Biomaterials for Bone Tissue Engineering Applications
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Module 6
Lecture No 28

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So in this module I will discuss the basic manufacturing processes of metallic bio materials, so essentially how you make the metallic implants in the large scale commercial scale production. And little bit about their mechanical properties, particularly how these metals behave under different modes of loading like tension, compression, sheer etc.

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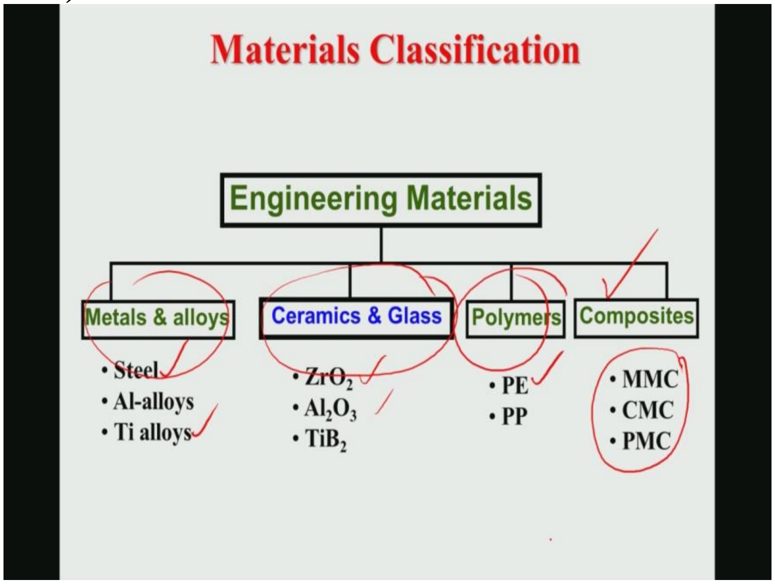

Now just to remind you that engineering materials, if you look at this particular slide, the engineering materials can be classified into three broad categories, metals and alloys, then ceramics and glass and polymers and one derived class which is essentially mixture of either metals and ceramics or ceramics and polymers or polymers and metals, so these are called composites. So composite is not a primary material class, however composite is a derived material class.

And three classes of composite is MMC stands for metal metric composite, CMC stands for ceramics metrics composite, PMC stands for polymer metrics composite. Now different examples are provided. Out of that steel and aluminum and titanium alloys are mostly widely used as metals bio medical applications. There are examples of ceramics which are given zirconia and alumina, they are again bio compatible ceramics, polyethylene is certainly used in bio medical application as well.

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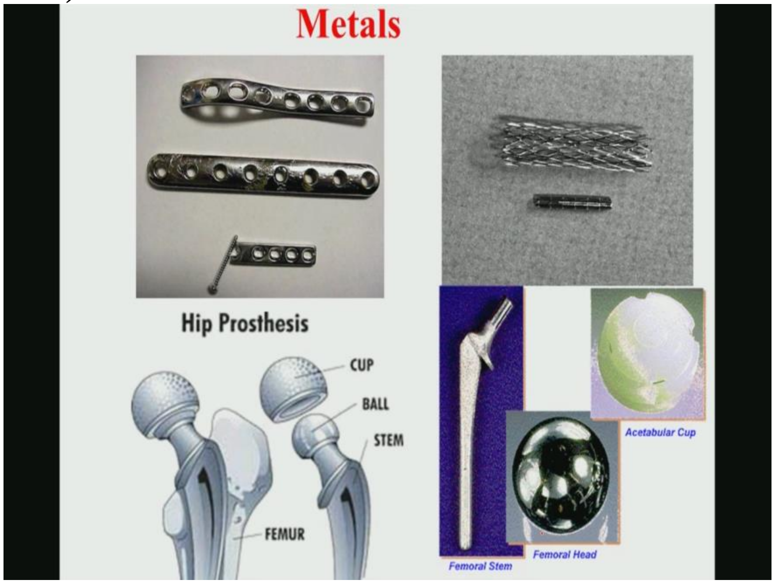

Now these are some of the commercial available and clinically used metallic materials. What you see in this slide is a large metallic plate, titanium plate, it can be titanium plate, it can be stainless steel plates and you can see certain holes here and you also see certain nails there. So this what happens this different fracture fixation during orthopedic surgery, this nails can get they can get into this holes of this plate and it can be screwed against that existing bone.

So this type of manufacturing, to make metallic plates with defines holes geometry is possible in reproducible manner in case of metallic bio materials. And that is clearly a advantage of metals over other materials classes like ceramic or polymeric materials. So in the case of ceramics and all because of their brittleness you cannot make these kind of holes because simply that entire material will be shattered into pieces.

But this metals, this making the different shapes and sizes of metallic implant is certainly an advantage. The other examples which I have also provided in the introduction of the course also like in the in the total hip joint replacement this metallic stem is widely used. That is mostly the stainless steel or titanium based alloys.

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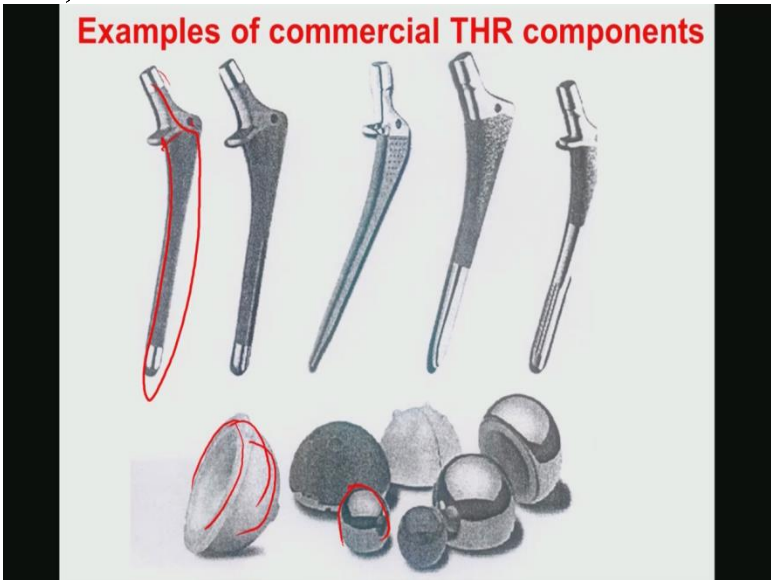

These are some of the commercial total hip joint replacement materials, you can see the stem materials and you can also, this is the part of the stem and this is the total hip joint replacement, and you can also see the acetabulum liner and socket here. And you also see that femoral ball head. This femoral ball head can be made of stainless steel, can be made of cobalt chrome alloys, also now a days ceramics are also used increasingly like alumina ceramic ball heads or zirconia toughened alumina ceramics balls heads these are also commercially available.

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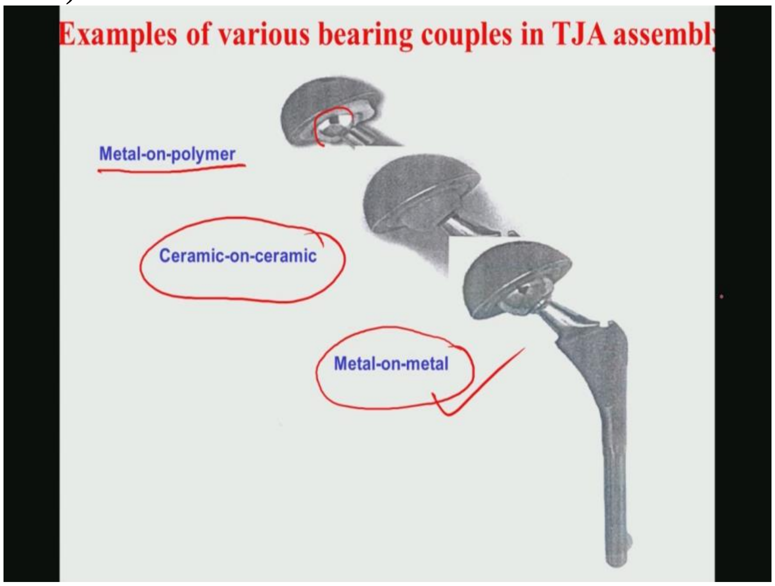

The examples of different bearing couples in the total joint assembly, here we have given some examples like metal and polymer, like this metal is funeral ball head, polymer is liner, ceramic on ceramic, which is not much used now a days or rarely used because of the unreliable mechanical properties, and metal metal which is being traditionally used and being manufactured by various orthopedic device manufacturing companies.

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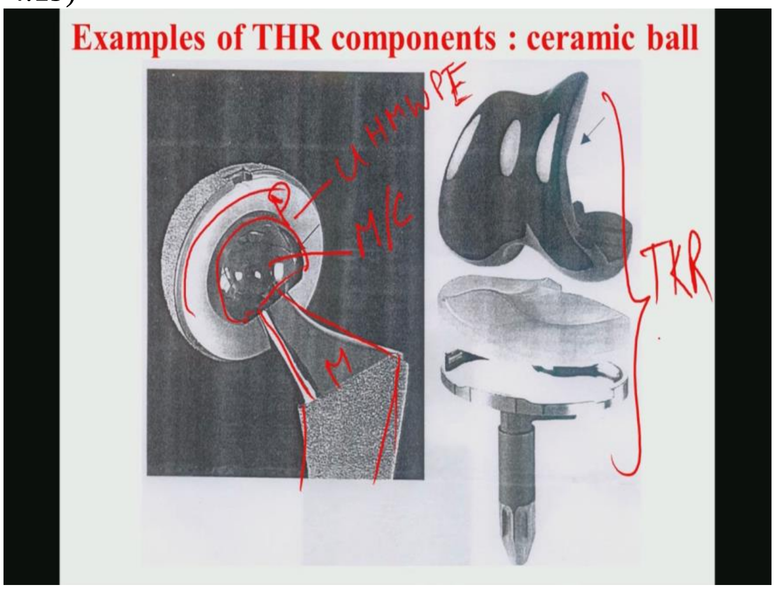

So this is the close up look of how this femoral ball head goes inside you think acetabular socket and liner and this acetabular socket liner, this is made up of ultra (())(04:31) polyethylene, that is highly (())(04:32) polyethylene. So this a very interesting example that total hip replacement. Here all the different primary material classes are used in an integrated manner. For example this is your polymer P, and this the femoral ball head which can be either metal or can be ceramic because ceramic ball head has a distinct advantage over the metals or polymers, simple because ceramics has much longer durability.

And when you come here this the neck of the fumer and then here this femoral stem, and this femoral stem part is typically made of titanium alloys or stainless steel based material, so on. So here again this is the clear example of the metal. So this is one if the example that where all three material classes are potentially used or commercially or clinically used. Metals, ceramics and polymers. And this the right hand side, this is that example of the total knee replacement. So in again there is a femoral component here and so on.

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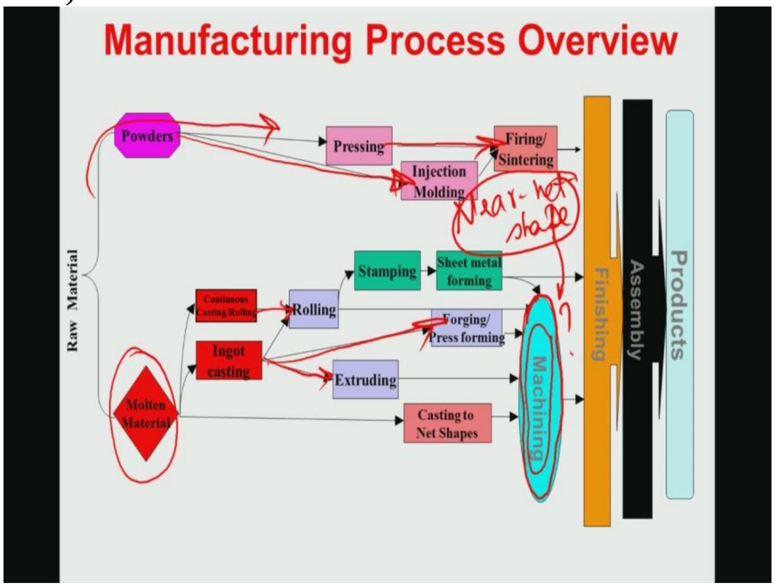

Now h coming aving said all, having given this particular background of this uses of this different metallic materials let me just show you now that how these metals can be processed in industrial scale production. Now there is two routes that you can process this metals, one is the molten metal route. So you make this steel based material let us take the example make the steel based material, so you do this continuous casting or ingot casting.

You give it a particular shape, then it will go though a series of the processes like rolling to make the plates, the metallic plates, or you can extrude it to make it rods or you can make this forging and press forming and then ultimately you need to make this implantable metallic material to a particular shape and this particular shape you have to give exactly as per the requirements in the patient;s defect site. So therefore one has to do machining also as one of the final stage and after the machining finishing, assembly and products.

Now finishing assembly and products, the classical example I have give you in the last slide, that is the total hip joint replacement where you make this metallic material. Now you have seen the ball head, this ball head typically requires that polishing on the top surface so that it will be in classic, it doesn’t have too much rough surfaces because rougher the surface of the ball head the more will be the friction when this ball head will make intimate contact and will be in reciprocatory motion against this (())(07.09) polyethylene.

In order to in order to avoid that kind of situation one has to have very smooth polished surfaces of the femoral ball head, and this polishing is a very important thing and since it is a very geometrically complex kind of a curvature and son on so this polishing is not an easy thing like flat sample polishing in case of traditional metallurgical technique. So this polishing itself is a challenge in case of a femoral ball head. So therefore, this machining and other kind of manufacturing techniques which are normally adopted to make some of the complex shaped device components like femoral ball head or acetabular socket, you need to have certain series of the manufacturing techniques in place to essentially get the final product.

Another process which is kind of used not to that extent but relatively lesser extent is the powder based processes. So you have the metal powders, then you press, then either you sinter it. Sinter means high tempering, I will cover in more details the sintering aspect when I talk about that ceramic processing techniques. Or you can do powder injection moulding and to make a near net shaped product.

So this powder injection moulding, the advantage is that, you can get more or less near net shaped product. Now near net shaped product is somehow very difficult here in a one step process in case of the molten metal based route. Whereas powders, injection moulding and then moulding and then you can have a specific mould shape so that you can get the implant exactly in a particular shape and size.

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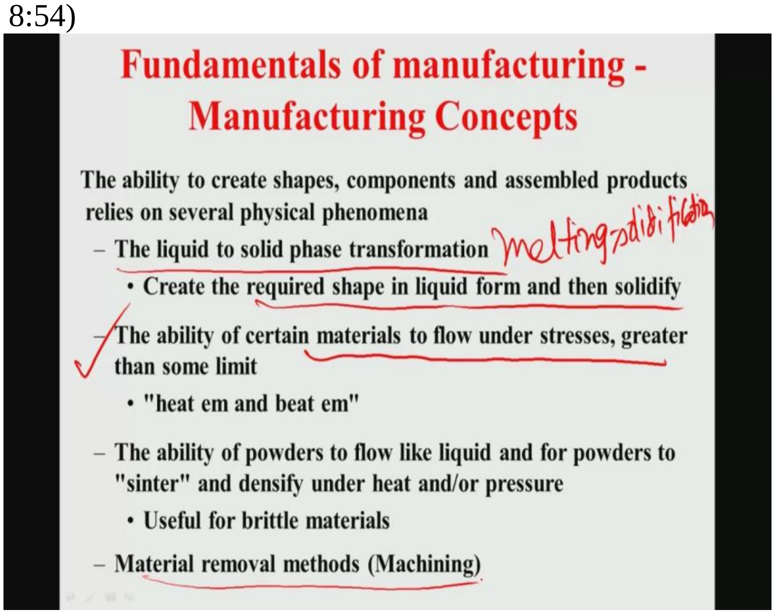

So manufacturing essentially the manufacturing means the ability to create the shapes, components and assemble products and that relies on various physical phenomena like one is the liquid to solid phase transformation that is I have mentioned just now. This is melting and solidification. So melting and solidification, this is one of the route for this liquid to solid phase transformation, and you can get the required shape in liquid form and then solidify.

The second one is the ability of certain materials to flow under stress . Like I will show you in the next one or two slides that there is something called bulk deformation process like rolling, like forging, like extrusion, where bulk material will undergo deformation under compressive stress or in some cases under tensile stresses. So if a material cannot flow or cannot be deformed under stresses and the material cracks then that material you cannot make into a very complex shape.

So one of the principles that is followed that heat them and beat them. What is the meaning of that? You heat them at high temperature so that metals becomes ductile or metal can flow and then beat them means then you deform them to a particular shape that you want to provide in the final application. So this is the second concept that I have mentioned. Third one the ability if powders to flow like a liquid into the particular mould and then sinter.

Sinter means it is a high temperature treatment. High temperature means that any given material has a specific melting point TM, so you have to heat at a temperature above TM by 2 or above .5 TM. And if necessary you can apply present also so that under application of pressure this material will be densified and will be shaped into a particular device shape. And final one which I would not be discussing to a greater extent, that is called machining process.

So machining also, there are two types of machining process, one is called conventional machining process, another is called non conventional machining process. The examples of conventional machining process is drilling for example. You can make it cutting and other things. And non conventional machining process like electro discharge machining, electro chemical polishing , these are like non conventional machining process where you can do this machining process very carefully by application of that electrical energy, or chemical reaction route or so on and so forth.

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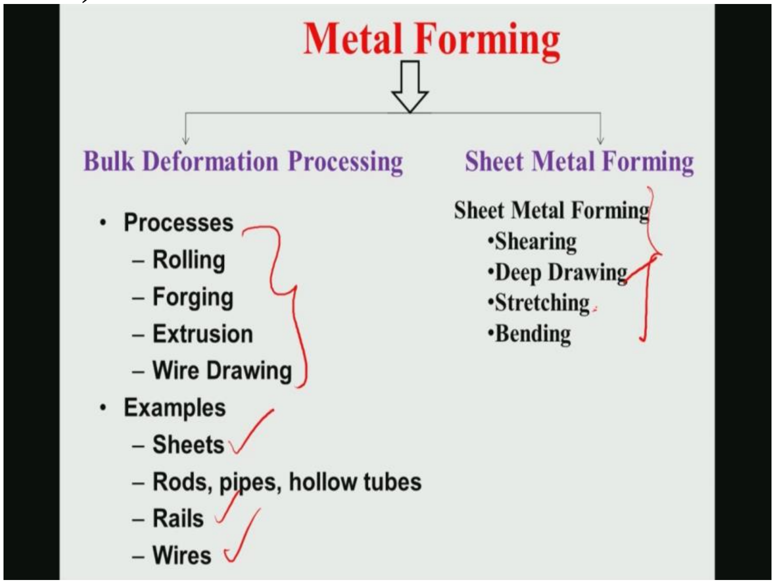

So now now coming to the metal forming processes like what is the bulk deformation process. Now bulk deformation processes are listed here, that is rolling, forging, extrusion, and wire drawing. So these kind of manufacturing processes and their description and their understanding comes under the purview of the conventional metrological engineering principle.

So therefore I will go little slow, in case that you know you you people are form different background so that you would be able to understand and realize that how this processes are conducted or accomplished in the industrial scale production route of the metallic implants. So what is the output after rolling or after forging what are the things you get, it is you can get metallic sheets, you can get wires and these wires can be nickel titanium wires which can be used in cardiovascular stents.

Or you can get metallic sheets or metallic plates which you can use for the fracture fixation, device and so on. There is also another technique called sheet metal forming like you have a large sheet and the when you do this forming, like you can do deep drawing, stretching, bending, etc.

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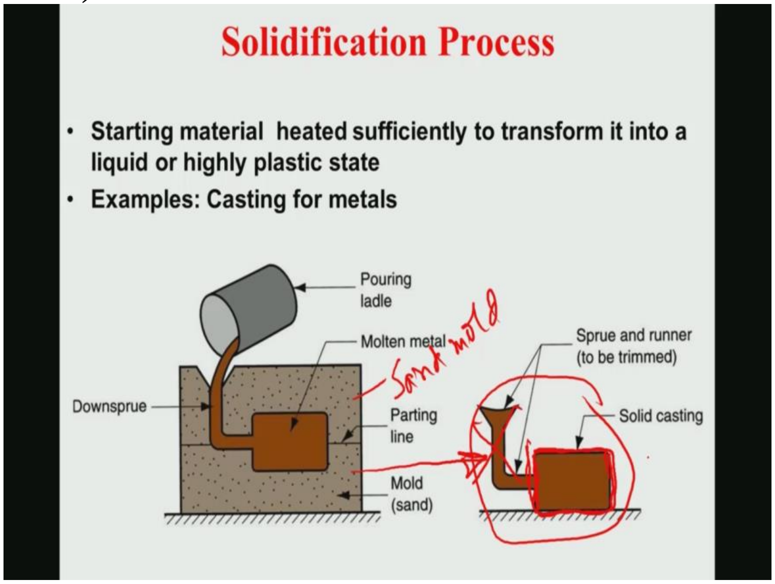

So this is the first step that is in the metal manufacturing that is solidification. Solidification means you start the material in molten carnations, then you pour this molten metal through a mould. This is a traditional, conventional mould, this is sand mould. And this once you use this sand mould then once this metal is to be heated above the melting temperature. The reason being now if you heat the metal to the melting temperature and then simply pour the metal into this mould then what will happen?

That by the time that molten metal will fill that mould cavity, it will be solidified on its way. So that is why you have to give it some overheating that means if the metal meeting point is 1600 degree Celsius, you have to heat it to 1650 or 1700 degree Celsius so that the moment it will fill the entire mould cavity the temperature of the metal mould is still above the melting point so that it will remain in this one, and so that it will simply release the heat and then it will be densified.

So after this solidification you get this kind of object right. What you see immediately that this part needs to b cut. So this part needs to be simply machined away and this is your bulk part. So the way I am sketching, so this is your bulk part. Now in this bulk part you get this metallic billet and this is called work piece or billet.

Now this metallic pieces you cannot use it for any bio medical applications, unless you give them a particular shape like in the form of plates, or in the form of sheets or in the form of nails, those kind of useful shapes. So therefore after the solidification whatever is the output that will be the starting point for further bulk deformation processes which can be accomplished by rolling, forging or other bulk deformation processes.

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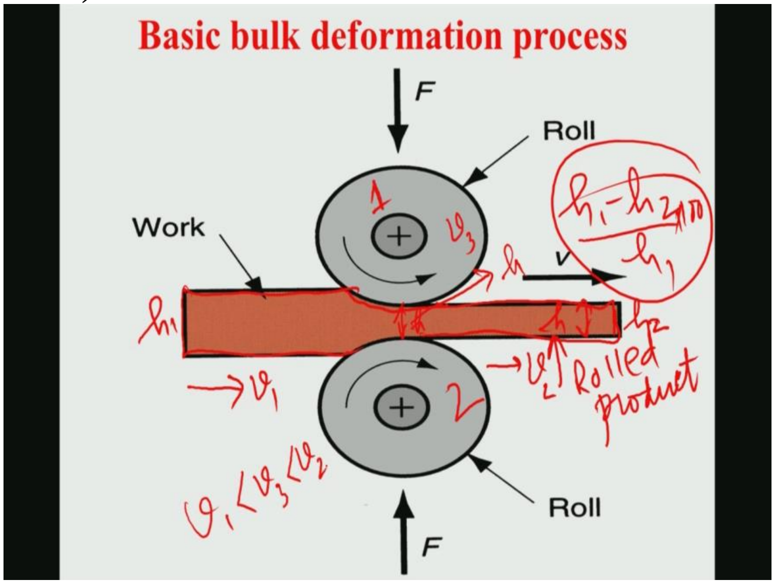

So let us start with that simple example of rolling. So what you see here, this is the roll number 1 and this is the roll number 2. So these two rolls, what you see these are like rotating in a opposite direction. And the moment then it starts rotating in the opposite direction what will happen? This work piece, the moment, this is the work piece I have mentioned in the last slide, so this work piece will be dragged into the rolls ok and it will be dragged into the rolls and it will be coming out.

Now depending on what is the roll gap or roll gap height or h. So depending on what is the value of h here, that final thickness of the plate also would be the same h. So by tailoring this h value or tailoring this gap value, you can have some control over the thickness of the rolled product. This is I call a rolled product. Ok? So depending in the rolled product thickness, then you can understand that how much deformation the metal has taken up, and that is simply if this is your h1 and this is your final thickness as h2, so the final deformation would be total height change divided by initial deformation into 100.

Ok? So this is your total deformation that the metal. The second thing what would be the speed. Suppose this is the speed, v1, this is the speed v2 of the rolled product and this is your, this is your rolling speed is v3, so certainly v1 should be less than v3 should be less than v2. Or in other words exit speed must be higher than the entry speed.

Exit speed must be higher than rolling speed. Otherwise metallic materials will be simply stuck in between the rolls, it cannot come out. So this comes from the simple physics rule.

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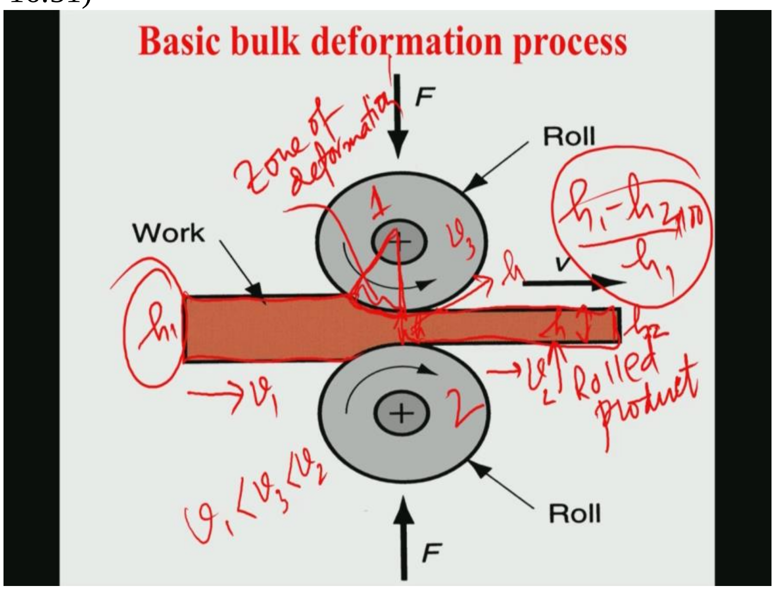

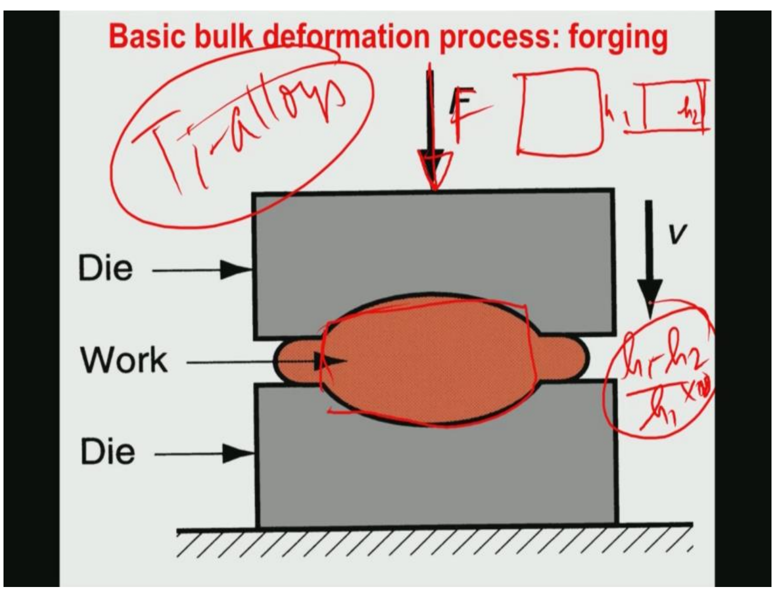

Now second one is the forging. So forging means you have a forged mould cavity here so you put your metallic work piece there, then you apply the compressive forces. By the way if you go back to this, if you go back to the rolling process also so this rolls will be experiencing this normal compressive forces and this normal compressive forces, this is your deformation zone. So the way I have put this arch this is your deformation zone.

So this is your zone of deformation. So at this zone of deformation the height of the metallic work piece will be reduced from h1 to h2 progressive because you see this h2 height is the same as the roll gap height here. Ok. H2 height is the same as the roll gap height h so therefore here the rolling process is also accomplished by, or is also accomplished by compressive stresses.

The same is true for the forging, because titanium is one of the alloys, titanium alloys, many titanium alloys are used in the forged conditions. So this forging essentially means you put the work piece between the two plate between the dye, upper dye and bottom dye. Then you apply the compression process. In the compression process is in the initial height is h1 then after the forging what will happen the height will be reduced but the width will be higher.

So if the width so if the height is reduced if the height is now h2 again the compressive strain would be h1 - h2 by h1 into 100. So what is the change in he height with respect to the original height multiplied by 100, that will be your compressive strain or compressive deformation.

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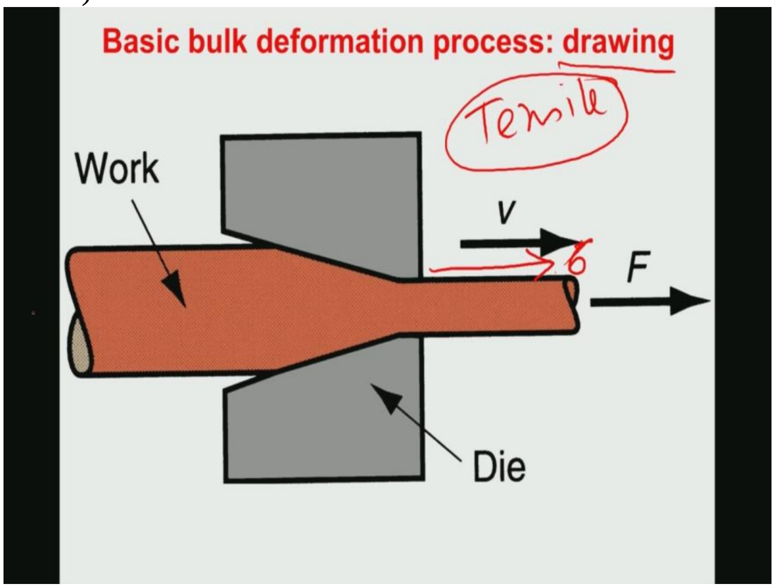

Third one is extrusion. As the name suggests extrusion means you have a late block of the material stop then with the help of this ramp, you just put this, apply the compressive pressure. You just force this work piece to go through the orifice of the dye. So this is your dye orifice. So what would be the diameter of the final extruded tube or the extruded product?

The diameter would be d. So this d would be nothing but the extrusion dye orifice dye diameter. Ok so this d is very critical, this v also that way that velocity of the extrusion process. Fourth one is the wire drawing. So wire drawing essentially means that this, the definition between extrusion and drawing is, drawing is the only one metal deformation process where the metal experience tensile forces. The way this extrusion and drawing is different, in the case if drawing, you apply the tensile forces here, so you apply the tensile force here, at the dye orifice end, so essentially you pull the wire from the other end if the dye orifice and your metallic work piece will be forced to exit from the dye orifice.

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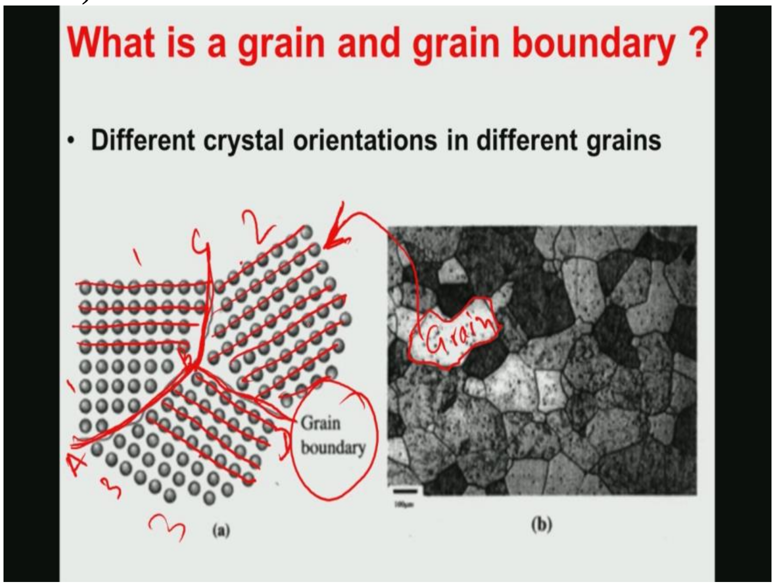

Now some of the things is important in case of metals particularly the grain and the grain size. Now this is the simplistic definition of the grain and then grain size. What I have shown here, this is the 3 grain structure. 1, 2, 3. Now this grain, you can see any metal if you put in the microscope, this is your grain ok. Now if you look at the same grain in the transmission microscope with higher resolution, then what you'd be able to see, you will be able to see this kind of grain morphology.

And this grain morphology is that, in grain number 1, this atomic plains, they are oriented in a specific orientation. In grain number 2 the atomic plains is oriented in different orientation. In grain number 3 atomic plains are oriented in certainly different orientation than grain 1 and grain 2. So what happens as a result, if you consider this grain boundary length ab and bc, Ab essentially is the boundary between grain number 1 and grain number 3.

And this is region of the mis-orientation. Because here the orientation of the atom is neither that of grain number 1 nor that of grain number 3. Similarly if you consider the grain boundary length of bc, here the orientation of the atom is neither of the grain number 1 nor of that grain number 2. Similarly if you consider that bd grain boundary region so it is between the interface between the grain number2 and grain number 3. Therefore grain boundary region is typically described as the region of mis orientation or grain boundary region is also described of the region of higher energy.

Why higher energy? There are atom-atom bonding is somehow locally broken. Inside the grain boundary all the atomic plains are continuous. At the grain boundary region that continuity is broken therefore the grain boundary region is a region of mis orientation. Now depending on what is the difference in the disorientation, whether it is a small angle grain boundary then the angle of mis-orientation is between 1-5 degree or 1-8 degree, if it is higher angle grain boundary then angle of mis-orientation is even higher like it goes to 15-20 degree.

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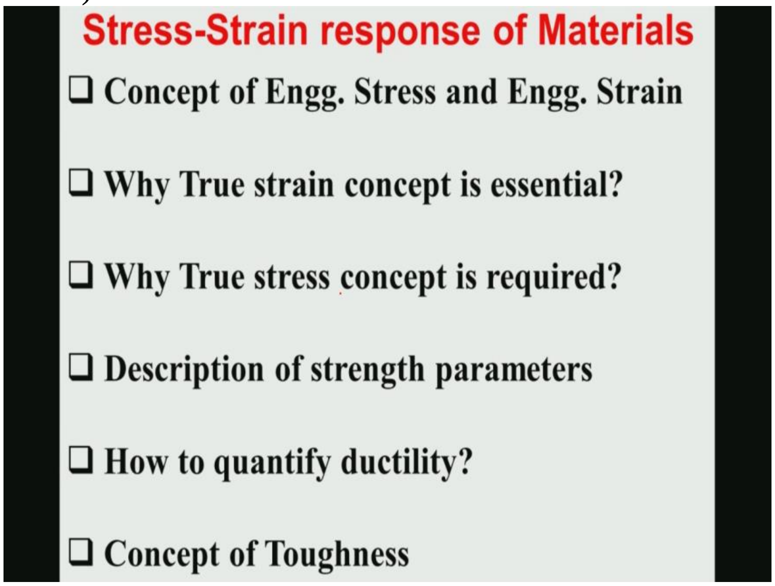

Ok. Now coming to the little description of the mechanical deformation of the metals like you know stress strain concept and so on.

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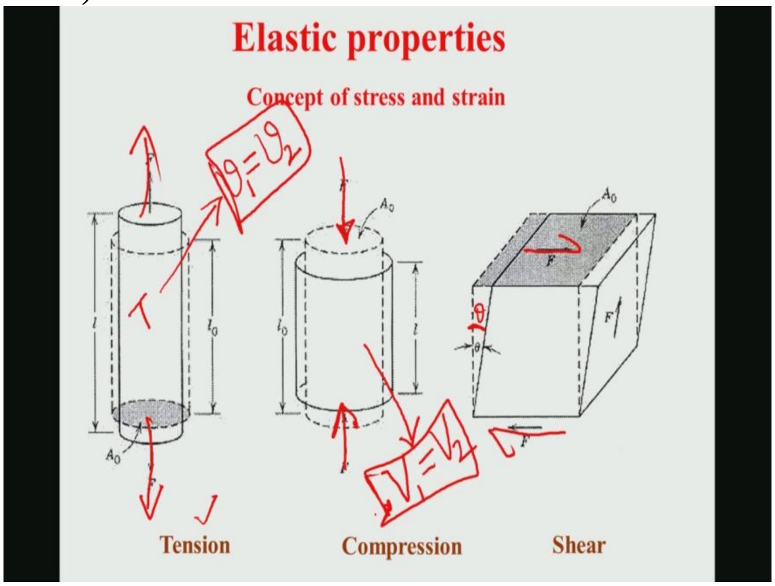

So let us first describe in a very simplistic manner what is tension. Tension means you essentially pull it by two equal forces in two opposite direction. What is compression? You are actually squeezing the metal by application of equal force but in the same direction. What is sheer, sheer essentially you are applying same force but in two opposite direction on two parallel faces of a cube. So tension, compression and sheer, the material changes differently.

In case of tension, the material changes ok length or material increase it is length but reducing it is diameter. In case of compression the material reduces it is length but increases it is diameter. In case of sheer, the material simply there is angular distortion. Right, that is the angular strain is theta. So if you know that strain, strain is nothing but ratio of the change in that dimension due to the application of some force divided by the original dimension.

So now another things that you have to remember that during all this deformation processes whatever I have described in the last 10-155, minutes or so, forging, rolling, extrusion and wire drawing this is called plastic deformation processes. Now in case of those deformation processes, volume will remain constant. What it means that before the application of the tensile stress, For e.g. if you take the case t here, before the application of the tensile stress if the volume is, of the material is v1, after the application of tensile stress at any given instance if the volume is v2 then v1 must be equal to v2.

If it is compression again before the application of the compression stress if it is capital V1, after the compression stress it is is capital V2 then the volume will remind constant. So this conservation of the volume is maintained depending on the, irrespective of the mode of whether you are applying tensile forces or tensile stresses, or compression stresses.

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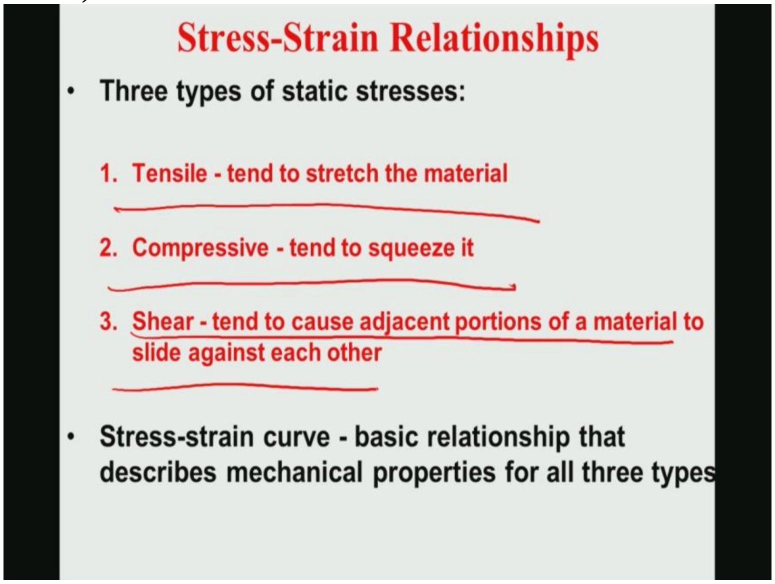

So let us go through the next one. That is that this is what I have mentioned to you to stop this is the summary to stop tensile tend to stress the material, compressive tend to squeeze it, sheer tend to cause the adjacent portion of the material to slide against each other.

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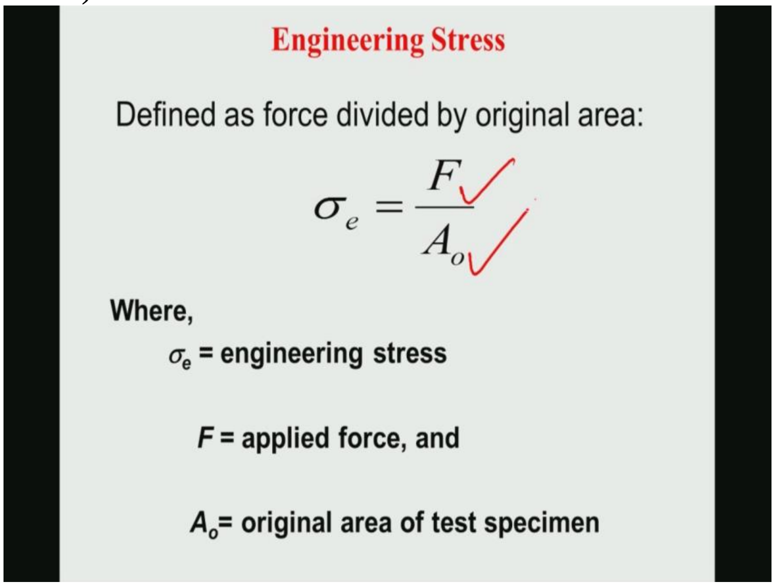

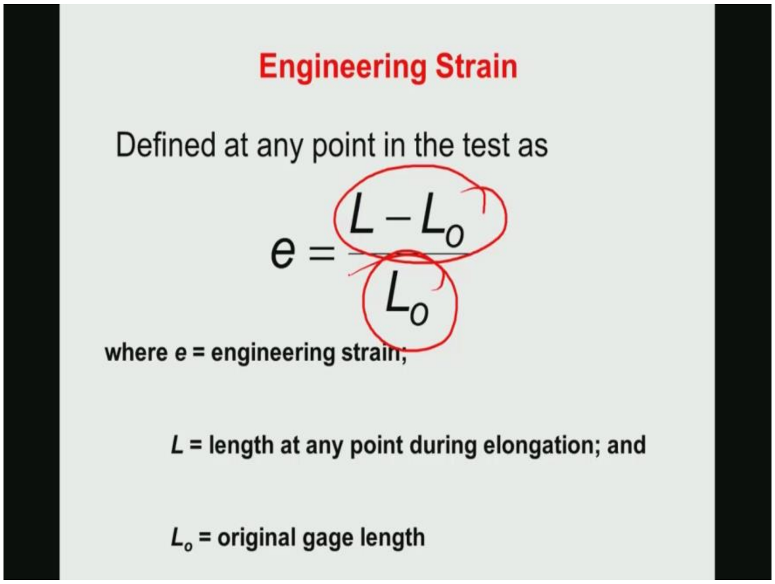

Now this is the basic definition of the stress. Stress is nothing but force divided by initial cross-sectional area, strain is nothing but change in the length divided by the original length, that I have mentioned before.

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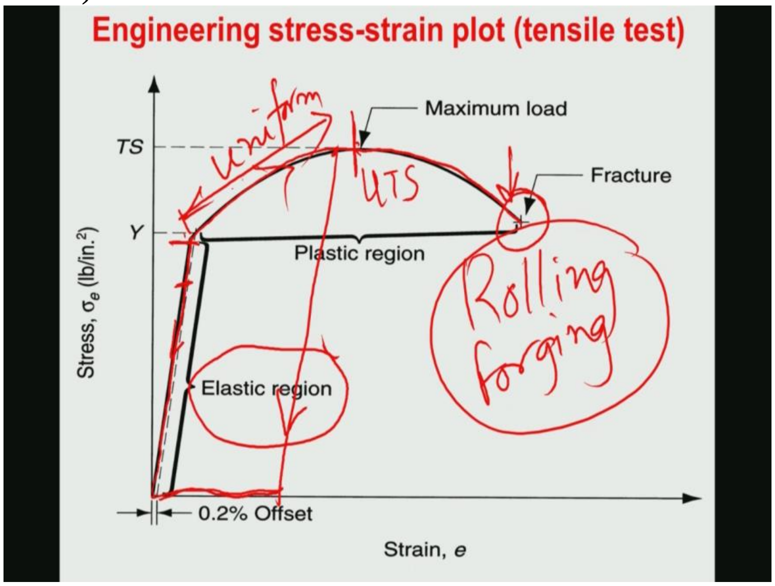

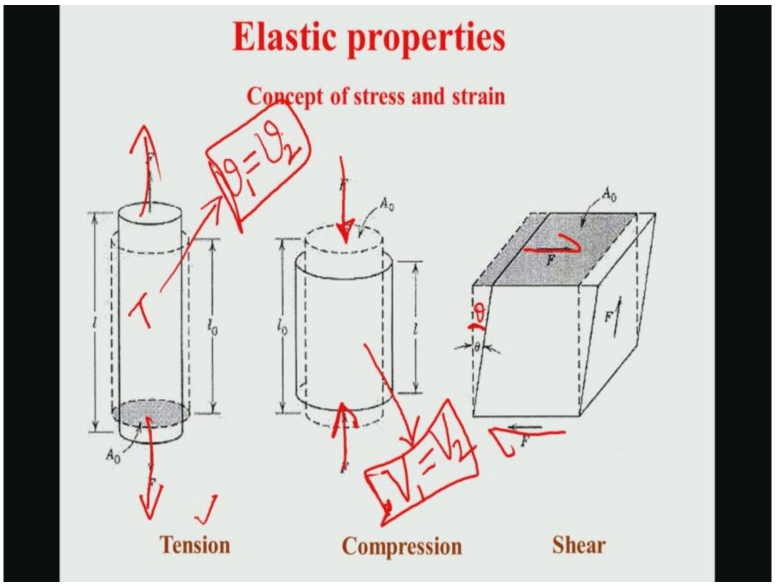

So this is very important stress strain relationship or stress strain response of a metal. So let me explain this little bit carefully. So you have that initial linear region then after that it undergoes non linear deformation. So this region is called elastic region. You know that elastic guard or elastic rubber, so if you stretch it, the moment you release this force, then elastic rubber will come back to its original position.

But in case of the metal what will happen? If you put it larger stress or if you put them under larger stress, when it goes to plastic region then if you go to, you want to, so any place up to the elastic region if you release the force then it goes back to the original phase. But if you go up to this level, then you try to go back to the original position, it will never go back. So then there will be some residual strain that will remind there in the metal.

So this plastic deformation property is very important because this plastic deformation property will essentially dictate how much deformation that a metal can undergo under the process of rolling, forging or extrusion, this kind of deformation processes.

Ok so larger the material can undergo deformation without fracture. So you have to you have to avoid the fracture. Another thing if you go into more detail of this deformation processes, so this is the region called uniform deformation. Uniform deformation essentially extends from the point of the yield, yield means now metal will not undergo elastic deformation any more. Metal will undergo now plastic deformation. So from the point of the yield to the point if maximum strain that is called UTS, ultimate tensile strain, up to the point of UTS metal will undergo uniform deformation.

What is the meaning of uniform deformation? If you go back to this basic description of this tension what I said as you apply the load, I'm focusing on this part, if you apply the load the metal will stretch. So increase in terms length will be in commensurate with the decrease in the diameter of the cylinder. So if that kind of relationship is maintained in this particular region, that is the uniform deformation region, so here that means the increase in the length is in commensurate with the decrease with the diameter, that means longitudinal strain and transfer strain, they commensurate each other, then it will give rise to uniform deformation.

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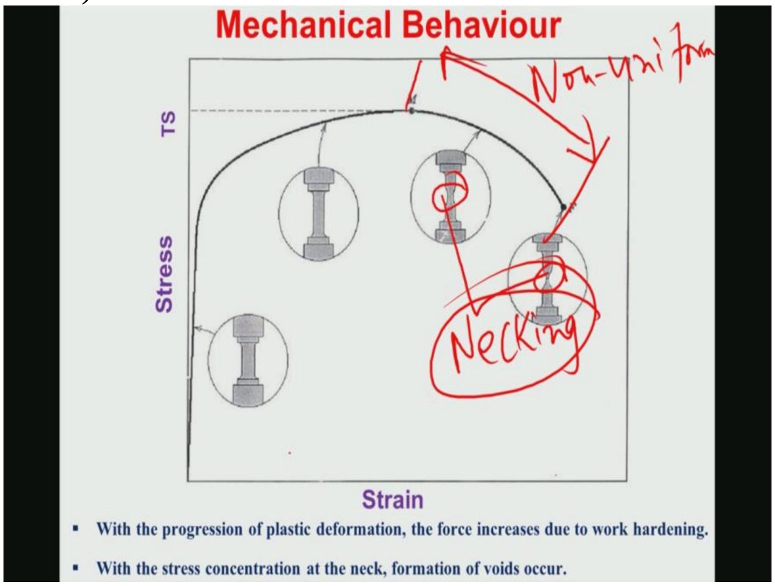

In case of non uniform deformation which has been mentioned here, this is called non uniform deformation, what you see in non uniform deformation that from here this point to this point, the decrease in the cross sectional area is much faster or is much more. Or decrease in the cross sectional area takes place to a much larger extent compared to increase in the length of the sample. So therefore this region essentially will undergo necking process and necking is one of the example that it will undergo non uniform deformation processes.

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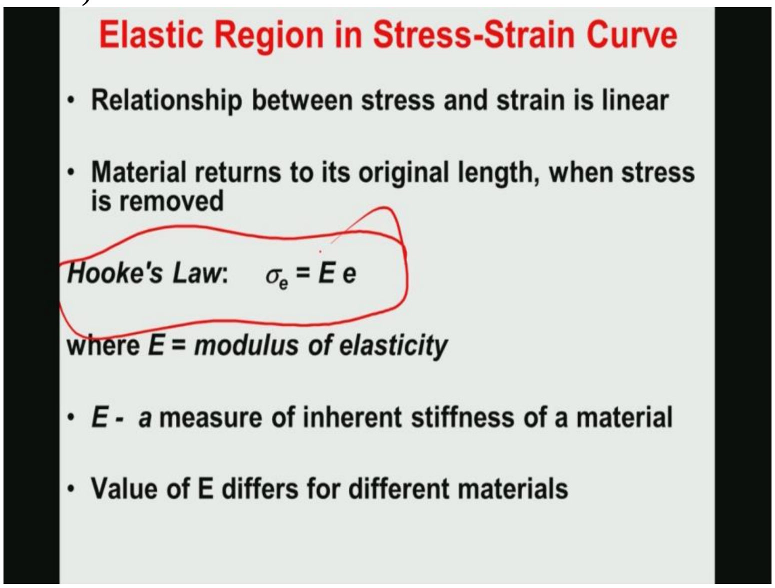

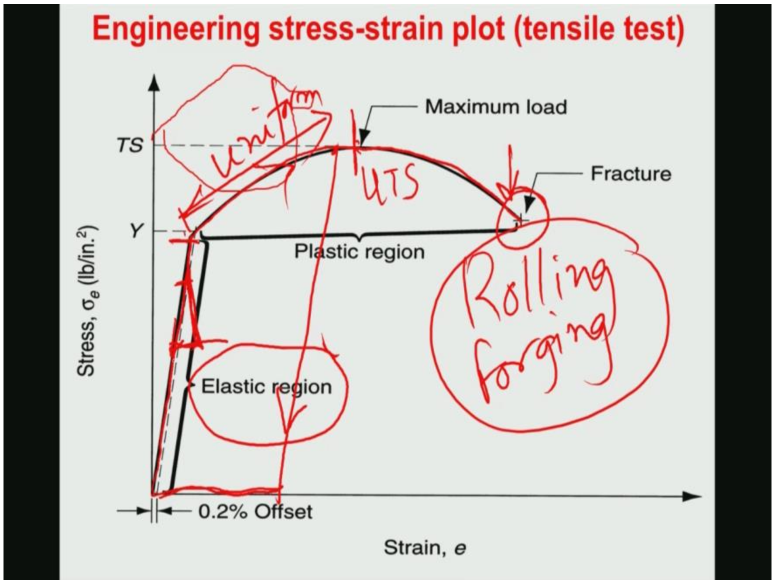

Ok so up to the point of the yield Hooke is law will be valid. Hooke is law essentially means stress is equal to elastic modulus into strain. So how you can get elastic modulus, is very simple, you take this any material stress-strain response. You take the slope of this curve then in elastic curve and then you get the elastic modulus. Okay?

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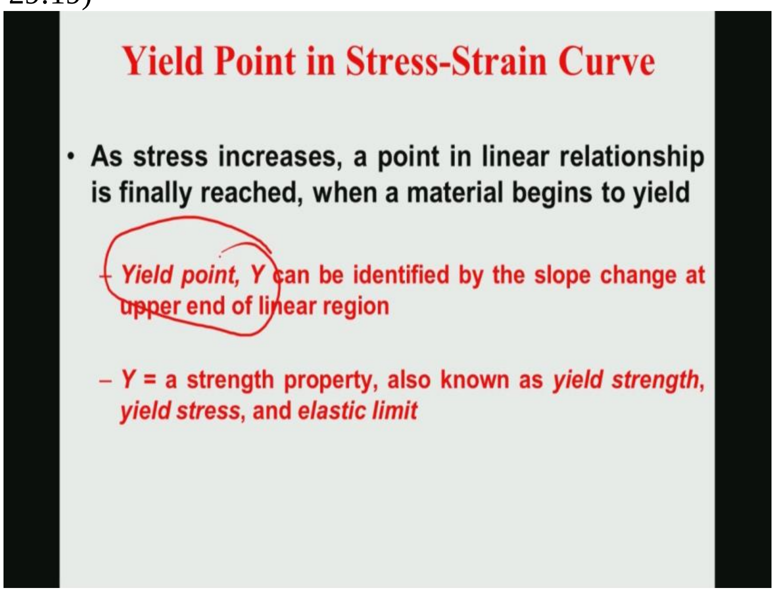

The other things which is important which is the yield point that is the point at which the metal will not behave anymore in elastic metal but it will undergo plastic deformation, that is called yield strength.

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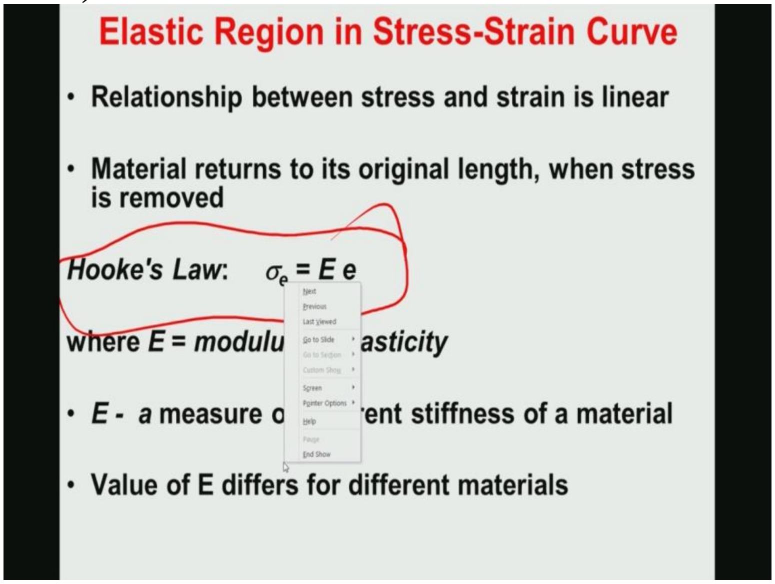

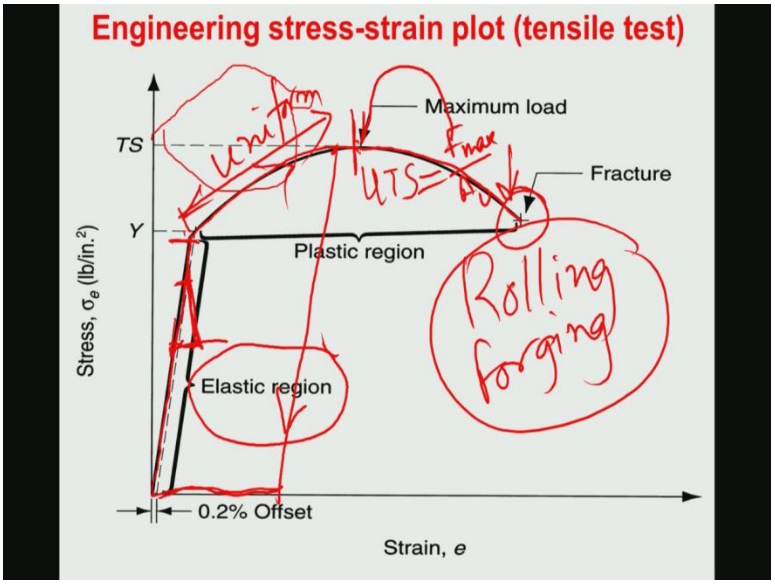

Now ultimate tensile strain as I told you all this strain property essentially is measured force divided by cross sectional area. So what is the force that is what is the maximum force and therefore this UTS or ultimate tensile strain essentially, it is the force maximum divided by initial cross section area. What is the force maximum, that is the point if force maximum. So these are some of the important parameters which essentially determine the mechanical properties of the materials.

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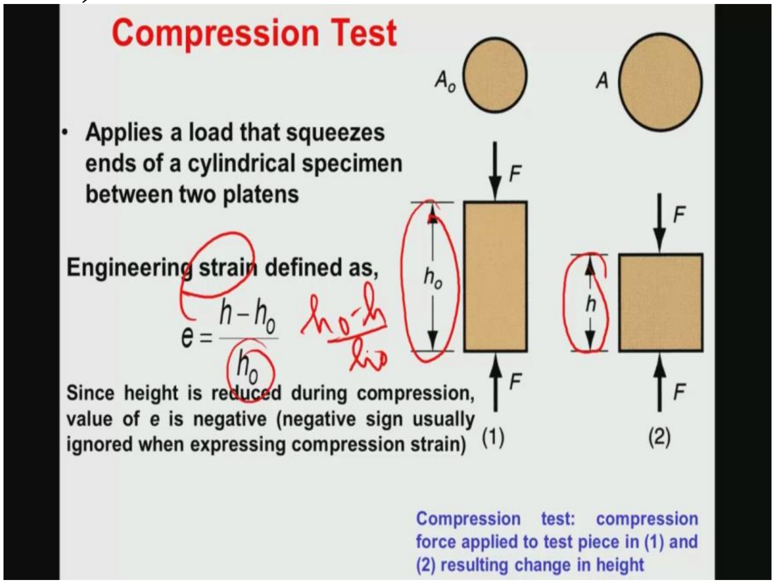

Now coming to the it things, it is called compression test. In the compression test I have already mentioned that what is the strain how to define the strain, define the strain means what is the final height h, what is the initial height not, and what is the initial height h not, that is that gives you the strain. Okay? Now you can this you can do it this way or you can do it reverse way also like h not - h divided by h not.

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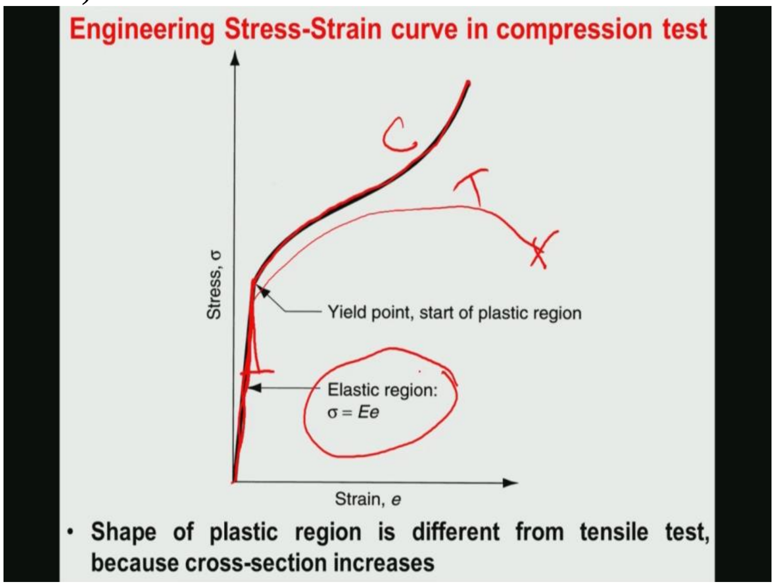

This is that compression stress strain response in case of metals. The fundamental similarity or fundamental similarity between the tension and compression is that in both cases we started with the a linear response. In case of compression the metal will undergo non linear response but it keeps on increasing. So in case of the tensile response then what will happen, metals will behave this kind of this. But in compression this response is quite different.

However in can also measure the slope if this linear curve and again here the Hooke is law is valid. That is stress is equal to elastic modulus multiplied by the strain. So the slope of this elastic curve will give you essentially compression modulus.

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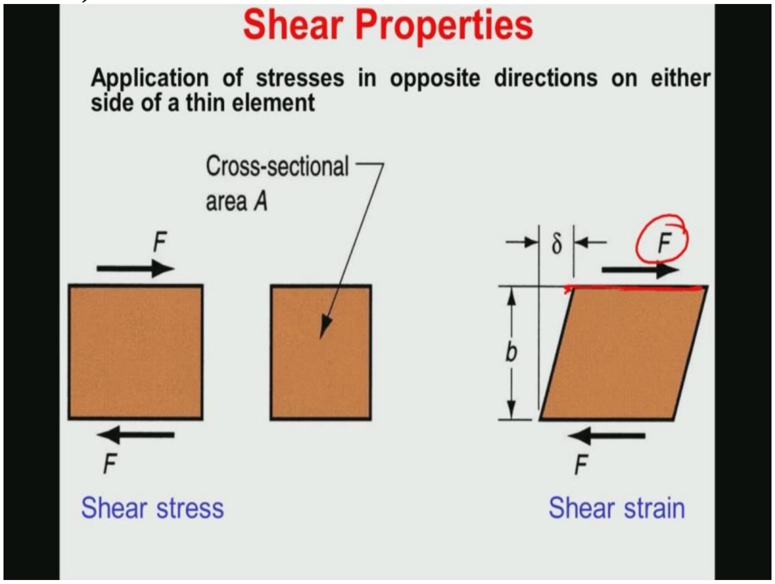

Last one is the sheer properties. Now sheer stress is defined again by the force divided by the cross sectional area. What is the force? You are applying force here. What is cross section area? That is the area of this plain. So this is the cross section area.

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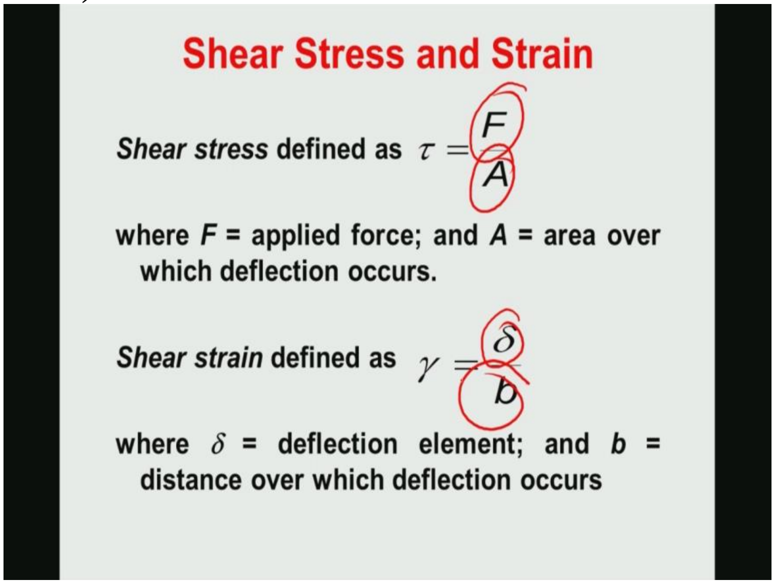

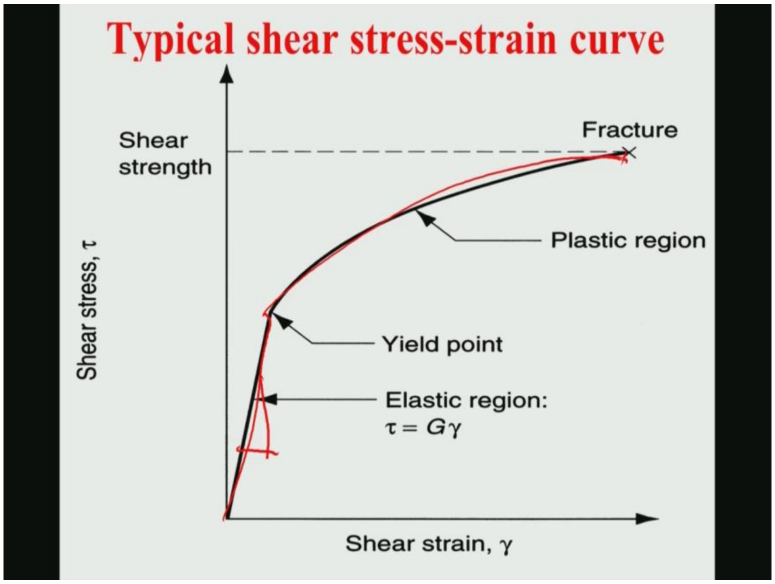

And sheer strain is deflection element divided by the distance over which deflection occurs and what is the typical sheer stress sheer strain response? You get an elastic response divided by followed by the fractured plastic region. Again in the elastic region the slope will give you the modulus of the sheer modulus. And then it goes to plasticity, goes to fracture. So this brings us to the end of the manufacturing and some of the properties of metal implants.