Medical Biomaterials
Prof. Mukesh Doble
Department of Biotechnology
Indian Institute of Technology, Madras

Lecture - 05
Properties (Mechanical)

Welcome to the course on Medical Biomaterials. We will continue with the mechanical properties that a biomaterial should have, especially when the material is going to face stress either in the form of elongation or compression or sheer forces. Then we need to consider all these mechanical properties.

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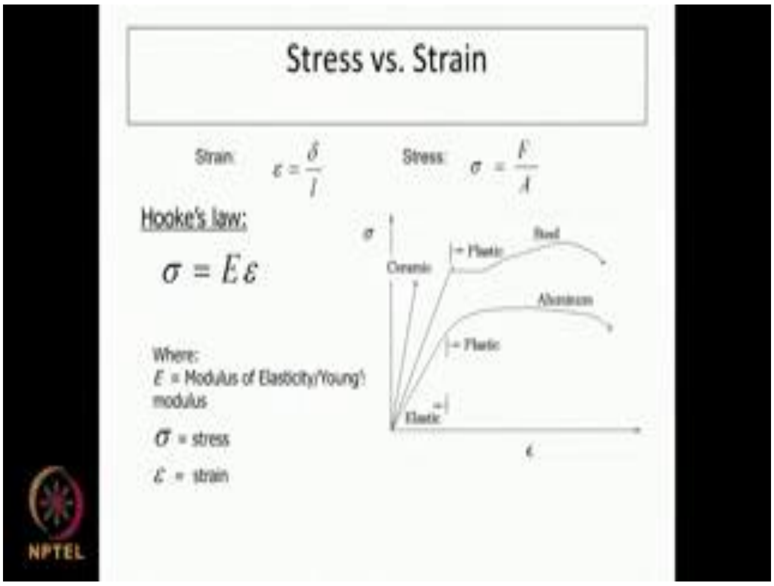

We talk most important property which is called the stress strain relationship. They are all connected by something called hooks law, where on the left hand side we have the sheer stress and on the right hand side we have the sheer strain. So, they are connected by a term called Young's modulus or modulus of elasticity. So, the sheer stress is going to force that is acting on the material divided by the area. It could be elongation force or it could be compressible force. And the strain is given by the change in the length divided by original length.

So, as you can see elongation will not have any one edge whereas, the stress will have units of force divided by area. So, we may have say Newton divided by millimeter square or meter square or centimeter square. So, if you look at the graph that is connects the stress or the strain stress on the y axis stress on the x axis you may have the elastic region where the material will follow the hooks law and the slope of this line will be the modulus of elasticity or Young's modulus. And after that it inters the plastic region and finally, it breaks that is called the yield strength.

So, this maybe for steel whereas, aluminum will have a lesser Young's modulus; so graph will slope this graph will be much lower. And then it will have a very large plastic region because aluminum is expanding as you keep pulling it. So, whereas, in the plastic region the material will not come back to it is original length, even if you remove the force. Whereas, ceramic if you look here at certain value of stress it will force, it will just snap. So, it will not go through the plastic region at all that is the big problem of ceramics. They have very poor tensile force they cannot take much tensile force, here it will just break.

So, if you have places where you need to have a tension like if you have joints where there is a tensile forces acting on or there is a compressive force especially in the foot region or in the leg then ceramic is not a good material to use at, because they do not go into this elastic and plastic type of deformation, as steel or aluminum can do that and So, we also looked at a problem which tells you how to calculate stress strain modulus velocity range so on actually.

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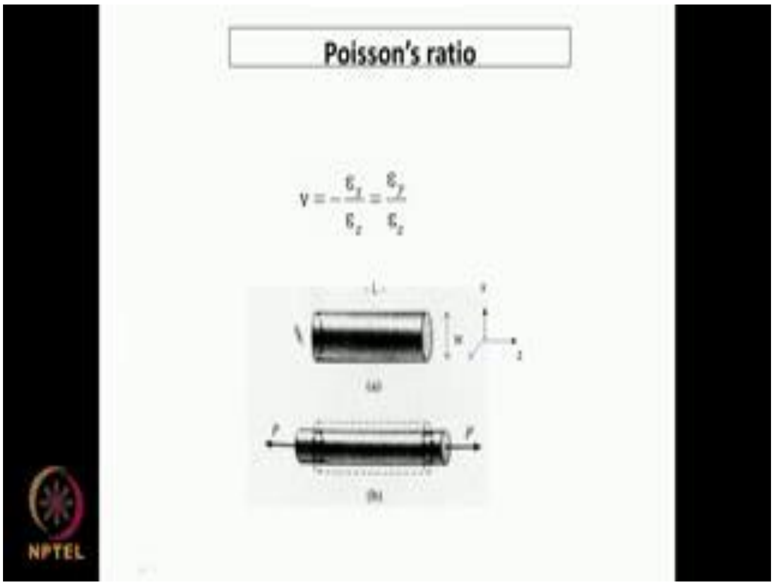

Another important term is called the Poisson's ratio. Poisson ratios suppose you have a rod and you are pulling the rod by applying forces on either direction. Then obviously, there will be a strain. That means, there will be an elongation of the rod and simultaneously in the other direction there is a direction also there will be some change. Because of the elongation that ratio is called the Poisson's ratio. So, when I pull the rod there is elongation that will be there will be an increase in it is length simultaneously in perpendicular direction, there could be there will be a decrease in the diameter. So, that ratio is called the Poisson's ratio.

And there is a negative input here when you have a elongation in one direction possibly there will be a reduction in the dimension in the other direction in the perpendicular direction that is why you have a negative term. Poisson ratio is very important in medical application I will show you some examples that. So, Poisson's ratio is also very important for us to know for materials whether it is metals or whether it is rubber or plastics and so on. So, this table sort of gives you an approximate idea about what could be the Young's modulus and what is the Poisson's ratio.

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Material	GPa	Poisson's ratio
aluminium, Al	70	0.34
copper, Cu	123	0.34
gold, Au	80	0.42
lead, Pb	15	0.45
steel, Fe(C)	206	0.33
iron, Fe	206	
brass (70% Cu, 30% Zn)	110	
quartz, SiO_2	310	0.37
glass (silicate)	70	0.25
alumina, Al_2O_3	355	
MgO	207	
SiC	414	
vulcanised rubber	3.4	0.4
polystyrene	3.8	0.4
polyethylene	0.14	0.4

As you can see for many rubbers it is 0.4; that means, the strength ratio of strengths is almost half from each other. If you go to steel Poisson's ratio is about 0.33. Aluminum is 0.34. So, many metals you are talking in terms of 0.3 to 0.4.

And if you look at the Young's modulus as you can see steel is very high 200, whereas aluminum is 70 copper is about 120 and so on. So, if you go to quartz you are talking very high Young's modulus, 300 odd whereas, rubber like material it has got very low Young's modulus 3 Giga Pascal's. So, slope of the stress strain will be very low. As you can see the oxides all the ceramics oxides 3 alumina quartz magnesium oxide they are all quite high when compared to aluminum copper gold and led like that.

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Let us look at a problem I have a rubber drain tube it is got a Poisson's ratio abut 0.4 and diameter of the tube is 8 mm and the length is 25 mm there is a force applied on it, it a force of 100 Newton's to pull it out. So, when you do that there is an extension of 0.02 mm between these calculate the normal stress normal strain Young's modulus, what is the decrease in the diameter when you pull, because as I said Poisson's ratio gives you ratio of difference and the changes in the dimensions in 2 perpendicular directions. So, Poisson's ratio epsilon x by epsilon z 0.4 as given; so Poisson's ratio is a epsilon x by epsilon z 0.4 as given here. So, that will be a negative term here.

Now let us calculate normal stress that is very simple force by area normal strain increase in length divided by original length Young's modulus is a ratio of stress by strength. So, the 2 the tube diameter is 8 mm square. So, area is pi d square by 4. So, 50.2 mm square force is 100 Newton's. So, force by area gives you the stress. So, this hundred divided 50 you get about 1.9 Newton per millimeter square. Now strain is delta l by l delta l is 0.02205. So, when I divide it becomes 0.0008 Young's modulus stress by strength. So, we get 2487 Newton per millimeter square.

Now, the Poisson's ratio minus epsilon x divided by my by epsilon e z. So, there has to be a minus term here, because when it gets extended in one direction it gets shortened in another direction. So, which is given by 0.4, I know epsilon x that is 0.0008. So, the in the other direction it will be 0.002 because you are multiplying by you are dividing by 0.4. Because e x divided by e z is equal to Poisson's ratio. So, e z divided is given by e x divided by the Poisson's ratio. That is why you get 0.002. So, the tube diameter is 8 mm. So, the change in the tube diameter is 0.002 into 8.016. So, the diameter of the tube gets reduced by 0.016 millimeter. So, when the tube gets elongated by 0.02 mm the diameter gets reduced by 0.016. So, if it is a rubber drain tube it is carrying some body fluids. So, diameter gets reduced. So, the chances are the rate of drain can go down. So, you need to keep that in mind that is a very interesting situation you may have.

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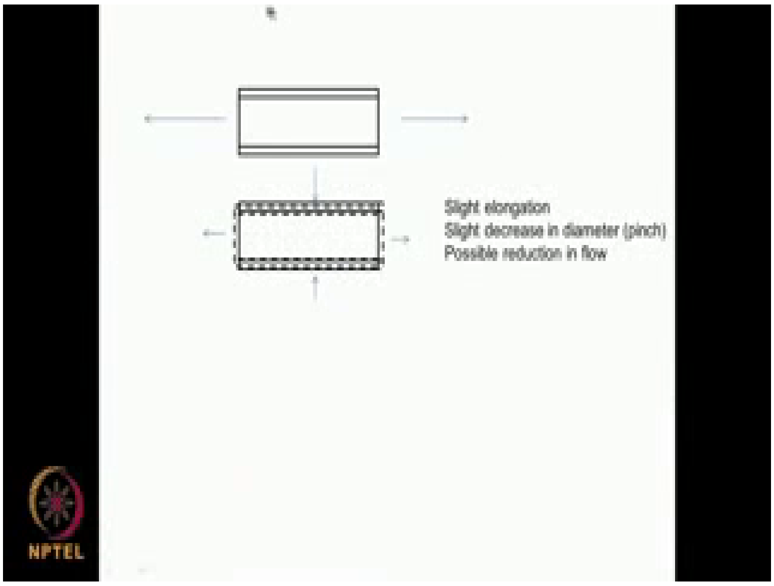

So, the tube is there is a force acting. So, it gets elongated. So, slight elongation. So, there is a slight decrease in the diameter because of the Poisson's ratio. So, there could be a possible reduction in the flow. So, there could be a possible reduction in the flow. So, you need that is a situation which can happen.

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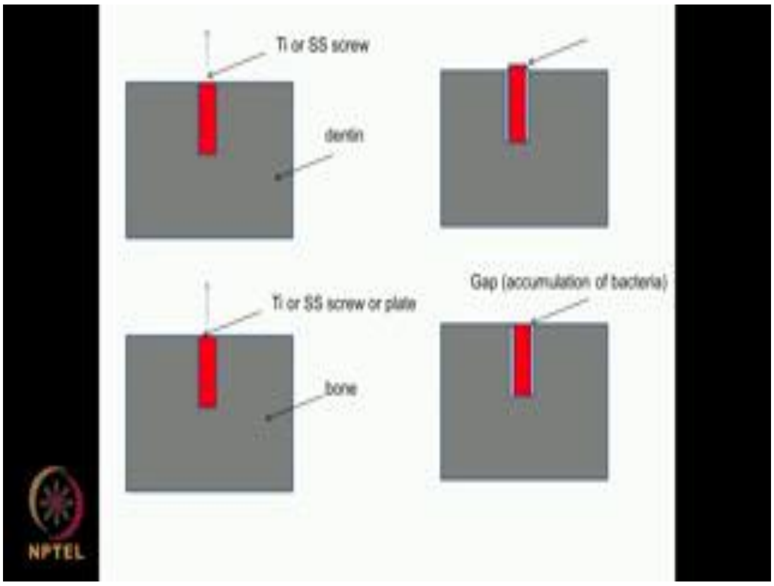

This can become very serious in such a situation. For example, titanium or stainless steel screws are used in oral surgery, especially for putting in artificial tooth or artificial caps and so on. Or titanium or stainless steel screws or plates also put in bone especially in orthopedic situation. If these screws face certain tensile force, for example, there could be a small elongation because of the tensile force as we saw. Conversely it could be a small contraction in their diameter also because of the Poisson's ratio because for metals Poisson's ratio is almost 0.4.

So, if there is a contraction. So, you may have a situation like this there is a contraction. So, a small gap could be created whether it is dentin in oral cavity region or whether it is in the bone, there could be a small gap created which could be lead to bacterial colonization bacterial infection and so on. So, because of this change happening in the dimensions as represented by Poisson's ratio one could have situations like that. So, in the tooth region when you have metals and the metals undergo tension, there could be a small gap created over a period of time which could be sourced for accumulation of bacteria same thing can happen in the bone region also. So, these are some issues that can happen in realistic situations.

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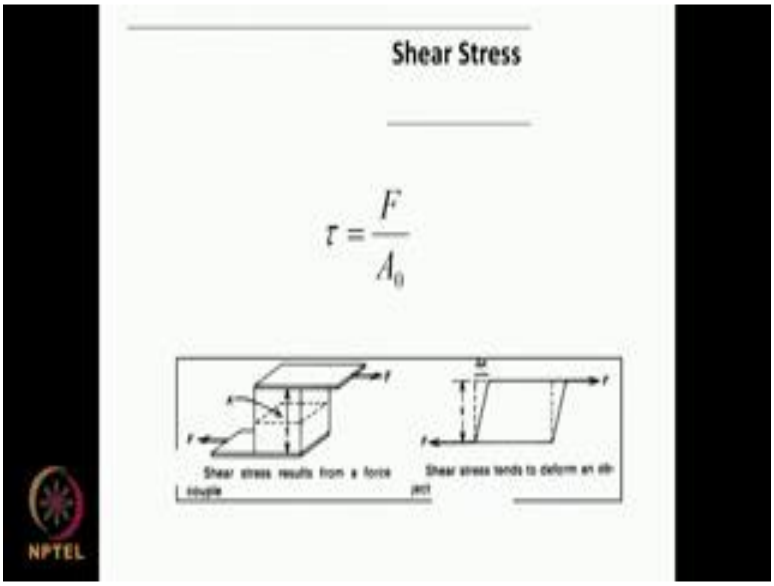

Just like tensile forces acting in a longitudinal direction. It could also have shear forces acting on material this is very common specially teeth. Teeth when they come in contact there is a lot of shear that is happening. So, the surfaces of the tooth get sort of blunted. And again you can have something called shear stress which is given by force. And the area that is in contact shear stress results from a force couple. So, there is a suppose I have lower jaw lower teeth when upper jaw upper teeth, they come in contact with each other, it is not exactly meeting each other, but because there could be a slight dis displacement in the jaws there will always be possibility of shear forces acting on the teeth.

So, there is again when there is a shear forces which is sort of parallel to the surface get it be a small displacement is called delta x and this could be the length. So, the shear strength could be delta x by l. So, you see that how to calculate shear strength here. Because of the shear stress the surface gets displaced. So, displaced from it is original place to a new place. So, that difference is delta x. So, the length is l. So, delta x by l is shear strength. So, delta x by l is shear strength.

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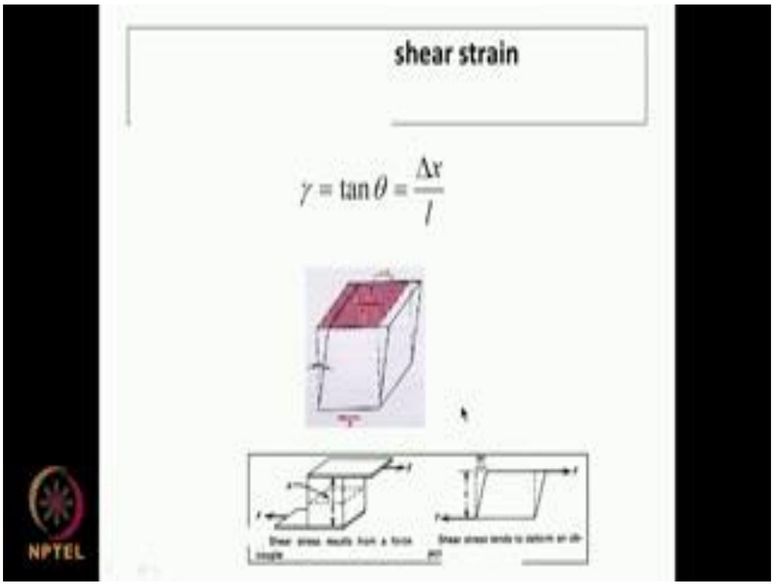

These are also equal to tan theta if we look at trigonometry or geometry. So, the shear modulus is given by shear stress that is force by area and the shear strain is delta x that is the displacement divided by the length.

So, materials will have different shear modulus. Just like Young's modulus shear modulus also could be different. As you can see here for many of these material shear modulus is lesser. Shear modulus happens because of 2 forces, one force happening parallel to the surface on the top and correspondingly there is another force in the opposite direction happening again parallel.

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Material	GPa
aluminium, Al	24
copper, Cu	45
gold, Au	28
lead, Pb	5.4
steel, Fe(C)	89
iron, Fe	
brass (70% Cu, 30% Zn)	
quartz, SiO_2	30
glass (silicate)	30
alumina, Al_2O_3	
MgO	
SiC	
vulcanised rubber	1.2
polystyrene	1
polyethylene	0.05

So, it is like rubbing and that displacement the material. So, these are some values of shear modulus for some material. As you can see shears or rigidity modulus as it is called is lesser than Young's modulus, as you can see these numbers as against these numbers. So, Young's modulus for materials are much higher than the shear modulus or rigidity modulus.

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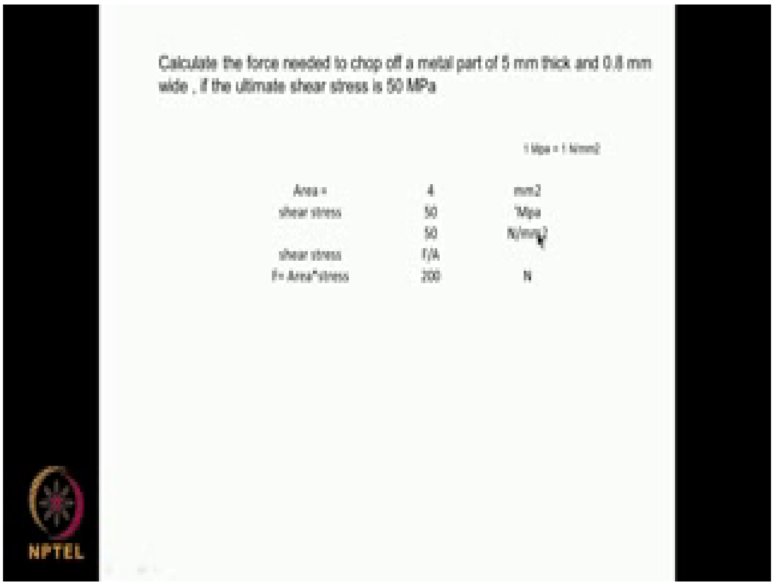

Let us loot at a small problem. Calculate the force needed to chop off a metal part of 5 mm think and 0.8 mm wide. So, it is got 5 meter thick and 0.8 mm wide. The ultimate shear stress is 50 mega Pascal's, what is the force required? How do we calculate this? Area is equal to it is rectangular cross section. So, 0.8 into 5 that is 4 millimeter square, shear stress is given by 50 mega Pascal; 1 mega Pascal is 1 Newton per millimeter square. So, it is 50. So, shear stress is forced by area. The force is equal to area in the stress. So, shear stress is 50 areas is 4. So, we multiply we get 2 hundred that is the force required 200 Newton's you understand.

So, the area is 5 into 0.8 meter square. Shear stress is 50 just converted these mega Pascal into Newton per millimeter square. Then shear stress is forced by area. So, force is equal to area into shear stress. So, we multiply into 4. So, we require 200 Newton force to chop off this material, because 1 mega Pascal is equal to 1 Newton per millimeter square. So, you see we need to understand all these conversion factor Newton's to mega Pascal Newton to mega Pascal per and millimeter square and so on. So, you need to have good knowledge about these conversion factors.

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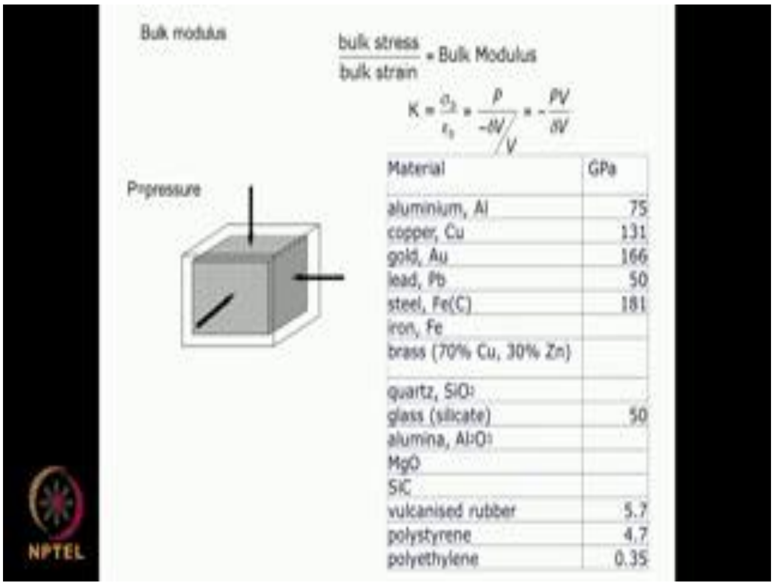

Then there is something called bulk modulus. Bulk modulus is uniform compression of material, because this as a pressure. So, suppose if a material is dipped inside a vessel containing say fluid act acting on with the certain pressure. So, the material is undergoing a compression in all direction. So, there is a bulk stress and there is a bulk strain. So, here volume comes into the picture the change in the volume divided by the original volume is bulk stain. And the shear stress is nothing but pressure because force by area is again pressure; if you remember in your school days. So, the bulk strain is change in the volume divided by original volume. This is called the bulk modulus these are some bulk modulus data for different materials you can see here.

So, this type of forces come into play if I am especially when the forces are acting in all the directions on the material. So, that the material there is change in the volume of the material not change in the linear direction, but change in volume. Because change in volume is complete in all directions. So, in that sort of situation Young's modulus we put in change in the length divided by original length whereas, bulk modulus we put change in the volume divided by the original volume.

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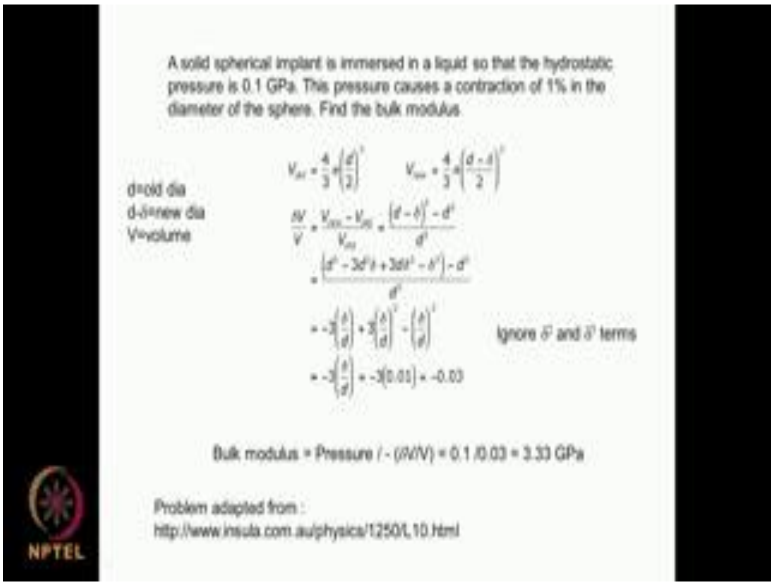

Let us look at the problem. This problem is adopted from this (Refer Time: 18:43) a solid spherical implant immersed in a liquid. So, that the hydrostatic pressure is 0.1 Giga Pascal. This pressure causes a contraction of 1 percent in the diameter of the sphere find the bulk modulus. So, the there is a pressure element here. There is a change in the volume causes a contraction of 1 percent in the diameter of the sphere. So, we need to calculate what is the change in the volume. So, the change in the diameter is one percent. So, we need to calculate change in the volume. So, it is little bit tricky not too much tricky.

Let us look at it. Suppose d is the old diameter, d minus delta is the new diameter, because the material has contracted. So, that is why I am subtracting V is the volume. So, old volume is 4 by 3 pi r cube. You remember in your school you must have studied. So, instead of r you put d by 2. That is the old. For a new volume we put 4 by 3 pi d minus delta by 2 cube. So, change delta V by V is given by V new minus V old by V old. So, we need to take this subtract this and divide it by the V. So, when we do that we get d minus delta cube, minus d cube divided by d cube. All these 4 by 3 pi has disappeared and they get canceled.

So, d minus d whole cube if you remember you must have studied in your school again, d cube minus 3 d square delta plus 3 d square delta plus 3 d delta square minus d cube there is a d cube outside. So, we can cancel these 2. Then we divide by d and. So, it becomes minus 3 delta by delta cube. Then you have minus 3 delta by d. That is because of this term. And this one is minus 3 delta by delta whole square. These 2 gets canceled. So, we have like this you understand how you got this. So, you have delta by d whole cube, then delta by d whole square and then delta by d this comes here these 2 gets canceled.

Now we can ignore these 2 because delta itself is going to be very small. So, the delta square or delta cube can be ignored. So, we will just take this. So, delta V by V is given by minus 3 delta by d. And delta is 0.01 percent. So, delta V by V is given by minus 0.03. So, what is the formula the modulus? Bulk modulus is given by pressure divided by minus delta V by V. Which is given by minus 0 0.3 and pressure is 0.1 Giga Pascal. So, 0.1 divided by 0.03. So, this becomes 10 by 3 which is 3.33 Giga Pascal’s. So, where is this 3 .3 3 as you can see some of the polystyrene or vulcanized rubber can have a bulk modulus in that order. So, if I take rubber material and it is immersed in a solution which is giving you a pressure of 0.1 Giga Pascal. So, there could be a contraction in the diameter with the order of one percent.

So the it is an interesting problem which tells you about the overall change in the material dimension. So, originally we saw Young’s modulus, where we are talking about change in the linear dimension. Then we saw the shear modulus where because the shear forces the material will gets pushed or moved then we talked about the bulk modulus. Where the material dimensions are changed in the overall. So, all these are very relevant in implants and devices you have to keep that in mind.

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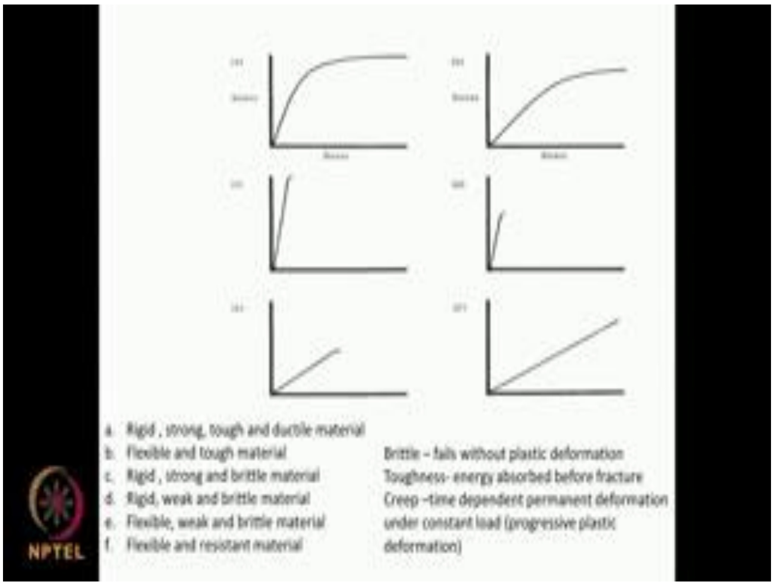

So, there are different types of material which one faces in real life situation especially in the area of biomaterial, because like ceramic as I said is a brittle it does not have a plastic deformation. Stainless steel goes into both elastic and a plastic. If you take poly ethylene type of material, they have very low Young’s modulus. So, they the graphs will be rest strain graphs will be of lower dimension. So, the different types of materials are possible. This is what this feature tells us. Look at this this is a rigid strong tough and ductile material. So, we because we have a good elastic region and plastic region is also there. If you look here we are having an flexible and ductile region be because the graph the increase in the elastic region is not as good as this.

Now, see it is a brittle material it is a rigid strong and brittle material. Look at the d it is not as big as this; so rigid weak brittle material if you look at e flexible weak and brittle material and if you look at f flexible and resistant material. So, what is this we are introducing lot of term like brittle; that means, materials which fails without plastic deformation like this especially ceramics aluminum oxide (Refer Time: 25:09). Tough material materials which energy absorbed before fracture; like this you know before fracture is actual breaking, but it is able to go like this you know that is why we call tough material. Then there is another term which I am going to introduce which is called creep. So, creep is supposing we have a constant load especially you have implants inside the leg and there is a constant load acting on it. So, in such situation because it slowly starts deforming permanent deformation under constant load and it is a time dependent. So, it is time progresses the material slowly starts deforming under constant load and this deformation is called is a permanent. And this is a progressive plastic deformation.

It does not happen for materials like stainless steel. Where the permanently it gets deformed at constant load, but many biomaterials, many biological materials not biomaterials biological materials undergo this type of creep; that means, time dependent permanent deformation under constant load. We will talk about those later in more detail.

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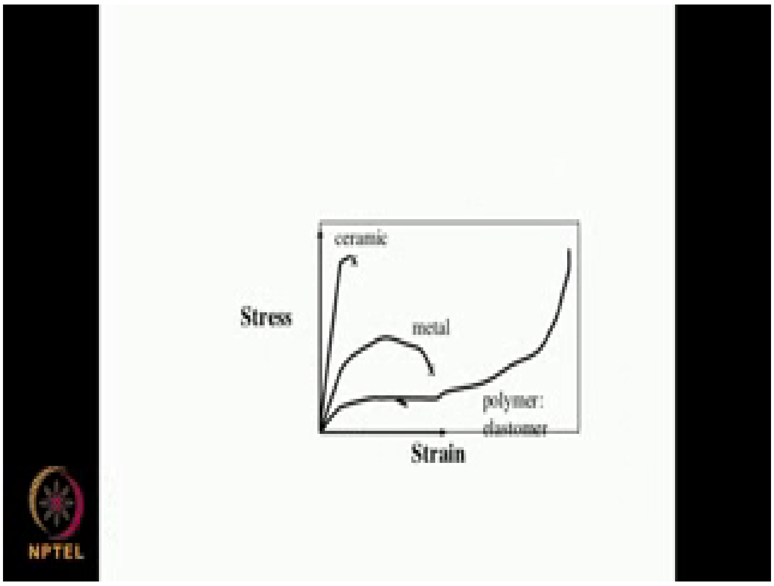

So, once again to recollect ceramic it goes up and it snaps. So, it is a brittle material whereas, metals stainless steel it will go up and then it will absorb the energy. It is ductile and deformation takes later. Whereas, polymers have very low elastic region it will have a large plastic region once.

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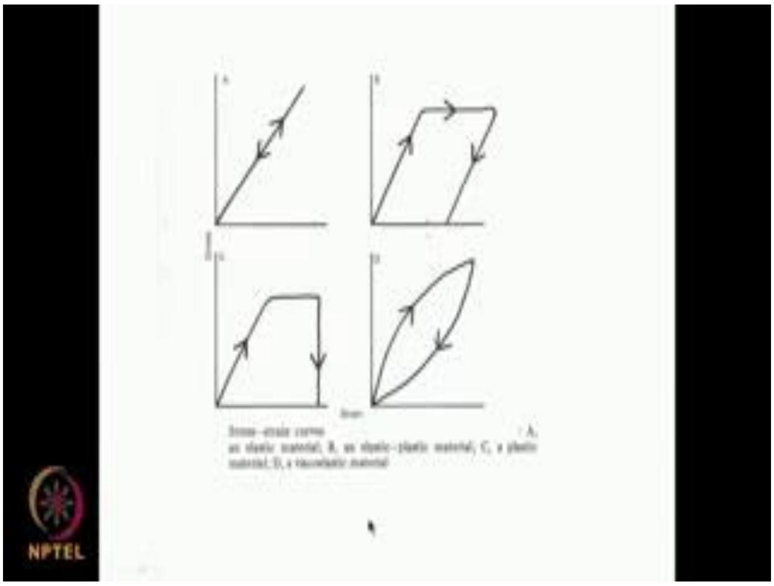

So, just for recap as such if you look at stress strain curves and if you take an elastic material; once the load is removed it will come back especially in the elastic material. So, it will follow the same straight line whereas, if it is in elastic plastic material, it will come back, but it will come back through a different path, whereas if you take a plastic material it will have this type of drive. So, the slopes are different. The way it is going up the way it is coming down. And there is something where it goes like this something like a hysteresis and this is called a viscoelastic material. So, if you have a stress strain graph, where it follows the same linear when it is going up or it is going down, when I keep removing the stress or force it comes back in the same way we call it an elastic material, whereas if it comes back, but something like this a hysteresis then it is called a viscoelastic material.

Whereas, if the material goes up as you increase the forces, but then as you decrease the forces it comes through a different pathway, but parallel, but different that is called. So, we have a elastic plastic material. So, we can have elastic material plastic material plastic material, and viscoelastic material. All these are possible in real life especially if you look at different types of polymers, they all will undergo this type of polymers rubbers silicon they all undergo this type of behavior.

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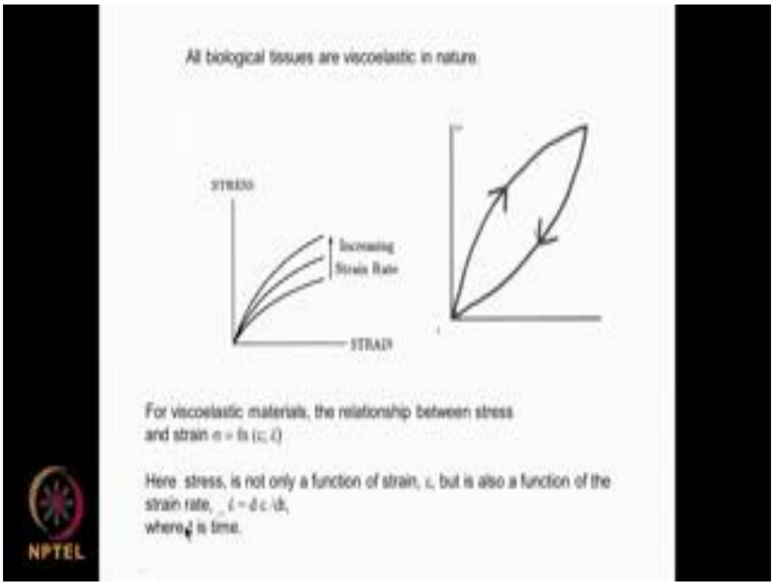

So all biological tissues are viscoelastic in nature; so if you have the stress versus stain graph here with time these strain rates they will start behaving in a different way. So, they will not only depend on the stain, but also on the strain rate. So, the stresses in strain are related not only with respect to the strain, but also on the strain rate. So, stress is not only a function of strain, but it is also function of strain rate that means; the time comes into the picture. I mean all the biological tissues are viscoelastic in nature. And we will spend more time in the next class.

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I would like to acknowledge these websites from which some of those figures are taken up.

Thank you very much for you time.