# Fundamentals of Materials Processing (Part- II)

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## Lecture – 01
## Introduction to Metal Working

Welcome back friends. We are in now going through part 2 of this course on fundamentals of materials processes. In part 1, as you remember, we went through solidification, fundamentals of solidifications and the other module was fundamentals of powder metallurgy. In this part 2 we will be again covering 2 different aspects of materials processing, fundamentals of metal working which I will be taking, 10 hour lecture on that and then there will be 10 hour lecture on fundamentals of thin film deposition which will be taken by Professor Anshu Gaur.

I hope most of you have gone through the first 2 courses, but if not, it is not a issue because, both of these are independent courses, you may go through those lectures; the NPTEL lectures, they will be available online you can go through them and understand the fundamentals of other 2 aspects. As of now, we will go through these fundamentals of metal working and fundamentals of thin film. So, when we are talking about metal working what are the things that we will study?

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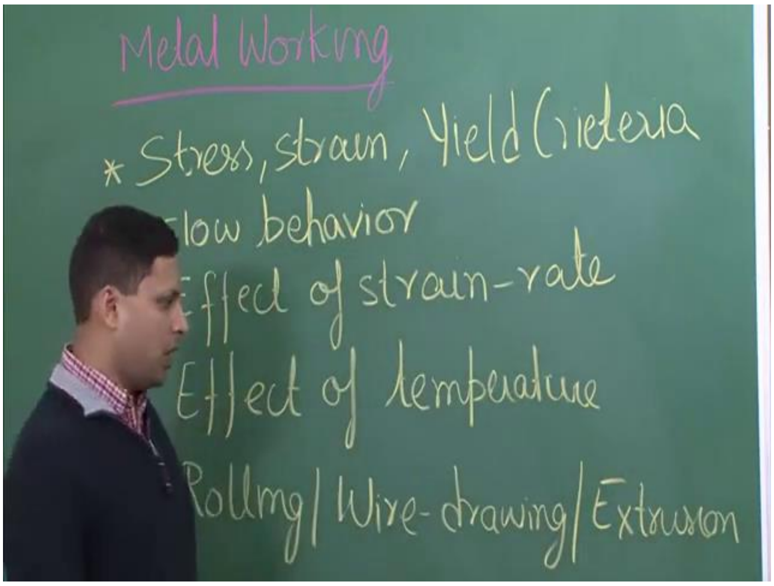

Let us draw down our small list of items that will go through. So here, so we will be going through fundamentals of metal working, what are those fundamentals?

In the most fundamental is of course, understanding about stress, strain and the yield criteria because whenever you are doing any kind of deformation which is larger; large fraction of processes that come under metal working, there your need to understand what is the yield criteria because we cannot simply define those in our original simple terms of tensile test and tensile; the yield plasticity from the simple unilateral tensile tests and therefore, when we take a look at stress strain, we will extend it further to understand yield criteria. Then will move on to understand flow behaviour again related to stress strain and related to yield criteria. Then we will take a look at understanding effect of strain rate.

You will realize very soon through the course that there are 3 very important parameters when we are talking about metal working strain, strain rate and deformation. These are the input parameters that you impose during the formation or the deformation processes and therefore, effect of individual, the combined effect all are these are important to understand. So, once we have the effect of strain rate will also understand the combined effect of strain and strain rate then we will understand the effect of temperature and the combined effect of all 3 and then we will take a look at; go through some of the simple models to understand the mechanics and through that we will go through some of these processes like rolling, wire drawing, extrusion. These will be our main topics or the main examples that we will use in understanding the mechanics the force requirement and so on.

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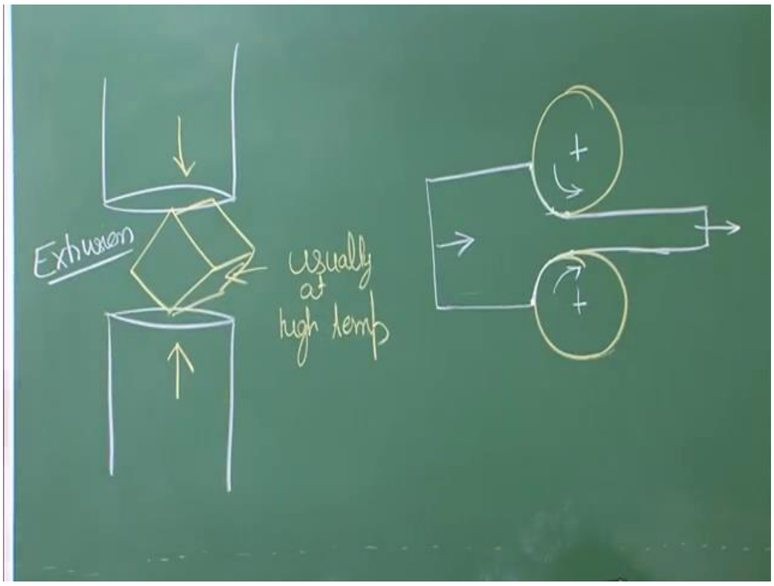


Now, when we say metal working, what are the examples that come to your mind? One of the most common processes, not most but some process that you must have heard of is something like this, can we guess what this is? Here you have 2 annuals which come together and you have a work peace in between these 2, let us say rectangular block like this and this is usually at high temperature and these angles are forced against each other.

This is extrusion, now extrusion you want to know, what is the strength or load at which this material will start to deform? What is the force because according to that you will determine, what will be the force that you will supply to these annuals, then once you know, then you will also need to know at what rate these annual should move because what will that determine? That rate will determine the strain rate. What is the strain rate because different material will have different properties at different strain rates now it is not only the strain that makes a difference? It is also the strain rate that makes a difference then why are we using high temperature? Why not at room temperature of course, one of the simplistic explanation is that at higher temperature you are able to deform the material easily.

But at how much high temperature, would you like to have it very close to the melting temperature that will require you to heat it to a very high temperature which is very energy consuming. So, all those questions need to be answered and that will be answered only if we are able to understand the relation between stress pain, the effect of temperature and the inter relation between these on the material, so this is one example. Another example where you would need to understand the fundamentals of materials processes for metal working is the most common take might have heard of in of all the metal working process and that is rolling.

We have 2 roles, from mostly 2 roles, you can even have more than 2 roles and you have a slab that is going in like this under slab going; coming out like this and these are 2 drums which rotate like this. Now once you look at it, it will look like a very simple process, but there are several intricacies over here, first what is the strain? Is the strain just in this direction or is this strain also in the in the longitudinal direction and not only that in most of these cases, we assume that the strain in this third direction is 0 which means that it turns out to be a plane strain condition and in the plane strain condition how are the different elements getting deformed? What is the strength, what should be the load that should be applied by these drums on to the material? Can it be thin down to any extent? All these answers will come only if we understand the fundamentals, not only that look at the velocity of the material of this sheet that is passing.

Now, the if this is being deformed and it is thinner out here then; obviously, the velocity at this stress, this part is much larger than the velocity at this part, if we assume that this part is twice the thickness of this, it means that the velocity here is twice that of this region which means that at this point, the material is moving at let us say V1, then at this point it is moving at V2. So, there is a continuous change in velocity from here to here, but the drum is moving at one single constant velocity and therefore, it would mean that the drum is slipping against the material at each and every point except at one point is somewhere in between where it is exactly the velocity of the drum is exactly equal to the velocity of the slab over there.

What does that lead to? That will lead to a lot of friction. How does that friction play a role? Is it good, is it bad? All those things we will be able to answer when we get through this through the fundamentals of this course. Let us look at still another example which is extrusion, now there extrusion can be direct extrusion, it can be indirect extrusion the one that I will draw over here is direct extrusion.

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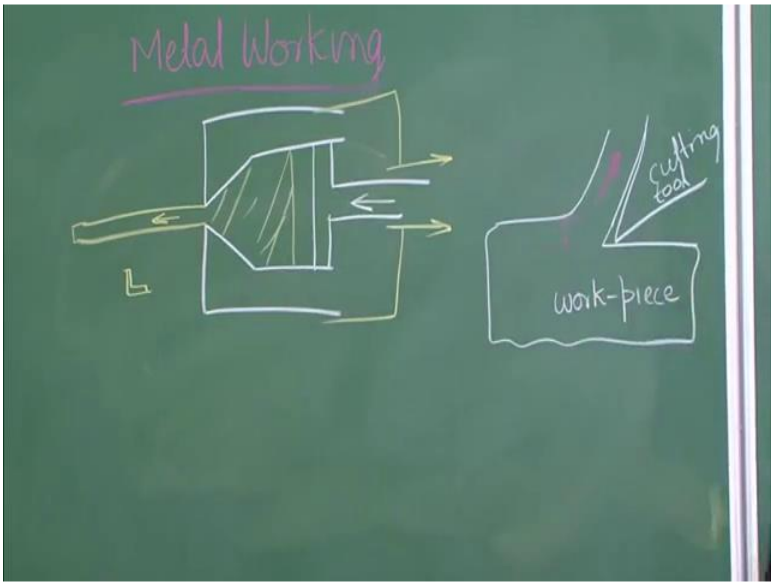


You have a die like this and inside you have a piston which moves like this and in here, you have metal which is forced through this orifice and you get longitudinal structure. Now this longitudinal structure can be of any cross section, for example, it can be a I section, you remember you having seen those L frames, the aluminium shaped L frames, this is how their manufactured.

They are extruded, now here this is direct extrusion, meaning the piston in moving in the same direction in which this part is getting extruded; however, we can have different shape or different configuration where when you press in this direction actually the material will also come out in this opposite direction. So that is called indirect extrusion and there are advantages and disadvantages of both of them and there are friction, one of the most important one is the friction considerations, but not only that, how much again the strain is required, what is the yield what is the strength at which or the stress at which the material will deform, it will start to yield or flow. Those things we will be able to again understand only if you are able to go through this course.

Now these are some of the deformation processes, but there is still one more process that you may not usually associate with metal working, but it is also metal working and that is machining. So, here I am drawing one particular example of machining which is plane strain machining, why or the lathe machining, here this is your cutting tool. So, this is called a single point machining, this is your work piece, there are several different kinds of machining process which all come under metal working and this is your chip that is forming out. So, this is your removing this part, this part is getting removed and this is also metal working, again not only how much load that will come on to the cutting tool which will determine what is its life.

But also the strain, strain rate and temperature will be different depending on what is the machining configuration and because of that there will be different micro structure on the surface leading to different properties and for that we need to be able to predict what will be the strain, strain rate and temperature.

So, one thing that we are able to gather from until this point is that there are 3 important parameters when we are talking about metalworking in most of these and that is strain, strain rate and temperature particularly during deformation and that is what determines the not only how much load is required, but also what will be the final properties of the material. That is what our whole course or these next 10 lectures will be rotating around.

Now before we move ahead it is important that we have or describes some classification for metal working.

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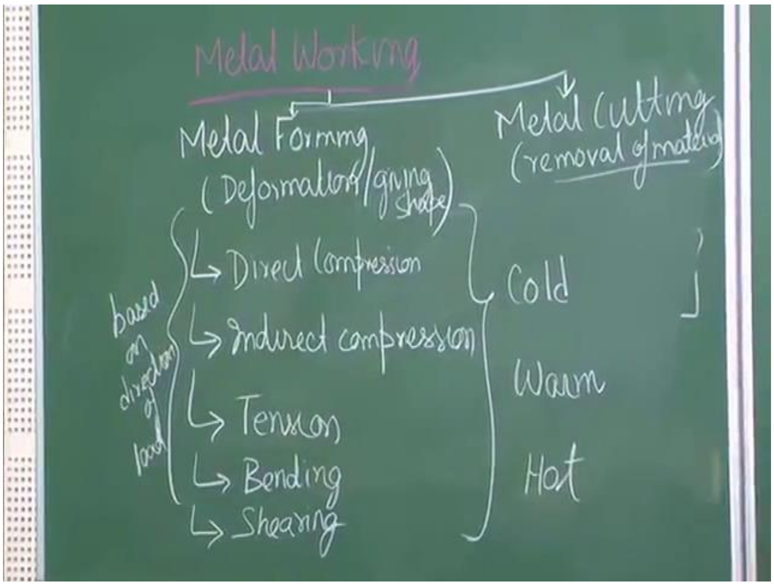


The metal working can be described in to 2 main groups, one is metal forming and the other is metal cutting or metal removal. So, all the machining processes like drilling, grinding, machining, all these come under metal cutting. So, you are involved with removal of material. In here you are always involved with some kind of deformation or giving or shape to the through the metal so, deformation or giving shape. So, these are the 2 broad classifications, but even under these we can further sub divide them into some more based on what is the direction of the force?

One of them is direct compression, indirect compression. So, this is basically describing which direction the load is working or the force is working on to the material because you are doing deformation or giving shape. So, you are applying some load or force on to it now which direction is it is it compression in the direct compression mode like in the extrusion that we saw or is it indirect.

So, like in the indirect extrusion that was the indirect compression, tension when your pulling something like our tensile test that we that we conduct or when your pooling a rode for example, in wire drawing, then we have bending, for example, sheet metal working that involves a lot of giving edges to the metal that involves bending and then shearing like cutting the metal. Cutting in the sense metal sheet; cutting the meal sheets when you are dividing it or taking off portion of it then you are shearing it and this is our most of the metal cutting processes like we said where your main purpose is to remove the material.

For example, you may be trying to make some chamfer and over there, you will cut or remove the material. So, you will be doing some kind of cutting. So, all those processes come under this. So, this is based on direction of load, now when we are doing deformation you will see that there are 3 main temperature zones people use and that has to do with the physical metallurgy of the materials because in these 3 different zones materials behave completely different and therefore, these classification of metal forming can again be divided into 3 different zones or temperature zones; cold, warm, hot and when I say cold, warm and hot, it is not at the absolute temperature for example, even if you cold or if we even if we roll led at room temperature, it is not cold rolling it is actually hot rolling.

Because it depends on the temperature at which the material melts. So, with respect to that we describe a temperature and divide it into 3 zones which are called cold, warm and hot temperature zones. So, this is one classification of metal forming and overall we have metal working in two different classifications metal forming and metal cutting. There is still one more classification for metal forming and which is based on what is the thickness of the material, for example: if you are dealing with bulk material like very large pieces where we have the main purpose is to give a shape then it is called bulk deformation and the other one is when the purpose is not to make or given a shape, but just to change the configuration like in sheet metal.

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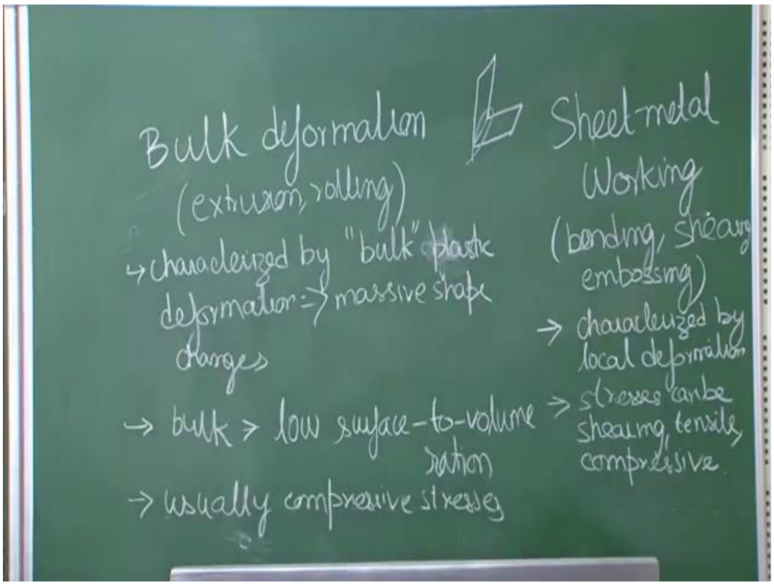


These are called sheet metal working and some of the examples, we have already seen for example, extrusion, rolling, etcetera, all those things that generally we relate with deformation or actually nothing but bulk deformation on the other hand sheet metal working involves something like bending operation. If you have a sheet metal and you want to give it a one shape for whatever reason or you want to have a emboss on the metal sheet then those kind of oppression, you are not actually changing the shape, you are just give changing the configuration. So, the main purpose here is changing configuration and something like bending, shearing, embossing, these are all related to sheet metal working.

If we where to define it then bulk metal; bulk deformation would be characterized by of course, bulk deformation which means bulk plastic deformation which implies massive shape changes and when we say bulk, what we mean is large or actually low surface to area volume ratio sorry low surface to volume ratio meaning for per unit volume, the surface has to be low on the other hand if we look at sheet metal per unit volume, surface would be very high because these are sheet, these are flat and out surfaces here usually compressive stresses is what is used usually compressive stresses are what are used.

Now, on the other hand when we talk about sheet metal working, this is characterized by local deformation. So, if you look at bending operation, what you would see? Sheet metal like this, it has been bent from a flat shaped into this. So, where is the deformation taking place? It is taking place only in this region. So, it is a very very localized deformation that we are talking about and therefore, it is characterized by local deformation, on the other hand if you remember, when we are talking about extrusion or rolling or forging on all are those whole of the material was actually getting deformed. So, the deformation was not limited to any local region.

And here is stresses can be mostly shearing, but it can as well be tensile, compressive, etcetera. So, these are some of the classification that is very commonly given in text books that you should be aware of and with that now we are in position to move on to more detailed understanding of some of those these aspects. So, let us start with stress and strain. So, now, every time we talk about stress and strain, we have; we always talk about stress and strain, when we are talking about deformation, but then we need to define it at some point. So, let us start with the definition now to begin with you must understand that there are actually 2 different definitions of stresses based on what is the parameter you are using, what is that particularly when we are talking about deformation?

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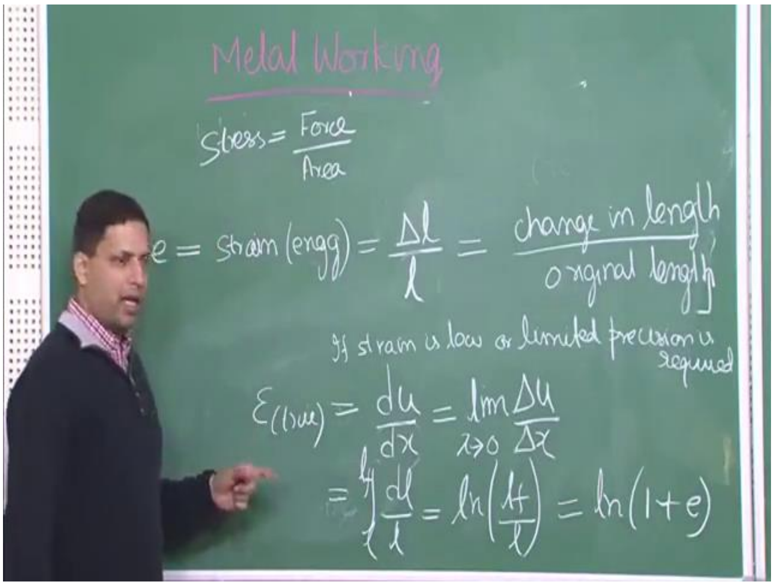


Stress is nothing but force per unit area, now here if you are deforming then of course, this area will change and if this area changes therefore, you have to determine or you have to ask whether you are talking about instantaneous area or you are talking about original area and based on that this is stress value would change and it will be called engineering stress or the true stress. But in order to define this, we will need the value of strain and therefore, I would first describe strain over here, strain particularly the engineering strain. So, I will write engineering strain again, we talk about change in length per unit l length, that is the usual definition given for a strain, but that is actually the engineering strain why because length that we are taking over here is usually the original length at the beginning of the deformation.

If you have done some amount of deformation then we say that what is the total change with respect to that original length at that was there at the beginning; however, at each and every instant of time during deformation, the length was also changing and therefore, the strain value at a particular instant would also be different because you will use a different l value and therefore, we need to be therefore, we have this 2 different definition of strain engineering strain and the true strain. So, this first let us look at our usual the more common and easy one which is the engineering strain. So, this is change in length by if you are talking about a very small amount of deformation or if you are not interested in very high precision then engineering strain is sufficient.

If strain is low or limited precision is required then you use this engineering strain, now let say you deform a material to some extent, then you again perform another step and you deform it even further and then you do such kind of multiple steps. So, in that case, you would be interested in finding out what is the total strain that has been imposed on the material assuming for the timing? Let us say that it is unidirectional strain of course, strain can also be multi axial. So, let us say for the time being that we are talking about uniaxial strain. So, what will be the total strain after each of these multiple steps? In that case, we cannot just take this value because as we saw at each and every instant, the strain was changing and therefore, what we represent at the end is not really the true strain.

And therefore, we need different definition for strain usually defined or in a particularly in our course, we will use this symbol for true strain. So, write now I will put subscript true. So, this defines instantaneous change in value. So, u is the displacement, x is the point at which this instantaneous displacement has taken place or if you where to approximate it this will become limit delta u by delta x extending to 0. So, this will be your definition mathematical definition of true strain. So, this is actually talking about strain at each and every point in time and therefore, it is also talking about change in the denominator which earlier we where assuming to be a constant value.

Now whatever strain we get is our actually our true representation of the strain and therefore, you can add it, if you have multiple steps and it can be very easily shown that if you have a unidirectional deformation, then this can be if l was the starting and lf is the final then this will become dl by l which is equal to ln, l f by l and therefore, you can again lf is the final length and lf minus l would be have a delta l. So, we can relate to the engineering strain and this will come out to 1 plus e. So, we are using e for the engineering strain and epsilon for the true strain. So, your epsilon or the true strain is actually natural log of 1 plus e.

Do not get scared by all these equations, these are just straight forward things, but when we put this in a formal way, it may look a little intermediate, but these are nothing scary about all these. So, you have all you need to remember at this point is that you have there are 2 engineer, 2 kinds of strains, the engineering strain and the true strain and if you want to a find the value of true strain, you can use this equation which is ln 1 plus e vary is the engineering strain and engineering strain we know is very straight forward to find delta l y l. So, that is the message from this. So, that was for strain.

Now similarly we will have 2 different equations for stresses - engineering stress and true stress.

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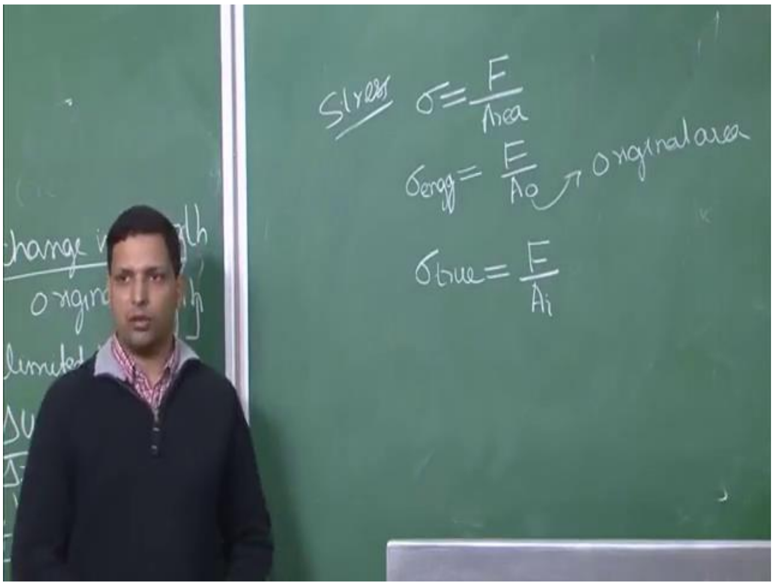


Stress if you remember is given by force by area, now again what we like we mentioned earlier that if your area itself is changing then it means that your stress should also be changing and therefore, if you want the instantaneous stress, you will have instantaneous area just like we, if you wanted to have instantaneous strain you needed to have instantaneous denominator value and that is why the true strain value was more accurate. If you take F by A naught, where A naught is your original area even of the deformation, if you take this then this gives you the engineering stress. So, this is your what? What change do we need to make? If we want to make a true strain or a sorry the true stress then we need to change it to F over A instantaneous.

We will come back to this equation again in the next class. So, just remember that there are 2 different strain and 2 different stress, we will come, we will show what will be the equation or realization for sigma true just like we had the relation for true strain, we can also have a relation for true stress. So, we will come back to this in the next class.