agar aap dekhoge to yahan pe area increase ho raha hai. Is sample mein bhi aap dekhenge to area aapke gauge length se shoulders tak increase ho raha hai. To aapko to yeh pata chal gaya hoga ki reason kya hai yeh dog-bone shape samples ka, kyunki area yahan par zyada hona chahiye. Yahan par kam hona chahiye, isi tarah se cylindrical samples mein area yahan par kam hona chahiye aur yahan par zyada hona chahiye. To yeh hamari gauge length ho gayi. Isko hum cylindrical samples mein ek minimal parallel length ki baat karte hain. Aur iska cross-section hum area agar hum baat karenge, agar yeh hamari radius hai r to iska cross-section area hoga πr^2. To yeh to ho gaya hamare dog-bone shape sample ka. Humne shape ke baare mein baat kiya to inke sizes ke baare mein bhi hum baat karte hain. To uske liye kuch manak hote hain ya standards hote hain. To standards jaise kuch-kuch standards hain jaise hum kuch standards follow karte hain ASTM Standards—ASTM ka full form hai American Society for Testing of Material. Aur tensile test ke liye hum yeh standard istemal karte hain. Kuch-kuch Bharatiya manak bhi hain jaise BIS manak bhi hai. To hum ASTM ke standard ke baare mein baat karenge jo books mein kaafi milega aapko. Jaise sheet sample humne istemal kiye to uska length se uske area ka ratio jo hona chahiye ya square root of area ka jo ratio hona chahiye vo $(l/\sqrt{A_0}) = 4.5$ hona chahiye. For round samples or cylindrical samples— aapka jo length aur uske diameter ka jo ratio hona chahiye vo $(l/D_0) = 4$ hona chahiye. Yeh hamare initial dimension hain samples ke. To ek link yahan par hum de Rahe hain jo aapko class notes mein mil jaayegi. Yeh video hai tensile test ka jo aap dekhenge aur samjhenge ki yeh tensile test kaise karti hai. To abhi hum chalte hain ki tensile test ka ek thoda sa main vivaran dena chahta hoon.

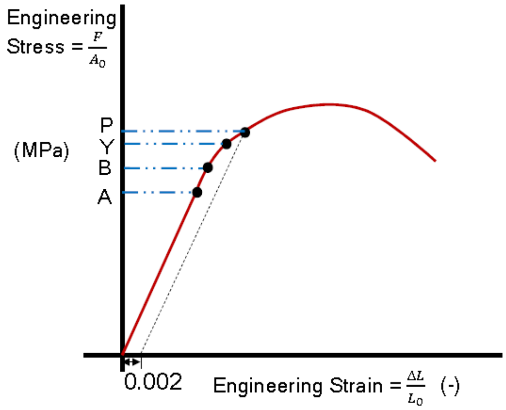


To tensile test hum carry karte hain UTM se jiska naam hai Universal Testing Machine. Abhi hum usko universal kyon kehte hain? Kyunki yeh jo frame hai, deformation frame hai ya testing machine hai, isse hum compression, bending saari cheezen kar sakte hain—three-point bend, four-point bend test, variety of test hum kar sakte hain. Isliye hum usko Universal Testing Machine kehte hain. To yeh hamara sample ho gaya dog-bone shape sample aur hum uske axis ke around isko hum deform karte hain. Yaani hum is sample ke axis ke around—yaane yeh sample ka agar main maan loon y-axis hai—to iske around hum force apply karte. Yeh hamari gauge length ho gayi. Yahan par humne do points mark karke dikhaye. To sample hamara jaata hai in dono jaw ke beech mein. Yahan par hamara sample rehta hai. To yeh sample yahan par pakda jaata hai. Isko upper jaw kehte hain aur is neeche part ko hum kehte hain lower jaw. To yeh upper jaw moving rehta hai and lower jaw stationary rehta hai. In dono mein se ek jaw move karega, ek jaw stationary rahega. To kisi machine mein upper jaw move karta hai, kisi machine mein lower jaw move karta hai, par dono mein se ek move karega, ek stationary rahega. Aur hum move kaise karte? Isko ek constant crosshead velocity se move karte hain. To jo hum crosshead velocity bhi maan ke chal raha hoon main yahan par, to vo hum parameter dete hain millimeter per minute. To is crosshead speed se hum material ko bolte ki deform kariye. To us hisaab se is speed ko maintain karne ke liye jo force chahiye vo hum measure karte hain. To vo force measure karne ke liye hum load cell ke istemal karte hain. Jo material par jo force lag raha hai vo continuously yeh load cell monitor karte rehta hai. Aur hume displacement measure karna hai to hum uske liye extensometer—yeh jo device hai—iska istemal karte hain. Yeh do hamare do points jo yahan par maine mention kiye the, ye inke beech mein hum extensometer lagate hain jo yeh sample ka dimension kya change ho raha hai ya displacement kya ho raha hai vo pata karte hain. To hume kya data milega? Isse hume milega yeh load cell se load ka data aur hume is extensometer se milega displacement data. Aur humne dekha hai ki load ko kaise convert karte hain stress aur strain mein. To humne dekha hai ki load ko main initial cross-section area se divide karunga to mujhe stress mil jaayega. Aur main change in length ko measure karunga aur usko main initial length se divide karunga to mujhe strain mil jaayega. Jaise ki mujhe explain karne dijiye. Jaise yahan par yeh mera initial length ho gaya L_0. Aur jaise-jaise sample deform ho raha hai to yeh doosra point is point se displace hoga. To yeh mera ho gaya ek length in any instance → L. To yeh ΔL ho jaayega = $L - L_0$. To strain hum nikaalenge engineering strain = $\Delta L / L_0$ jo meri initial length hogi sample ki. To is tarah se hum load aur displacement ko stress aur strain mein divide karenge.



To hamare paas load versus strain ka data jab aa jaayega tab hum usko ek stress-strain curve mein plot kar sakte hain. To main ek stress-strain dena chahta hoon jo metals aur alloys ke liye hamesha dikhta hai ek stress-strain ke strain ka nature. To hum plot karenge stress Y-axis pe aur strain plot karenge hum X-axis pe. To humne dekha hai ki jo X-axis par rehta hai vo hamara rehta hai strain. To humne stress jab hum Y-axis par plot karenge to stress milega hume force jo mil raha hai material par aur us divided by uska initial cross-section. Aur strain hume milega change in length upon original length. To stress ka unit kya hoga? Stress ka unit hoga MPa yahan par. Aur strain ka unit hoga—strain ka koi unit nahin hoga, yeh dimensionless parameter hai constant. To jab hume stress-strain curve milega is tarah se to yahan par maine chaar bindu mark kiye hain is strain curve par. Yeh chaar bindu ko main naam de raha hoon A, B, C aur D. Aur in chaaron bindu ki correspondingly, ko yahan se yahan tak deform kiya point A tak. Aur maine material ka stress hata diya to kya hoga? Jo bhi change in dimension hoga vo relax ho jaayega aur material apna original shape le lega. To yaani material elastically recover karega. Aur material ka agar dimension agar aap dekhenge to usmein koi Change aapko milega nahin. To isliye kehte hain ki material ka original dimension retain rahega agar main is point tak deform kar raha hoon aur material ko chhod raha hoon. To yeh ho gaya mera elastic part. Zaruri nahin hai part linear hi ho, yaani straight line ho. Kuch material jaise polymers hain, un case mein yeh part linear nahin rahega ya straight line nahin rahegi. To yeh jo curve maine dikhaya yeh mostly metals, alloys ya ceramics ke liye hai, aur kuch polymers ke liye bhi hai. Par mostly kuch polymers ya elastomers mein yeh region linear nahin rahega. Bas doosra jo part dikha hai, yeh jo hai plastic part hai. Is part ko hum kehte hain point B ke above yeh part hai hamara Plastic part—plastic part yaani kya hoga? Agar maine material ko is point tak deform kiya, maana yahan tak maine deform kar liya, aur maine stress chhod diya, to agar main phir dekhunga stress chhodne ke baad material ke dimension check karunga to mujhe permanent change milega material ke dimension mein. Aur main usko kahoonga ki there is a permanent change, yaani usmein ek permanent change milega mujhe dimension mein. To yeh jo part aur yeh jo nature hai, yeh jo behaviour hai, yeh mera plastic behaviour hai. To mere paas do behaviour ho gaye material ke—ek elastic behaviour aur ek plastic behaviour. Yeh main stress-strain curve se Baat kar sakta hoon ki kaunse stress tak mera material elastic behaviour dikhayega aur kaunse stress ke baad mera material plastic behaviour dikhayega. To yeh yahan par mostly yeh part jo hota hai plastic part, yeh non-linear region hota hai. Aur yeh linear jab hum metals aur alloys ke liye baat kar rahe, to iska agar hum slope nikaalenge, to slope nikaalenge = stress / strain. Yeh humne baat ki thi. Yeh jo ratio hai, yeh hamara Young's modulus hai. Yeh kisi material ki property hoti hai. To yeh hum kaise nikaalenge? Jaise dekha jaaye, humare paas do data point hain. Yahan par ek mera $strain_1$ ho gaya e_1 aur yeh mera stress ho gaya S_1. Aur ek doosra stress mil gaya mujhe S_2 aur uske correspondingly strain e_2. To mujhe slope jb nikalna hai to elastic nodulusmera aajaega $(S_2-S_1) / (e_2-e_1)$ to isko hm kehte hai delta S upon delta e Isko aise bhi likh sakte hain, yeh jo ho gaya hamara slope, yeh ho gaya hamara elastic modulus. Abhi hum dekhenge do points jo humne define kiye the. Yeh do points—point A ko hum kehte hain proportionality limit aur point B ko kehte hain hum elastic limit. In dono points ke baare mein hum jaanenge next slide mein. Par abhi ke liye dono points aap maan ke chaliye: yeh point A proportionality limit hota hai aur point B hota hai hamara elastic limit. To proportionality limit hamesha elastic limit se pehle aata hai, to aur kam stress pe ata hai yeh aap yaad rakhiye ga to agar maine is point A tak deform kiya mera sample to point A tak mera jo sample maine deform kiya aur maine chhod diya is sample ko to wahan par mujhe koi bhi dimension change nahin milega is sample mein jo initial dimension hoga sample ka woh retain rahega. Point B tak agar maine deform kiya hai sample ko to mujhe kuch dimension change to hoga sample mein par woh hum measure nahin kar paayenge. Measure nahin kar paayenge yaani hamare extensometer hamare extensometer detect nahin kar paayenge woh dimension ko, dimension change ko. Extensometer jo hamara hai woh capable hi nahin rahega is dimension ko measure karne ke liye jo change in dimension hai woh measure hi nahin kar paayega. To is point ko hum kehte hain elastic limit. Par is point B se point C mein agar hum dekhenge yeh to hamara plastic region hai. To humne jab force apply kiya to yahan par dimension changes aayenge sample mein aur yeh sample agar hum tensional force apply kar rahe to yeh sample ki length badhegi. Par agar hum dekhenge humne humne gauge length mark kiye the to yeh gauge length ka jo cross section area hai jaise jaise hamara ΔL badhega waise waise jo cross section area hai woh ghatega. Par yeh jo Cross section area ghat raha hai yeh uniform tareeke se ghat raha hai yani same tareeke se ghat raha hai. Yahan par jo cross section area rahega ya is gauge point pe cross section area rahega woh same hi rahega. So isiliye isko kehte hain hum uniform deformation. Mujhe likhne dijiye isko — isko isiliye is part ko bhi hum book mein uniform deformation ki tarah se bhi jaana jaata hai. Is plastic deformation mein abhi hum is point par aate hain. To yeh point jo hai agar aap dekhenge is poore stress-strain curve mein, point C jo hai yahan par material maximum stress dikha raha hai. Isko hum kehte hain ultimate tensile stress ya tensile stress. Strength kehte hain. Yeh jo stress hai yeh maximum stress material demonstrate karta hai. Agar koi bhi point dekhein yahan par stress-strain curve mein sirf C jo hai, woh maximum stress dikha raha hai material mein. To yahan par kya hota hai — yeh point tak to humne bataya ki length of sample badh raha hai, aur yahan par is region ke baad agar aap dekhenge to yeh cross section uniform change nahin ho raha hai. Yeh cross section ek locally change ho raha hai. Mujhe explain karne dijiye. To humne initial agar cross section yeh mere do points se, point A aur point B maine mark kiye, agar yeh change ho raha hai to yeh… To yahan tak mera cross section area Uniform change ho raha tha, but sudden point C ke baad yeh cross section area aise change hoga aur phir aur zyada decrease hoga — locally decrease hoga. Yeh locally jo change ho raha hai aur locally cross section area jo decrease ho raha hai, yahan par yeh localized deformation ho raha hai. Is part ko hum kahenge *necking*. Isko hum kehte hain necking. Yeh jo part hai, yeh jo change ho raha hai, local change area ho raha hai sample ke beech mein — isko hum kehte hain necking. To jaise-jaise mera deformation badhega material par, waise-waise yeh cross section area aur decrease hoga aur decrease hoga. Aur humne jana Hai ki hamara jo stress hai — jo stress, stress hum baat karenge F/A. To jaise-jaise mera cross section area ghatega, stress badhega. To yahan par mera material sabse zyada stress experience karega, stress yahan par badhte jayega. Aur finally kya hoga — material yahan par fail ho jayega. Yahan par material fail ho jayega kyunki yahan par stress itna badh jayega ki material usko le nahin paayega, aur yahan par material break ho jayega. Is point D ko hum kehte fracture. Yahan par material catastrophic fail hota hai. Aapko pata nahin chalega ki kitna jaldi yeh sample break ho gaya, isiliye is point ko kehte fracture. Aur is point ke correspondingly isko kehte hain hum fracture strain. To yeh bhi ek parameter hai jo hum istemaal karenge material ki jab hum tulna karenge, tab yeh fracture strain bhi hum istemaal karenge.

Measures of Yielding: Transition from Elastic to Plastic



Hooke's Law $S \propto e$

$S = E\,e$

Proportionality Limit:
Hooke's law is strictly obeyed

Elastic Limit:
Beyond B- Permanent or plastic deformation starts. No measurable strain on sample

Yield stress/strength:
Yielding of material i.e. a permanent measurable deformation on sample

- Measuring yield strength (YS) becomes difficult
- Accepted procedure: deform sample to 0.2% longer than before the test.
- Stress corresponding to 0.002 strain offset called as "Proof Stress"

This schematic is exaggerated, in practice, points A B Y P lie very close to each other

To abhi humne do part dekhe the — elastic aur plastic part. Abhi hum un dono part ko measure dekhenge, material yielding ka, yaani jo transition ho raha hai elastic to plastic. To yeh hamara stress-strain curve hai, aur yeh maine chaar point mark kiye hain yahan par. Yeh pehle do points A aur B. To pehla point mera proportionality limit tha, doosra point Mera elastic limit tha. To proportionality limit kya hota hai — jaise yahan par Hooke's law humne define kiya. Hooke's law me hum baat karte hain stress is proportional to strain, ya stress proportional hai strain se. Aur humne Hooke's law ko likha ek material constant ke through, to ye S=Ee. To point A tak hamara Hooke's law strictly obey hota hai, yaani iska koi ullanghan nahi hota Hooke's law ka. To isiliye is point ko hum kehte proportional limit — yaani jo mera strain hai uske hi barabar mera stress rahega, aur jo ki material ke property se hum jod sakte hain. Elastic limit to yeh Mera point A ho gaya, yeh mera point B ho gaya. Elastic limit kya hota hai — elastic limit me material deform to hota hai par yahan par hum vo deformation, jo strain hai material ka, vo hum find out nahin kar sakte, hum usko nikal nahin sakte extensometer se measure nahin kar sakte. To yeh jo point B hai, yeh hamara elastic limit ho gaya. Point Y jo hai, yeh hamara yield point hai. To yield point me kya hota hai — yield point par aur yield strength ko hum yield stress ya yield strength bhi kehte hain. is corresponding stress ko. is pe material yield hota hai. Yield yani elastic to plastic deformation chalu ho jata hai. To hum is point pe permanent deformation sample pe dekh paate hain. To humne agar iske beyond material ko deform karna chalu kiya to hum yahan pe dekhenge ki material ke dimension me permanent changes aana chalu ho jayenge ya hum usko measure kar paayenge. Par kabhi-kabhi kya hota hai, kuch-kuch material me ye point bhi measure karna experimentally thoda difficult hota hai. To hum ek kaam karte hain — hum ek strain de dete, pre-strain de dete material ko, ek 0.002 ka strain hum de dete material ko, aur iske correspondingly ye ek just accepted value hai. Iska koi thoret kal importance nahin hai. Ye jo value hai ye hai ki hum material jab hum yield strength measure nahin kar paate tab hum ye actual strength de dete hain sample ko aur uske correspondingly strength hum define nahin kar paate. Us case me proof stress mera yield stress ka kaam karta hai. To ye ek accepted procedure hai. To isko hum kaise nikaalenge? To humne strain to de diya, agar humare paas stress-strain curve hai to humne ek 0.002 ka strain yahan par main offset le liya aur yahan se ek parallel line draw karoonga jo ki is linear region ko parallel rahegi. To ye jahan intersect karegi uske correspondingly Dena chahta hoon jaise maana ki humare paas ek material hai uska maine elastic modulus le liya 200 GPa aur uska initial length agar mere paas ek sample hai uska initial length maine le liya 10 mm gauge length ki baat kar raha hoon main. To mere paas ye do parameters hain material ke aur maine isko deform kiya material ko aur mujhe iska proof stress nikaalna hai. To proof stress nikalne ke liye mujhe pata hai ki mere paas strain hona chahiye 0.002. To agar mujhe mere paas elastic modulus hai to main proof stress aaram se nikaal loonga. To proof stress mera aayega σ_p aur main usko S_p likhoonga. Abhi hum is symbol ka bhi importance jaanenge baad mein. To ye proof stress mera aa jaayega elastic modulus into strain to 200 into 0.002 aur ye aayega lagbhag 400 MPa. Ye value thi GPa mein to ye aayegi MPa mein. To 400 MPa mera proof stress rahega agar mere paas ye strain hai. Ye bhi iska bhi hum mahatva jaanenge isko main e likh raha hoon abhi. To agar mere paas proof strain jo 0.002 hai to change in length kitni aani chahiye? To mere paas strain ki value already di hai jo $e=\Delta L/L$ ye hai mere paas 0.002 to delta L aa jaayega 0.002 into 10 mm to ye aa jaayega 0.02 mm yaani ye aa jaayega mera 20 microns. To aap janiye jo change in length hai proof stress pe change in length jo hai proof stress pe ye 20 microns hai, bahut kam value hai change in length ke liye. So aap jaan sakte ho ki mera material sirf 20 micron deform ho raha hai for 10 mm sample ke gauge length ke So ye jo points hai A, B, Y, P ye jo saare points hai ye yahan pe thoda door door dikhaye hain par ye jo saare points hai ye paas rahte, bahut paas rahte hain stress-strain curve pe. Ye just hamaare understanding ke liye hi humne door door dikhaye hain. To ye jo ho gaya hamara engineering stress-strain curve aur isme humne elastic aur plastic parts dekhe. Ye chaar points dekhe – proportionality limit, elastic limit, yield stress aur proof stress. In chaaron ka mahatva bhi humne jaana hai. Aur bahut saare parameters jaise maine bataya ki mechanical parameters hum nikaal sakte hain tensile test se, woh hum aage jaanenge agle video mein.

Dhanyavaad.