Plastic Working of Metallic Materials

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Module No # 01
Lecture No # 01
Introduction to plastic working of metals

You are welcome to this MOOC's course plastic working on metallic materials today.

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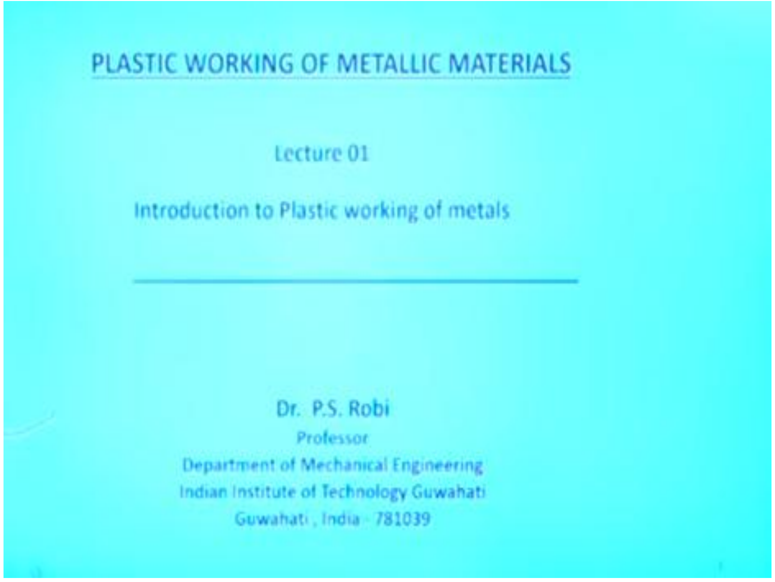

I will start with the first lecture that is the introduction of plastic working of metals.

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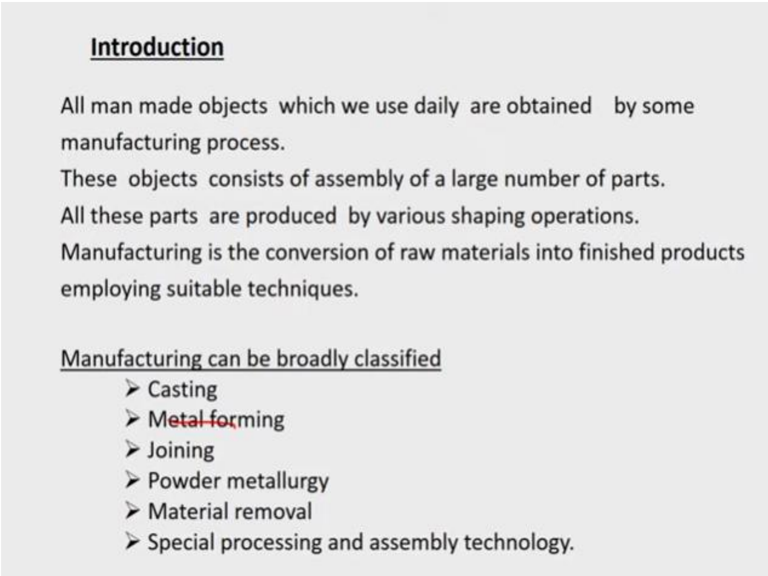

See all manmade objects which we use daily are obtained by some sort of manufacturing processes and these objects now consists of assembly of a large number of parts if you take any of this object which you are doing using daily you are consist of large number of parts. So for example an automobile parts itself consist of more than 15,000 parts of various components and each of these components are manufactured by different techniques.

So like even with the connecting the car frame body so the body itself consist of different parts the chassis is there, the wheels are there, the axle is there, the steering system is there, suspension system is there, brake system is there. So you will find that it consist of more than 15,000 different components which have been manufactured by different techniques and all these most of these manufactured by various shaping operations.

So you can say that manufacturing is the conversion of raw materials into finished products employing suitable techniques okay and this manufacturing can be broadly classified into the manufacturing techniques can be broadly classified into casting where you get the shape where taking a molten metal pouring it into a mold a shape to mold and they allowing into solidify. So and after the solidification you get that particular component the shape of the mold itself.

And then okay after that you will be doing some other operations then another is the metal forming process in which you will find that say either the material there is a bulk deformation which is taking place which is deformed in a bulk or you will find that sheet metal operations are there. Say if it is bulk forming like connection rod crankshaft and other parts you know you may it by forging the different sections of the automobile body parts itself consist of different angle section channel sections I-sections all these things are there those are made by other techniques metal deformation processes.

And may be sheet metal operation is there where you do the sheet metal operations and another method of shaking getting their shape is the joining technique. Say for example if you want a bridge, the bridge cannot be made by casting technique or metal forming technique of course there are metal forming techniques to get certain compound the structure or shapes and that will be you just add on to it.

So that you call to it as the additive technique you add on to it by joining or maybe there are some cladding techniques for obtaining some specific shape. Whereas in welding or joining technique different components are joined together may be it may be a permanent joining or it may be temporary joining. Permanent joining means you go for welding operation or bracing operations whereas for temporary joining operations it is like a say fasteners nuts, bolts, screws and all these things which are using for a temporary joining operations.

So and finally build up the shape say you cannot cast a bridge so that is why this is taken into this by joining technique. Another is powder methodology technique where metal powders may be a alloy powder can be there or individual powders are there and you add the powders are obtaining the specific composition you are just mixing thoroughly blending it and sometimes you know you do the mixing technique is there so that you know mechanically alloyed powder also you can get it the latest trend is there.

So that metal powder or alloy powder you just compact into in a die by means of a die and punch assembly and then you compact so that you get a particular shape and with the required dimensions so these so that green you call it as green compact these are then taken to a furnace and you do a sintering process that means you are exposing to a higher temperature for sufficiently long time.

So in that process during the compaction process what you got was that individual powder they were having a mechanical boundary. So it may not have a sufficient strength only that strength required for handling only you are getting it. The other case when you are sintering there is chemical bonding between the individual powder particles of that called compacted piece and finally you get a uniform composition throughout the structure and the required shape and dimensions are obtained and you will find that this technique is used for some special cases where other technicians may not work.

Like say casting you may not be able to obtain it the advantages are there in a casting you may find lot of segregation and coring which are coming plus other casting defects may come into picture. And say you may not have a proper control of the grains size whereas in powder metrology components you have a proper control of the grain size a homogeneity in the composition you can get it and all those things comes into picture but that is the powder metal technique.

So you can get especially when you wanted smaller components in large then powder metrology is the solution for that. Another is a material removal or you call it as the machining technique it can be the conventional machining technique from the bulk material you remove the material so that you get the final shape. But in this lot of losses are coming into picture and say this consist of say traditional machining techniques like machining it in a lathe a shaper or milling machine or other tech say drilling say then you have broaching you have the planner.

So all those things are there you get can get the final shape or you have the nonconventional technique specifically which is used useful for some specific materials. Say like electrochemical machining, electric discharge machining, laser machining okay then electron beam machining chemical machining. So all these things are there which comes under the material removal this case material loss is there sometimes if it is a costly material one cannot afford the loss of material okay.

Now the last case is the special processing and assembly technology which are the evolving or developing technologies which are being used and some of the examples are say semi-conductor devices micro electro mechanical devices say now a days the latest trend is the NEMS Nano electro mechanical devices under the things people are putting lot of effort into this. So like special processing and assembly technology has been developed recently, some of other examples are the 3D printing rapid prototyping lithography technique these are the emerging trending those are the special processing and assembly technology.

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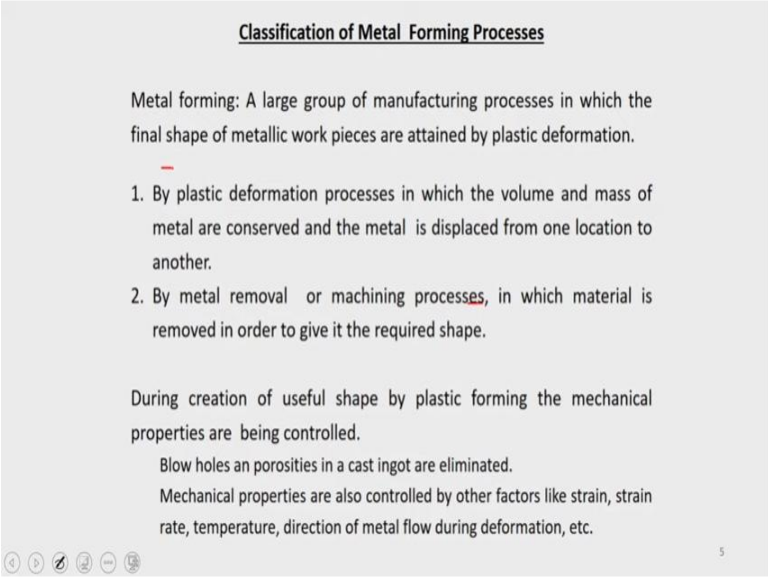

And with this so I have already mentioned all this techniques here when you come to because these course is basically for metal forming or plastic working of metal which comes under the metal forming process let us look into the classification of the metal formation processes. So metal forming is nothing but a large group it consist of a large group of manufacturing process in which the final shape of the metallic work pieces are obtained by plastic deformation

It is just by plastic deformation by plastic deformation processes in which the OEM and mass of metal are conserved and the metal is displace from one location to the other during deformation whatever be the material there is a shape change so metal moves from it displaces from place to the other and then you get the final required shape okay. But there is not much loss of material in this.

And another method is by metal forming is the metal removal or machining process in which material is removed in order to give it these two are broadly classified as the metal forming process. So we will this course will be mainly concentrated on the deformation processing or plastics working of the metal. So during creation of useful shape by plastic forming the mechanical properties are being controlled.

So when you are going to deform the material you will find that the properties of the material changes because many times it improves there may be defects in the bulk material in the as received form may be like if you are having a casting technique the primary processing was casting technique and it that you may have lot of blow holes lot of inclusion and other thing by with the strength or the material may be reduced.

So but during plastic deformation these are minimized with we cannot tell that completely eliminated. Say for example when you subjecting it to deformation the blow holes or pin holes or any other gas defects okay which are there inside the material which was formed during the casting technique they get cold welded. So you say that it is eliminated though it is 100% not eliminated and say may be inclusions are there it may be broken up into fine certain phase particles and distribution.

So, all those things comes into picture during the deformation. So by which the mechanical properties gets increased. See and now when you are deforming the material there is something called as preferred orientation. So metal deforms around certain particular crystallographic direction and in that case you will find that anisotropic properties are coming into picture. The material after deformation you will find that the properties are increased along or improved along certain particular direction and may be with concomitant decrease in the other direction so that is there.

So, one as to look into direction of metal flow during the deformation the mechanical properties are controlled by say strain range the temperature direction of the metal flow during the deformation etc., During the plastic deformation there is a chance depending upon whether it is done in the hot condition or in the cold condition there is a change that refinement of grains can take place. And when there is grain refinement it increases the yield strength of the material. So those type of advantage are there during the deformation processes.

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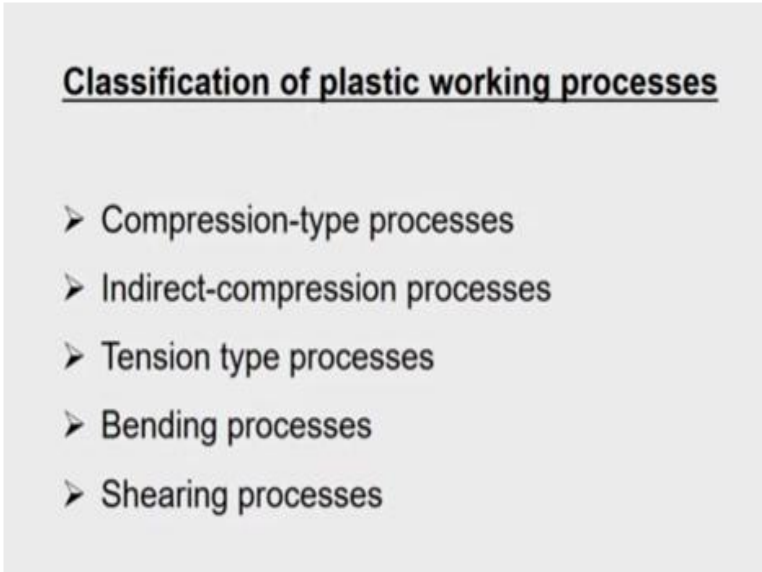

So when you classify this plastic working processes you can classified into depending upon the nature of the stresses or type of work which is being done. So you have that some of them majority of the plastic working consist of those technique where the process undergoes the material undergoes compressive stresses. So, like the compression type process are there then indirect compression process are there.

You may not applying a direct compression stress but you may be applying a tensile stress that which in the work piece and the die material there is going to be a compressive stresses then tension type process are there generally which is the sheet metal operation bending process bending operation to get a particular shape. Shearing operation, where you wanted to shear the material.

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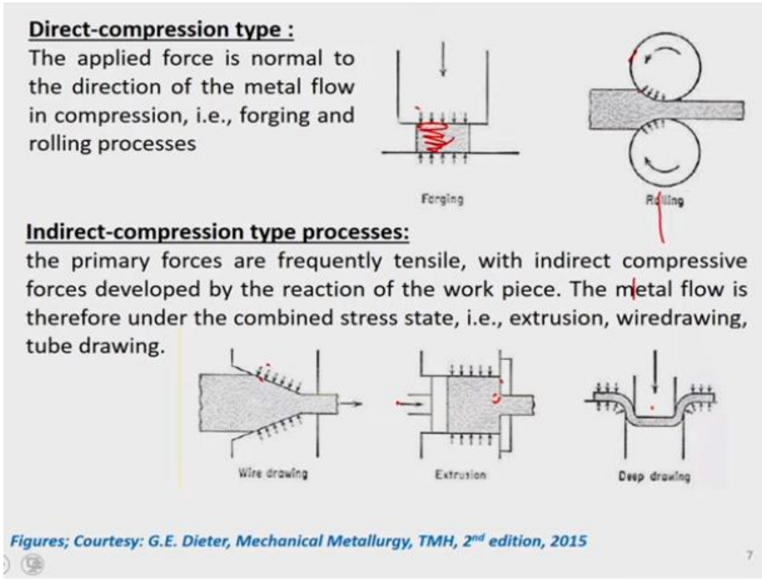

So these examples are direct a compression type a simple example is a forging the open die forging between or closed die forging between two die's the work piece material or shaded piece is the work piece material which you will see here that is being compressed between two platters. May be inside this die if you give a shape and if you are just compressing it the metal will just flow maybe you might have seen this small children playing with the plasticine that clay and making the models the same thing you can just press it then you will see that the metal pieces just flow and then if there is a cavity here it will fill up the cavity, the mold cavity.

And then you get the final shape of that this is a typical example of a forging. Forging itself consists of open die forging and closed die or impression die forging now in this case. So this is a between two roller you will find that the material passes between two roller so the interface between the material and roller you will find that there are compressive stresses which are acting on that.

So, this is called as the rolling operation a typical example of the rolling operation is extracting the sugarcane juice on the roadside you will see most of the in most parts of our country you will see that is a typical rolling operation but in industrial rolling where you are doing on sheet metal work these things are different okay. But the principle is the same rolling operation and another is the second classification of the indirect compression type process.

See for example there is a die here, into the die the converging die is there and into that you insert a material and pull through the other end. So you are applying a tensile load here but you will find that the interface between the work piece and the die there are compressive stresses. So that is why it is called as indirect compressive stresses, say an extrusion process. Extrusion process is typical so this is a typical of a wire drawing operation extrusion is every day you are you using a extrusion process in your home.

The first thing you do is get up take your tooth paste and press it on the back side and through a small nozzle the piece comes out this is a typical extrusion process okay. So here because that is a semi solid part it is not difficult but in for your metals now you may have to apply a stress in this direction shown by this between through a piston arrangement piston and cylinder arrangement and this is your die. So between the die that is your orifice the metal is forced through this region but you will find that the compressive stresses are developed on the lateral side of the die, inside the die.

And here depending upon the shape of this opening you get the particular shape of the component which you are getting and the size and another is the deep drawing operation how you make say may be a cup and the other things steel tumbler you make it now those are by the deep drawing operation you have die here kept it and then okay through means of a punch and at the surface you are just holding it and threw a punch you are just drawing it okay.

So it will go it so there are tensile stresses developed it, there are bending stresses developed it, there are compressive stresses developed it and see this deep drawing operation becomes as slightly a complex nature of stresses are there.

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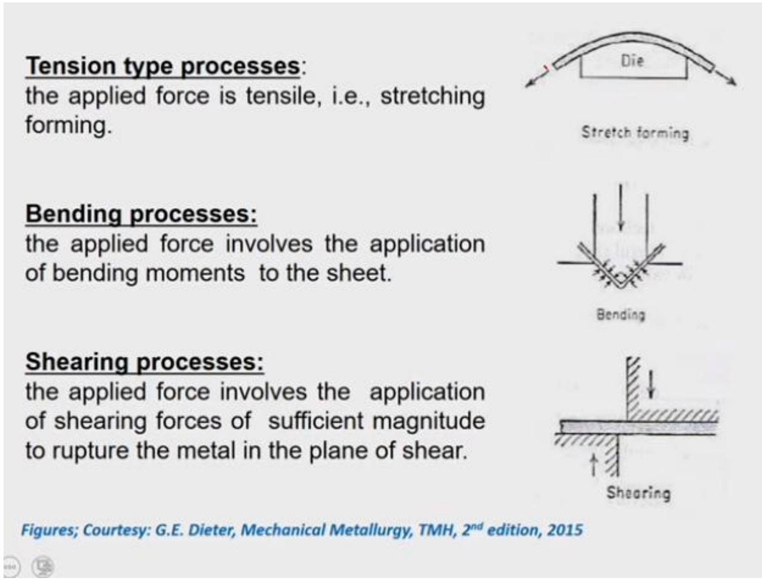

Then the tension type process these are stretch forming you will see (()) (16:03) use in the automobile body parts where you wanted to get the shape okay, so you have a material which is kept here sheet metal which is kept and through means of a die you are just pushing it so may get there are tensile stresses are developed inside the material and you get the shape. The bending process where you are getting a say it is showing for a 90º bend angle but you can a very compressed condor's shape by bending operation you can get it then another is the shearing processes where you cut the material shear the material into small pieces as per your requirement. These all involved is metal forming process sheet deformation processing technique.

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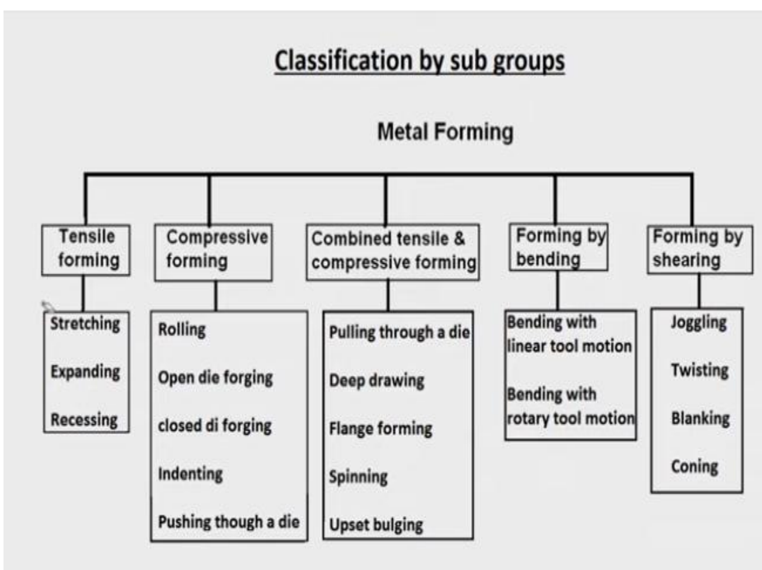

Now you have classification by subgroup the metal forming process. So, one is tensile formation where you are have stretching expanding and recessing you have compressive forming examples are rolling, open-die forging, cross die-forging indenting, indentation is another process of compressive process pushing through a die. So that is the extrusion combined tensile and compressive forming is there pulling through a die, deep drawing, flange forming.

We will come to that later metal spinning where you are just rotating the work piece material and then pressing it on a mandrill to get the shape inside shape of which will be same as the outside shape of your mandrill. So that is the spinning operation, then upset bulging, you are just upsetting it to get a maybe typical example is your nut and bolt operation under them okay. Forming by bending, bending with linear curve motion and bending with rotary tool motion these are two different techniques then forming by shearing, joggling, twisting, blanking, quilling these are all shearing operations.

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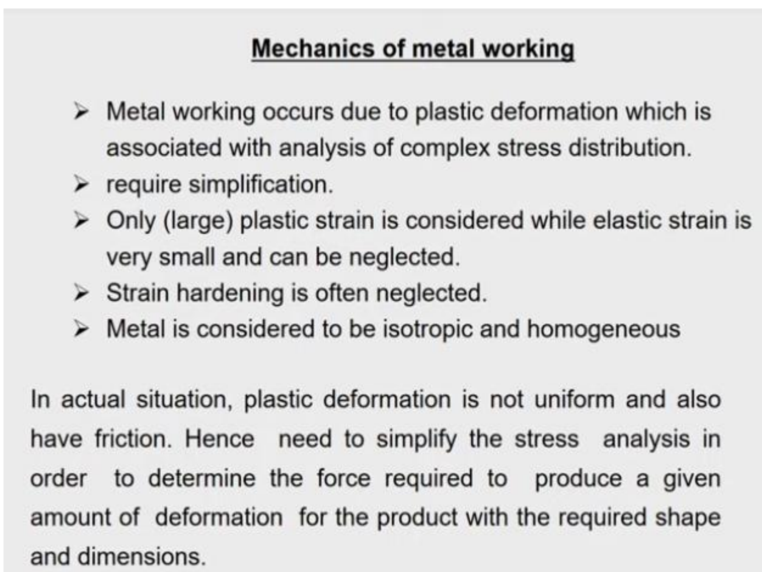

So next is that when you wanted to study about this metal formation the most important thing you have to study is the mechanics of the metal work because you have a material and this material as, you should know about what are the relationship between the stress and the strain. When you are deforming how much the stress will increase so you are required load how much it will increase maybe because of that at some point of the defector forming you are required to know all these things.

And if there is a chance that a defect is going to form so in that case you have to stop it at some point do some other process and again come back. So maybe a process you call it as annealing, intermediate annealing and again come back. So you should have a very clear cut knowledge about a stress strain relationship or the material behavior under various condition these are the most important thing.

So the metal working occurs due to plastic deformation which is associated with the analysis of complex stress distribution and this requires simplification. Only large plastic strain is considered, see when you look at the stress strain relationship between any material when you are looking into that one thing is important that is as from the point of the view of a design engineer. Design engineer is interested only in the elastic range that means where the strain is very small, so his limitation is it is the point at which the metal starts plastic plastically deforming.

So he will not going to that level where plastically deformation is taking place that means the strain is very small whereas for the point of view of a metal working engineer working in with a dealing with metal working then the plastics strain which is considered is very large. If a design engineer is looking at a strain of point say 2% the person who is working with the dealing with the metal working operation the strain may be more than one or sometimes 10 in some super plastic deformation case the strain will be may be 100 or 1000 it may go to a very large amount also, so that is there.

But in the simplest way we can say that from when you are dealing with the mechanics of metal working the strain is large where it is purely in the plastic strain which is considering. So you that is the path where you have to look at it while the elastic strain because it is very small compared to the plastics strain that will be neglected. And when you are working with a real material, the material undergo strain hardening that means the more and more plastic working your yield strength the stress necessary for further plastic deformation that keeps on increasing.

But for the simplification when you are looking at it these are the things elastic strain you neglected the strain hardening often neglected but finally at the end you will again introduce it back. And most of the cases is the metal is considered to be isotropic and homogenous this is the case where you start with but later you may come back to the case where it is non-homogenous or isotropic and other thing.

So these are the simplification which people go for when you are discussing with the mechanics of metal working. In actual situation plastic deformation is not uniform that one should understand and also have friction which is coming. Friction which is coming due to internal friction, it results it in the strain hardening the friction which comes has a result of the interaction of the work piece with the dye or the tool.

So that also comes this also increases your stresses required a lot helps the need to simplify the stress analysis in order to determine the force required to produce a given amount of deformation for the product with the required shape and dimension this is required.

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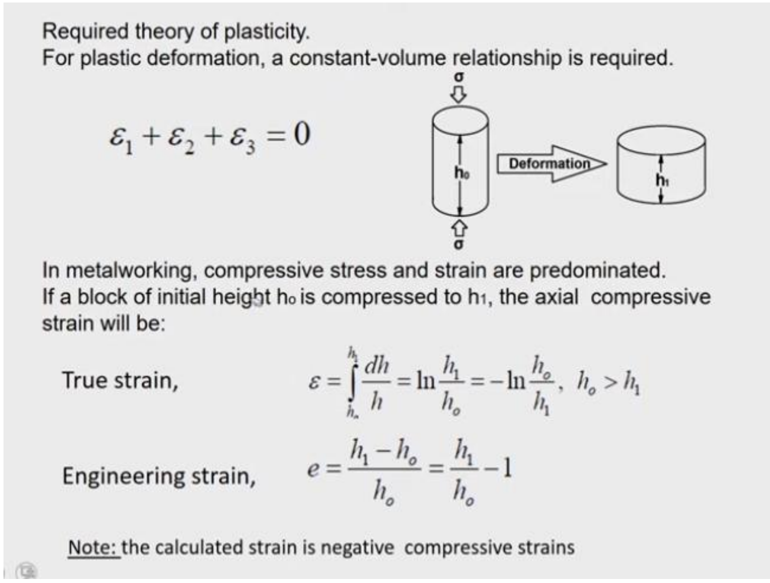

So, when you look at the cases at certain cases we will come to that part the relationship between the stress and strength but let us say that the other simplifications are for plastic deformation always you assume a constant volume relationship. The volume of material remain same maybe with the initial height of h_0 and a diameter h or d when you are compressing it is a height decreases but when you assume then you will find that the diameter keeps on increasing so the volume at the initial and the final stage remains constant, this is another assumption.

And in such case, the three components of strain the sum of the strain components, ε_1, $\varepsilon_2$and ε_3 this is equal to 0 this is the first assumption of constant volume. This is assumption of constant volume relationship. And in metal working processes, you find that majority of the case it is the compressive stresses and strains are being used most of the operation when you look at it.

So if a block of initial height is compressed from h_0 to h_1 the axial compressive strain will be you can find that this we will come to that soon the strain is $-\log h_0/h_1$ where h_0 is greater than h_1 where h_0 is the initial height of the material. So in engineering strain so this is the true strain this is a engineering strain you can get it as $h_1 \ / \ h_0 - 1$, but when you are discussing with the stresses which are compressive in nature you will find that this strains are taken as negative.

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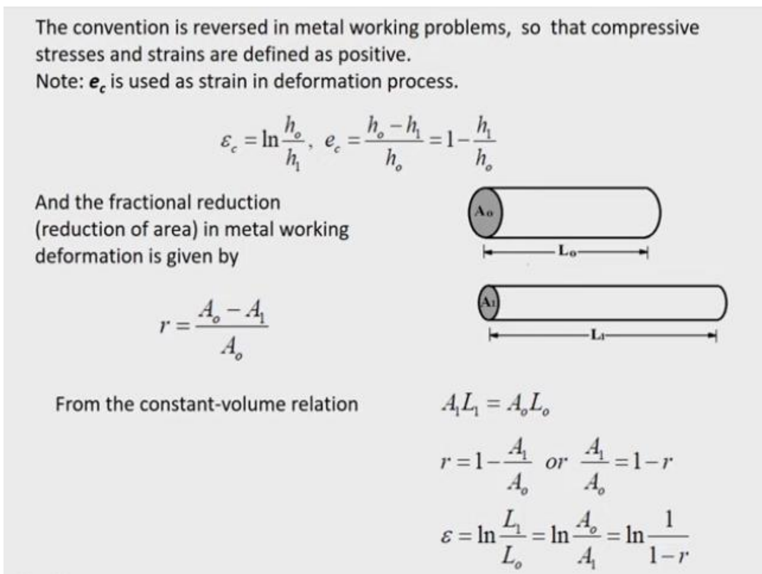

So convention is reversal metal working problem, so that the compressive stresses and strains are defined as positive okay. So you define it as positive and then you do the analysis, only thing is that it does not matter whether it is compressive or tensile what matters is what is the amount of strain you have given in plastic working of metal that is why so there is not going to be much only thing when you do the calculation you have to be very careful what you are taking it.

So that way compressive strain you are getting as $\log h_0/h_1$ so this is the other case it was $\log h_0/h_1$ and here it is $1 - \frac{h_1}{h_0}$ and the fractional reduction metal working this is another parameter which people takes case is that r equal to this defined by $\frac{A_{0-A_1}}{A_0}$ and from the constant volume relationship we can always relate this fractional reduction in terms of strain as this or $\frac{A_1}{A_0} = \frac{1}{r}$ and the strain epsilon that is related to your fraction reduction as log 1 / 1 – of this relationship you may very often encounter when you go ruined of this one.

$$\varepsilon_c = \ln\frac{h_0}{h_1}, e_c = \frac{h_0 - h_1}{h_0} = 1 - \frac{h_1}{h_0}$$

$$r = \frac{A_0 - A_1}{A_0}$$

From the constant volume relation,

$$A_1 L_1 = A_0 L_0$$

$$r = 1 - \frac{A_1}{A_0} \text{ or } \frac{A_1}{A_0} = 1 - r$$

$$\varepsilon = \ln\frac{L_1}{L_0} = \ln\frac{A_0}{A_1} = \ln\frac{1}{1 - \mathrm{r}}$$

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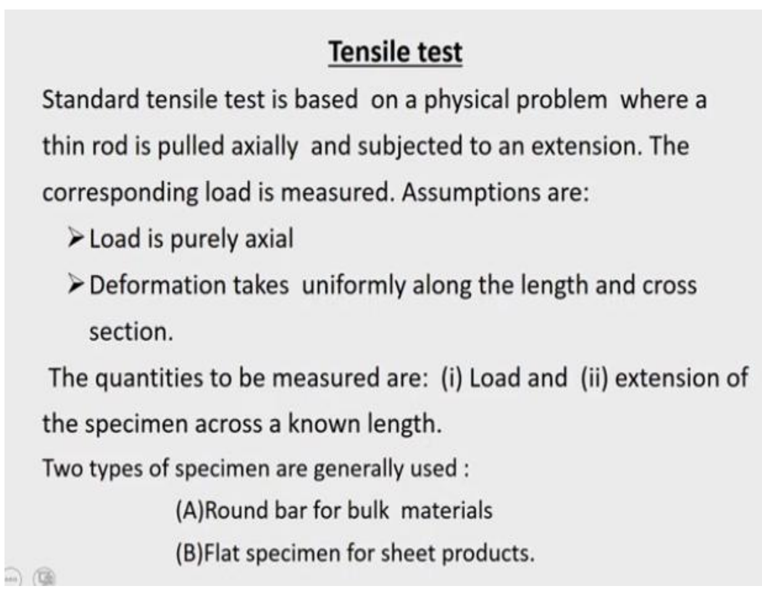

Now how to have the relationship between this stress and strain for the material because whatever you are going to do you should have a thorough understanding of the behavior of the material when you are subjecting it to plastic deformation. So, you should know the information which you can obtain is by a simple tensile test or a compression test. A compression testing you take a cylindrical sample press it the way we have shown it and finally after some amount of strain you get the measure the load and the strain and then you get the relationship.

But it is very often convenient to get the more information at tensile test because when you are deforming the material. The material will not fail under purely compression this is a general rule. So the material when it is subjected to some sort of stresses it will fail when there is somewhere some tensile stresses are developed then only the internal defects will start performing and then the final failure will take place.

So the best thing, the simplest thing which people look at is to conduct a tensile test. Now, let us discuss about how the tensile test is done what are the information we can get it and how we can analyze the tensile test result. So standard tensile test is based on a physical problem where a thin rod is pulled actually it is pulled and subjected to tension, okay. The corresponding so in that machine when you are pulling it what is the load which is required for pulling, your measuring it and so that is the load required the corresponding load is measured.

But when you are doing this tensile testing the basic assumptions are the load is purely axial, there is no bending and other things are of combination. So you have to have your specimen in such a way that there is only axial stresses, okay. Then deformation takes place uniformly along the length say, the uniform deformation is taking place. So if the length is increasing correspondingly for maintaining the uniform deformation you will find that the diameter is decreasing.

So decrease in the diameter also is uniform okay so across any section when you look at it the diameter should remain constant at any point so that deformation takes uniformly takes place uniformly along the length and along the cross section. The quantities to be measured during the tensile test are one, the load by which you are applying because you are subjecting it to a strain and when you are pulling, what is the load which is coming but what are the stresses which are developed that is what you wanted to find out.

So the quantities to be measured are load and extension of the specimen across a known length when I am pulling it if I know the dimension a non-length and then how much it is expanding when you are pulling it that is the extension you can measure it. These are the only two parameters which you are going to measure, when you are conducting a tensile test. For conducting the tensile test you have different specimen test but generally people use to two types of specimen, though non-standard specimens are also there.

One is the round bar for measuring conducting a tensile test on a bulk sample round cylindrical type thing with a reduced cross sectional at the middle and another is flat specimen for the sheet products.

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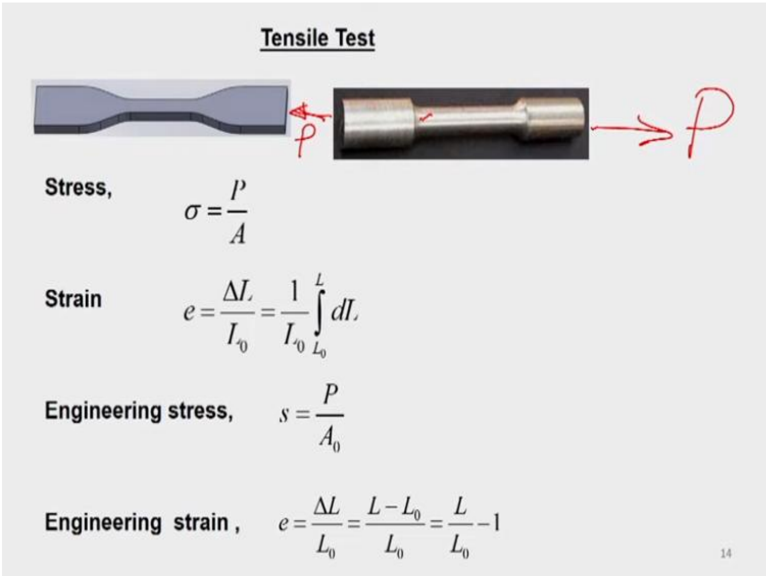

So this is the round bar say a uniform round section is the cylindrical piece is there at the center portion you have a reduced cross section with a some radiuses are given, as per the ASTM standards you get the standard dimensions for this if you are conduction a test you follow some standards, generally, throughout the people follow this ASTM standard though in a European countries you know they also have different standards and other thing.

But more or less the principles are same and if you are having a sheet metal work you have a flat specimen say from a rod you just cut it at the middle there is reduced section okay and these two parallel sessions. Now these are parallel pieces say, you can say from here to here there is parallel length here also there is also there is parallel length on this you can just clip and extends some meter on non-length you call it as a gauge length of non-gauge length is fixed you attach it to that and then finally what happens is that during the testing that distance keeps on increasing and you can measure the extension.

So the terminology which is used are stress defined by nothing but the external load P, so here when you are pulling you can just pull it here by load p. So this p by this cross sectional area may be at any instant that is called as the stress that is the defined by the stress and almost all of you are familiar with the definition of stress. So I am going into that. Another is strain is that change in the length say if the distance was here and after loading when you are pulling it now there is a displacement in the length, so that this displacement the extra displacement is the delta L / L_0 which we can write in the integral form a 1 / L_0 integral over L0 to L dL.

When you are doing a test what are the measurement you are doing you are measuring the load and you are the measuring the displacement. You know that initial cross sectional area of the sample the initial gauge length you know once these two things are there you can find out the stress and the strength okay in terms of the initial cross sectional area if you measuring then you call it as a engineering stress defined as S is equal to at any instant where P is there divided by initial cross section area.

So that is the engineering stress. Why it is called as engineering stress is because it is importance only for a design engineer, okay, where his stresses are not going to a value beyond the elastic limit okay. So it is much below the Young's modulus value of the material. And so engineering strain also the change in length per unit initial length gauge length that is what e given by this relationship that means change in length the delta L is nothing but L – L_0 divided by $L_0$where L_0 is the initial length and so you can write it as instantaneous value for any value of L.

$$\sigma = \frac{P}{A}$$

$$e = \frac{\Delta L}{L_0} = \frac{1}{L_0}\int_{L_0}^{L} dL$$

$$S = \frac{P}{A_0}$$

$$e = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} = \frac{L}{L_0} - 1$$

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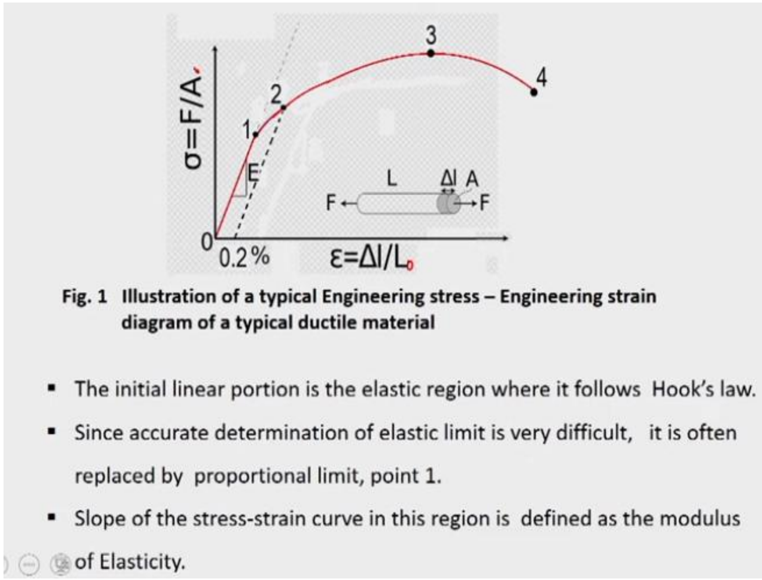

So that is the e value you can calculate by L / L naught – 1. So this is how you get a typical stress strain curve. So in this when you look at it, what we can see is that the initially there is linear path so this load versus elongation plotting it you will get the same type. Only thing is that here the stress divided by area and the strain by delta L / L when you are doing it you will get this type of a plot.

Initially, this is a typical engineering stress versus engineering strain plot, so where this L should be L naught should be here. So initially you will find a linear path the curve is very linear it obeys a linear relationship that is stress is proportional to strain, the famous Hook's Law okay. So in this region you have the, this is called as the elastic region so when you remove the load from any point in this region may be from 0 to 2.

When you are unloading it when you remove the load it will again come back to the initial length so that whatever extension took place that become 0, the moment you remove the load that is what. So that is the region of elasticity now it not easy to find out which is the point at which this elastic limit is reached beyond with certain case you know it will not come back to the initial portion.

So there is the very difficult it is a very tricky situation, so in for that case from 0 to 1 the material behaves in a linear way. So that is the region of linear elastic region and the slope of this stress strain plot at in this region is nothing but your Young's model of value of the material.

Now from here, so up to this point when you remove it will come to the 0 position, that is there would not be any displacement and still you increase it is no longer linear there is a some amount of non-linearity comes into picture.

So linearly it should have been one like this but it is moving along this lines say from 1 to 2 but still till it reaches the point 2, you will find that it remove the lot it again come back to initial position. So that means there is no permanent extension which has taken place or permanent deformation has not taken place. But at some point, you will find that if you remove it a small amount of permanent deformation as set in metal has deformed plastically then you call it as but it is very difficult to know and conducting a test say loading unloading, loading unloading and other things that depends upon what is your step jump so it becomes very difficult.

So generally what people do that so you just keep on loading it and then you take you draw a line parallel to this initial slope of this line which has strain of 0.2% or 0.002 of your gauge length so that is 0.2% strain you mark a point and draw a line parallel to initial slope of the line, wherever it means you get the 0.2 this is called as offset strength or 0.2% offset strength. This is the normal method of determining the Young's modulus, sorry a yield strength of a material this is under the assumption that any component when say a strain of up to 0.2% a permanent strain of up to 0.2% is can be accommodated without a changing much of the performance of the material.

So that is under that condition, that subject to that condition only people are taking this yield strength as this one. Because this is very difficult to find out at what exactly at what point the deformation as taken place. So this is the thing, so initial linear portion of the elastic region where it follows Hook's law. Since accurate determination of velocity limit is very difficult it is often replaced by a proportional limit.

The slope of the stress strain curve in this region is defined as the modulus of the velocity so all those things are there. Now from 0.2 when you increase it you will find that the yield strength keeps on increasing.

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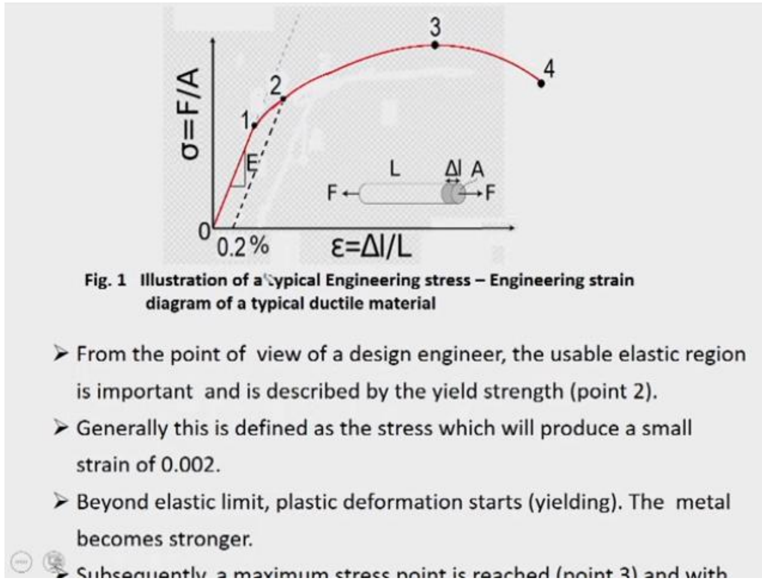

So from point 2 the yield strength keeps on increasing. So when you unlock the specimen at any point beyond 2 you will find that there is a permanent deformation takes place and with the more and more straining this permanent deformation keeps on increasing. Because initially you know whatever was the elastic energy absorbed that will always determine constant but you will find that the stress necessary for plastic deformation that keeps on increasing with the increase in strength.

So that means the material under goes strain hardening. So the strain hardening is nothing but the increase in the yield strength as a result of the previous plastic deformation. It keeps on increasing and it reaches a maximum value at some point maybe we can say that in this curve it is at point 3, beyond that you will find that the load keeps on decreasing, so when the load keeps on decreasing and somewhere at 0.4 it fails at a lower stress it fails.

So this point so point 1 is proportionally limit where stress is proportional to strain. Point 2 is yield strength where beyond that the material under goes permanent deformation of plastic deformation and 2 to 3 is the region of homogenous deformation from 2 to 3 when you deform the material the material deforms homogenously, that means with a whatever increase in length is there it maintains a constant volume relationship the cross sectional area decreases and entire length of the gauge length entire section of the gauge length you will find that the decrease in the cross sectional area is or the cross sectional area remains same across the length.

And, but point 3 you will find that instability sets in, the specimen at some area is cross sectional area decreases, maybe these are the region where there is a stress concentration or it may be a region where there is a defect which is there, internal defect is there so that result in stress concentration whatever it be whatever things are. Maybe it may be the region the minimum cross sectional if there is no defect also ideally if you look at it if there is no defect but still during the specimen preparation there is some region where the cross sectional area is minimum it will be at that region because that is the region of stress concentration.

So at point 3 a necking, a reduced cross section takes place, the phenomena is called as necking like the neck know it is a cross section which is lesser than our body and our head so that is why it is called as necking. So somewhere the necking takes place and then with a further straining the neck region that there the deformation starts increasing like a localized deformation takes place and it is a cross sectional area keeps on decreasing and at some point it cannot with stand the load and then it fails at point 4.

This is the typical case for a typical engineering stress engineering strain diagram for a typical ductile material like aluminum, copper, nickel etc., these are the pure alloys.

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In plastic deformation , the strains are usually large. Hence the strain is represented by the term true strain or natural strain, **ε**, which is the ratio of change in length referred to the instantaneous length instead of original gage length.

True strain $$\varepsilon = \sum \frac{L_1 - L_0}{L_0} + \frac{L_2 - L_1}{L_1} + \frac{L_3 - L_2}{L_2} + \ldots$$

i.e. $$\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0}$$

So when you are determining the stress and the strength so whatever may discussed was the initial gauge length and initial cross section of the specimen were taken. So either A0 or L0 where taken in our calculation say P by A naught so that is a engineering stress and delta L / L naught where L naught is the initial gauge length. So based on that that is why we call it as a engineering stress engineering strain plot.

That will give you can idea how much the material can with stand how much load the material can with stand that is the best idea for the information which we can get it from that. But as a specimen deform plastically, from region 2 to 3, so there is mistake, from region 2 to 3 the gauge length extension is accompanied by a reduction in the cross section area. So when the cross sectional area decreases you have to find the exact cross sectional area at any instant and then the load divided by that instantaneous value of cross sectional area you have to take it.

So the actual stress sigma across the cross section is therefore higher than the engineering stress and the true stress that is accurate so that the true stress given by sigma. So remember S we will be using for engineering stress and sigma for the true stress similarly if e for the engineering strain and epsilon for the true strain will be using. So the true stress is given by P by A so in plastic deformation the strains are usually large.

Hence the strain is represented by the term true strain or natural strain because the deformation is very large that is epsilon which is the ratio of change in length referred to the instantaneous length instead of the original gauge length okay. So that is what we are telling, so if you just take it for each deformation which is taking place maybe from starting from L naught it as deformed to L then what is the strain increment to that so that is what you have to do.

So total strain will be the sum of these strain increments which is given by the like this sigma over L1 minus L_0 by L_0 plus L2 minus L1 by L_0. So at instantaneous strain you have to calculate it, instantaneous length you have to calculate or cross section area you have to calculate it and then find out. So this is the sum of all the strain in increments is the total true strain which you call it as. So the integral form you can write it as epsilon is equal to integral over L_0 from L_0 to L dL by L that is equal to log natural log L by L_0.

$$\varepsilon = \sum \frac{L_1 - L_0}{L_0} + \frac{L_2 - L_1}{L_1} + \frac{L_3 - L_2}{L_2} + \cdots$$

$$\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0}$$

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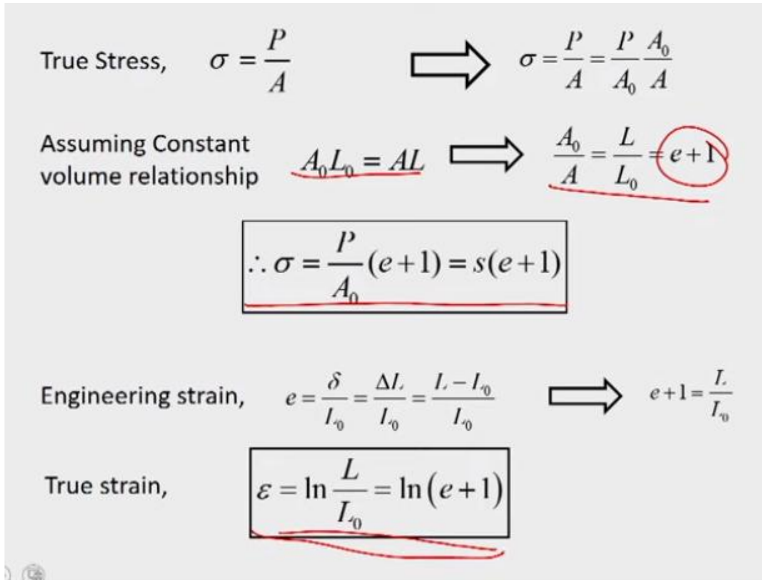

So true stress is given by this relationship which we can write it as sigma is equal to P by A equal to P by A_0 into A_0 by A, you can find out the relationship between what is $A_0$by A. So that is if you are assuming the constant volume relationship A_0 by A, A naught L_0 equal to A into L where this is the initial cross section area and the initial length whereas A and L is the instantaneous cross sectional area and instantaneous value of the length gauge length due to the expansion.

So from this you can find out A naught by L equal to L by L_0 so that is some our relationship earlier with e you will find that e equal to A naught by A minus 1 so from that we can write that A by A_0 by A equal to l by L_0 equal to e plus 1. So these $A_0$by A, if you substitute here you will find that the true stress relationship is given by sigma equal to P by A_0 into e plus 1 that is given by P by A_0 is your engineering stress into engineering strain plus 1. So that is what the relationship between true stress and engineering stress in terms your engineering strain you are getting it.

Similarly engineering strain is given by e is equal to delta L by L_0 that is L minus L_0 from that you will get this relationship, from this it implies that e plus 1 equal to L by L_0. So these epsilon is equal to log L by L_0 so we can write it has L by L_0 is nothing but e plus 1 so you get this epsilon equal to e plus 1. So this two relationship how to determine the true stress and the true strain in terms of engineering stress and engineering strain you can easily get it by this relationship.

$$\sigma = \frac{P}{A}$$

$$\sigma = \frac{P}{A} = \frac{P}{A_0}\frac{A_0}{A}$$

$$A_0 L_0 = AL$$

$$\frac{A_0}{A} = \frac{L}{L_0} = e + 1$$

$$\sigma = \frac{P}{A_0}(e + 1) = s(e + 1)$$

$$e = \frac{\delta}{L_0} = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

$$e + 1 = \frac{L}{L_0}$$

$$\varepsilon = \ln\frac{L}{L_0} = \ln(e + 1)$$

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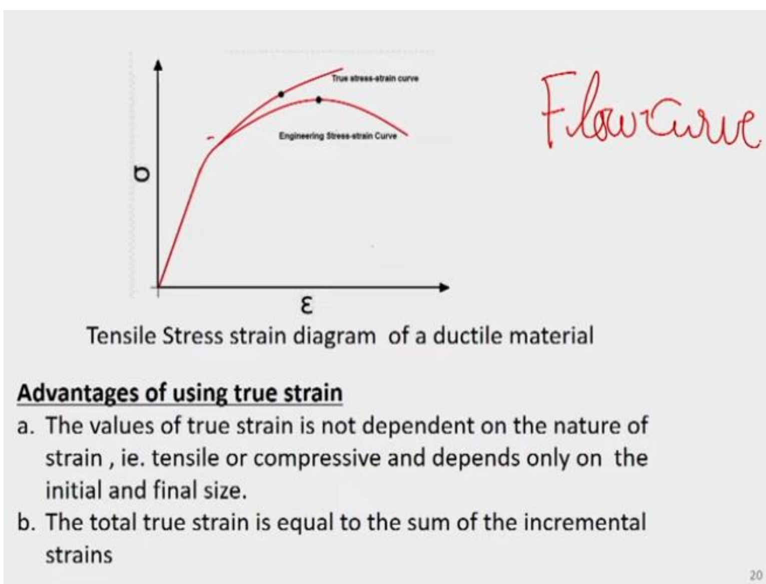

Now this is the common stress strain axis I have taken but if you plot the engineering stress strain curve and the true stress, true stress true strain curve you will find that it is different. In that true stress true strain curve because of the necking, you will find that localized necking is taking place, the cross sectional area at that point of necking is very less so there the stresses are increased. Though your external load is decreasing, that is because of the reduced cross sectional area.

So you will find that the true stress true strain plot will be this and whereas the engineering stress engineering curve will be like this after the ultimate tensile strength or maximum load is attained the engineering stress engineering curve will show your dip or reduction in the stress value with the strain till it fails whereas true stress true strain curve, we are considering the actual cross sectional you will find it continuously keeps on increasing till failure.

So advantage of using the true strain at that, we will do some problem and then you will understand it, the values of true strain is not dependent of the nature of the strain. That is the whether it is tensile or compressive and depends only on the initial and final size. If I just have a piece like this and I just elongate it into double the size of this, calculate what is the stress the engineering strain and engineering strain for these two from say maybe L naught to L maybe if you are just doubling it.

You just assume maybe 50mm to 100mm if you are increasing it so calculate the true stress and engineering true strain and engineering strain. Now again you deform it compress it back to the original shape and then you find it out. You will find that if you are doing this total strain by engineering strain concept, you will find that this strain there is some value but when you are taking the true strain concept because reduction in the length you are considering it as compressive in nature.

So there the some of these things will be 0, so that is one thing so total true strain is equal to the sum of the incremental strain that also is there. So maybe from 50 to 100 when you are going from 50 to 60, 60 to 70, 70 to 80, 80 to 90, 90 to 100, in each case you calculate from 50 to 60 what is the length? So from engineering stress strain point of you and post strain point of you just calculate it and do that some of the strain increment then you will find that the total strength from 50 to 100 is equal to the sum of the strain increments, when you are using the true strain concept.

But if you using the engineering strain concept you will find that total strength is not the sum of incremental strength, okay, so that is the thing so these two advantages are there. But in any case, the when you dealing with the plastic deformation of the material this true stress true strain curve is called as the flow curve, say you call it as flow curve. This is very much important for plastic working of material the reason is in this if you know how much amount of strain the material has been subjected to before you got it, you can understand that if you know the relationship in you can really find out what will be the plastic deformation the yield strength of the material. Yield strength will keep on changing from on the flow curve depending upon the strain. So if you are buying the material from the market and saying and your supplier is selling okay this is the material after annealing it is subjected to a strain of point 2 or it is subjected to point 5.

Then you can find out what will be the exact yield strength of the material, so that will keep on changing that is one advantage. Or if you get a material, the material is known to you and then you find that okay it is yield strength of some value then if you have this stress strain with you can find out how much amount of strain has been given to this material before you used it or before or you received it.

That is the advantage of this, so at any instant of time or when you are deforming the as I mentioned earlier the deformation will not be homogenous at different section the amount of strain may be different. So you can find out at which section the maximum strain will take place and that is the point where you have to concentrate. So that failure will not take place so all those important information you can get from this flow curve and for the kinetic for studying the deformation behavior of the material, this true stress true strain curve is more important. And there are various ways of representing the stress strain curve we will come to that later.

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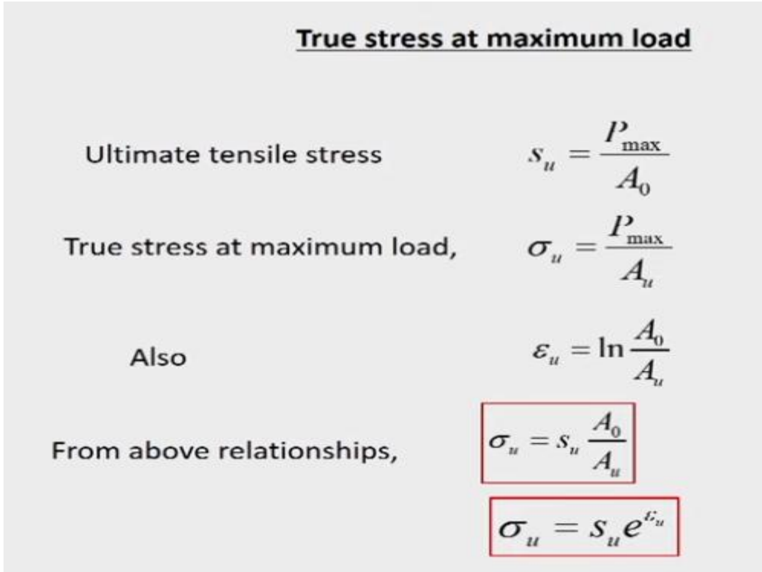

But in this we found that ultimate tensile strength where the maximum load is there you have calculate, you wanted to find out the relationship between this true stress at maximum load. So ultimate tensile stress is given by say Su given by P max what is the maximum load by $A_0$when the true stress at maximum load sigma u is the P max by Au where you should know what is the initial cross sectional area.

Also you know that the strain at maximum load is log $A_0$by Au. So from the above relationship you can find out see if you substitute into this we can get this epsilon u is equal to Su into A_0 by Au or epsilon u the true stress at maximum load is nothing but Su into say e raise to epsilon u.

$$S_u = \frac{P_{max}}{A_0}$$

$$\sigma_u = \frac{P_{max}}{A_u}$$

$$\varepsilon_u = \ln \frac{A_0}{A_u}$$

$$\sigma_u = S_u \frac{A_0}{A_u}$$

From the above relationships,

$$\sigma_u = S_u e^{\varepsilon_u}$$

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Instability in Tension

Once the stress has reached a maximum value, the engineering stress –strain curve shows a decrease in the stress value.
This region is accompanied by necking which generally occurs at regions of stress concentration due to minimum cross sectional area or presence of defects.

In real materials, during homogeneous deformation, undergoes strain hardening thereby increase the load =carrying capacity of the specimen due to plastic deformation.

This is opposed by the gradual decrease in cross sectional area of the specimen. Localized deformation (onset of necking) begins at maximum load. At this stage, increase in stress due diminution in cross-sectional area of the specimen becomes greater than the increase in the load carrying ability for the metal du to strain hardening.

Now another thing which you have to consider is there, we discuss after reaching the maximum load the cross sectional decreases at some localized area and that localized region the plastic deformation is very large so there is no longer the material is deforming in a homogenous way. So what happens is that, there is an instability in tension. So instability in tension we have find out.

So once the stress has reached the maximum value, the engineering stress strain curve shows a decrease in the stress value with the strain. This region is accompanied by necking, which generally occurs at regions of stress concentration due to maximum cross sectional area or presence of defects. In real material during homogeneous deformation it undergoes strain hardening thereby increases the load carrying of the capacity of specimen due to plastic deformation.

So on one hand you will find that the material under goes plastic deformation, so there is it undergoes strain hardening, so because of the strain hardening the stress necessary for further deformation increases. But other hand you will find that the cross sectional area of the specimen keeps on decreasing. When the cross sectional area keeps on decreasing, there is actual stress keeps on increase, so that means these are two opposing fact.

The load carrying capacity it increases and that it is opposed by gradual decrease in cross sectional area of the specimen so localized deformation begins at a maximum load and at this stage increase in stress due to diminution in cross sectional area of the specimen becomes greater than the increase in the load carrying ability for the metal due to strain hardening.

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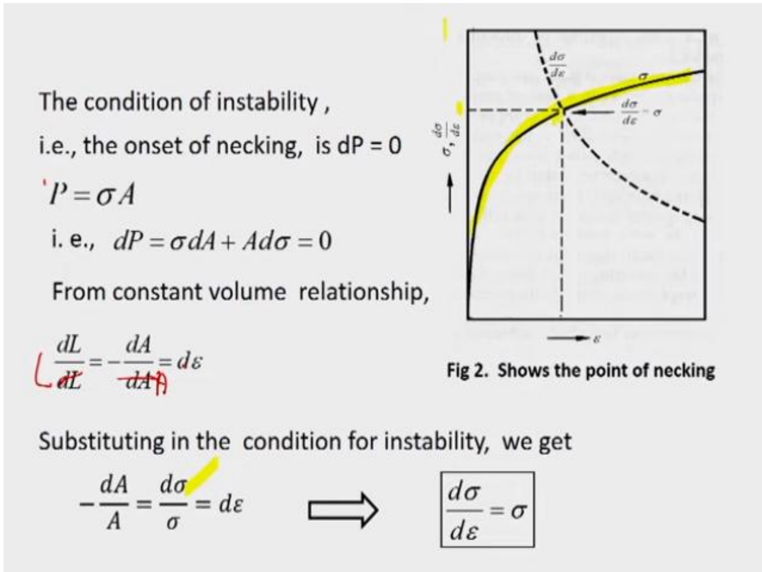

So that condition of instability is there at maximum load you will find that the change in load is 0 that is dP is equal to 0 that is the condition for tensile instability and you know that P the external load P is nothing but stress into the cross sectional area instantaneous value of cross sectional area. So that means writing in the differential form you can write the dP equal to σdA plus $Ad\sigma$ and since the condition of instability onset of necking is equal to 0 you get it to 0.

So but from constant volume relationship we already get this relationship dL by sorry this should be dL by L somehow this as L and dA by A is equal to $d\varepsilon$. So if you substitute into this you can get dA by A is equal to $d\sigma$ by σ equal to $d\varepsilon$ or it implies that finally you arrive at $d\sigma$ by $d\varepsilon$ is equal to ε. A condition for tensile, that means if you are loading this, if this your true stress true strain curve or your flow curve and then you find out the $d\sigma$ by $d\varepsilon$, taking that function and then you start plotting with versus ε, you will find that when it reaches at any point where the $d\sigma$ by $d\varepsilon$ is equal to 1 that is the point the strain at which this takes place and your stress at maximum load will be based on that. So that is how you calculate, so here this is a point at which you will find that $d\sigma$ by $d\varepsilon$ is equal to σ.

$$P = \sigma A$$

$$dP = \sigma dA + A d\sigma = 0$$

From constant volume relationship,

$$\frac{dL}{dL} = \frac{-dA}{dA} = d\varepsilon$$

$$\frac{-dA}{A} = \frac{d\sigma}{\sigma} = d\varepsilon$$

$$\frac{d\sigma}{d\varepsilon} = \sigma$$

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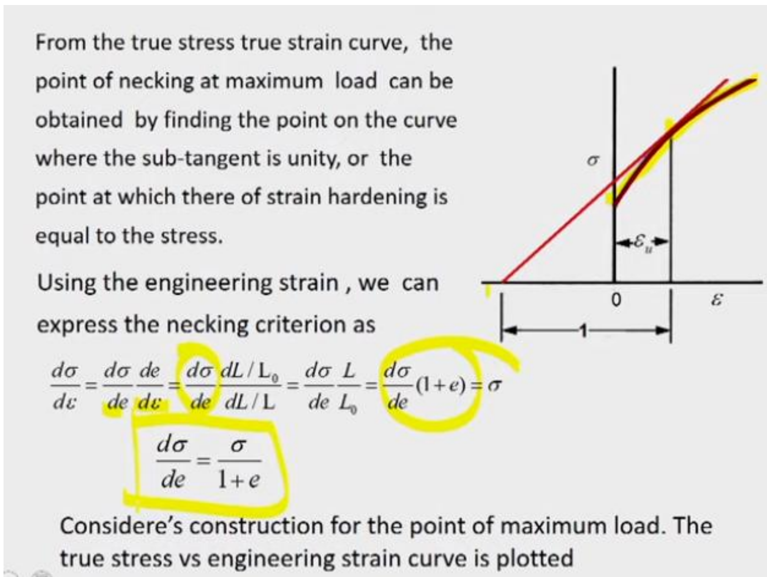

So from this, true stress true strain curve the point of necking at maximum load can be obtained by finding the point on the curve where the sub tangent is unity because if this was your curve flow curve so you find out you draw a sub tangent at which from there it is meeting strain axis at 1 okay so that is what. So that is the point at which but it is very difficult to exactly find out where it is you have to keep on doing a little bit of iteration and then only you can get it by physically measuring it.

So becomes very difficult so instead of that, instead of true strain curve if you just take the engineering strain, then we can explore the necking criteria's $d\sigma$ by $d\varepsilon$ is equal to we can write it $d\sigma$ by de into de by $d\varepsilon$. So that you can write at d deceleration and this is equal to dL by L_0 by dL by L, so that is equal to you can finally get this relationship $d\sigma$ by de into 1 plus e that is equal to σ or $d\sigma$ by de is equal to this relationship that is equal to your true stress divided by 1 plus engineering strain.

$$\frac{d\sigma}{d\varepsilon} = \frac{d\sigma}{de}\frac{de}{d\varepsilon} = \frac{d\sigma}{de}\frac{dL/L_0}{dL/L} = \frac{d\sigma}{de}\frac{L}{L_0} = \frac{d\sigma}{de}(1+e) = \sigma$$

$$\frac{d\sigma}{de} = \frac{\sigma}{1+e}$$

So that is the condition for this, it is called as the considere's construction for the point of maximum load the true stress versus engineering strain. So when you just plot that two stresses instead of true strain you plot the engineering strain then it becomes easy the from that point 1 plus epsilon u know it will give you the value from there if you draw the plot you can find out the stress the maximum stress or the point of instability, that is the point of necking or point of plastic instability you can always find it out from that point which we will be discussing the next lecture.