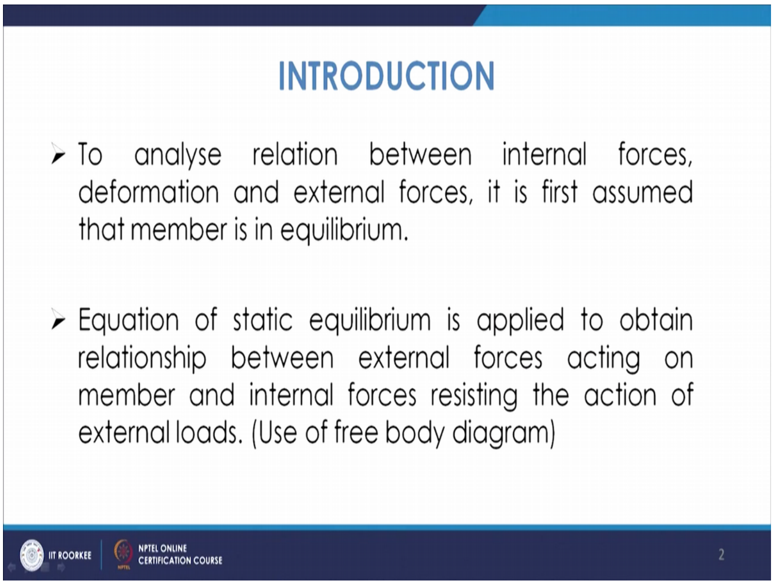
Principles of Metal Forming Technology
Dr. Pradeep K. Jha
Department of Mechanical & Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture-03
Behavior of Materials

Welcome to the lecture on Behavior of Materials. So, in this lecture we are going to discuss about the different behavior of materials because ultimately it is the material which is subjected to the different types of forces, especially when we talk about the metal forming processes, we have a mechanical I mean forces like compressive tensile or shear or bending or so. So, when you to know that, when the forces are acting on the body, how it behaves

Now, materials are of different type and it will behave differently. So, they are to be analyzed. Basically when we go to analyze the forces because once the force is acting on the body, then the body undergoes certain formation. At the same time you know, if you look at there will be internal resistance against the deformation are against the forces. So, at different place you will have the different you know the forces of different nature and in that way you have the definition of stress. And then that is measured in terms of strain or so, depending upon the materials property. So, in this lecture we are going to discussed about those issues.

(Refer Slide Time: 01:53)



So, to analyze the relation between internal forces deformation and external forces it is first assumed that is the member is in equilibrium. So, that is what I mean the purpose is to say that when we are going to analyze the forces, analyze the member which is under the action of various type of forces like internal forces; then deformation and external forces. Then first of all you assume that the member is in equilibrium. And for that equation of static equilibrium is applied to obtain the relationship between external forces acting on the member and internal forces resisting the action of external loads.

So, that is how basically when you have a body and when you apply the loads, in that case you have; in the inside of the body there will be resistance to it. So, if you look at if you remove certain part and if you look that how that is represented by, you know you have other system of forces because that is being basically you know resistant.

So, in that case that is how you see that equilibrium conditions are maintained. In that case you see that this is the set of equation which is or the you know force balanced equations or that way. So, that that is what it is. So, ultimately you draw a free body diagram. You isolate certain part of the diagram. You see that what are the forces acting on one part and from the other part you have the balancing off and then that way there is a free body diagram concepts. That is how the equilibrium concept is kept into the picture and basically that is how you analyze the situation.

So, do you must know that what is the distribution of stress. Basically we know that in normal terms, we are mostly concerned with stress. How to measure the stress? So, because everything we quantify in terms of stress values, we say that this much of stress is generated. And the material can sustained up to this value of a stress. If the stress value reaches beyond certain limit, then the material will may fail. So, the stress is nothing, but that is basically in a very rude sense and basically the internal resistance which is acting that on a certain area, when we defined that is the stress. Although stress is defined more appropriately in terms of tensor and that is defined at a point.

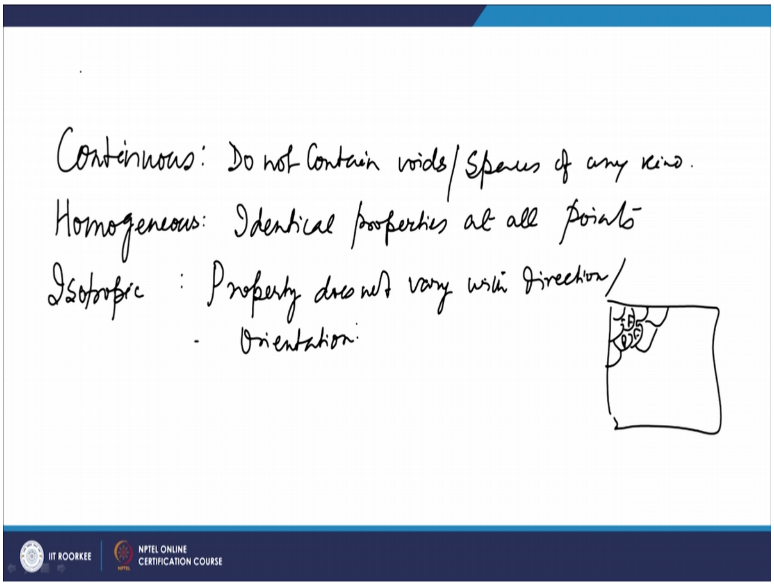
So, normally what we mean to say that when you apply the forces, then there will be internal resistance is acting and you know because of the forces, you will have deformation or you will have the strains acting. And once you a strain measured then basically you calculate the value of a stress depending upon where you are. If you are in the elastic region, in that elastic region basically the Hooke's law is valid. If you go into the plastic joint Hooke's law is no longer valid. So, you have other type of relations which talk about

So, basically what we do is normally, you measure the strain. Strain is the measurable quantity not the stress. So, strain is measured and once you get the strain distribution or strain at the points, then depending upon the I mean other relationships like if you are in the elastic region, then we know that stress is proportional to strain by a constant known as Young's modulus of elasticity

So, once you know that strain once you know the Young's modulus of elasticity, you can find the values of the stress. So, also the expression for the stress will be substituted into the equation of equilibrium that is what we discussed in the last slide that you have to have the member to be in equilibrium. So, once you get that expression then you put that into the equation of equilibrium and that way once you solve these equations you get, the quantity which you are interested into.

So, for the analysis of these conditions, you need to have certain set of assumptions. And the assumptions are like the body should be continuous, homogeneous and isotropic. So, what is what you what means bodies continuous? So, we can write that when we talk about the continuous bodies.

(Refer Slide Time: 07:01)



So, the conditions are the body should be continuous. So, what are the continuous bodies? The continuous bodies are the once which does not contain any voids or spaces of any type. So, they are they do not contain voids, or spaces of any kind.

Now, what is what does that mean when we try to analyze? When we are trying to analyze the equations of equilibrium and we try to analyze the behavior of the material? We assume that the material is does not contain in a void. Now this is not a very practically you know correct assumption, but for the analysis point of view you have to assume it; because when we cast the material or any material there are chances that there will be voids. There may be voids in terms of casting defects or there may be any space in between.

So, basically when you apply the stresses, you cannot assume; [vocalized- noise] if suppose the crosses an area is same or. So, you assume that there is no void. The property is completely so, the that metal will come later. So, you assume that the material is continuous. There is no void. So, that is because there was there will be void and that part will not support any load. So, in fact, if it has void, then the measure value of a stress has to be more because the void will not contribute in a bearing that you know resistance loading or resistance to the deformation. So, ultimately the effective area will be lesser. So, your stress value will be larger in other cases in other areas. So, in that case, we will have to have that kind of assumption. So, we assume that the material is continuous.

Next is that the material is considered to be homogeneous. So, what is homogeneous? So, homogeneous means it has identical properties at all the points. So, when the material is supposed to be having identical properties at all the points, then it is said to be homogeneous. Otherwise it will not be homogeneous. So, you assume that now this again is not consider to be practically completely true because when we talk about the materials at microscopic level. It is composed of a large number of constituent phases and they have different properties

Suppose ferrite and you know austenite or ferrite and perlite or so. So, everything has the different properties, but you cannot take it. If you if you do them the macroscopic analysis, then it is possible to see that, but otherwise when we do the metal forming analysis in that case, you have to assume because we are talking on the macro scale. So, and that scale you have to assume that because once you take certain volumes. Suppose you are talking about certain part. So, you have a all the different type of phases. So, you may have ferrite perlite and all that. So, in this so, this may be ferrite, this may perlite, this may be ferrite or so.

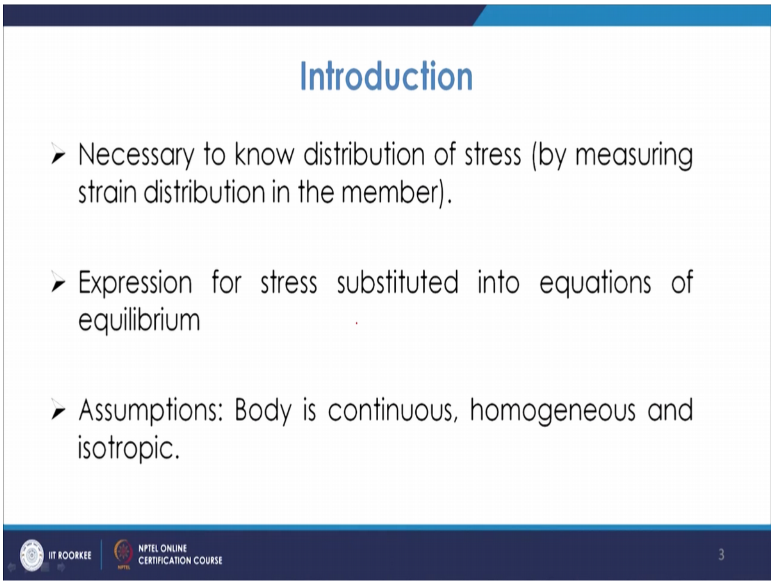
Now, when we talk about the macroscopic deformation, then this reason is nothing. You might have, if you take about certain point even point range or so, you may have very large number of these you know phases or grains. So, that is why we do not take these you know properties of the different individual you know phases or the grains into concentration and in that case we take it as I am you know the homogeneous one because if you take the macroscopic images if you take certain results. So, you will have identical type of you know properties. So, that is why you take the identical properties at all the points because we are analyzing at the macroscopic level.

Then the third point which is important which all the assumption, which is important is the isotropic; the isotropic nature means it has you know, the property does not basically vary with the direction or orientation. So, property does not vary with direction or orientation. So, what happens that many a times as we discussed that the you know anisotropic develops in the case of larger you know when we do the forming to a larger extent. Now we assume that the property does not vary with the direction or orientation and based on that we analyze. So, end this assumption has to be taken because otherwise you will have to an isotropic taken into concentration.

Now an anisotropic develops in certain cases because when we try to orient the grains in a particular direction. So, certainly the isotropic properties are little bit you know changed. But then we assume that the material has the isotropic nature. So, those, these are the three assumptions and do this we keep in mind while dealing with these situations, while dealing with the metal forming analysis and while, we deal with the properties because we have the many constitutive relationships and you have to have the you know use of these relationships at different points or in the different conditions.

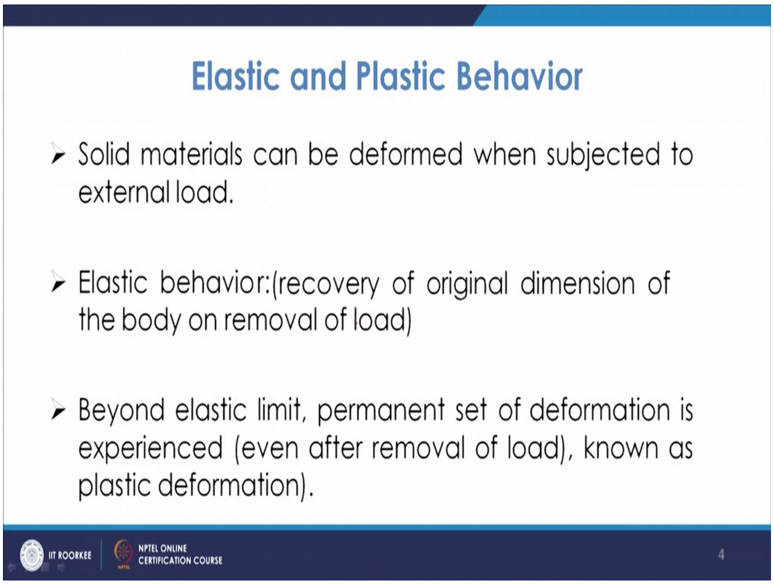
So, these assumptions are basically require to be valid, as we told that you have different; you know grains the orientations may be they different crystallographic orientation may be different. So, practically it may hamper, but when we talk about the macroscopic scale. We assume that these properties are basically you know these assumptions are required to be valid.

(Refer Slide Time: 14:22)



So, this is the assumption when we deal with the metal forming technology.

(Refer Slide Time: 14:26)



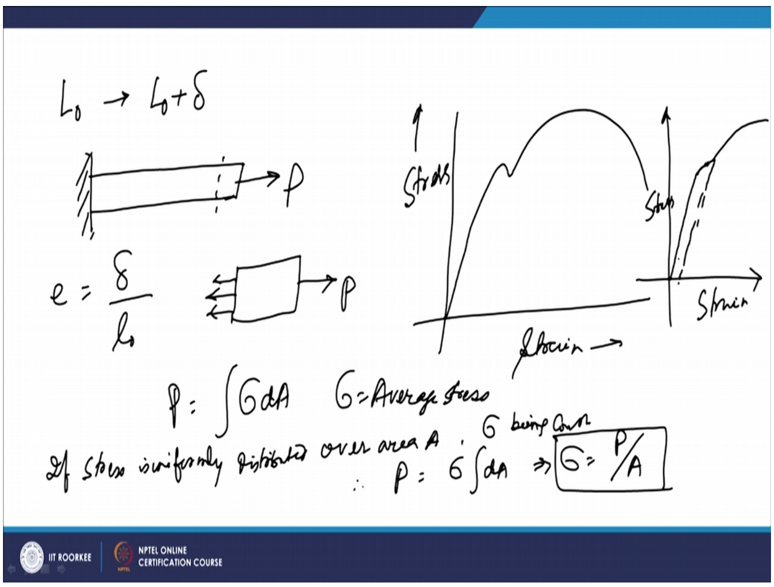
Now, we talk about the elastic and plastic behavior of the material. So, as we know that the material in this case, in the case of metal forming technology, we talk about the forces which are applied on the body and the force will create or cause the deformation in the body.

Now when we apply the load or the force, then the deformation may be in the elastic range or it may go in to the plastic range. So, the there are two way the material behaves; one is the elastic behavior and another is the plastic behavior.

So, we all know that what is elastic behavior. Basically when we are going up to the elastic limit and I mean in a brutalist or in a rude way, we tell that because in the elastic when we go to certain range or when you go to a stage where there is deformation and when we remove the load; in that case the material comes again or specimen comes to comes back to its original position.

So, that is the elastic condition. So, that is what recovery of original dimension of the body on removal of load. So, that is your elastic condition and elastic behavior of the material. And then and once you go beyond certain limit, then there will be permanent set or deformation is experienced and that is even after the removal of load. So, even if you remove the load then it is still that permanent set or formation is remaining. So, that is known as the plastic deformation.

(Refer Slide Time: 16:39)



So, basically when we talk about the elastic ranges. In those cases, what happens that you know you to talk about different you know tensile stress strain curve. By this you can have the you know elastic and plastic behaviors representation; so normal typical tensile stress strain curve. So, this is your stress and this is your strain. So, what happens that we know that once you go up to this point; then if you leave, then it will be coming back to its original position.

So, there will not be any permanent strain. Otherwise once you go beyond that, then there will be permanent set. So, depending upon that you have permanent offset, so some percentages kept and then after that if you go in these reason, then there will be there will always be some permanent deformation remaining. So, so that is your plastic range and one is your elastic range

Now, when we talk about the value of stresses and strains, the average stress and average strain is normally calculated. And as we discussed that we have elastic limit as to elastic limit, you have elastic behavior and beyond that you have the plastic behavior up to; in the plastic region you have you know wherever the stress is proportional to strain you have the Hooke's law valid and after that Hooke's law is not valid because stress is not linearly proportional to strain. So, the slope of the curve will be the Young's modulus velocity like that we proceed and otherwise you have the you know. Once you go beyond that you will have different set of relationship which basically come into picture.

So, when we talk about these stress or strain. So, in those cases what we see normally stress is nothing, but when we apply the load, then at any section you have the resistance acting. So, so for example, suppose you have a member and this is the member and then you apply a load P to it. So, then what happens earlier you had the length of initial length was L naught and then that changed to do L naught plus delta. So, that is your change in length. So, you had the initial length. Suppose of up to this and then this is a length that is delta which is removed. So, basically delta is the change in length and then, we define the engineering strain e as change in length upon original length. So, that is what it is. So, this is your engineering strain what we defined that to be.

Now, what happens? As we discussed that when we talk about the calculation of stresses, then what we do is you have the element and this element we are stretching with the load P and then, now what we see is that there will be resistance against these forces at this particular section. Now this is the, here the resistance which is acting on this area. So, that the load is per unit area that is; so basically this which is acting. Now the average stress multiplied by this area. Basically average stress is acting on this area. Now stress may be different on all the different you know points

Now, if the stress is normal to the cutting plane and so in both cases, if sigma be the stress. In that case you can write that P will be summation of sigma d A. Now if so here sigma is the average stress. We call the sigma as the average stress and if the so, sigma is average stress and that is you know integrated to that area that should be equal to the P and if stress is uniformly distributed over area A. So, in that case and if say sigma is basically constant in that case, so what will happen? And if sigma constant, so what will happen? P will be sigma d A; so, sigma being constant, so sigma will be P by A. So, that is what we normally tell

Now, stress normally will not be uniform over the area A. So, basically this is the representation for the average stress as I told that when we talk about the stress with that we will see in the latter classes. So, it will be defined at the points. Now if you we assume here, this is normally distributed over the area A and in that case we have taken the A as a as sigma being constant, but then if you have the different points where you calculate the stress at all these different points and depending upon its orientation or so, the stress is calculated.

So, what we see that you have the for the stress to be uniform absolutely. Your every longitudinal element must be you know strained in the same amount because as we know that we measure the strain and based on the strain you calculate the stress. So, there will have to experience the same amount of strain and then you use the Hooke's law to find the amount of stress what we get.

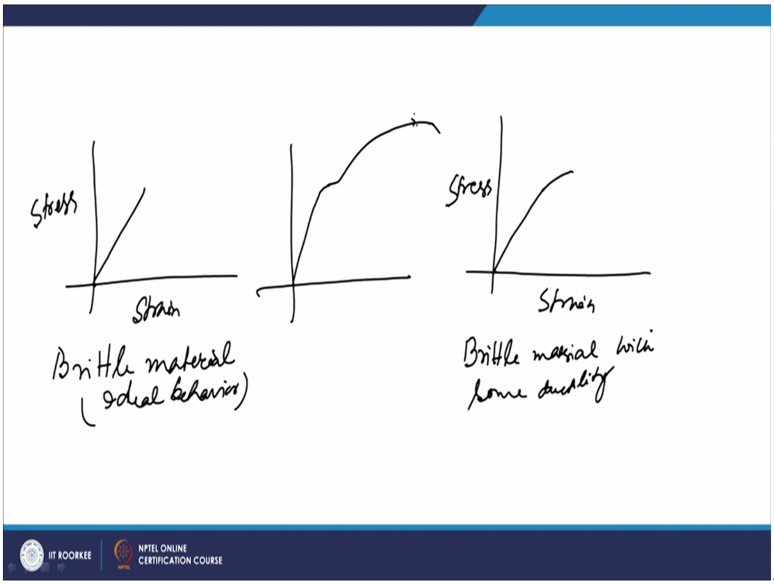
Now, we know that in the range of the elastic limit, your Hooke's law is valid; I mean up to the proportionality point and then in that case you calculate the value of this stress by using the you know the value of the you know Young's modulus of elasticity, the property of the material and that way stress is calculated.

Now if you talk about typical stress strain curve, now you have different results as we told. You have the elastic region where the Hooke's law is valid, then you have you know, further once you go beyond the elastic region. In fact, when we look at the you know stress strain diagram, you will go up to certain point where it is the linear variation of the stress and strain. So, this is where the slope is valid and then there will be some non-linear variation

So, up to here also if you leave, then the material will come back to its original position. And then after that you know after that when it goes, so then once you leave from this point latter on then it goes into the plastic zone. So, you have a zone of linear one where the stresses so, this linear zone on when we talk about. Now here the slope of the this curve in this zone that will tell us the value of the Young's modulus and then you have a zone where still it is elastic, but you know that that is not the linear. This linear region is valid and then you reached at a point.

So, then you reached at the point and here if you go, then you have you are going into the plastic range. So, you have some plastic deformation which is known as the yield point where you have some you specify certain strain and so, that to you say that now it has it has yielded and after that it is going into the plastic region. So, that way you have elastic as well as plastic deformations defer plastic behavior of the material under the different conditions.

(Refer Slide Time: 26:01)



Now, what happens this is normally typically the stress strain diagram of a ductile material. So, if you talk about the different behavior of materials, now the materials may be different and it will behave in a different manner. Now if you talk about the ductile materials, as we see that in the case of ductile materials, you will have appreciable deformation whereas, if you talk about the brittle material then in the case of brittle material, the it will go like this and then it will break. So, ideally brittle material will behave like this.

So, if you have stress if you have stress and strain like this and the material will fracture here. It we will not have any appreciable deformation in such cases. So, this is brittle material. This is ideal behavior. Now if the brittle material may have some amount of ductility. So, in those cases, you will it will go like this and then it will be somewhat showing something. So, it will be the brittle material with slight amount of ductility.

Now, the thing is that in case of engineering applications, you need the ductility because when we talk about the brittle materials, normally they are said to be failing in a catastrophic way. So, as you see that in these cases, as you increase the load the stress value is increasing and at this point, it is simply going under fracture. Whereas, in the case of ductile materials, there will be yielding and then the cross-section will go on decreasing and then slowly the material will fail.

Now, in the case of you know brittle materials, what happens that normally you have the presence of cracks or notches or so. Discontinuities are there because of which the cracks are there and when you are putting the load; when the load is increased, then the stress will be increasing and at one point of time, it will fracture. So, it does not you no give any indication.

Now in most of the cases whenever there is failure, whenever you have the presence of notch or stress concentration ranges then in both cases at that localized point. The stress value becomes higher the localized build up of this stress will be increasing. And then wherever you have stress concentration the crack may be formed and then, the crack will try to propagate and basically in the case of brittle materials.

When the presence of crack is not that way even essential because if these cases the yield strength and tensile strength of the material are normally same. If you look at this stress strain diagram, here in this case says the yield strength and tensile strength is same whereas, in the case of which you look at the normal ductile materials which will go like this. So, this will be your yield strength whereas, this will this will be your tensile strength.

So, in these cases yield strength and tensile strength is different whereas, in the case of brittle material your yield strength and tensile strength they are same normally same because the material starts you know break their itself.

So, you know brittleness otherwise is you cannot say that any materials in terms of absolute brittleness or ductile you know ductility because again the material behaves in a brittle manner or a ductile manner that depends upon some other conditions also and one of the one condition is the temperature. So, if you see the, if you increase the temperature and sometimes the brittle materials also behave in a ductile manner or if you decrease the temperature the ductile material behave in a brittle manner.

So, so that is why there is transition of these properties also ductile to brittle that is known as ductile to brittle transition behavior again that is one property because you need to you need that the material should behave, now material should fail in ductile manner. And if the temperature is very less in that case the material may fail in a brittle manner

So, if it is fail in a catastrophic manner, then many A times there may it may lead some dangerous consequences. So, that is normally seen in the case of the places where the temperature, suppose you go to the region of Kashmir or in the very high altitude area where the temperature is very very less. And if the material properties not altered in that case, the normal materials may which are otherwise ductile. They may behave in a brittle manner and they may. so appreciable deformation.

So, basically the main thing is that when you have a appreciable deformation, you know that it has yielded. So, so you can you know take precaution that itself, but in the case of brittle materials; you cannot take precaution because its yield strength as well as tensile strength both are the same. So, so that is how you must be knowing. So, that is how these two materials behave while they are being subjected to the loading conditions and while they are way being failed.

So, again the material, I mean you know they may one is which is you know ductile or which is brittle in the tension, that may be ductile under the hydrostatic condition. So, hydrostatic condition is another condition which may be you know many times may be applied or maybe you can say that this is hydrostatic condition where because. So, so that way you have to analyze the situation you have to see that how the material has to be behaved.

Thank you very much.