Principles of Metal Forming Technology
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Lecture – 04
Failure of Materials

Welcome, to the lecture on Failure of Materials. So, as we talk about the materials in the case of metal forming they are subjected to loads and under that action they are being deformed, there is plastic deformation, there is failure. So, the failure maybe in different ways and in this lecture we are going to discuss about the different modes of failure under which the material may fail and we will be talking about them in a little bit of detailed manner.

So, the machine elements which are under the action of loads; They are subjected to you know various kinds of you know stresses and in that process if they fail or there is break down so in the following manners there are basically categorization of this type of fail in three ways.

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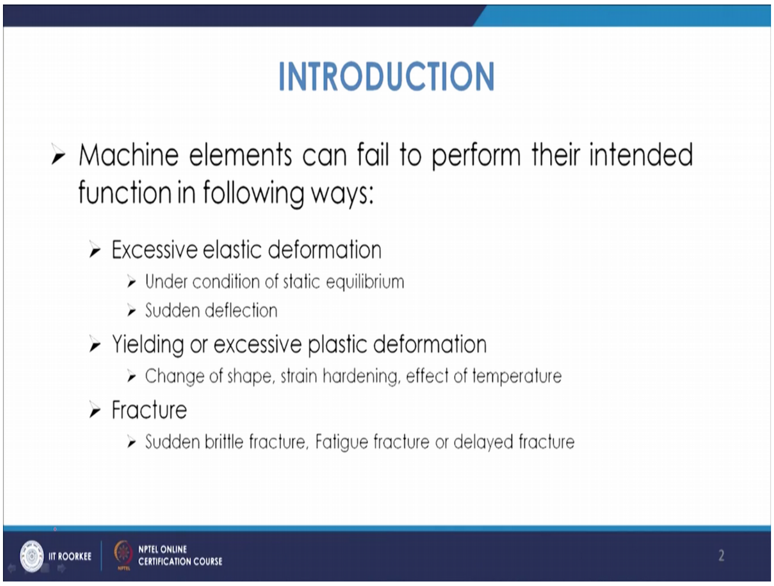

One is excessive elastic deformation So, when you have excessive elastic deformation you will have the two conditions that is under the condition of the static equilibrium you have and then one is the sudden deflection that is when we put a load suddenly impact load or so, buckling is the example of such type of failure.

Then you have also the yielding or excessive plastic deformation because here when we are putting the load and then it when it goes in the stress value reaches beyond the yield point, then you have the plastic deformation starts and in that case that is also a kind of failure of the material. And in that you have the effects like you have the there is change of the shape of the material, the material you know the element of the material changes its shape.

Similarly, you have the parameters which are important are the strain hardening and then you have the effect of temperature all these are there in that. So, that we will discuss and then you have the fracture also so, the fracture again that is categorized under the sudden brittle type of fracture, then fatigue fracture or the delayed fracture.

So, these are normally the different you know ways by which the machine elements fail and we will see that how you have you will discuss about it.

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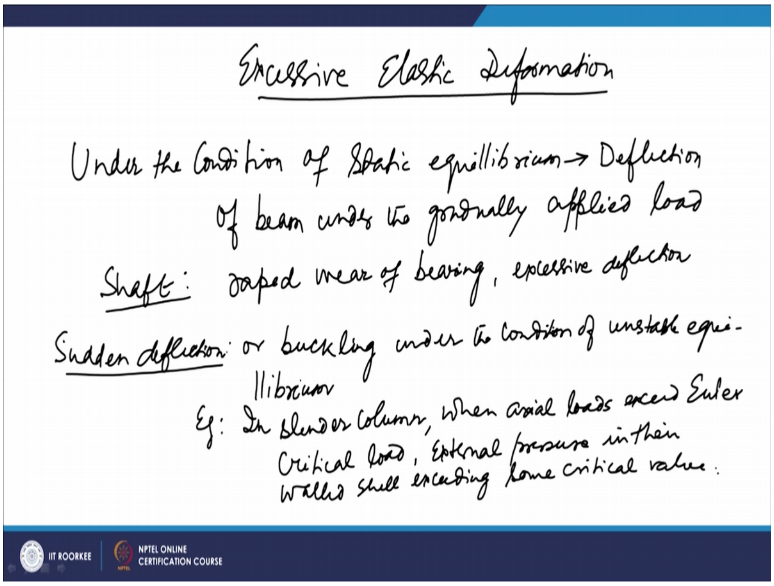

So, the first case is the you know excessive elastic deformation and in that there are two ways. So, if you talk about excessive elastic deformation so, in that there are two things one is under the condition of static equilibrium. So, that is under the condition of static equilibrium and you can have such you know cases, where if suppose there is a beam and you have the load. So, so there will be deflection in the beam under the gradual applied load so, that this is like deflection of beam under the gradually applied load.

So, in such cases what happens that you have to certainly set a criteria that what should be the maximum deflection at which you assume that the material has failed, because here the load is basically gradual and then you have for this actually there may be many conditions under which such fails occur. And suppose you have a shaft and so, shaft is an example of a such kind of deflection and under that you have so, that is under certain load and the reason may be suppose you have a shaft.

So, the shaft may be you know too flexible. So, in that case if it is too flexible then there will be a rapid rate of you know wear. So, that is because of the excessive deflections. So, you will have rapid wear of you know bearing, ok. So, I mean if the shaft is there and if you have the deflection of the beam in those cases you will have the rapid wear of bearing. And then excessive deflection and in that case the making parts which are closely making parts so, that may be by you know interacting with each other and there may be damage to the shaft also. So, this is the example of the condition of static equilibrium where you have gradually applied load and there is deflection.

Then you have also the sudden type of sudden deflection. So, one is one of the cases are the cases where you have gradual deflection another case is cases are the sudden deflection. Now, the sudden deflection you can take the example of buckling or so, where in the so or buckling under the case of under the condition of unstable equilibrium. So, you know normally it happens in the case of slender columns where the length is too large and when the actual axial loads are basically exceeding the higher Euler critical load or the external pressure against a thin walled shell which is exceeding a critical value.

So, normally you can say that you can in slender column when axial loads exceed Euler critical load or, you may have also the example of suppose if you talk about the thin walled shell. So, in that if you see that the external pressure if you have thin walled shell and you apply the external pressure then that also exceeding certain critical value; So, external pressure in thin walled shell exceeding some critical value.

So, these are the examples of you know excessive elastic deformation and they are categorized under the you know under the you know condition of this elastic deformation and in these cases the failure will be controlled by the moral of electricity because you are in the electric elastic range. So, the failure will be controlled by the moral of electricity not by the strength of the material. So, normally what we do is in such cases you try to increase the stiffness of the material and that can be done by changing the shape or by the cross section. So, you must have you know seen the cases like I section or channel section you when you study the strength of material in those cases we talk about these properties, in that we know that by taking the diffrent you know sections where you increase you know its resistance to buckling or so, so that can be the you know remedy under such cases.

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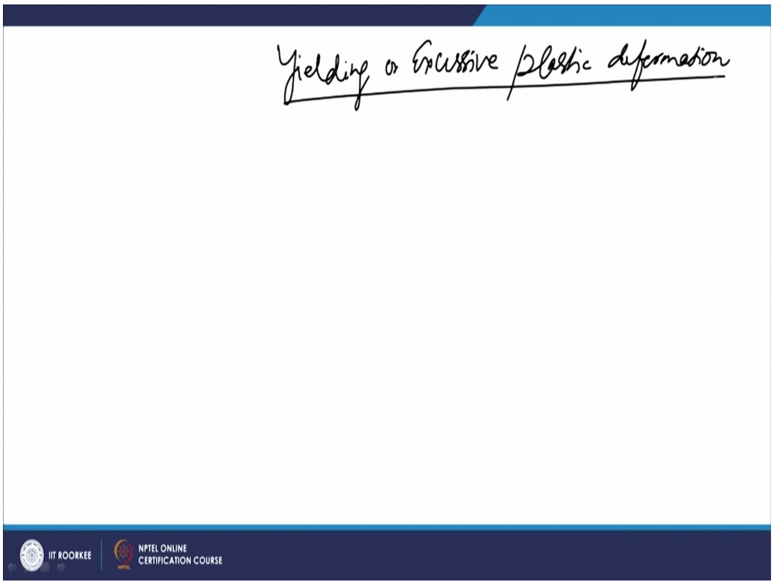

Now, the next the second point is the yielding under excessive yielding or excessive plastic deformation. So, that is what I mean we are going to discuss mostly in the case of material metal forming, normally we are concerned in the this you know type of failure where the material yields and goes under the plastic deformation.

Now, what is yielding? Basically, once you have yielding then that will lead to the permanent shape change. So, now, what happens that in such cases you have the metal for the metal if you if it is done at the room temperature then the metal undergoes strain hardening. So, metal strain hardens as the it defends deforms.

So, you have basically complex state of loading and you have suitable failure criterion is basically set in those cases because you are in the plastic region, you have a set of stress to which has to be you know formed which has to be known and then you have to choose the different failure criterion in those cases.

Now, in such cases basically temperature is also you know important. So, when the temperature is basically you know larger in those cases the strain hardening no longer exhibited and many a times the metal will continuously deform at constant stress. So, you might have seen certain you know cases like in the case of turbine blades or so, when your temperature is quite high then this strain hardening concept is not valid.

So, in those cases what happens that the material will constantly deform even at constant value of a stress and in that type of deformation is a time dependent type of yielding and that is you know that is a phenomena known as the creep. So, in those cases the stress is not proportional to the strain. So, that is what normally you have the cases in the case of yielding or excessive plastic deformation.

So, once you may have the effect of you if you do it below and also you may we have studied about the hot type of hot forming or you have cold forming. Now, in the case of the temperature being smaller one you have the strain hardening, when you go to the temperature to too high in those cases the creep phenomena comes into picture.

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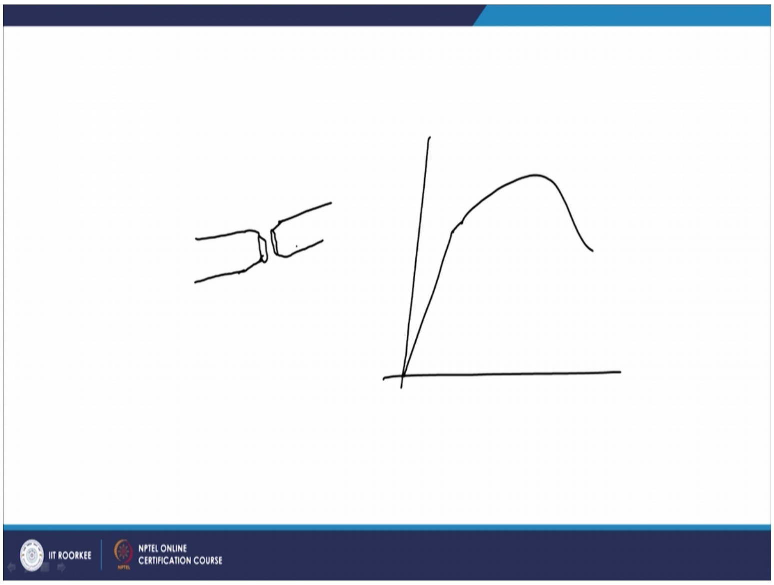

So, we already discussed about the yielding in such cases and for typically ductile materials as we know that in normally you have a the stress strain curve if you look at so, it goes and then it comes like this. So, what happens that this is up to the this point of proportionality and then you wants to you come here this is up to this you have the elastic limit.

Now, the thing is that in the case of the yielding under this plastic deformation if you have the ductile materials and if you are seeing the cross section, the cross section will start changing after the yield points. So, there will be deformation started and in this cases you have cup and cone type of structure fracture because at the point of yielding. Once you look at this specimen so, it will somewhat you know it will be decrease in the dimension and then so, the this way the two portions will be look looking at there will be decrease in the dimension at the point and then slowly the they will be getting a part and then they will fail.

So, such is the mode of the failure in the case of ductile materials. We already discussed that in the case of brittle materials there is no such warning. So, that basically you do not get any warning and the cark crack initiates and then it fractures. So, that is the case in the case of brittle materials. The thing is that when you have the temperature changes when I have or you have the loading rate of loading conditions changes the mode of the failure becomes different.

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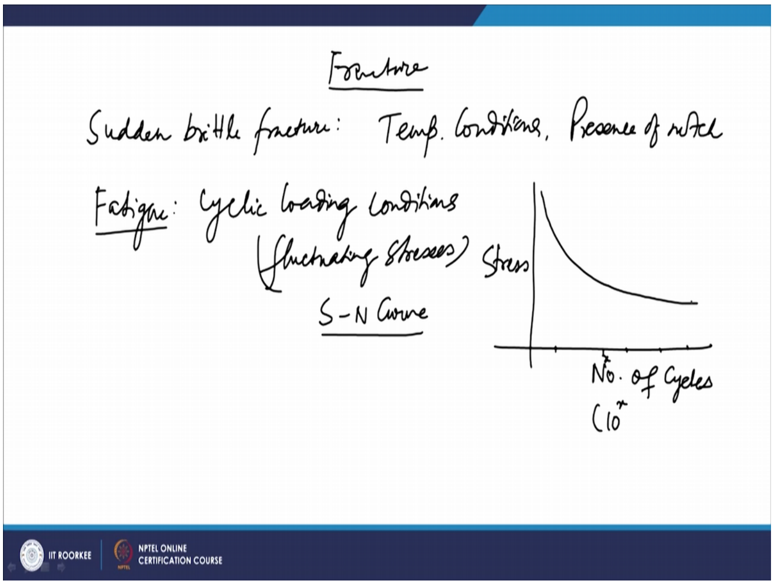

So, the third type of failure or I mean third case which we were discussing it was so, if you look at we were discussing about the fracture and the fracture can be you know seen in three ways. So, if you talk about the. Fracture mode now, the metal fractures in three general ways one is the sudden middle brittle fracture. So, that we know that when we talk about the brittle materials they do not give you any indication. So, that will not give you any indication and there with without any appreciable deformation the fracture.

Now, this is also true for some of the ductile materials also. As we discussed that it is not a you know you cannot say the concretely something is brittle or ductile depending upon the conditions it the failure mode may be brittle or the ductile. Now, even the ductile material may behave in a brittle manner there may not be any appreciable deformation prior to fracture. So, the case may be because of the you know the conditions of temperature. It may be because of the presence of complex state of stress.

So, in those cases you know there may be a cases where if you have suppose notch so, may be because of the temperature conditions or presence of notch. So, even presence of notch that leads to you know presence of complex state of stress and in those cases also your sudden brittle type of fracture you know mode appears then another mode of failure under these fracture is the fatigue.

So, many machine parts are failing because of the fatigue. Now, what is fatigue? Fatigue type of failure is the one where the machine basically element is subjected to the fluctuating type of float load. So, when the failure is because of the fluctuating type of float load that have normally happens in the machine shaft source or. So, which are moving as a load acting on them. So, on the cyclic cycling I mean there is a cyclic type of a load or alternating cyclic loading conditions. So, under that if the machine fails if the machine element fails then we tell or we also tell that there are fluctuating stresses or alternating stresses.

Now, because of that when there is you know fail in the element then we call the it to be the fatigue failure. So, what happens in these cases normally the stress is in the term of cycle, you will have in one cycle it will be under the you know in the positive side in the in the cycle it will be under the negative side. So, it has the alternating type of a stress development in the material.

Now, in these cases what happens that a minute crack will be normally so, you know starts at a localized point and normally that is in the form of notch or so, at the point of the notch or wherever the stress concentration is larger at those point say minute point crack will initiate and that crack will basically propagate as the cycle progresses. So, that will be basically progressing gradually on the over the cross section of the member. So, so that way once it progresses and then it may go over a whole cross section and then material fails.

So, in these cases in the case of fatigue failure there will be no visible sign of yielding. In fact, at the average stress so, in those cases and these stress values at which the they fail they are well below the you know the entire tensile strength of the material. So, that is why when you do not expect that they will be failing at these because you feel that it will go up to the entire strain tensile strength of the material, but they actually fail well below that in the case of you know fatigue.

So, in these cases basically you designed based on the empirical you know relationships or so and these failures basically for that normally what you do is they are represented by you know S-N curve. So, they talk about the stress and the number of cycles. So, there will be this will be the stress value and this will be the number of cycles. So, this number of cycle will be you know 10 raised to the power you know x. So, this will be x basically 10 raised to the power. So, you know this will be something like 10 raised to the power 1, 10 raised to the power 2, 3, 4, 5 or so. So, like that you know you will have cycle up to which the material can sustain and this value you have stress.

So, if the stress value is larger, then in that case the material may sustain very less number of cycles and if the stress value is the smaller then the material may sustained for larger number of cycles. So, in that case the endurance strength is basically you know set. So, this is known as the endurance limit, the stress value at which it can go for finite infinite number of cycles.

So, basically it is where I mean it is the large or lesser value and if the stress value is not going beyond these then material has very high you know life and if it goes more than that then you can see that they have they will sustain for lesser number of cycles. So, this way the that the fatigue failures are they are they are characterized or they are basically presented they are interpreted for the materials which undergo such kind of failure.

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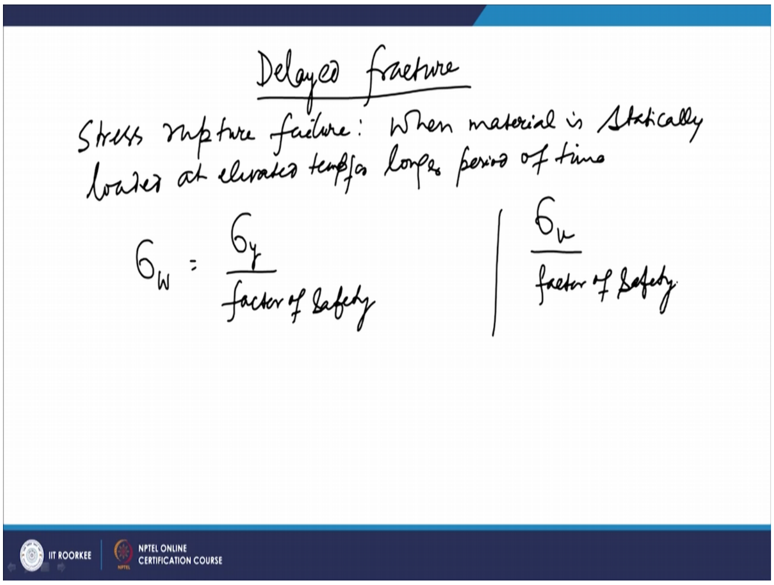

Now, there is another kind of fracture and that is delayed fracture. So, you know I mean normally the stress rupture failure is the example of such failure. So, stress rupture failure; now, in this what happens when the material is you know statically loaded at elevated temperature and for longer period of time.

So, when material is statically loaded you know, once you are statically loading the material at elevated temperature or longer period of time so, in those cases I mean for a longer period of time. So, in those cases these stress rapture failure occurs and depending upon the value of the stress and temperature there may be yielding prior to fracture.

So, if the material has the stress the material under the stress conditions stresses in those cases because when you make the material the stresses are there inside the material and in that when you are deforming the material under statically, under the limited elevated temperature for longer period of time. So, in those cases these failure occurs even at a smaller value of the stress value.

So, that is why what we see is that the material fails at the lower value of its stresses. So, such failure is known as delayed fracture. So, in those cases you have to see that the material does not contain more value of residual stresses. So, that may lead to the early failure of the material because of the stress rapture failure.

Now, the thing is that we need to design these materials to you know to safe guard against these failures. So, normally what we do is we normally define I mean design based on the factor of safety. So, you have working stress or workably workable stress and workable stress will be based on the what is the yield stress and then you may you may have the factor of safety.

So, this is based on you know the factor of safety you have to have the factor of safety, so that the workable stress which you which is a you know which is coming it will be will strain divided by the factor of safety or you may have the that may be based on the yield stress or that may be based on the tensile strength. So, ultimate tensile strength and then you may have the factor of safety.

So, these things are required to be you know understood that you have to design the material you have to have the material and you have to see that they fail in what conditions and how they will be behaving whether you will have what is the condition of the temperature, what is the condition of the you know rate of loading. So, that also basically affects the type of loading of type of you know failure of the material.

These type of delayed fracture or a stress rupture fracture failure they are also occur n in the presence of the hydrogen sometimes in the case of steel, when there is hydrogen that time also such fracture occurs. So, that needs to be kept in mind that sometimes you we control the hydrogen, so that the stress rupture failure can be prevented. So, that is about these cases.

Now, coming to the factor of safety; so, we understood that you provide the factor of safety because when you are going to use for the critical applications so, in those cases you have to have adequate value of the factor of safety. So, that the stress value does not reach you know to that value to that alarming value where the material fails and in that manner you take larger value of the factor of safety for such critical you know applications.

So, what we discussed in this lecture that the material may fail in different way when we talk about the you know deformation modes you have different deformation modes, you have many parameters which affect these mode of failures. You have a parameters like how you are how the materials subjected to the loads, what is the temperature conditions, what is the strain rate conditions. So, that basically affects you know the more of failure.

So, how the material will fail in that you know such situations and then the brittle materials are there they also can behave in a you know ductile manner, if the temperature is increased.

So, even we know that many brittle materials are also formed when you go for may be increasing by increasing the temperature or if you take the application of the forces in hydrostatic fashion even the brittle materials can be formed by using the these hydrostatic type of forming techniques. So, when we talk about certain type of extrusion hydrostatic extrusion that is based on this concept itself. Then, you have you must know that when you are using same material in the different locality where the temperature conditions are different then they will they may there are chances of failure in a different way.

Then, when you are manufacturing the materials and if there are points of if there are points of cracks or sharp discontinuities that may affect you know the life of the component that may you know impede basically the chances of the failure of the material. So, these are the you know parameters which need to be looked into while discussing about the behavior of the materials, so that the failure can be predicted and ultimately this failure mode.

Basically, why it is important because when we talk in the material metal forming context so in that we basically we apply the stress is stresses and under that application of stress, what is the value of I mean stress state of system how the material will fail what way it has to go and fill the cavities. So, these things are you know utilized while dealing with such you know systems of materials.

Thank you very much.