Machining Science - Part I
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Lecture – 01

Hello and welcome to the first session of the Machining Science course. Before we start the course, let me give you a glimpse of what you should expect from the course and what we are going to cover throughout the sessions of the machining science course.

In the introductory part of the machining we will be discussing what is machining and what is the place of machining in manufacturing processes; How the various surfaces are obtained in machining; advantages; disadvantages etc. Next we will discuss the plastic deformation and the stress strain in the introductory part and, we will also discuss the mechanism of plastic deformation in the atomic scale.

Next in the chip formation in machining we will look into the slip lines through which the deformation occurs and the chips are segregated from the workpiece. We will see the defects in the crystallographic structure of a material and how along the crystallographic structure or the plane or along the slip line the deformation occurs. We will also discuss elastic and plastic deformation in the atomic scale and the amount of shear stress necessary to affect the slip that.

Further discussions will be on the basic machining processes followed by the cutting tools and the types of machining: orthogonal and the oblique cutting - just a glimpse, what they actually are. Next we will discuss the types of chips: the continuous chips, the discontinuous chips and a type of continuous chip with the built-up edge formation. We will discuss the mechanism of the built-up edge formation, what is the physics behind it and how to prevent the formation of the built-up edge.

Next we will discuss the tool nomenclature, that is, how the tool angles are defined in different countries or different systems. For example: in coordinate system, in the orthogonal rake system, in the normal rake system and so on. Then we will see how we can convert those angles; suppose in India we are using the orthogonal rake system and we have a tool which is purchased from the coordinate system. So, how we can convert those angles and why we need to convert those angles.

We will discuss the forces occurring during the cutting process and how those forces can be modeled. We will discuss it through the Merchant's circle diagram, which you may be very much aware of. Now, from the Merchant's circle diagram we will be discussing the stress, strain, the strain rate and how to determine them analytically.

Next to that, we will be discussing the Lee and Shaffer model, that is another model, and the principal is different than what the Merchants have used. We will discuss the nature of the sliding friction and how the friction in metal cutting happens. What is the difference between the friction in metal cutting and the sliding friction. We will discuss Zorev's model for better understanding the issues.

We will discuss the turning process: physical parameters, forces, power consumption, material removal rate, time per pass and so on. Similarly, the same thing we will be discussing for different other processes like shaping and planing, for drilling, for milling and so on. We will discuss the forces in machining and how to measure those forces, what are the different kind of dynamometers that we have for turning, for drilling, for milling and so on.

In the tool wear and tool life we will be discussing the requirements of ideal tool material, why the tool wears out, what kind of wear happens and then what are the Taylor's tool life equation. We will explain what is the drawback of Taylor's tool life equation, how the Taylor's tool life equation can be modified and so on. After that we will be discussing the abrasive machining processes; there we will be discussions on the nomenclature of a grinding wheel.

Then through a thermal model we will discuss how the grinding process can be improved by controlling different grinding parameters and how to control them; chip length in grinding will be the next topic in the grinding itself. Here we will find out analytically how the chip length can be determined in case of surface grinding, internal or external grinding and so on. We will discuss the oblique cutting, particularly in terms of the forces, in terms of the angles and how they are different when the tool is inclined with respect to the cutting velocity as in case of oblique cutting.

We will next discuss the economics of machining. In the economics of machining we will see how to find out, how to estimate the optimum cutting parameters at which we will get the minimum cost so that the purpose of the machining is served, and it is not only to get the final product with the right kind of accuracy, shape, finish and so on, but with the minimum cost. And, what are those machining parameters or optimum machining parameters for different criteria, for example, for maximum production rate or for minimum cost or for maximum profit rate criteria and so on.

Next, we will look into the thermal aspects of machining, that is, how to determine the temperature in the machining zone; particularly the chip tool interface temperature. And what kind of different models exist and through those models we will be discussing the thermal aspects of machining. Finally, we will be discussing the surface finish; how the surface finish varies in case of the turning with a sharp tool or with a rounded off tool or in case of a milling or in case of grinding and so on. Let us now begin this course.

Now, let us see what is the place of machining in the gamut of the manufacturing processes. Before we start let me say that the idea of all the manufacturing processes is to get a final product, final product of right shape, size, accuracy finish and of course the cost.

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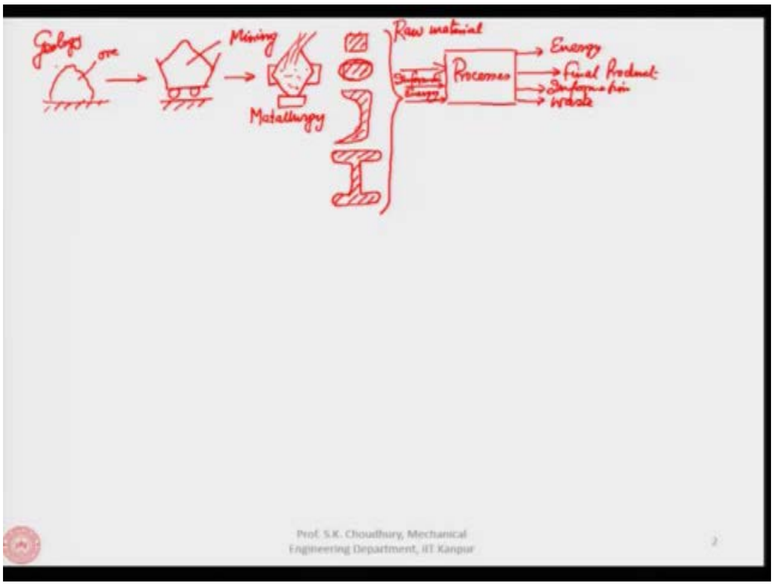

So, in that let us see how many engineering disciplines are involved. Let us say we have the ore here in the mother nature. This ore has to be found out, this has to be extracted. So, here we have the geologists, we have the geophysics people who are involved there. The ore, after being extracted, is transported for further processing. So, here the mining people have to be involved. After that this ore is being mined, it is transferred to the metallurgist people.

Let us say this is a kind of an oven and here the metallurgist people will further process the ore and they will make different kind of raw materials in the form of long rods, Channels of I-shape sections, U-shape sections etc. So, this is the raw material which the metallurgy people will be getting from the molten metal ore of which the mining people are supplying.

So, this is the raw material that we are getting and this raw material will be processed. Now, this will be going into some sort of processes which are actually the manufacturing processes. So, here we have the raw material, we have the information, we have the energy involved there. From the processes what you are getting is the final product, and along with that we are also getting the energy which is the input energy being converted to another form of energy and we are getting the information. Along with that of course, we are getting the waste. For example, in case of machining it is in terms of the small chips which is a waste, which is being removed from the basic workpiece surface.

So, as we can see that there is a whole series or whole gamut of the engineering disciplines which are involved in getting the final product from the ore, from the mother earth.

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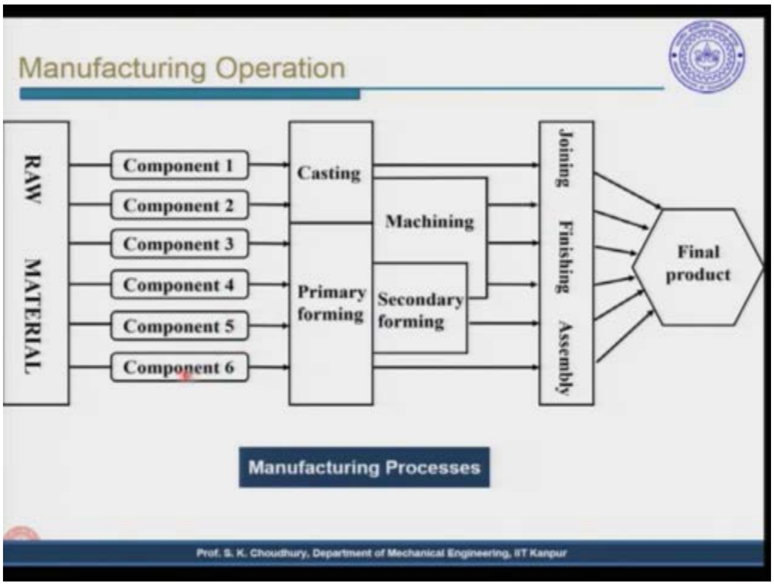

And, here let us see what is the position of the machining that will be studying. So, here we have the raw material as you can see at the extreme left, from the raw material we have the components: component 1, component 2 and so on. Now, all these components will be going through different kind of manufacturing processes. Now, these manufacturing processes can be either the constant volume manufacturing processes or it can be material additive process. For example, in case of welding, in case of additive manufacturing or it can be a material removal manufacturing process which is the machining.

So, it can be either casting or primary forming which are the constant volume, here the volume is not changed. Volume of the workpiece is equal to the volume of the final product or it can go through the machining or it can go through the secondary forming. Here all these are manufacturing processes including the joining, finishing, assembly and so on. So, the place of machining is here and all the components from 1 to 6 may not go through all the manufacturing processes.

For example, here what is shown is that the component 1 going through casting and after that it is going for joining. Meaning that there are various casting processes which can make the final product as you know or it can go through casting, then machining and then it can go through joining and so on. So, for example, here the component 6 can go through primary forming and then directly to the assembly. After that we will be getting the final product.

Here I wanted to show you the place of machining in the manufacturing processes. All of them are manufacturing processes - casting, primary forming, machining, joining, finishing, assembly and so on.

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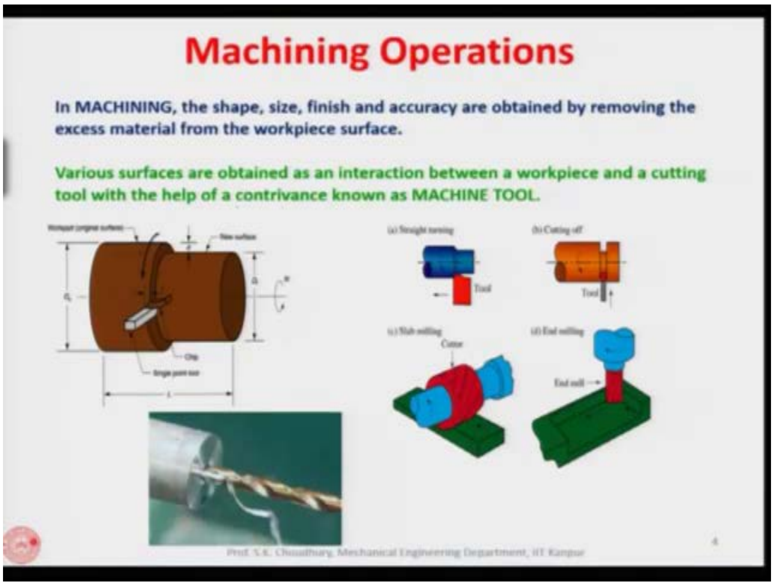

Next let us see how to define the machining, how we can say what is machining. So, machining is one of the manufacturing processes. Machining can be defined as one of the manufacturing processes by which we can get the final product and that would be according to the shape, size, finish and accuracy by removing the excess material from the workpiece surface. Now, this removal of the excess material from the workpiece surfaces is facilitated by a tool which we call as the cutting tool and a contrivance or a machine which we call as the machine tool.

Now, the different kind of shapes that we get during the machining, either a flat surface or a cylindrical surface or a tapered surface or a hole in drilling; We can also get different kind of slots by milling, end milling for example. So, these surfaces that you obtain will depend on different kind of relative movements between the tool and the workpiece. For example, if the workpiece is rotating and the tool is moving parallel to the workpiece axis, in that case you know that we will be getting a cylindrical surface.

If the tool moves not parallel to the workpiece surface, but at an angle, we will be getting a tapered surface. The tapered surface can be external tapered surface or it can be an internal taper surface. The flat surface we can get from the milling - either it can be a slab milling or end milling as it is shown here, or we can also get by turning. Let us say during the turning process if the tool is fed perpendicular to the workpiece surface, we will get a flat surface which we call as a facing as you know.

So, here we can see different kind of surfaces obtained as an interaction between a workpiece and a cutting tool with the help of a contrivance which is known as the machine tool. So, we have the tool, we have the cutting tool, we have a machine tool and there is a relative movement between the tool and the workpiece to get the different kind of surfaces.

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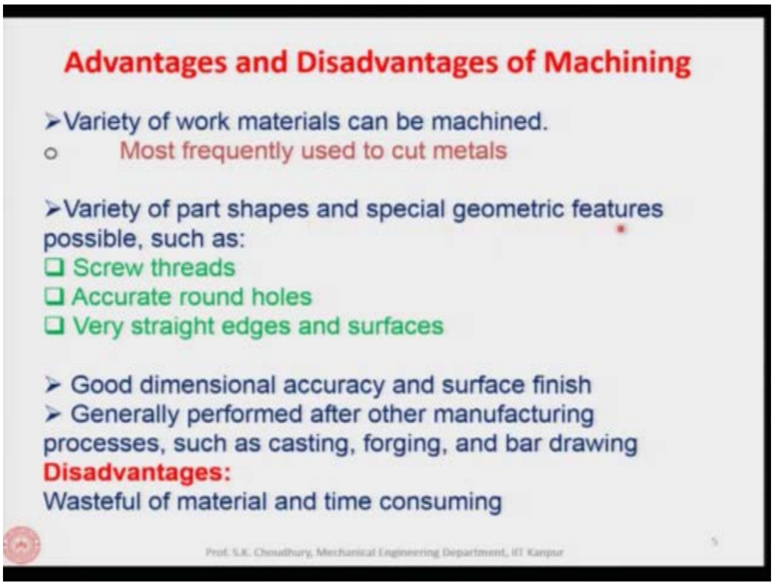

Now, what are the advantages? Why the machining is so important and one of the most important manufacturing processes? It is basically because the variety of work materials can be machined which is difficult in case of, let us say, metal forming or casting for example, as you know that if the shape of the final part is very complicated in that case the fabrication of the pattern for such casting process it is very difficult and removal of the pattern is difficult. Most frequently used to cut metals is the machining.

Now, the second point is that variety of part shapes and special geometric features possible such as for example, screw threads. Very precise screw threads are very difficult to fabricate using metal forming or the casting processes. Cold rolling can be used, but again the accuracy will not be as high as in case of machining. We can get accurate round holes which is very difficult through the casting or metal forming.

Very straight edges and surfaces may not be possible to obtain in case of casting and metal forming and that is why after casting and metal forming many of the parts go through the machining process to get very straight edges and the surfaces that can be obtained through the machining process. Good dimensional accuracy and surface finish which is a very special characteristics of the machining which may not be possible to get through the casting or through the metal forming.

Generally performed, as I said already, after other manufacturing processes such as casting, forging and the bar drawing to get better surface finish, get the straight edges and so on. Only disadvantage probably for the machining process is that there is a lot of wastage in the material; meaning that machining by definition itself it is the removal of excess material from the workpiece surface to get the shape, size, finish and accuracy. Therefore, material which you are removing in terms of the small chips that is actually considered to be a waste. So, wasteful of material and it is time consuming.

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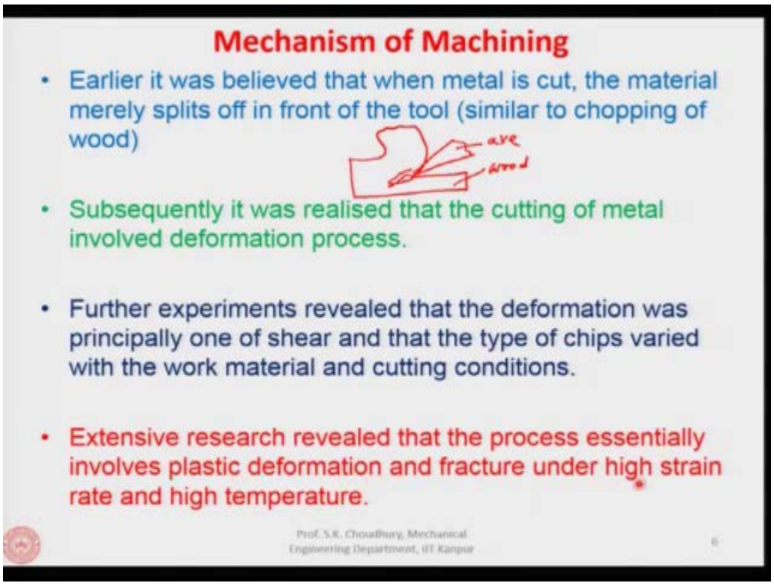

Let us look at the mechanism of machining, how we can explain it. Earlier in the very beginning it was believed that when metal is cut, the material merely splits off in front of the tool; that is similar to the chopping of wood. Suppose we are chopping wood, this is a wooden piece and this is an axe. So, earlier it was believed that there is a crack formed and the crack is propagating and that is how the material is segregating in case of metal.

Like in the case of the wood, they were thinking that the metal also merely splits off in front of the tool like an axe in case of the wood cutting. But in case of metal it does not happen that has been realized little later. And, subsequently it was realized that the cutting of metal involves the deformation process.

Further experiments revealed that the deformation was principally one of shear and that the type of chips varied with the work material and the cutting conditions. What kind of chips you will be getting that depends on the work condition; that means, the cutting parameters particularly and also depends on the work material.

For example, if it is a cast iron work material, which is a brittle material, you will get the chips which are different from if you are machining the mild steel which is a ductile material. In case of ductile material continuous chips are formed, in case of the brittle material like cast iron, chips formed are discontinuous. Extensive research revealed that the process essentially involves plastic deformation and fracture under high strain rate and high temperature.

This has been realized through hundreds of years that it is actually not the propagation of the crack like in case of wood chopping, but it is deformation and deformation is a plastic deformation. So, initially when the cutting tool interacts - starts interacting with the work piece, plastic deformation occurs. And, because of the plastic deformation the material gets segregated when the deformation changes from elastic to plastic and then it segregates from the workpiece surface in terms of the small chips.

Now, since there is a plastic deformation involves in the metal cutting, so, probably we should understand what is plastic deformation, particularly in case of the metal machining. The good example is the tensile test of a material through which we can understand the plastic deformation process.

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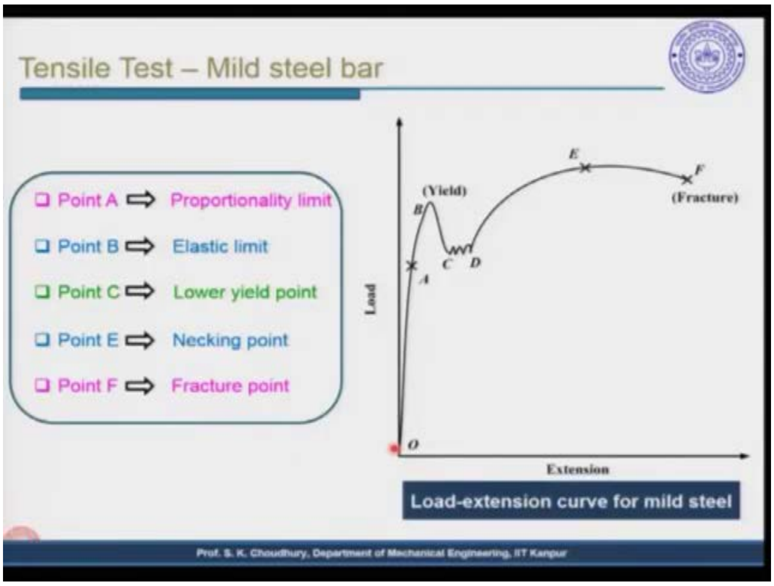

We have, let us say, a mild steel workpiece and it is being elongated and the force and the elongation or the extension and the load are being measured. So, if it is a mild steel workpiece, it is a ductile material. So, when we are applying the force, it is elongated up to a certain level, up to a certain point and as we know that up to this point the material remains in the elastic stage, meaning, that if we remove the load from this point, the material will come back to the initial position.

So, from O to A, this deformation is known to be the elastic deformation; there is no permanent deformation happening in the metal. So this point, point A is called the proportionality limit; meaning that here the load and the extension is proportional. Load is proportional to the extension and if the load is removed it will come back to the initial position. Now when the load is crossing the point A, the curve as you can see is no longer linear, meaning, here the proportionality is disturbed, but the material from the point A to point B is still remaining elastic.

From the point B the yielding starts and therefore, the point B is called the elastic limit; meaning that up to that point B it is elastic. The elastic limit is crossed as it is crossing the point B when the yielding starts and when the yielding starts, the load drops. And, there are very small changes in the load with the proper extension from C to D and therefore, point C is called the lower yield point. So, this is the upper yield point and this is the lower yield point.

Meaning, that here the yielding starts at B and this goes up to the C and then from D it goes in a very non-linear way and then the strain hardening occurs. So, from D to E the strain hardening occurs and the point E is called the necking point; I am explaining later what is necking point. After the necking point is crossed, anywhere between E and F, the material can get fractured. Material can get fractured means in terms of machining that the chip is getting removed from the body of the workpiece.

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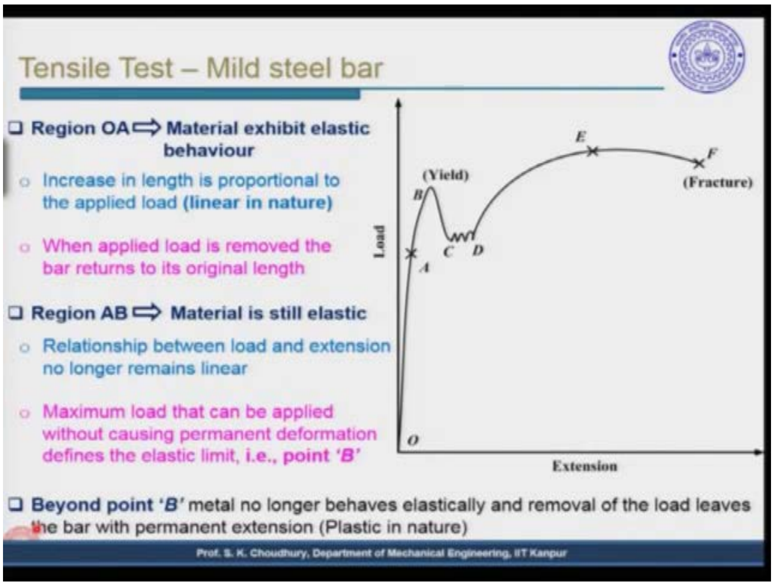

Now, let us see here. In the region OA, material exhibits elastic behavior. From O to A, increase in length is proportional to the applied load which is linear. Now, from A to B, this linearity is lost. When applied load is removed, the bar returns to the original position, I already told that. Now, in the region AB the material is still elastic, relationship between load and extension no longer remains linear, but the material is elastic. Maximum load that can be applied without causing permanent deformation defines the elastic limit - that is the point B.

Beyond point B metal no longer behaves elastically and removal of the load leaves the bar with permanent extension which is plastic in nature. So far what we said is that there is an elastic deformation. So, from this point the elastic deformation ceases, and the plastic deformation starts. Meaning, that the deformation which is occurring in the material is permanent; if we remove the load the material will not come back to the initial position.

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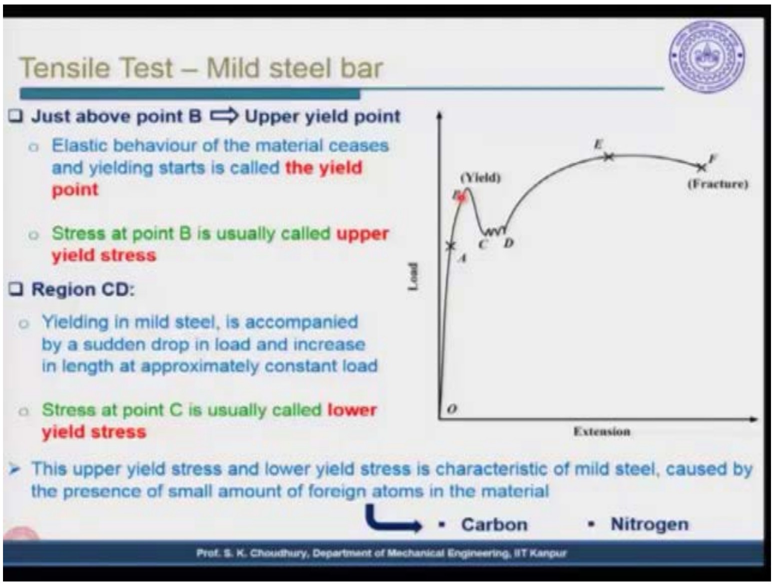

Just above point B, this is called the upper yield point, elastic behavior of the material ceases and yielding starts - this is called the yield point. Stress at point B is usually called the upper yield stress and in the region C-D yielding in mild steel particularly is accompanied by a sudden drop of the load; an increase in length at approximately a constant load. Stress at point C is called the lower yield stress. This upper yield stress and lower yield stress is characteristic of mild steel caused by the presence of small amount of foreign metals in the material. It can be carbon, it can be nitrogen and so on.

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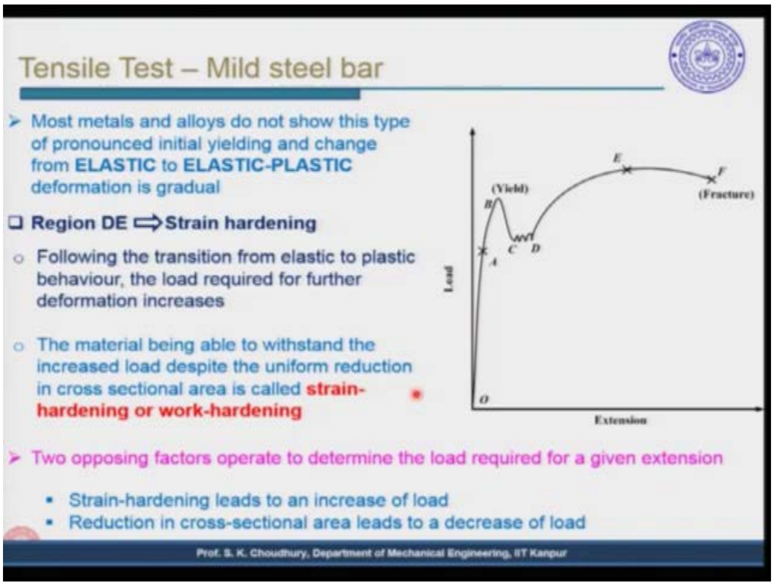

Most metals and alloys do not show this type of pronounced initial yielding and change from elastic to plastic, elastic plastic or plastic deformation is gradual. But, in case of mild steel this is the picture. Now, region D-E is the region of strain hardening; following the transition from elastic to plastic behavior, the load required for further deformation increases.

Now, the material being able to withstand the increased load despite the uniform reduction in cross sectional area is called the strain hardening. This is the definition of the strain hardening, that is the ability of the material to withstand the increased load despite the uniform reduction in the cross sectional area. We will discuss the remaining things in the next session.

Thank you very much.