Mechanics of Machining
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Lecture – 01
Deformation of Metals

Hello students, we are going to a start a course on Mechanics of Machining. This is the first lecture of that. I am Uday Shankar Dixit professor in Department of Mechanical Engineering at IIT, Guwahati. You can see the gate of our institute it is very scenic campus. Now, we come to the subject. What is machining?

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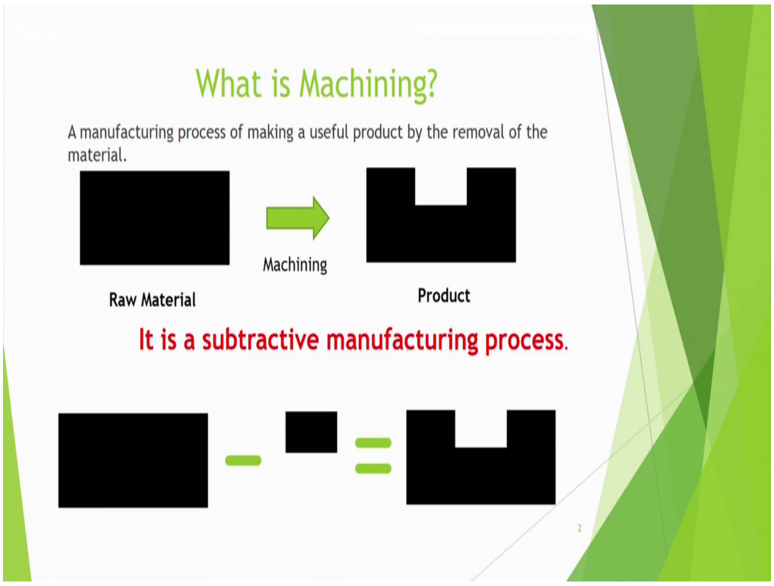

Machining is a manufacturing process of making useful product by the removal of the material. You can very well see that suppose we have got a raw material, we perform machining then we can make this type of slot. This is one example. So, you have got raw material and then you are making a product out of that. You are adding value to the raw material by doing machining, ok.

It is a subtractive manufacturing process. There are number of manufacturing processes, among them this can be classified I had subtractive manufacturing process. Why it is called subtractive manufacturing process? Suppose this is a raw material, it is a rectangular in these I subtract the small rectangular then you all getting this type of product in which there is a slot, so that means we are removing the material that is why it is called subtractive machining process, ok.

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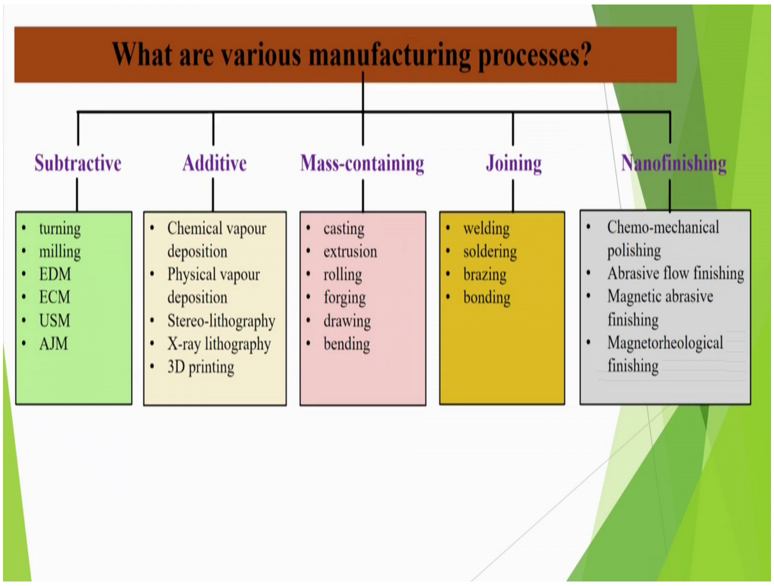

Now that means, there are other type of manufacturing process is also like additive manufacturing process, mass containing manufacturing processes, joining, nanofinishing; we will not cover all these process in this course we will mainly concentrate on the subtractive processes that means, we will concentrate on machining. You can see that here in machining we have got turning milling these are conventional machining processes. Then you have got some non conventional machining process like EDM that means, electrical discharge machining.

Here, you create a spark and that removes the material by melting of the material, but even vaporization of the material can also take place, but we will not cover this in this course then there is electrochemical machining it is opposite of the creating. You are removing the material by applying the fire voltage principle of machining. Then there is a ultra sonic machining USM process in which they are use a slurry in which you mix up the abrasive particles and then there is a tool that is vibrating at a very high frequency more than 20 kilo hertz and this removes the material that is also a non conventional machining process. Then we have got abrasive jet machining process in which you have jet of air in which abrasive particles are mixed up and then you blast it on the component then it removes the material that is called abrasive jet machining process.

In additive manufacturing processes you can have many categories like you can have a coating deposition, that is chemical vapour deposition, it can be physical vapour deposition. Then there are some lithography type of processes, among them there is a stereo lithography process, then there is a X-ray lithography, liga process which is used in electronics industries is also part of additive manufacturing process.

And nowadays you must be hearing the name of 3D printing. These are rapid proto typing processes. There are different type of 3D printing devices there are different techniques have there, those come in the additive manufacturing process. In basically in 3D printing you do a manufacturing by depositing the material layer by layer that is why it is called layer based manufacturing also.

Then we have got mass containing processes in which neither we deposit any material nor we remove any material in a state we change this form of the material, but mass remain same. So, that is why it can be called mass containing processes. One example can be of metal forming processes, in metal forming processes you carry out the plastic deformation. After plastic deformation the material is not return back to the original position. So, we will get this type of things, so that is why it is called a metal forming process by means of plastic deformation. Among them you have got extrusion in and then we have got rolling we have got forging, we have got drying, we have got bending.

Then there is one process casting, in the casting material is not deform plastically instead it is melted. So, there is a fetch change. And that material that suppose there is a solid material it becomes liquid and then it is cored inside the moored then you get a product that is casting process. Then you have got processes which can be called joining processes in which there are two components different components which are joined. For example, you have welding, you have soldering, you have brazing and then they can be adhesively bonded. You can put some fevicol and you can join two pieces of wood that is a joining process.

Then there is a nanofinishing, in nanofinishing you have got chemo mechanical processing in which there is a chemical reaction and then there is a mechanical reaction also, tool is rubbing and removing the material at the same time some chemical material is also flowing there. So, that is why it is called chemo mechanical polishing. Then there is a abrasive flow finishing, in which there is a abrasive material means it may be in the form of a semi viscous liquid and in that something is moving and then it is removing the material that is called abrasive flow finishing.

Then we have magnetic abrasive finishing in which magnetic particles and abrasive particles are mixed and they are removing the material magnetic particles basically dialectic the motion of the overall combination of the particles and abrasive particles will carry out the actual machining. So, that is called magnetic abrasive finishing. Then there is magneto rheological finishing is also there in which the rheological properties of the material is used that these are the various nano finishing processes.

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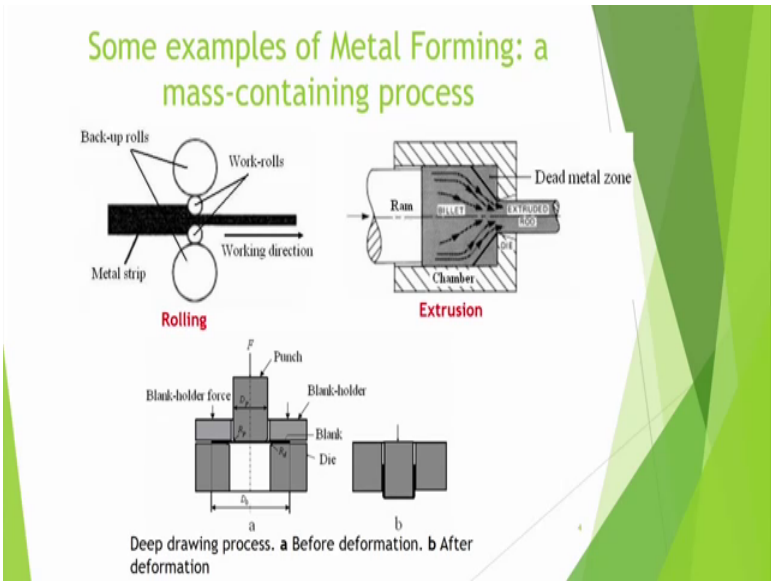

Now, some examples of mass containing process like metal forming, I am presenting here like rolling. You are seeing that here in the figure there is a sheet whose thickness will be reduced by rolling process. So, it is a friction induced process, fiction force is necessary in this process, rolls are rotating these are called dual rolls and there is friction between the rolls and the strip. So, that friction force pulls up the material and then the thickness of the sheet is reduced.

Then there are two backup rolls which are supporting the work rolls and they wide the excessive deflection of the work rolls. So, back up rolls are also there. Then another meter forming process is extrusion process in which you have got one billet and there is one ram. Now, this billet can be heated or it can be at cold state also. Now, ram apply the force on the billet then you can see that there is a flow of the material is shown these material is flowing and it is coming out of the die, die can be made of various type of class sectional shape and you can get different type of products. So, this is the extruded rod. And there is and the site some material does not flow at all that is called dead metal zone.

Then these two processes rolling and extrusion they can be considered as the bulk deformation processes because material is they are removing the material in the bulk large quantity of material is not removing, but rather deforming the material. So, this is a measured deformation.

Then there are other processes which are called sheet metal forming processes. In the sheet metal forming one example is the deep drawing process. Suppose you have got a sheet and you want to make a cup out of that then you can put a blank holder can hold that blank, you can apply a appropriate amount of blank holder force. Then there is a punch that punch is moving downwards and it is a blushing the sheet then you are getting a type of cup here. So, you are seeing that before deformation that one picture, then you are seeing after deformation. So, these are the examples of metal forming processes bulk metal forming process and sheet metal forming process, ok.

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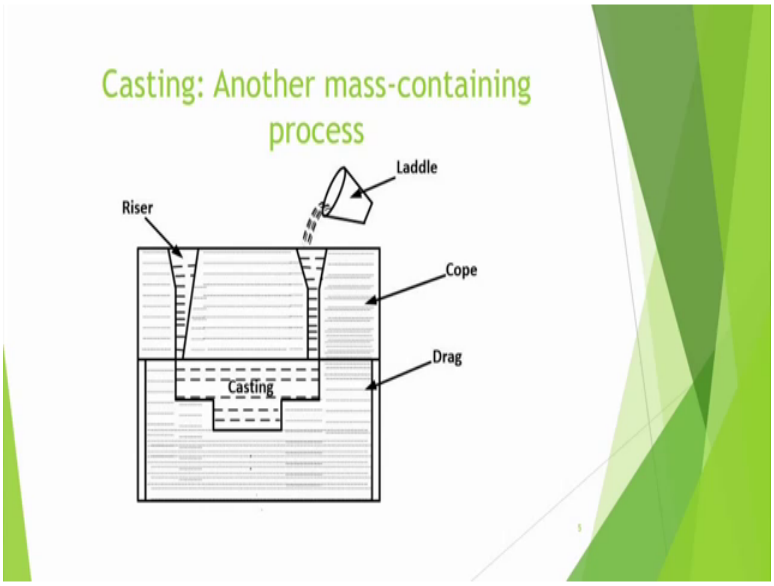

Now, then I come to the another mass containing process that is casting. In the casting we make a mold here a sand mold is shown, it is consisting of two parts here lower part is the drag upper part is the cope then there is a ladle. In the ladle marten metal is there and that is putting the metal in the renal and then material is going through the mold area and it is rising up to the riser and then we are making casting is get solidified. Of course, some portion of riser and renal you have to cut later on, but that can be again used there is no wastage of material only there is a fetch change. So, that process is also there that is called casting process, ok.

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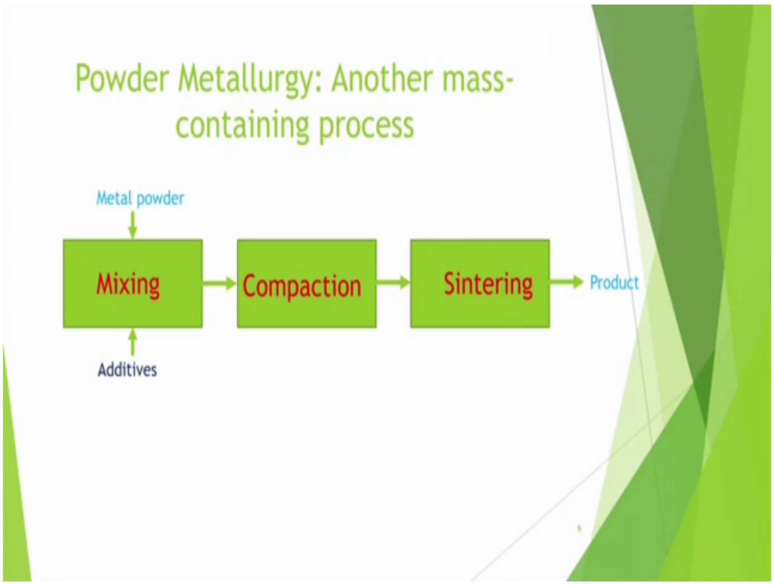

So, now, similarly there is another mass containing process. Just like metal forming process that is a powder metallurgy process. In the powder metallurgy process you have got the metal powders and in that you can mix up some additives, some binders and then you can mix them thoroughly. So, first operation is the mixing that means, you have to mix the metal powder and binder and then after that you apply the huge amount of pressure that means you cause the compaction.

Then after that compaction has been done then you sinter. Then sinter means it is a type of heating the material at a very high temperature in that there is no melting, but the particles will huge among in each other so that means, there is a fusion, but not really the melting of the whole things. So, the it is a that process is called the sintering process in this you will get a product which may have some porosity it is not highly dense that means, suppose you compress some powder metallurgy product its density may be increased also by compacting because there are some forcing between.

So, I have discussed 3 type of mass containing processes, one is the metal farming process in which you take a material and bring it into the state of plastic deformation, then you can shape it as you desire. In the casting process you bring the metal into the liquid state powder metallurgic process is that type of process in which you have got metal powders. Metal powders you can create by various other wage which I am not going to discuss here, but that powders are available of different sizes and then you can compact them and you can make powder metallurgy product, ok.

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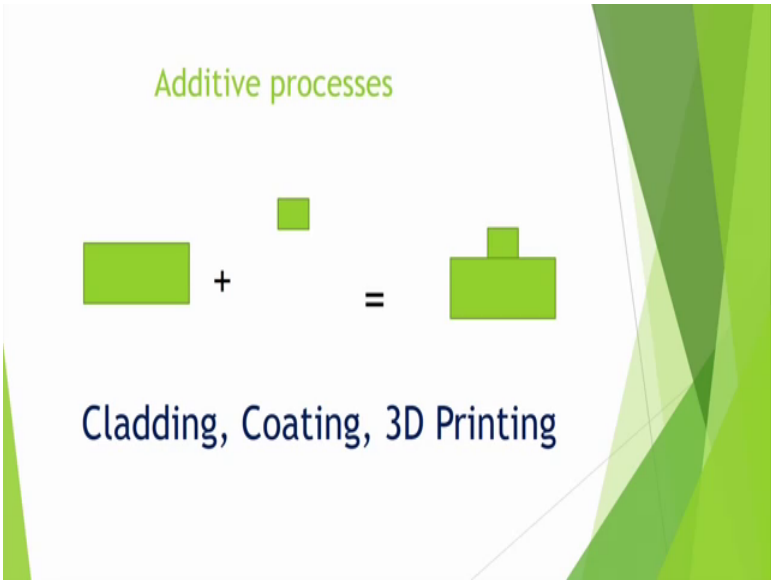

Then there are some additive processes like example can be cladding coating. In the cladding you may deposits some different type of material and some other material; like, suppose I have got some vessel of copper in that I can basically put the cladding of the gold, so that it science because entire part of the gold will be expensive. So, what I am going to do that?

I am going to take that part of may be copper or glass and in that I am going to put the gold. And similarly coating, we apply the coating on the surfaces that can also we called as a two process. What is difference between cladding and coating? Mainly it is in terms of the thickness, coating is a very thin cladding is having sufficient thickness example is that suppose you have got a rectangular piece, I have shown in the figure here and then you have got another this one piece and you add them together you are getting this type of shape which becomes a another product.

Similarly, 3D printing is also very popular nowadays in which you deposit the material layer by layer and you can make any complex type of sheet. So, this is called 3D printing additive process.

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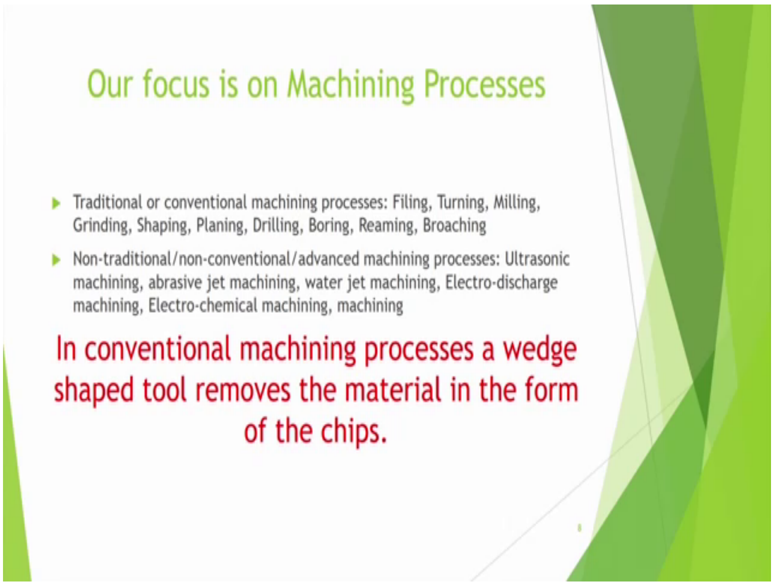

Now, our focus basically in this course is on Machining Processes. So, let us concentrate on the machining processes, machining processes can be traditional or conventional machining processes machining is one of the oldest process millions of years ago human beings used to do machining means removing the material may be by a stone tools. So, there can be various process in a fittings up, you do filling by filling you remove the material that is also machining because you are removing the material.

And in traditional machining processes you are removing the material in the form of chips. So, a small chips are there they are getting removed. Then there is a turning process which is performed on a lathe machine in which a work piece is rotating and then you are moving a tool relative motion between tools and work piece that is removing the material in the form of the chips that is called turning process. In the milling process there is some cutter which has got number of teeth's and it removes the material that can make rectangular type of pieces or it can make free from surfaces, so many things you can make in the milling machine.

Grinding machine is usually used for getting good surface finish or sometimes removing the material from a very hard surface. So, that grinding of machine is implied in which number of abrasive particles are basically bonded in the feels. So, there are multiple cutting edges. During the cutting these abrasive particles also break into two pieces means they and they generate new cutting edges and they are basically cutting and they are removing, but that is also a machining process.

Shaping is performed on a shaper machine you might have seen a shaper machine in which there is a tool that reciprocates. So, there is a reciprocating motion of the tool in one stroke it will cut in the return stroke that tool will get straightly lifted and it will not cut that motion can be first also. Planning is also similar to shaping difference is that in the shaping the tool is moving and the work piece is a stationary, but in the planning process the work piece is moving, but the tool is a stationary. Suppose the work piece is very heavy and very long then sometimes we use the planning process. There is a huge table is there that can move and tool is put at the same place, but from mechanics point of view basically both shaping and planning are same because there is a relative motion between the tool and work piece and that motion is of reciprocating type.

So, then there is a drilling operation is there which is used for making the whole you know twist drill is very common tool helical fluids are there and they cut cutting edges are there. Now, boring is basically enlarging any whole. So, it may be a single point cutting tool that enlarge is the whole boring can be performed an a boring machine or it can be performed on a lathe machine also. Reaming use as a reamer type of tool it provides very good surface finish to the whole and then there is a process of blotching, in which there is a tool which is somewhat tapered and gradually the depth of cut is getting increased and that way basically you are accomplish the in accomplishing the cutting. A example is that suppose you want to make a key way in the key way that closing machine can be used you can make internal gears then these are the traditional processes.

Now, there are number of nontraditional processes which are called non-traditional, non-conventional or we call advanced manufacturing processes among them you have ultrasonic machining, abrasive jet machining. In abrasive jet machining there will be air and abrasive particles will be in that air. Water jet machining which there is a jet of water that cuts the material or you can put some abrasive particles also in that they need becomes abrasive water jet machining. Then you have electro discharge machining, then you have electro chemical machining which provides very good surface finish because here you remove the material atom by atom.

And so these are various type of machining processes. Again I say that in conventional machining processes you use a wedge shaped tool that remove the material in the form of the chips. So, there is a physical contact between that. In unconventional machining process like laser beam machining process has not been written here, but that is also machining process in which there is a laser beam that can heat the material and it can vaporized and that is how get a you get the removal of the material.

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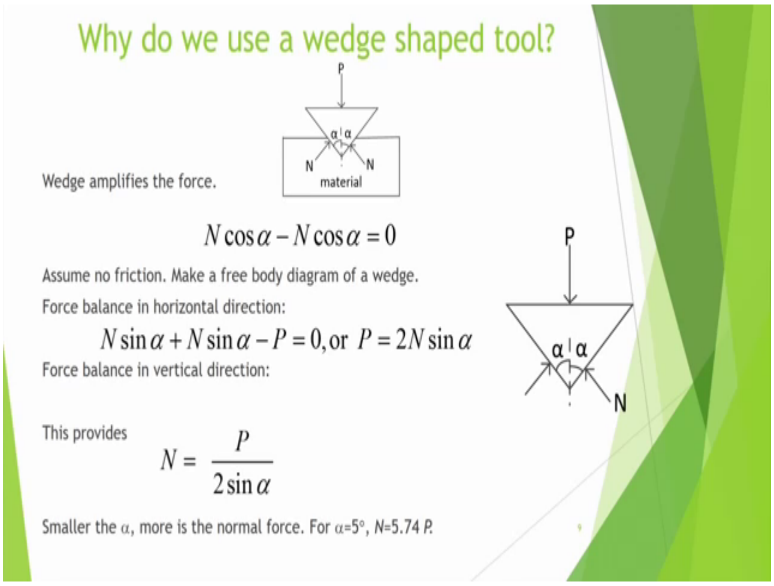

Now, why do we use a wedge shaped tool in the conventional machining process? If you see that even if you see millions of years of ago, people we are using wedge shaped tools means stone will be there, but it cannot do cutting properly unless it is made in the form of a wedge. So, here this slide is illustrating that concept very nicely. Wedge is a device that can amplify the force. In the figure you are seeing that here there is a material and this is a wedge which has got included angel of 2 alpha, semi angle is alpha some force is applied. You can make the free body diagram of that wedge. Free body diagram means remove the material just free the wedge form other things and replies any interaction by the forces. So, suppose you have here there is a N force here, N force here, P is the vertical force. And then you in the free body diagram you can study that what are the forces acting on that free body.

So, you make the force balance horizontal force balance will give N cos alpha minus N cos alpha is equal to 0. It is in equilibrium we are not assuming any friction. And force balance N cos alpha minus N cos alpha is a vertical force balance and horizontal force balance will give N sin alpha plus N sin alpha, minus P. No, actually this is the vertical force balance N sin alpha plus N sin alpha minus P is equal to 0 horizontal force balance was N cos alpha minus N cos alpha equal to 0 because you are resolving in the horizontal direction. So, you get N sin alpha plus N sin alpha minus P equal to 0 in the vertical direction. So, this is force balance in vertical direction and it becomes P is equal to 2 N sin alpha this provides N is equal to P divided by 2 sin alpha that is the relation. That means, normal force is equal to P divided by 2 sin alpha.

Now, you can see that smaller the value of alpha more is the normal force for a given P. For example, if I keep a 5 is equal to 5 degree then my N becomes 5.74 P that means, about 6 times more force we have got. So that means, you can apply large amount of pressure on that thing which can introduced large amount of compressive stresses and that compressive stress can produce the shearing and that shearing can remove the material that accept we will be studying later on.

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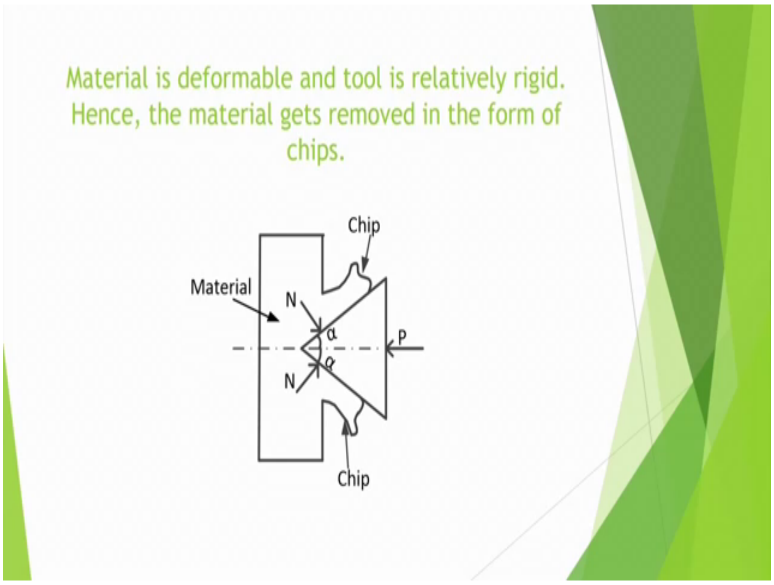

So, material you seems in the previous slide we did not consider that the material was deformable. So, we showed that the wedge is going inside the material and, but actual practice material is deformable.

So, when wedge will be inserted some material will come out and it will come out in the form of the chips that is shown here that there are chips, and we may be doing some parting operation cutting the piece into two part. So, the chips are there I am applying force P, it is inducing compressive stress is N of course, the friction also which are we are not talking at this movement.

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So, here you are seeing some photographs of the our machines of, it is a lathe machine it for it can carry out turning operation, facing, grooving and it can also do thread cutting. This machine is shown here.

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Then this is a radial drilling machine for making the holes. It is a radial drilling machine that means, in r theta coordinate system, you can move this head can move in the r direction and you can also rotate that r. So, that you can locate in proper position and you can make a hole that is a radial drilling machine.

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Then you are seeing milling machine here some milling machines are shown. Here there is one milling machine here and there is another milling machine behind in which there is a cutter this cutter is cutting the material.

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Then we have got electrochemical machining this is shown that interior portion is not visible to you, but from outside you can see and there is a motor pump is there which flows the electro light, and then you can make proper type of shape. So, these are the process of that machining.

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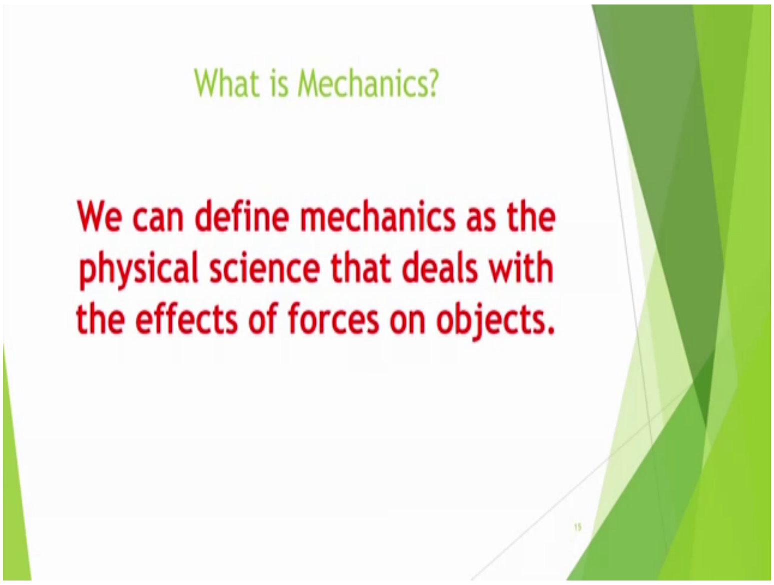

So, having described machining, now I am telling what is mechanics because this course is mechanics of machining. So, we can define mechanics as the physical science that deals with the effects of forces on objects. When we apply the force on the object what happens? When we apply the force object can move object can also deform also. So, there can be motion of the object because of the forces or sometimes there may be just deformation of the object.

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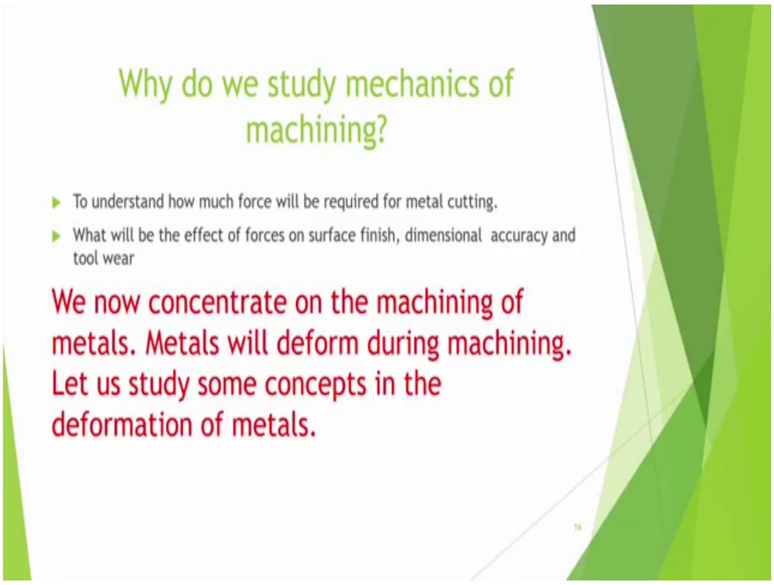

Why do we study mechanics of machining? What is the need? Because you know metal is cut there is a deformation and we are cutting by applying the force in conventional processes. Laser beam machining etcetera we are not applying the force instead we are melting. So, that we will not be covering in this force, but in the mechanics of machining we will cover those type of machining processes in which we are implying the force and then it is removing the material.

So, to understand how much force will be required for metal cutting we need to a study mechanics of machining. If you know that how much force is required then we can design machines properly. We have done a machine design course in machine design we design the components, but we must know what forces will be coming on the components, then we can design zincs and fictions also to hold the work piece then two guide the cutting tools we use zincs for that purpose also we need to know the forces.

Then what will be the effect of the forces on surface finish we want to know, what will be the effect of forces and dimensional accuracy and what will be the effect of forces on the tool we are that also we want to a study. So, we need to a study mechanics of machining. We now, concentrate on the machining of metals, we will not cover machining of other materials. Metals will deform during machining. So, therefore, let us first study some concepts of the deformation of metals that how metals deform, ok. So, that part we are going to discuss.

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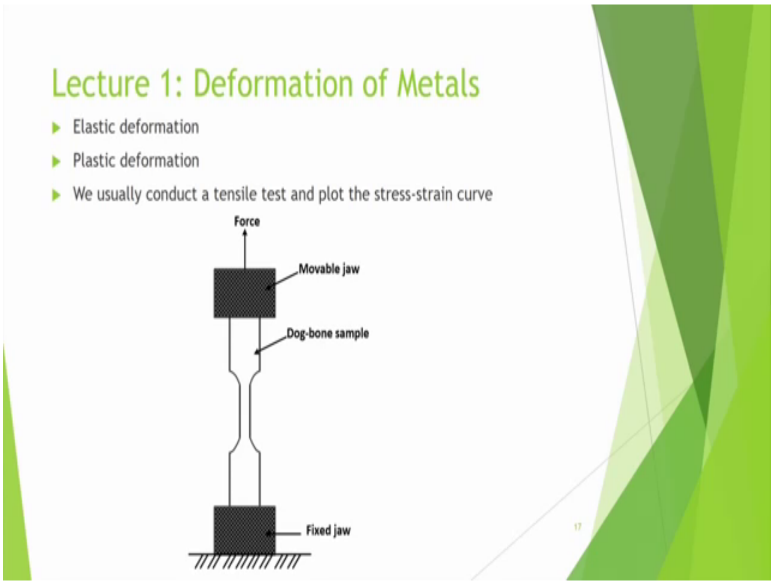

So, basically that what just introduction and now, this is the real lecture I am starting from this point.

So, first lecture one means deformation of metals when you deform a metal you get two type of deformation elastic deformation and you are getting plastic deformation also, so elastic deformation, plastic deformation. We all showing see this is the (Refer Time: 27:03), if I deform it is coming back to the previous position it is reversible, this type of deformation is called elastic deformation you stretch a spring it comes back to the original position. But then there is a deformation in which you deform, but the material does not come back to the original position. In fact, a plastic deformation and elastic deformation occur together when you deform a material then elastic portion recovers, but the plastic portion does not come back.

We usually conduct a tensile text and plot the stress strain curve to understand the behavior of the material. So, one simple text is that stress strain diagram which contain as many things about the material of course, not r things about the material. So, in this stress strain diagram we conduct any material testing rate if there is a machine that is called usually universal testing machine, in that machine we have got a fixed jaw then there is a moveable jaw in between we mount a sample which is in the shape of like a dog bone. It is a dog bone type of sample and then moveable jaw each moving upward by applying the force. So, there is a extension that extension in the thinner portion that means, that is gauge portion in that we can measure by a strain gauge or by extensor meter and then we can plot that deformation force visage elongation.

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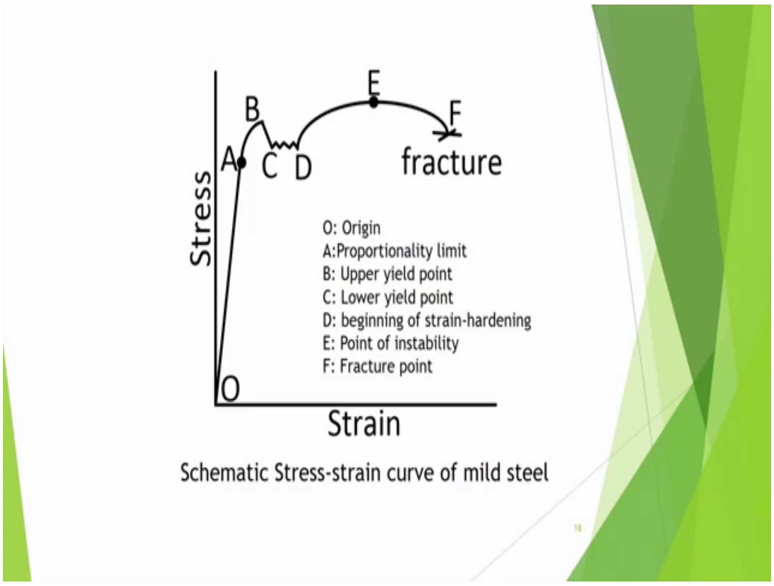

For example, this is a stress strain curved and this is a typical curve for a mild steel. In that what is happening that we have shown it somewhat exaggerated it is a schematic diagram only that portion OA from O to O that means, when the strains are very small and stress means force divided by area is also very small in that case stress and strain they are proportional. So, A is called the proportionality limit up to A, it is proportional and it is elastic also that means, if you remove the load at that point it will come back to the original position. And then at from A to B there is a elastic deformation, but it is somewhat non-linear. Here also the material will come back, but relation between stress and strain may be straightly non-linear. And at B there is upper yield point that means, yielding has start, so there is a plastic deformation.

And then there is a lower yield point you see that means, certainly the low dips and this point is called the lower yield point and it is the beginning of then at D there is a beginning of strain hardening. In between there are some fluctuations, some (Refer Time: 30:03) are there, this type of behavior usually is found in the mild steel which is not properly cold worked means it is mild type of thing in which we are getting that one. And then at a then there is a strain hardening from D to E there is a strain hardening that means, for deforming the material further you require more amount of a stress so that means, there is strain hardening. And this at E what will happen? That you will observe that suddenly the load comes down. So, this is called the point of in a stability.

Here the making starts and this will continue up to F, at F there will be fracture. So, you are seeing a fracture point at F this is shown here. So, this is the diagram of the mild steel.

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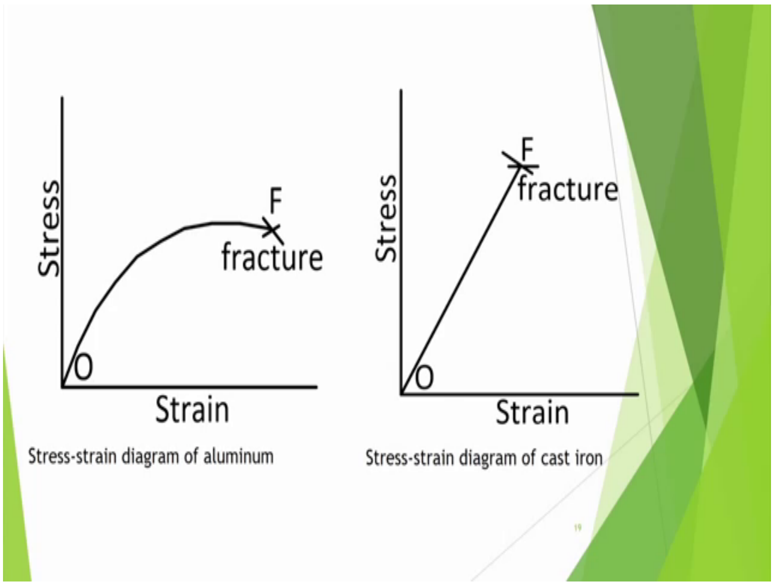

Similarly, this is the diagram of aluminum in aluminum you have got you do not get any distinct yield point also. So, how do we know that earlier the yielding has taken place, one convention is there that if from that point you unload it then some amount of permanent deformation remains and that amount is about 0.2 percent, 0.2percent amount is. So, that is called true free stress of the material which is considered equivalent to yield stress that true free stress can be defined that 0.2 percent strain be remained that at that point you can consider the plastic deformation has occurred. That means, 0.2 percent true free stress means it is 0.02, so that much strain is there.

And then on the other side you are seeing stress strain diagram of cast iron. In the cast iron is brittle mild steel and aluminum both are ducktail material there is a significant amount of plastic deformation, but in the cast iron there is a elastic deformation and then there will be certain fracture. There will not be any plastic deformation. So, this type of diagram you are getting that is called stress strain diagram of cast iron of course, the ratio of stress to strain change any stress divided by change any strain can be called the elastic modulus Young's modulus of elasticity that is very high, but here we have shown the schematic and therefore, in this Young's modulus of elasticity is not appear appearing very high.

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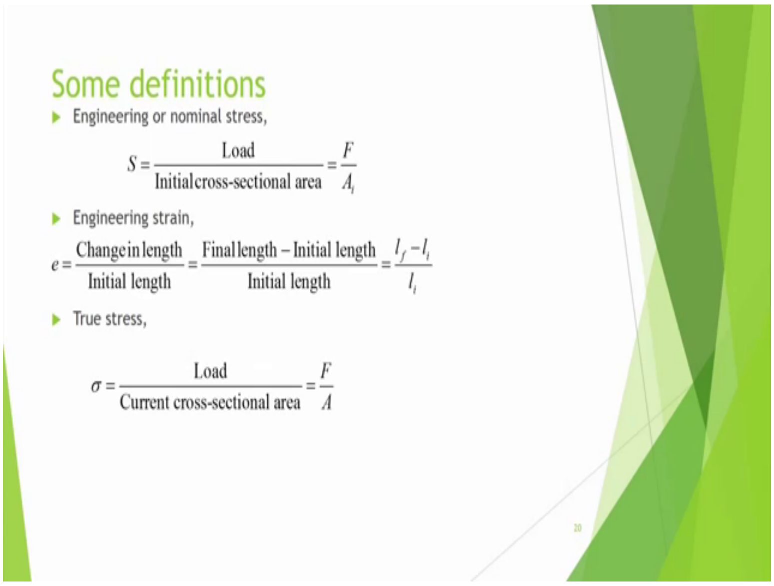

Now, let us come to the some definitions, of the stress engineering or nominal stress that is designated by s it is load divided by initial cross sectional area it is very simple that means, you applied some longitudinal load in the axial direction. So, F divided by A i, A i is the initial cross sectional area that is called engineering stress, and engineering strain is change in length divided by initial length. So, that can be called as final length minus initial length divided by initial length, ok. That means, l f minus l i divided by l i.

True stress is defining such a fashion that sigma is equal to load divided by current cross sectional area because if significant amount of plastic deformation has occurred and shape has changed there is no point in dividing the load by the initial cross section, instead you divided by the current cross sectional area that is why it is written like F by A.

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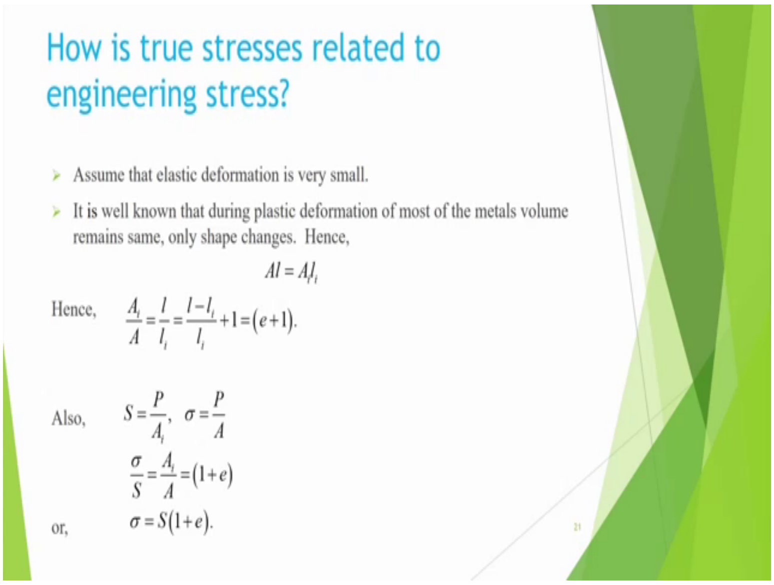

How is true stress related to engineering stress? Suppose you have got stress strain diagram which we have shown in the previous slides, those who are basically engineering stress and strain curves these are engineering stress strain. But I want to make two stress two strain diagram. So, there must be some relation between two stress and engineering stress.

Now, if assume we assume that the elastic deformation is very small and it is also well known that during plastic deformation of most of the metals volume remains same only the shape changes. Whereas in suppose it is a powder metallurgy type of product then some volume may also change that is also not very high. But in the most of the metals they are complete solid and there is no volume change hence we have A times l is equal to A i times l i, A i is initial cross sectional area and l i is the initial length and a is the current area and l is the current length.

So, hence by this equation you are getting A A i by A is equal to l by l i, that relation is there because A i l i is equal to A l. So, this can be written has l minus l i by l i plus 1 means just I how added in this form. So, it becomes e plus one. And now, we have s is equal to P by A i and sigma is equal to P by A. So, sigma by S becomes A i by A and which is already it is written here it is nothing, but e plus 1 or 1 plus e. So, therefore, sigma becomes S times 1 plus e, ok.

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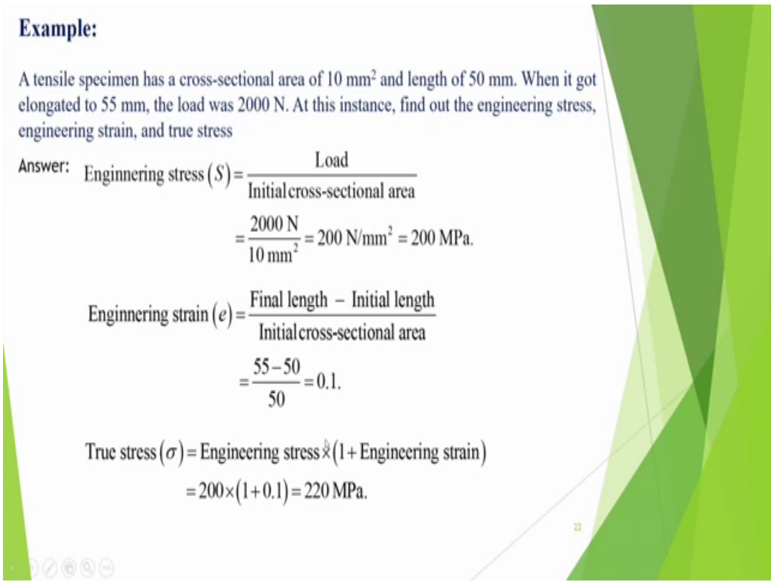

Now, here it is a one example is given suppose you have got a tensile specimen it has got a cross sectional area of 10 mm square and length of 50 mm, ok. So, when it got elongated to 55 mm the load was 2000 Newton it was observed on the machine that the load was 2000 Newton means 2 kilo Newton when it got a elongated by 55 mm that means, extension was 5 mm. At this stress find out the engineering stress, engineering strain and true stress.

So, how do we find out engineering stress? Engineering stress is S that is load divided by initial cross sectional, area that is 2000 Newton divided by 10 mm square this becomes equal to 200 Newton per mm square. 200 Newton per mm square is 200 into 10 to the power 6 Newton per meter square that means, it is 200 mega Pascal and engineering strain e is equal to what it is final length minus initial length divided by initial cross sectional area that means, it is 55 minus 50 divided by 50 is equal to 0.1.

So, engineering strain is basically 0.1 and true stress sigma is equal to engineering stress into bracket close 1 plus engineering strain bracket close so that means, it is 200 into 1 plus 0.1 is equal to 220 megapascal, ok. So, you have got that engineering stress as 200 megapascal, whereas the two stress is actually 220 megapascal. So, engineering stress is 200 megapascal, true stress is 220 megapascal.

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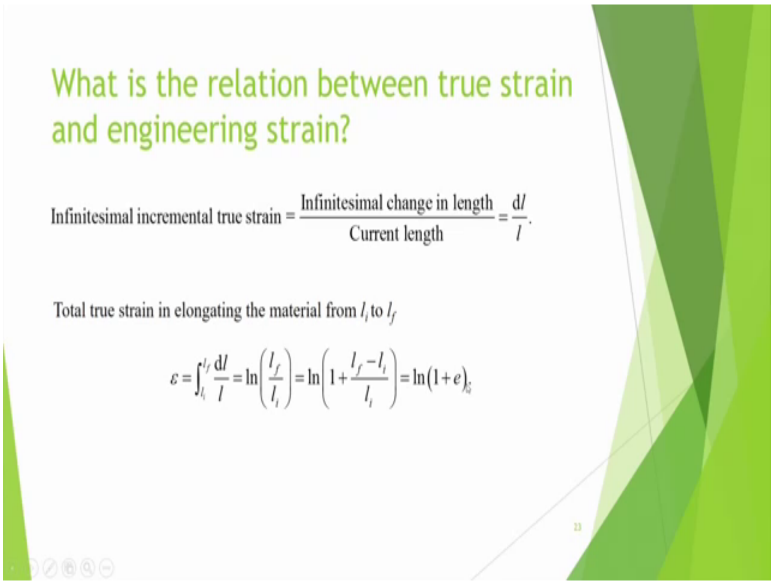

Now, what is the relation between true stress true strain and engineering strain? We define infinitesimal incremental true strain as this that is infinitesimal change in length divided by current length that means dl divided by l. So, total true strain in elongating the material from l i to l f is epsilon is equal to integration dl by l and limits are from initial length to final length l i to lf. And if we open it becomes ln l f by l i and which becomes ln 1 plus lf minus l i by l i which can be written as ln into 1 plus e, ln bracket inside the bracket 1 plus e, e is the engineering strain. So, this irrigation we have got.

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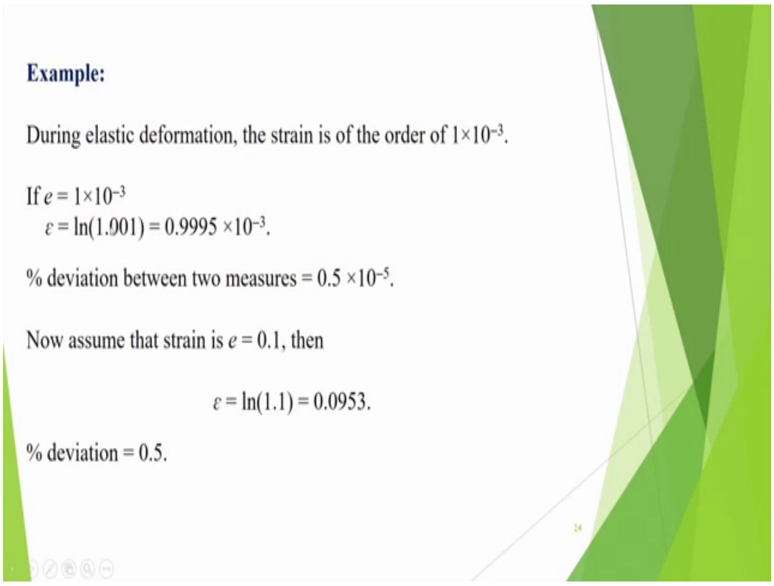

And then one example, during elastic deformation the strain is of the order of one into 10 to the power minus 3. It is a very small strain you know something like 1 meter rod is there and it may stretch by 1 millimeter [FL] so that means, the strain is 1 divided by 1000 that means, 1 into 1, 10 to the power minus 3 that much is small strain is there during the elastic deformation.

So, e is equal to 1 into 10 to the power minus 3 therefore, by that formula two strain has come out to be ln 1 plus 0.001 that means, 1 ln 1.001 which comes out to be 0.9995 into 10 to the power minus 3 almost same, because percentage deviation between two strain measures is only 0.5 into 10 to the power minus 5. And now, assume that strain is e is equal to 0.1 then it becomes two strain becomes ln 1.1 and this becomes 0.0953. Now, in this case the percentage deviation is 0.5 so that means, in the plastic deformation difference between true strain and engineering strain is significant whereas here it is a elastic deformation there is no much difference, that is why generally we do not talk much about when we do engineering design because there most of the components are in the elastic state.

So, whenever really distinguish between these type of measures, but since we are going to understand the large deformation of materials, removal of the materials, huge deformation therefore, it is essential to know the difference of these type of measures this is.

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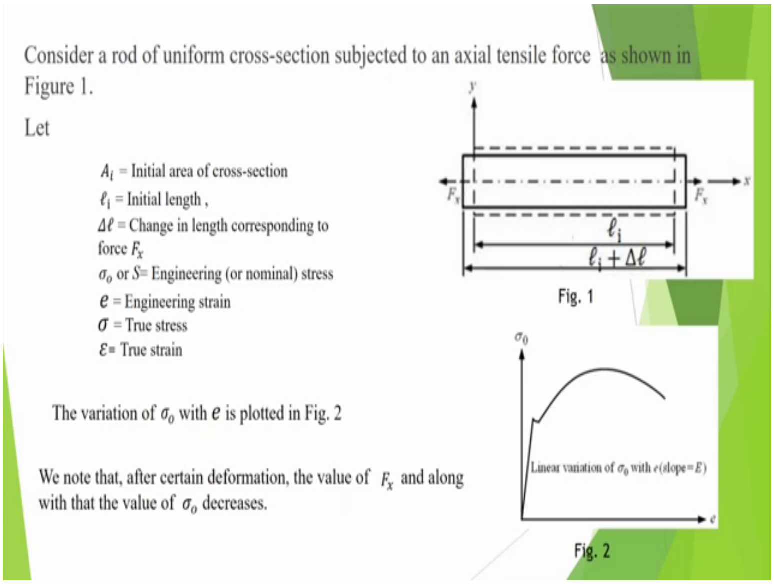

Now, little bit more slowly we will go about that uniaxial tensile test suppose there is a uniform cross sectional rod which is subjected to axial tensile force as shown in the figure x direction is the axis. This time I how indicated A i as initial cross sectional area l i as the initial length and delta l is the change in length corresponding to force F x, we are telling F x. Sigma 0 or s both are called engineering or nominal stress. So, we may of an use the symbol sigma 0 also, e is engineering strain, sigma is true strain and epsilon is true strain, sigma is true stress, epsilon is true strain.

So, variation of sigma 0 with e is plotted sigma 0 and e here you get a linear variation of sigma 0 with e and this slope is actually e which is Young's modulus of elasticity. And then after that there is a yielding there is small deep in the nominal stress and that is called lower yield point, and then again there is strain hardening up to this after that stress reaches nominal stress reaches a maximum volume and then there is a reduction in the nominal stress also till the fracture point. So, that is the picture that we have discussed.

However, in this we note that after certain deformation the value of F x and along with that the value of sigma 0 decreases.

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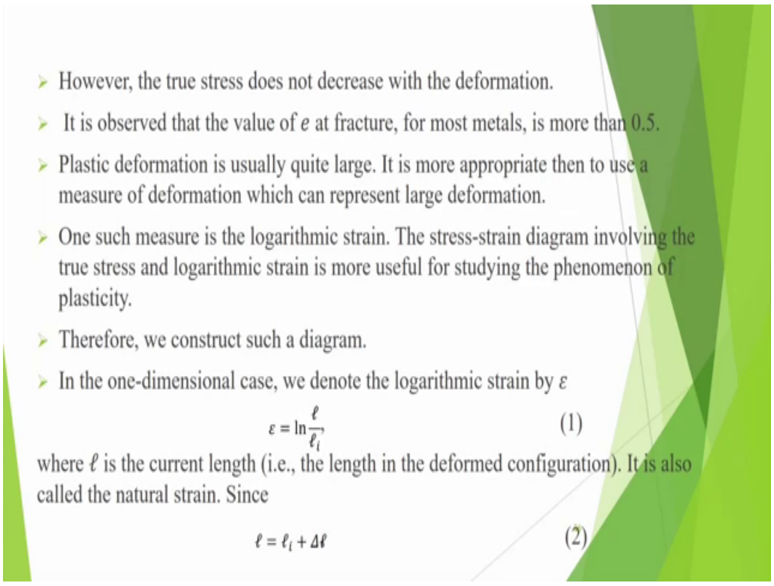

However the true stress does not decrease with the deformation. In most of the cases true stress in. In fact, keeps on increasing. Why you are seeing the decrease in the stress? Because by the time the stress as reached high value then lot of deformation also has occurred. So, that is why that piece has become thinner and that is why cross sectional area is reduced, that is why you are getting you are observing there is a decrease in the stress. It is observed that the value of e at fracture for most metals is more than 0.5 that means, strain engineering strain is generally more than 0.5, [FL] something like 50 percent elongation you care getting.

Now, plastic deformation is usually quiet large it is more appropriate then to use a measure of deformation which can represent large deformation. So, one such measure as we said true strain that means logarithmic strain. The stress strain diagram involving the true stress and logarithmic strain is more useful in studying the phenomena of plasticity and metal cutting also comes under the plasticity thoroughly.

And therefore, we construct such a diagram in the one dimensional case we denote the logarithmic strain by epsilon and epsilon is equal to ln l divided by l, where l is the current length that is the length in the deformed configuration. It is also called the natural strain and either name is the natural strain. So, since l is equal to l i plus delta l then and e is equal to delta l by l i. So, using these equations you get epsilon is equal to ln 1 plus e. This anyway I have already derive this, again I am repeating it epsilon is equal to ln 1 plus e.

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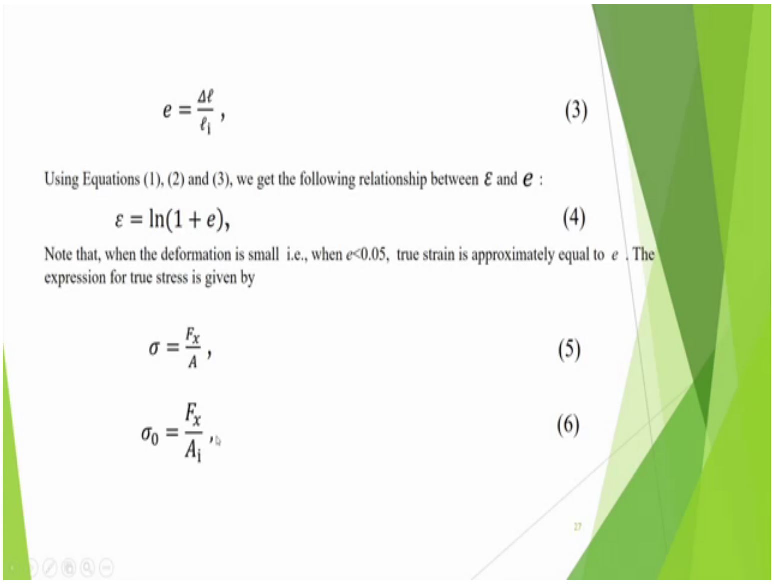

Note that when the deformation is small that is when deformation is less than e engineering strain is less than 0.05; 0.05 means it is very small, it is a above 5 percent, then true strain is approximately equal to e. The expression for true stress is given by sigma is equal to F x by A and nominally stress is sigma 0 is equal to F x by A i.

Then here as the volume remains constant during plastic deformation you get A is equal to l i by l into A i. Substituting these values in equation 5 we get the relation that is sigma is equal to 1 plus e and this is sigma 0, ok. So, that is what it is given here.

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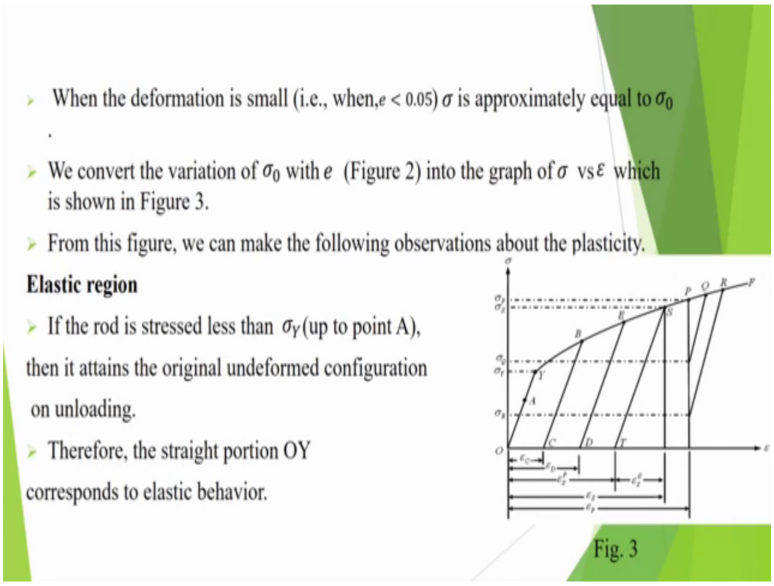

And now, when the deformation is small that means, strain is less than 0.05, engineering strain is less than 0.05 sigma is a proximately equal to sigma 0 there is no much difference. We can convert the variation of sigma 0 with e by using those equations into the graph half sigma versus epsilon true stress true strain diagram which is shown in the figure. Now, you see there is no dipping that means, stress is always increasing.

So, here from this figure we can make the following of generation there is a elastic region. If the rod is stressed less than sigma y that means, up to point a this is up to point A then it attains the original undeformed configuration and unloading, ok. And it is renewal also and then straight point straight portion OY it corresponds to elastic behavior, ok. Stress point O OY correspond to elastic A is any point in line OY. And then after that suppose you go to the point B and unload it then you reach here unloading each in the direction of only loading that means, in the direction of Young's modulus of elasticity slope of unloading curve is same as the loading in the elastic range.

So, you are reaching at point C and you are getting a permanent strain that is epsilon C and this is permanent strain other part has been recovered, ok. If you go to the next point again unload it here you get another type of permanent strain more permanent strain, but elastic portion is recovered.

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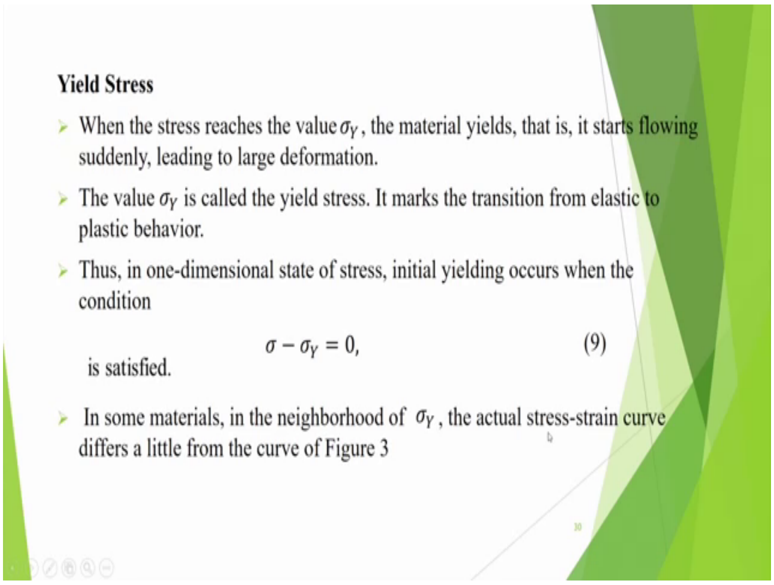

So, like that we can get yield stress is that when the stress reaches the value sigma Y the material yields that means, it is start flowing suddenly that an leads to large deformation. So, sigma Y is called yield stress it makes the transition from elastic to plastic behavior.

So, in a one dimensional state of stress initial yielding occurs when the condition sigma minus sigma Y is equal to 0 is satisfied. In some materials in the neighborhood of sigma Y the actual stress is strain curve differs a little form the curve of figure 3 that means, a actual strain curve may be little different also.

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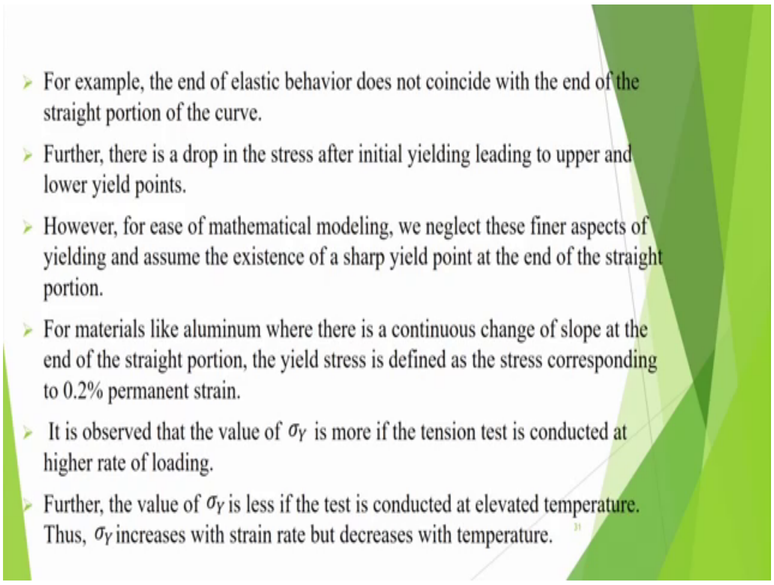

For example the end of elastic behavior does not coincide with the end of the straight position of the curve that I told that there is a proportionality limit [FL].

Further there is a drop in the stress after initial yielding to upper and lower yield points, but this phenomena in many cases we neglect. So, neglect these final aspects of this one and assume the existence of a sharp yield point at the end of the straight portion. For material like aluminum where there is a continuous change of slope at the end of the straight portion the yield stress is defined as the stress corresponding to 0.2 percent permanent strain permanent set or permanent strain that means, 0.2 percent that 1.

It is observed that the value of sigma Y is more if the tension test is conducted at a higher rate of loading that means, strain rate also has the effect on the yield stress of the material. If you rapidly conduct test means that you are moving size moving at a very high a speed in that case the yielding will occur at more amount of a stress. Further the value of sigma Y is less if the test is conducted at elevated temperature the sigma Y integer with a strain rate, but decreases with temperature. Always remember that for most of the materials sigma Y will increase with strain that means, already material has been deformed then sigma Y will be more it increases with strain rate also. If you are doing some test at faster rate, then sigma y will be more, but it decreases with temperature that is why a black smith heats of the material in his furnace. So, that its sigma Y becomes less and he can deform it.

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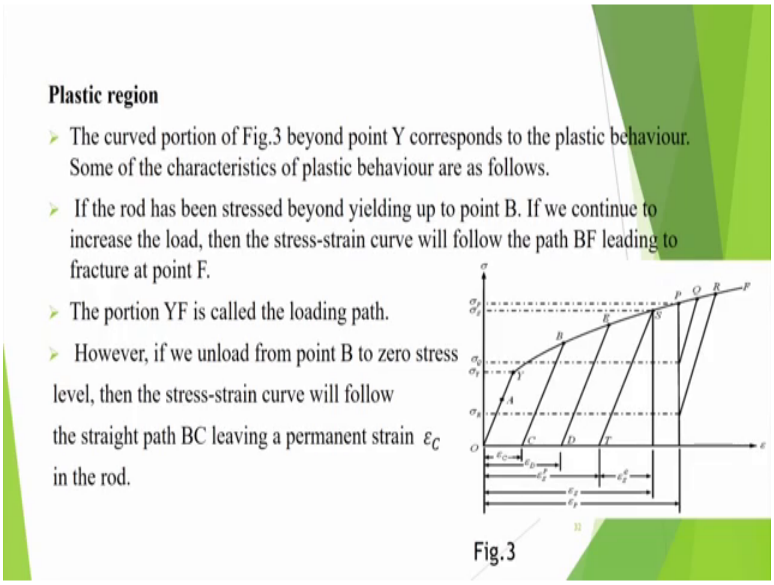

In the plastic region that means, beyond point Y it corresponds to plastic behavior if the rod has been stress beyond yielding up to point B suppose and if you continue to increase the load then the stress strain curve will follow the path bf leading to fracture at point F. That means, suppose we already the material strain hardened then we start we wrote you go up to this point BCD, and then after that there will be yielding and it will be this one and then there will be further increasing the rod. So, YF is called the loading path this is a loading path. However, if we unload from point B to 0 stress level, then the stress strain curve will follow the straight path BC leaving a permanent strain epsilon in the O rod.

So, you can remember this point also that unloading is basically the slope of unloading curve is same as the slope of the elastic curve that means, Young’s modulus of elasticity type.

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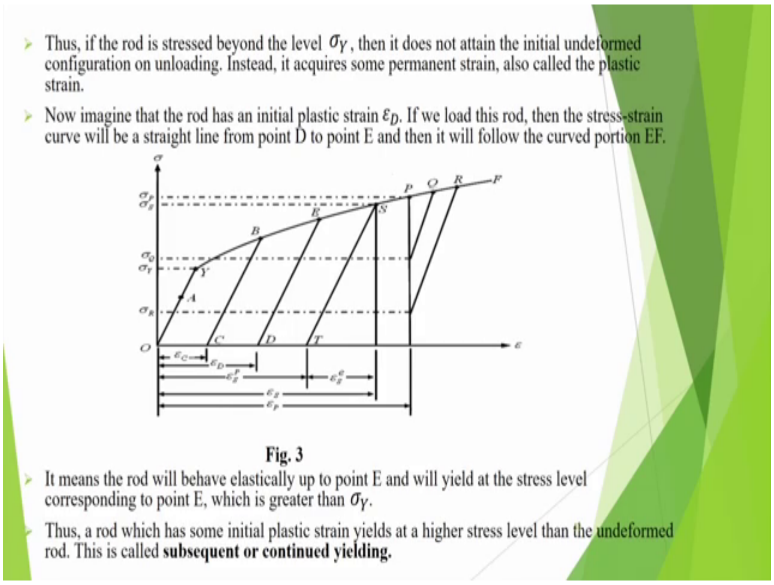

Thus, if the rod stressed beyond the level sigma Y then it does not attain the initial undeformed configuration and unloading instead it acquires some permanent strain also called the plastic strain.

Now, imagine that the rod has an initial plastic strain epsilon D if we load this if it has already D and if we load this rod then the stress is strain curve will be a straight line from point D to point E. And then it will follow the curve portion EF so that means, starting itself is from this point that relate because already it was having this much permanent set and then after that it goes and this goes up to this means as we increase the stress strain increases no doubt, but up to E it is elastic. It means that the rod will behave elastically up to point E and will yield at the stress level corresponding to point E which is greater than sigma Y.

Thus a rod which has some initial plastic strain yields at a higher stress level than the undeformed rod this is called subsequent or continued yielding it is called subsequent or continued yielding, ok.

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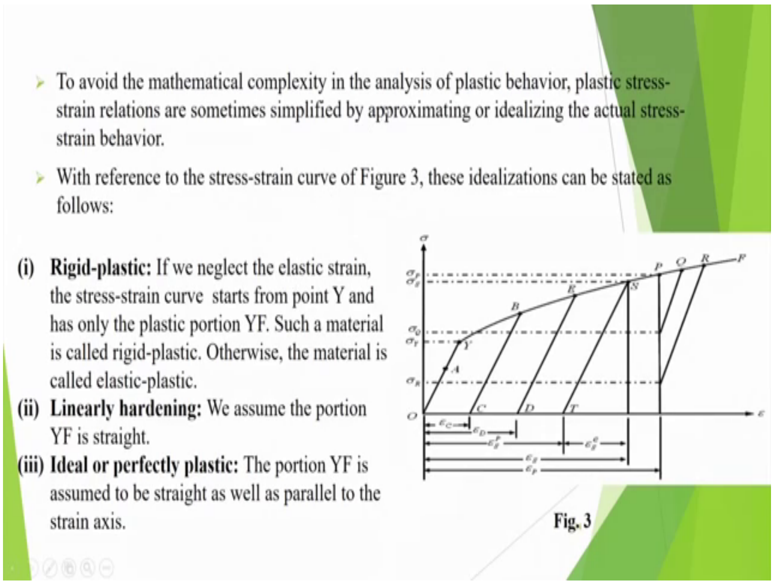

To avoid the mathematical complexity in the analysis of plastic behavior plastic stress strain relations are sometimes simplified by approximating idealized behavior. For example, we can say material is rigid plastic, if we neglect the elastic strain because elastic strain is very small 1 into 10 to the power minus 3 whereas, the plastic strain each 0.1, 0.2, 0.3. So, we can neglect the elastic strain then the stress is strain curve is starts from point y straight and has only the plastic portion YF, elastic portion is not there. Such a material is called rigid plastic that means, up to some stress material remains rigid and suddenly it becomes plastic that is called rigid plastic behavior, otherwise the material is called elastic plastic material.

Linearly hardening, suppose we assume the portion YF is actually straight all though it is having some curvature, but you assume that more or less it is a straight line then this is called linearly hardening, this is linearly hardening. And then we can consider ideal or perfectly plastic. If we assume that portion YF is straight as well as parallel to the strain axis that means, it is horizontal that means stress is not increasing. So, this type of behavior is ideal and it is perfectly plastic in which there is no strain hardening. So, strain hardening will be 0. So, ideal and perfectly plastic behavior is also assumed.

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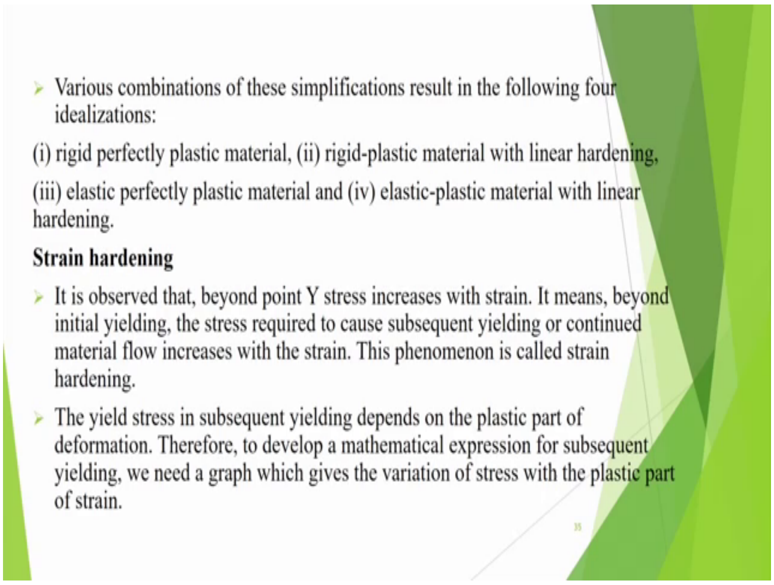

Then various combination of the simplification result into the following 4 idealization we can have rigid perfectly plastic material, we can have rigid plastic material with linear hardening, we can have elastic perfectly plastic material and we can have elastic plastic material with linear hardening.

Now, coming to the strain hardening, it is observed that beyond point y that means, beyond yield stress point stress increases with strain. It means beyond initial yielding the stress required to cause subsequently yielding or continued material flow increases with a strain, this phenomena is called strain hardening. This is called the strain hardening it is also called work hardening that means, because we do some plastic work then that is why there is hardening.

If the yield stress in subsequent yielding depends on the plastic part of deformation. Usually it depends on the plastic part of deformation. therefore to develop a mathematical expression for subsequent yielding we need a graph which gives the various of stress with plastic part of strain, ok.

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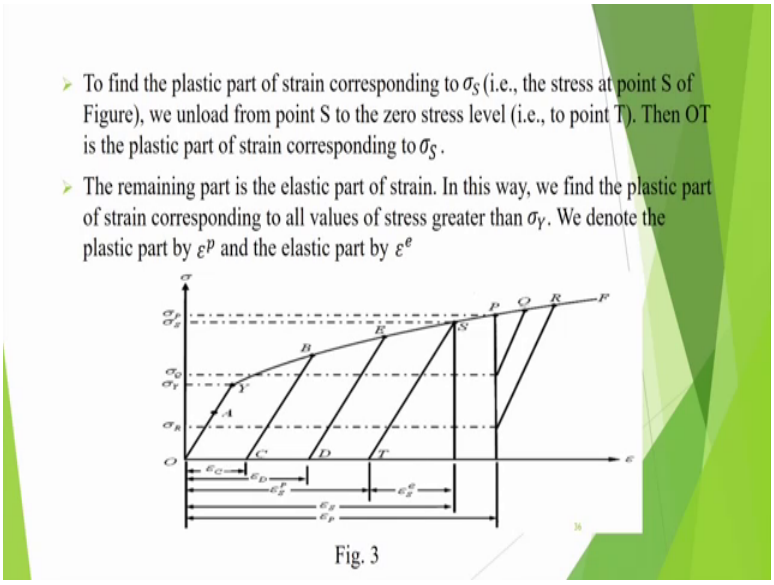

So, to find the plastic part of strain corresponding to sigma S that means, sigma s is shown here some stress at the stress point S of the figure we unload from point s to the 0 stress level that means, to point T suppose we are unloading it to a point T then OT is the plastic part of strain corresponding to sigma S. I have unloaded it up to here means unloaded means I came in the reverse direction and this ST is parallel to the OY line, ok. OY and ST both are parallel unloading is elastic and then here we are seeing that this is some amount of strain is left and this portion which is left here that is called plastic portion epsilon SP. And the remaining portion which got recovered that is elastic portion that is epsilon SE, ok. So, we denote the plastic part by epsilon P and the elastic part by epsilon E.

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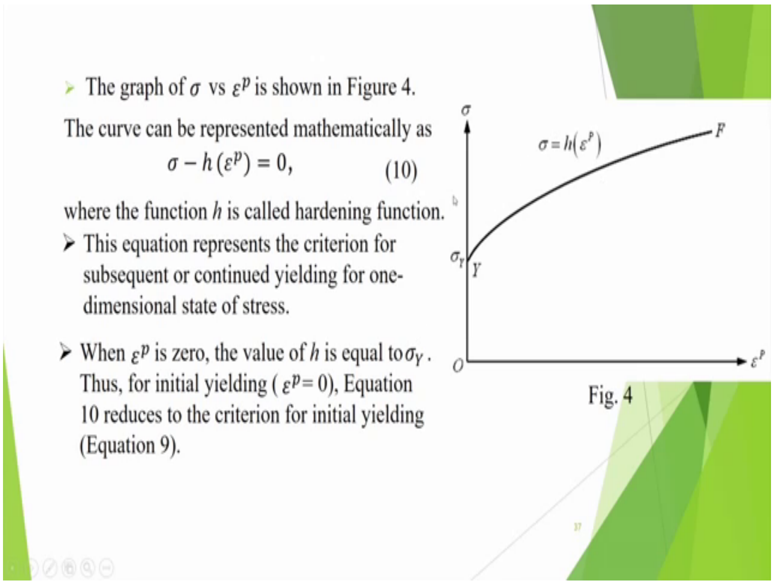

So, then right that we can do we can unload from various points and corresponding to each point I can find out the plastic, strain then I can plot a curve between sigma and epsilon P. Then we can plot because at each stress level I unload that means, I keep unloading at various points may be I hope conduct number of test. And then after that or I can plot a graph and again I can virtually unload that means, in my pen and paper and then we can see S this is the plastic part. So, corresponding to each stress I am getting the plastic strain and then I plot plastic strain in the x axis and flow stress or yield stress in the vertical axis then we get a relation that is sigma may be some function of epsilon P. So, we say sigma is equal to h epsilon P. This curve can be represented mathematically as sigma minus h epsilon P is equal to 0, where the function h is called hardening function. This equation represents the criteria for subsequent or continued yielding for one dimensional state of stress.

So, when epsilon P 0 the value of h is equal to sigma y that means, there is no hardening. So, value of h is basically sigma Y per initial yielding that means, epsilon P equals to 0, equation 10 reduces to the criterion for initial yielding. Equation 10 has been shown here that is here equation 10, this is this one and this will become equation 9 is this equation sigma minus sigma Y equal to 0 so that means, both coincide if epsilon P 0, ok. And for other cases there are this one some relations say.

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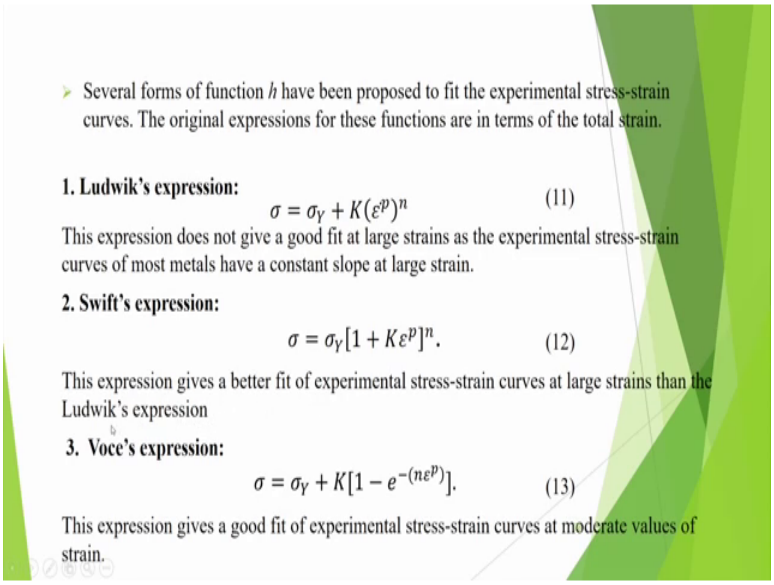

So, several empirical relations have been proposed these are some type of relations like you have got Ludwik's expression. Here sigma is equal to sigma y plus K times epsilon p into n this is plastic strain to the power p n. This expression does not give a good fit for large strains at the as the experimental is stress strain curves of most metals have constant slope at large strain, but in a small strain this is valid. So, we make another one that is called Swift's expression.

This is sigma is equal to sigma y 1 plus k epsilon p we put that through in the bracket and n is outside this is also based on the experiments you can find out these constants material constants K and n epsilon p is the plastic strain sigma Y is the yield stress.

And we have Voce's expression that is sigma Y plus K and this is one minus exponential then to the power minus n epsilon p. Here also it is indicating that as epsilon P is increasing then sigma is actually increasing because this portion will actually decreased, ok. So, that is why this overall it increases. So, this expression, use a good fit of experimental stress strain curve at moderate values of strain. So, there are such types of many such type of relations which indicate the strain hardening and these expressions can be used.

So, till this point I have told remaining portion we will continue in the next class in this class I have told you that what do we mean by machining, then we have told we you that what do we mean by mechanics and we have told that why mechanics of machining is important. I have shown some type of machining officials and after that I have portion basics stress strain diagram concept of the engineering stress, engineering stress, a engineering stress engineering strain, and true stress and true strain that type of thing has been done and we have shown that how we obtain the strain hardening relations.

Now, we will continue this lecture and then we will tell more about the machining that how the machining of relation takes place because we talked about the plastic deformation etcetera because machining is a basically a plastic deformation processing, which there is a plastic deformation and also there is a fracture, ok. So, till then good bye.

Thank you very much.