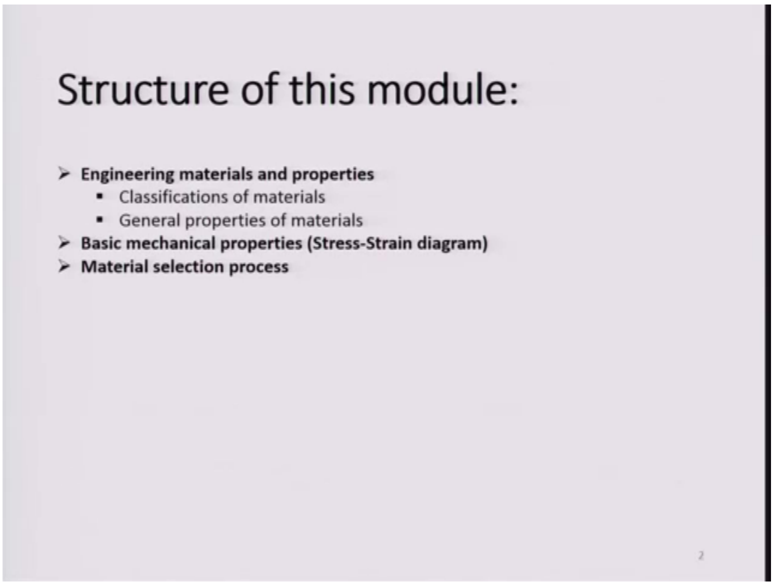
Design Practice
Prof. Shanthanu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture – 26 and 27
Material selection in Engineering design

Hello everyone. Welcome to the course Design Practice. I am Sanjay Kumar Course TA for this course, and on behalf of Professor Shantanu Bhattacharya. I will be taking few lecture modules for this course. In the past week you have already learned concurrent engineering in detail, and in the present of module 26 and 27, I will discuss a new topic, it is called material selection in engineering design ok. This topic is very important topic for the design purpose. For example, if you want to convert your idea into your practical or product, then what you will do? You will require a material to fabricate it ok.

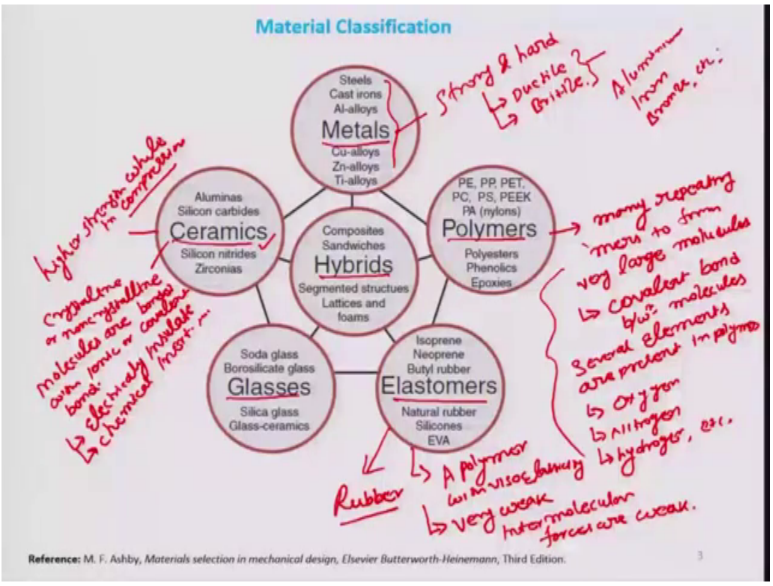
So, you know that in universe we have a variety of materials are available. So, to do the appropriate metal for your particular product, there some process is needed. So, in this module you will learn these things. So, in that this kind of things we will discuss in, we will discuss in our coming module ok, and structure of this module is following.

(Refer Slide Time: 01:18)



First we will study some engineering materials and properties, then their classification of some materials, then again general properties of materials. Then since in this module we will focus only on mechanical aspect of designing, so we will study some in brief mechanical properties; such for example, stress strain diagram and etcetera. And after that we will study material selection process.

(Refer Slide Time: 01:53)



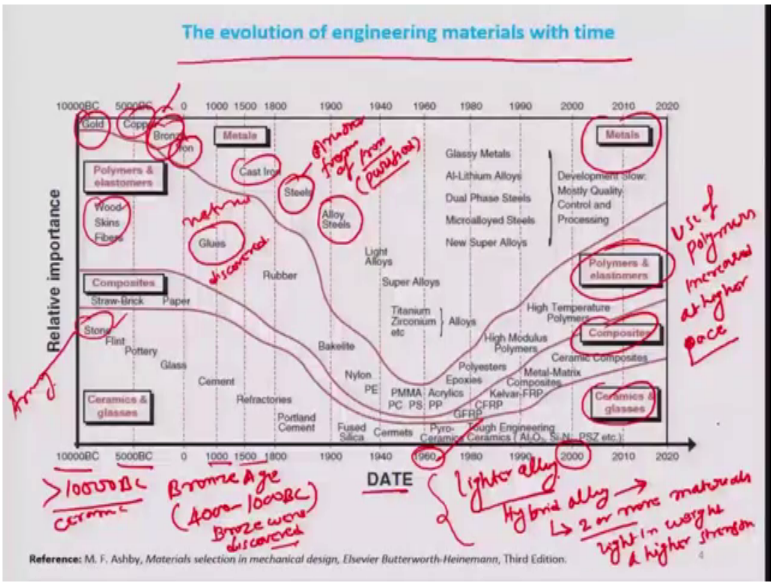
Now metal classification, in this you, we know that there are a variety of materials are available in our universe, and these are broadly classified in these groups; metals, polymers, ceramics, glasses, elastomers hybrids ok. Metals; metals are generally in crystalline in nature, and the items of the metals are held together by metallic bonding. These metals are very strong and hard, and some materials are ductile, some materials are very brittle in nature, and we will we will a study these things in detail in coming in next slide ok.

Now ceramic; ceramics are also it may be crystalline or non crystalline. And here molecules are bonded with ionic or covalent bond. Ceramics are very higher strength, of course, it possesses very higher strength while in compression ok. Ceramics are generally a brittle in nature. So, when you will apply a tension in this metal so, there will be a, it will fracture immediately compared to, in compression to metal a fracture will take place in a very a real time.

So, and this material, also these materials are electrically insulating, chemical inert etcetera. Polymers it is made with many repeating 'mers' to form very large molecule, and molecules are bonded with covalent bonding molecules and several elements are present in polymers such as oxygen, nitrogen, hydrogen etcetera.

Polymers are generally in ductile in nature. And now elastomer; elastomer is also a polymer with viscoelasticity. Elastomers are generally very weak, their inter molecular forces are very weak. Elastomers you can take example of rubber, for metals we have a variety of metals available in our universe, such as aluminum, iron, bronze etcetera. Now materials are discovered, variety of metals are discovered with a time ok.

(Refer Slide Time: 06:38)



So, we, we can see from in this table that is a variety of materials gold, copper, bronze, iron and their advent time is mentioned here. So, in stone age that is the 10000 BC, and here some materials were discovered that was the ceramic wood, skin, fibers, woods and stone were used as for their armory.

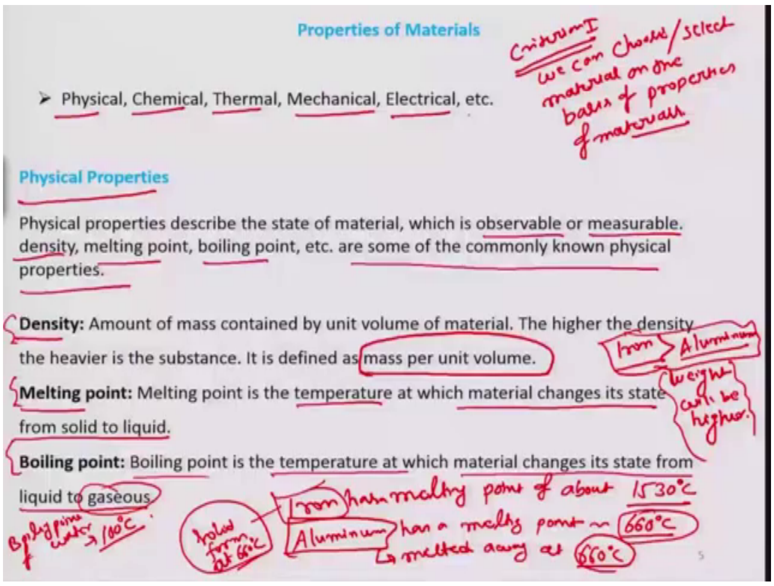
And in a bronze age, bronze area; that is the time period between 4000 to 1000 BC, here bronze was discovered. In iron age, iron age lies between 1000 to 1620 BC, and here you can say irons, cast iron and some natural glue from the tree was discovered. And cast iron was first was dominant in 1620s and we, but you can see from this plot that these materials.

The use of these materials continuously decreased with the time, and as well as their new materials was discovered at a span of time, depend on type, time see. And see we can see that in 18 50 steel was discovered; steel it is another form of iron, purified form you can say. Now, after that from the 1940-60s now people approaches towards the light alloy, lighter alloy, hybrid alloy.

Hybrid alloy, it consists of two or more materials. These materials are light. The main properties of these materials are light in weight and higher strength and from the past few decades, we can see that there the use of polymer based materials has increased enormously, as well as composites and ceramics ok, but a comparison with metals the polymer, the use of polymers increased at higher pace ok.

From this chart we can see that there are a lot of materials are available to design a any, any component of a system or as or you want to, or a machine something like that. So, we have a variety of choice. So, in these materials each material has some specific property, some specific quality and some disadvantages also, but to choose a proper material from this chart, it is a very difficult for a design engineer to which material will be suitable for our product.

(Refer Slide Time: 10:52)



So criteria 1; we can choose or select material on the basis of properties of materials ok. What are the properties? They are, each material possesses physical properties, chemical properties, thermal, mechanical, electrical, optical properties etcetera. The physical property, first we will discuss physical properties of a material.

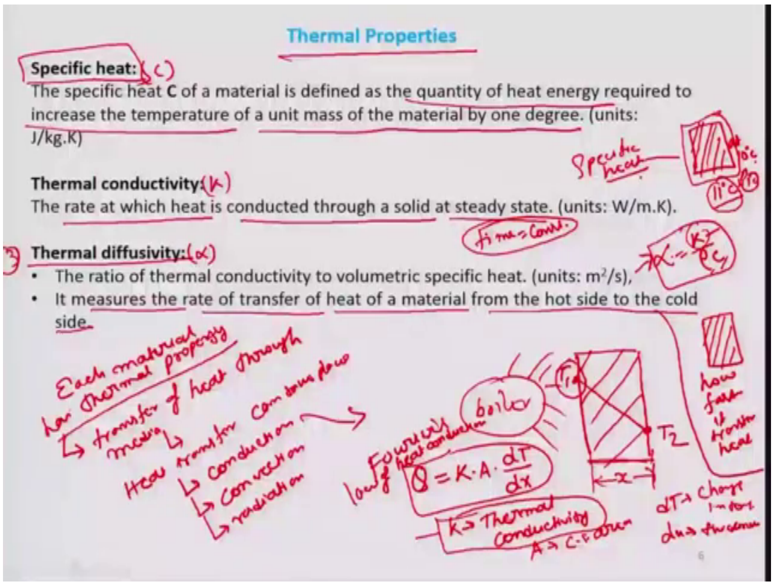
Physical properties describe the state of material which is observable or miserable, you can take property physical property of any material by your naked eye, density, melting point, boiling point etcetera are the some of the commonly known physical property. Suppose that density, what is the density? Density of any material can be defined as mass per unit volume ok, and amount of the mass content by unit volume of the material. If any material has a, suppose that iron, iron has a higher density than aluminum.

It means if you fabricate something using iron that weight will be higher. So, suppose that if you take a constraint that material part should be a lighter in weight, lighter in weight. So, you will have to choose very intelligently which material will be, will be suitable for your product. Melting point, melting point is the temperature at which the material changes its state from solid to liquid.

For example, iron has a melting point of about 1530 degree Celsius ok, while aluminum has a melting point around 660 degrees Celsius. So, you can see that at 660-degree Celsius aluminum will get melt, melted away at 660 degrees Celsius. While at 660-degree Celsius iron will be present in solid form. Boiling point; boiling point is the temperature at which the material changes its states from liquid to gaseous.

So, boiling point, you know everybody knows that boiling point of water; that is the 100 degree Celsius, it means at 100-degree Celsius liquid will start boiling and there will be it, it will start converting into gaseous media. These are the main permanent physical property of any material density, melting point, boiling point etcetera.

(Refer Slide Time: 14:45)



Now, we will talk about thermal property. Every, each material has thermal property. What is the thermal property? It is a thermal property means transfer of heat through media; that is the conduction, it can be, and heat transfer can take place using conduction, convection, radiation.

In conduction what happens, suppose that you have a one metal slab of thickness x, and at this point suppose that here is a one boiler and it emits heat and temperature at this place is T1 and. So, what happens, that temperature gets the, when heat will get transferred through this slab, so at in this way and there will be a temperature of T2.

So, if you want to calculate the, what will be the heat exact amount of heat transfer then what you, it is calculated using Fourier's law of heat conduction; that is the Q is equal to K into A into dT by dx, where K is the thermal conductivity, A is the area of the slab and delta T change in temperature, and d x is the thickness.

$$Q = KA\frac{dT}{dX}$$

Thermal conductivity; thermal conductivity is a property of material and it defines as a rate at which the heat is conducted through a solid at a steady state. Steady state means at time constant, time will be constant at the steady state, and another property is the in thermal property of any material is a specific heat, and specific heat of a material is defined as the quantity of heat energy required to increase the temperature of a unit mass of the material by one degree, means the amount, how much energy is required to increase; suppose that one this is your part, one sample is there at temperature 10 degree Celsius.

And if you are heating this sample and temperature gets increased to 11 degree Celsius. So, there is a increase in one degree Celsius. So, how much heat is required to increase the temperature of sample to the 11-degree Celsius means one difference is, net difference is one degree Celsius. So, that amount is the specific heat. Another property is the third property is thermal diffusivity and thermal diffusivity it is the measures the rate of transfer of heat of a material from the hot side to the cold side.

It means it signifies the any material, how fast it transfers the heat, and it can be calculated as thermal diffusivity is signifying alpha, alpha is equal to k by rho c, where k is the thermal conductivity, and c is your a specific heat of material and rho is the density of the material. So, if you know density of material specific heat and thermal conductivity, then you can easily calculate the thermal diffusivity of that particular material.

(Refer Slide Time: 20:00)

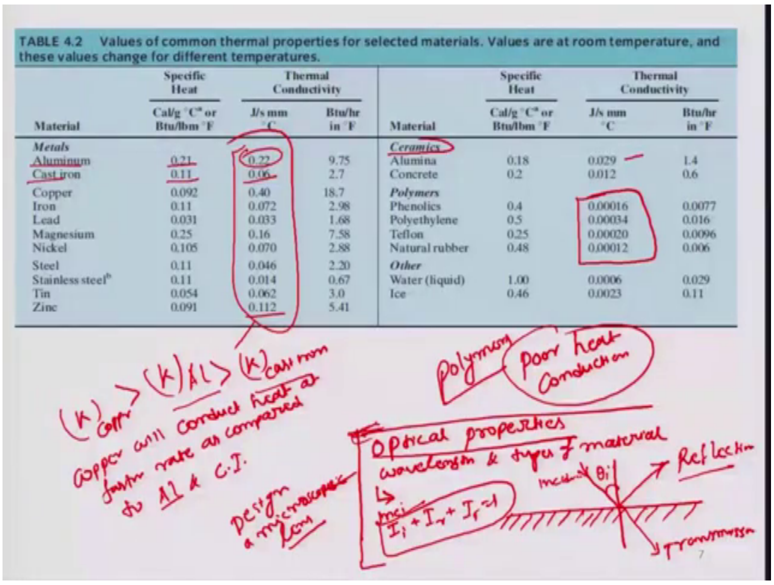


TABLE 4.2 Values of common thermal properties for selected materials. Values are at room temperature, and these values change for different temperatures.

Material	Specific Heat Cal/g °C° or Btu/lbm °F	Thermal Conductivity J/s mm °C	Thermal Conductivity Btu/hr in °F	Material	Specific Heat Cal/g °C° or Btu/lbm °F	Thermal Conductivity J/s mm °C	Thermal Conductivity Btu/hr in °F
Metals				*Ceramics*			
Aluminum	0.21	0.22	9.75	Alumina	0.18	0.029	1.4
Cast iron	0.11	0.06	2.7	Concrete	0.2	0.012	0.6
Copper	0.092	0.40	18.7	*Polymers*			
Iron	0.11	0.072	2.98	Phenolics	0.4	0.00016	0.0077
Lead	0.031	0.033	1.68	Polyethylene	0.5	0.00034	0.016
Magnesium	0.25	0.16	7.58	Teflon	0.25	0.00020	0.0096
Nickel	0.105	0.070	2.88	Natural rubber	0.48	0.00012	0.006
Steel	0.11	0.046	2.20	*Other*			
Stainless steel[b]	0.11	0.014	0.67	Water (liquid)	1.00	0.0006	0.029
Tin	0.054	0.062	3.0	Ice	0.46	0.0023	0.11
Zinc	0.091	0.112	5.41				

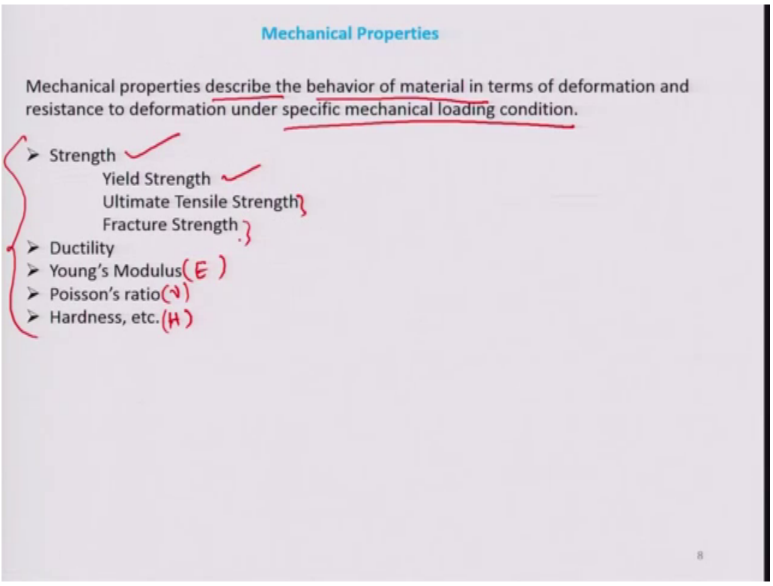
This table shows some common thermal properties of selected materials and you can see for metals such like; for example, aluminum, the specific heat is 0.21, forecast iron it is 0.11, copper 0.092 kilo Kelvin, Kelvin per gram into Kelvin thermal conductivity, if you see the aluminum at 0.22 joule per second mm, forecast iron 0.06 for zinc 0.112.

So, in comparison, what you are getting aluminum thermal conductivity of aluminum is higher than thermal conductivity of cast iron also, thermal conductivity of copper is higher than these two. So, it means will conduct heat at faster rate as compared to aluminum and cast iron. Some another ceramic you can say alumina is 0.029, for polymer. Polymers are very poor in heat conducting.

Now some other properties of material are that optical property. An optical property, it depends on wavelength and types of material, another parameter which can affect the optical property is the incidence angle; suppose that here is your one material and light is coming like this; that is the theta i, theta i is the angle of incidence that is make to the perpendicular to your material, and it’s get reflected that is the reflection, and that is the transmission incidence ok.

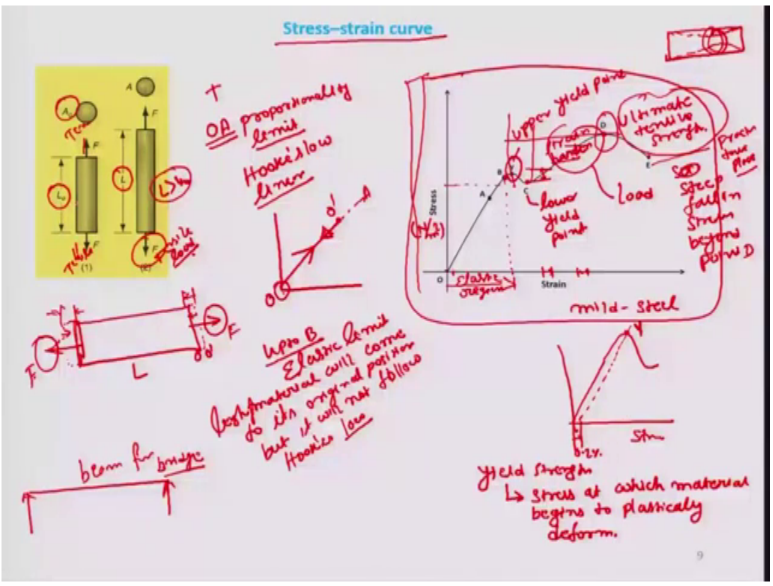
So, algebraically incident intensity Ii plus I r plus I t will be 1. Some metals are very reflective in nature; some materials are transfer very poor reflex very poor reflection. So, these properties are important if you want to design, suppose that microscope for example, microscopic lens. So, this optical property will play predominant role, but in this module we will focus only on our mechanical part, mechanical properties.

(Refer Slide Time: 24:05)



So, mechanical property, this describes the behavior of material in terms of deformation and resistance to deformation under specific mechanical loading condition and these are the various properties of comes under a mechanical property that is a strength, yield strength, ultimate tensile strength, fracture strength, ductility, Young's modulus, Poisson ratio, hardness. We will study in detail these things in coming slide ok.

(Refer Slide Time: 24:38)



First we will start from the stress strain diagram ok. Here what we are doing, we have, we take 1 bar solid bar of length L naught, initial length L naught and an axial force F is applied on both side and there is a that is the call tensile loading, tensile load is applied on both side axially and what happens after sometimes, when the load is applied, the material which stretched, axial and length is increased.

You can say that there is an increase in length due to the tensile load ok, and for that and corresponding changes in displacement by using your load applied, one plot is generated in machine that is the tensile machine. Here you can see that these are the various points in this plot A, B, Y, C, D, E and each point has some significance ok. So, we will discuss point by point.

Generally, stress has a unit of Newton per meter square, and each stress versus strain. Here O A that is called proportionality limit, means when you will apply a load on a bar. So, the length will increase axially, but after stop. Suppose that you have an after removing of this load F. So, what will happen, again this distance, it is just like a spring in nature.

This deflection will again a bar will come into its original position, it will return back up to that point O A, and this point follows the Hooke's law, it's a linear in nature. It means suppose that if you are applying a load and deflection elongation takes place so low and up to this point ok, and this point is somewhere between before the point A, and after stop applying the load what will happen, the load will follow the same path and it will come sit at origin its origin O O dash.

So, O suppose that it will o and this point is O dash. So, it will come from O dash to O that is the proportionality limit, and for B up to point B; that is the elastic limit, means after removal of load applied load, what will happen, it will again material, length of material will come to its original position, but it will not follow Hooke's law. So, up to this point B these are the elastic, elastic region ok.

So, if you are applying a load on any material, this diagram is for mild steel, every material will have a different kind of stress strain diagram for in. In case of mild steel, you suppose that if you are applying a load somewhere up to, somewhere this one. So, what will happen after removal of load? metal will come into its original position. So, that will be the elastic region. So, there is another point that is called Y Y, the location of Y can be traced from that like that, you just take a 0.2 percent distance, suppose that this is the strength stress and parallel to OA and wherever it will intersect that point is the yield point ok.

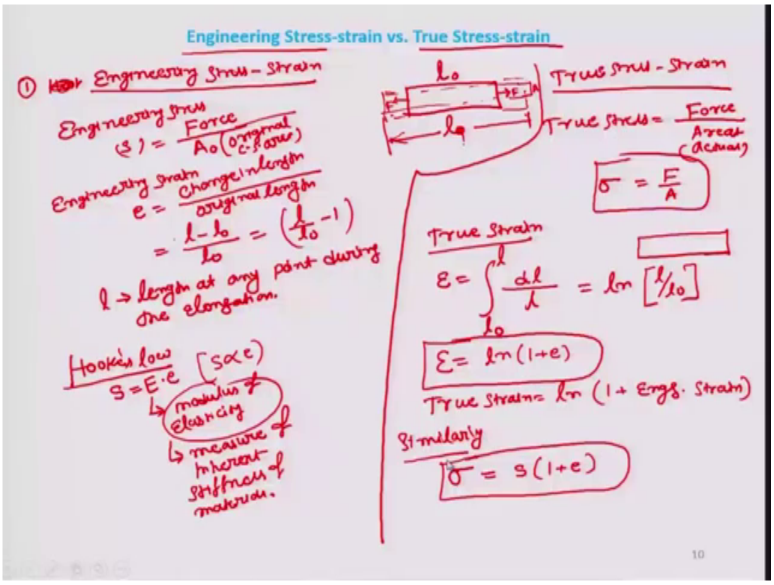
So, this is 0.2 percent of the strain, and yield strength can be defined as stress at which material begins to plastically deform. It means from there that; that is called y is the upper yield point and C is the lower yield point, and from C we can see that the stress value is seen to be rise again from point C here by hm, and from materiality. So, actually what happens from beyond C their material is getting strained hardened, this region it means load beyond y, elongation occurs at much faster rate, you can see that, there is a small change in the strength the value of a stress is very high ok.

Suppose that you are taking this much strain here in from Y to D region, in Y to D region, in a small deflection elongation, the change in stress is high. So; that means, elongation occurs at very much faster rate. And after reaching point D, after reaching point D what happens, making the shape of the bar gets start changing like that, you can say that naking takes place, making, making formation, it starts from point D and this point is called ultimate tensile strength.

It can be defined as the proper strength of any material up to which the material can sustain their shape in a plastic deformation and if you are continuously elongation is you are applying load then what will happen, the stress sudden steep fall in stress beyond point D, means making will take place, and this cross sectional area at place where fracture will take place, it gets reduced and. So, that up to at point E fracture will take place.

So, main motto of this steady stress strain diagram is that, what, suppose that if you want to design something and for a suppose that you are making a beam for a bridge ok. So, you will have to consider each materials ultimate tensile ultimate strength. So, that up to up to which that material can sustain itself; otherwise what will happen if you will suppose that if you are to join something material, which have a, which cannot sustain much load so that what will happen fracture will take place.

(Refer Slide Time: 35:05)



So, there is another term which comes in stress strain diagram that is called engineering stress strain and true stress strain. There is a difference between engineering stress strain and true stress strain ok. First engineering stress strain, first I will discuss engineering stress strain. Actually what happens during calculation of, stress is what, engineering stress can be defined as force that is applied in axial direction to the cross sectional area of the beam here; that is the cross sectional area of each A naught and force is F engineering study that is the A naught is original cross sectional area, before applied any load, and engineering a strain is defined as change in length due to applied load divided by original length.

So, what is the change in length suppose that first bar length is L naught and after applied load length for particular law at a particular load, length is L. So, change in length will be L naught minus L naught divided by L naught theta L naught minus L, where L is equal to length at any point during the elongation. So, Hooke's law of linearity for up to the for point O A what will happen, stress is directly proportional to strain and E to E, where E is the modulus of elasticity, it is a measure of the inherent stiffness of material.

$$e=\frac{l-l_0}{l_0}=\left(\frac{l}{l_0}-1\right)$$

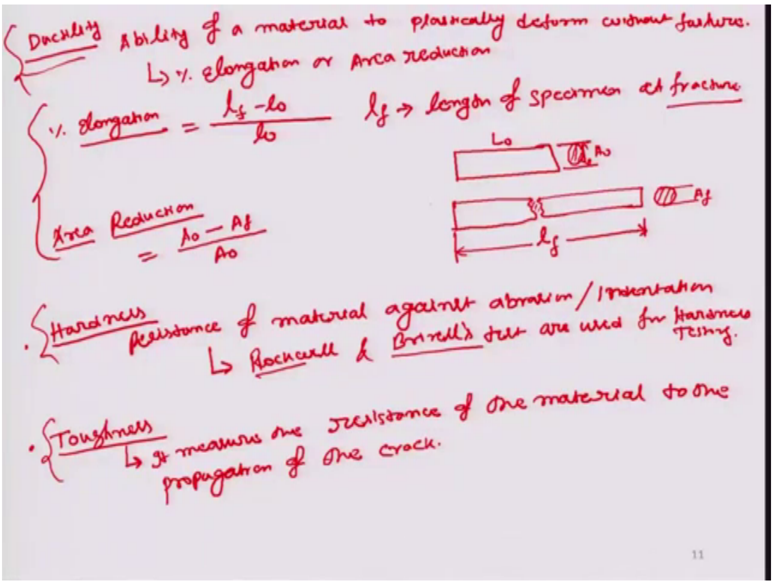
Now we will study true stress strain relation. What is the true stress? Which is the ratio of force per unit area; that is the actual area, means for a particular load F length is increased to L and cross sectional area is change to A ok. So, that is sigma is equal to F by A, A is the actual area at particular load, and true strain, true strain is equal to since deformation elongation takes place in continue continuously on applying of load.

So, we can write that using same thing change in length divided by original length. So, suppose that first initial length was L naught and final length is L at particular load and change in length what is d L and initial, and if you will solve log L by L naught. So, if we substitute the value of L naught from here, so what will happen 1 plus e, this is the relation between true strain versus and injuring strain, means two strain is equal to ln one plus engineering strain. Similarly, we can derive an expression for two stress versus engineering stress.

$$\varepsilon = \int_{l_0}^{l} \frac{dl}{l} = \ln\left[\frac{l}{l_0}\right] = \ln(1+e)$$

$$\sigma = S(1+e)$$

(Refer Slide Time: 41:30)



Now I will discuss some more mechanical properties like ductility or ductility that is the ability of a material to plastically deform without failure ok, and if you want to quantify ductility then you will have to measure either percentage elongation or area reduction. What is the percentage elongation? It is the ratio of difference between final length minus L naught divided by L naught, where Lf is equal to length of a specimen at fracture, what happens initially length, initial length is L naught.

$$elongation = \frac{l_f - l_0}{l_0}$$

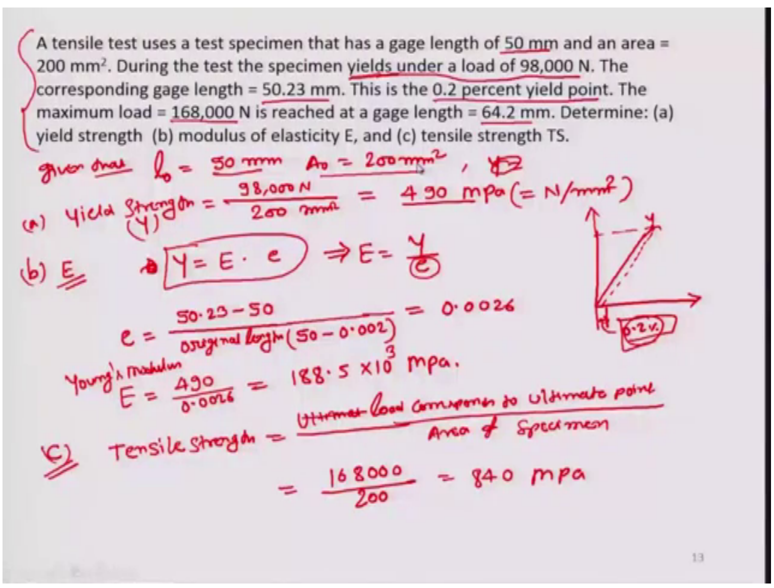
So, after fracture Lf, after fracture just divide both part and measured length of actual length of that specimen, so that is the length of a specimen at fracture. So, from here this formula you can calculate the percentage elongation of that specimen. Another is area reduction, again this is initial cross sectional area minus cross sectional area of specimen after fracture divided by original cross sectional area. So, first suppose that cross sectional area was A naught and now cross sectional area is Af.

$$Area\,reduction = \frac{A_0 - A_f}{A_0}$$

So after measuring the cross sectional area of the, actual cross section area after fracture of that specimen, you can calculate area reduction. So, these both terms define the ductility of any material. Now other properties hardness of the material hardness, it is the resistance of material against abrasion or indentation.

Generally, Rockwell and Brinell test are used for hardness testing. Now the toughness, it measures the resistance of a material to the propagation of a crack. These are some mechanical properties which are very important during the consideration of selection of material.

(Refer Slide Time: 46:14)



Now, we will do some problem solving example ok, here you can see that problem statement is that, a tensile test uses a test specimen that has a gauge length of 50 mm and an area of 20 mm squared; that is a cross sectional area during the test, the specimen yields under a load of 98,000 Newton. This corresponding gauge length is equal to 50.23 mm this is the 0.2 percent yield point ok, the maximum load is 168000 Newton that is a reached at gauge length of 64.2 mm. So, determined yield strength modulus of elasticity and tensile strength.

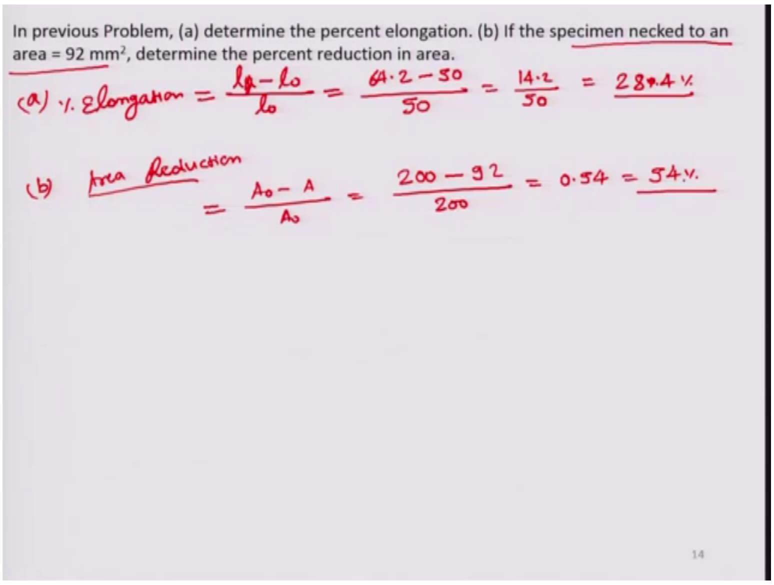
So, what are the things given that gauge length of 50 mm, L naught is equal to 50 mm A naught is equal to 200 mm square yield Y is equal to, means specimens yields under a load of 98,000 Newton. So, if you want to calculate yield strength, what this yielding, correspond load corresponding to a yielding point that is the 98,000 Newton and the cross sectional area of the specimen is 200 mm square.

So, that will be 490 mega Pascal or either you can write Newton per mm square. Now modulus of elasticity; modulus of elasticity we can calculate by Hooke's law, what is this states yield strength, Y is equal to young's modulus into strength, this one. So, E is equal to Y by E, so what is the strength. So, first we will see ordinal gauge length was 50 mm, corresponding gauge length is 50.123 mm and there is a 0.2 percent yield point. Earlier I had discussed for yield point as a parallel line is calculated, so 0.2 percent that is the yield point 0.2 percent ok.

So, if you calculate the strength, the change in length will be 50.23 minus 50, an original length. So, in this case originally, what will be original length. Actually we omitted this that amount of strength zero, for consider taken, we take 0.2 percent strength for locating the yield point, so we will have to take consider of that thing. So, 50 minus 0.002 percent on calculating that will be 0.0026 ok.

Now young's modulus E will be yield strength is 490 and strain is 0.0026 that will be equal to 188.5 into 10 to the power 3 Mega Pascal. Now we calculate tensile strength. So, tensile strength of any material that is equal to, load corresponds to ultimate point divided by area of a specimen, that will be equal to area of a specimen is 200, 840 Mega Pascal; that is the tensile strength

(Refer Slide Time: 52:08)



In the next problem, again what saying in previous problem the determine the percent elongation, if the specimen necked to an area 92 mm square determine the percent reduction area, to will use same data 50 mm gauge length cross sectional area 200 mm square, and on basis of that we will calculate percentage elongation. A percentage elongation with the length at fracture after fracture minus initial gauge length divided by L naught. Here and up to maximum 64.2 mm, not fracture you can say ultimate strength, 64.2 given minus 50 divided by 50 it is equal to, means this material can elongate 28.4 percent without any failure.

$$elongation = \frac{l_f - l_0}{l_0} = \frac{64.2 - 50}{50} = 28.4$$

Area reduction.

Again initial cross section area minus area at actual cross sectional area minus divided by a naught that is equal to, it was earlier 200 minus the specimen neck to an area 92 mm square, its 200 minus 92 divided by 200 that is equal to 0.54 in the percentage that you can

$$Area\ reduction = \frac{A_0 - A}{A_0} = \frac{200 - 92}{200} = 54$$

write 54 percent.

Till now you have already learned the various properties; for example, mechanical properties, physical property, electrical properties, thermal properties as well as optical properties ok. These properties are instrumental while selection in of material in your design purpose ok.

Now I am closing this module 26 and 27, and the incoming next module I will discuss about what the steps involved in the selection of a material ok.

Thank you thank you very much