Welding Metallurgy

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Lecture No 60

Design Features for Static and Fatigue Loading in Welding

Welcome to the lecture on Design Features for Static and Fatigue Loading in Welding. So, we had the introduction about the static loading and the fatigue loading cases. So, what are those considerations, which are required to be understood when we talk about the static loading cases in welding and while fatigue loaded cases in welding. So, we must have the idea about those things because that will help us to assess the failure of the component.

As a welding metallurgist, when you have to do the failure analysis, in those cases, you can have the use of these concepts as well. So, if you talk about the design features, when we talk in the case of static loading, so in those cases, as we have seen that we are designing based on the strength and rigidity. So we are talking about the allowable stress values and we are talking about the strains or stresses or so. So we will talk about the standard formulas.

Some of the design formulas which are used when we talk about the design under these different types of loading in the case of static loading case.

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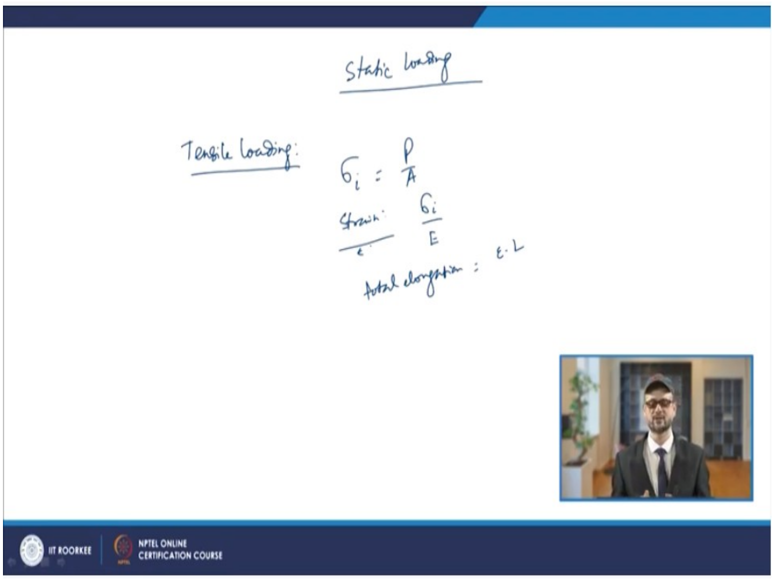

So, if you, say take the tensile loading. Now, as you know we must have the idea that when we have the any member which is subjected to tension, a tensile force is applied and that is applied in line with the center of gravity of the section and then it will be giving you the unit tensile stress and that will be P/A. So, that P is the tensile force which is applied to the member and then A is the cross section, right angles to the line of the force.

So, that way we get these stress value and that stress value should not, anyway that has to be less than the value at which it will fail. So, accordingly the design parameters are adjusted like that. So, then also if you talk about the value of the strain. So, as we see strain will be the stress value which you get divided by the E. So, that is stress by strain becomes the E value that is modulus of elasticity. So, accordingly, you can have the value that is σ_i/E. So, that way you can have these values.

And when you talk the totally longest elongation or displacement, so that will be εL, so that is your tensile strain, so that is this into the length of the member. So, that way you are going to have the calculation of dimensions or parameters in case of tensile loading.

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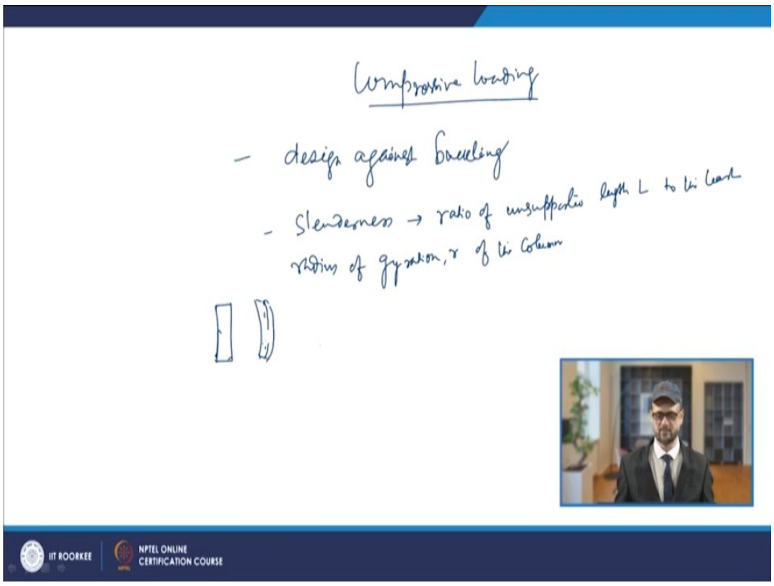

Now, if you have the case of compressive loading, so, if you come to compressing loading. So, basically, the members will be subjected to crushing if the compressive strength is exceeded the stress which is generated more than that compressive strength of the material. But that is very rare that case comes under the compression case. So, mainly, what we need to design in the case of compressive loading is the design against buckling.

Because depending upon the length of the member, you will have the slenderness effect that will be coming into picture. So, you will have to design against buckling. So, you will have columns if the slender ratio is measured, you will have the slenderness. So, slenderness is basically measured as the ratio of unsupported length L to the least radius of gyration, that is R of the column. So, what happens that this slenderness ratio becomes important, so, when your slenderness ratio will be higher, it will have more chances to buckle.

So in those cases the column will start moving laterally, in that case rather than getting crushed, it will start moving laterally and that will be also at a stress, which we lower than the yield strength of the material, so a component which is here it will try to buckle in the case of the, so what will happen, so sections will start buckling when your slenderness factor is coming into account and for that you will have the radius of gyration.

The least radiation of gyration is computed and you will have a range to this value of L to R, so that range has to be, that range is basically specified and if that range of value is not satisfied, in that case, you will have buckling experienced in the case of this comprehensive loads.

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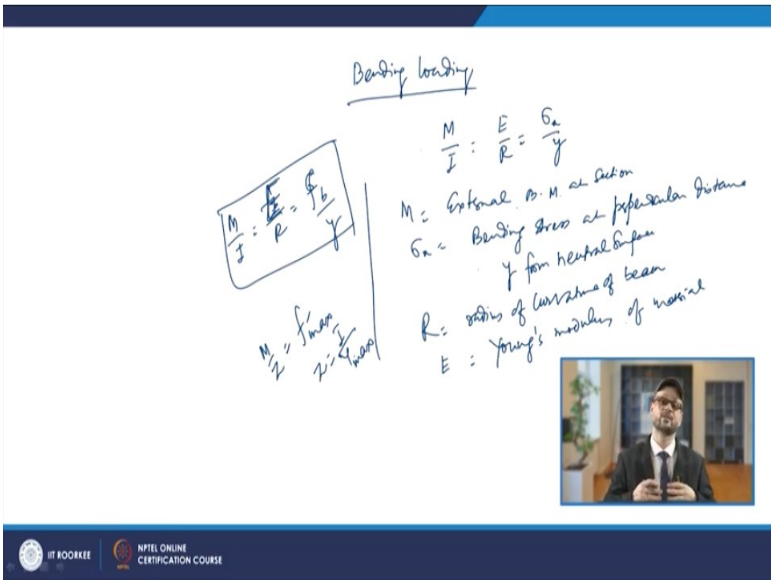

Then, next is your bending. So, you will have the bending loading. Now, in the case of bending, you will have the theory of bending, which is applied theory of bending tells that M/I will be same as $E/R = \sigma_x$/Y. So, you will have the different terminologies, which have different terms and which have different meanings. M is the external bending moment at section.

So, you will have section which is considered and then you will have σ_x is the bending stress is at perpendicular distance Y from neutral surface. So, that way you get. And then R becomes the radius of curvature of the beam and then you have rest left is the E that is your Young's modulus of elasticity, so that is of the material. So, many a times we replace this σ_x with the bending stress basically $F_B$of F. So, in that case if you replace this sigma x with the F_B, so your equation becomes M/I = F_B/R that will be sigma, so that is E/R.

So, you will have E/Rso that will be F_B/y. So, that way you will have, this is the bending or the Flexural equation that is known as and based on that you will be designing. Now, many times we design for the y_{max} in that equation and you will have $M/Z\ I_{max}$, F_{max} that is because of the y_{max} considerations because Z becomes I/y_{max}. So, Z is the section modulus, so if you take this section modulus as the parameter, you will have Z as the I/y_{max}.

So, these parameters can be computed for calculating the required dimensions and solving the problem when it comes for the bending type of loading.

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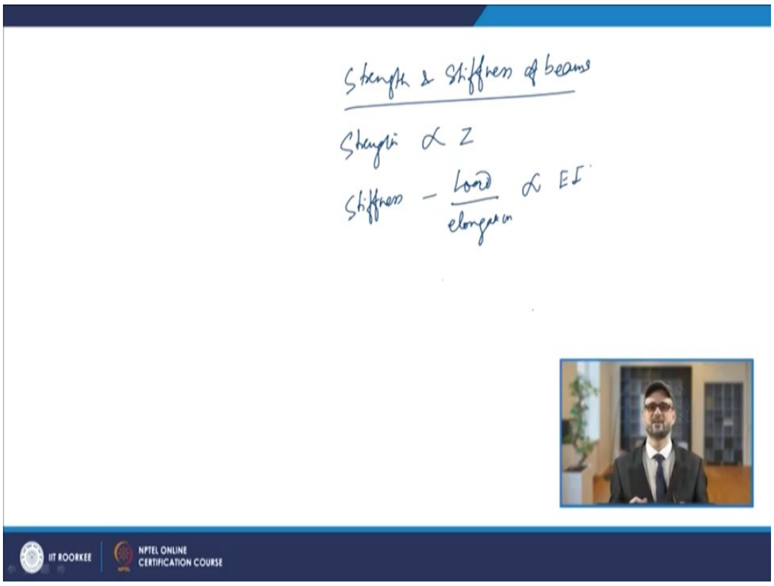

Now, you may have also the considerations of strength and stiffness of beams. So, what we do is that strength is normally proportional to the section modulus. So strength will be proportional to Z that we had discussed in our earlier class and stiffness is basically load by elongation, so that is your rigidity that is same thing which is represented by Young's model, so $\frac{load}{Elongation} \propto EI$.

So, to satisfy this condition, the beam should be deep for getting strength and stiffness of the beam, when we are talking about the welding and when we are designing for the static load conditions in bending. Then, we have other loading conditions also. Now, you may have also the case of torsional loading.

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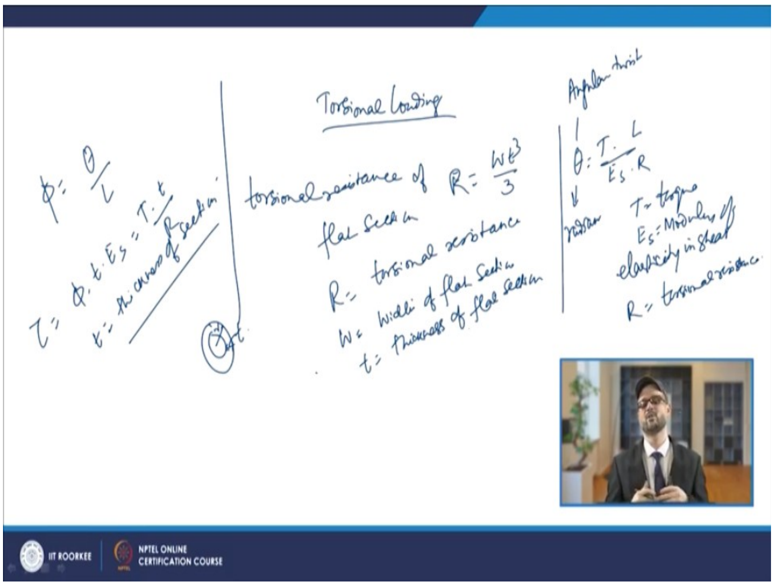

So, when you have the torsional loading, there are cases when this tunnel resistance is required and they will be, torsion which is there, so that will be creating in the design of bases and frames that creates problem while we design for the bases and the frames. So, basically, we have torsional resistance, which is required to be found out. So, a flat section, it is found by the formula $R = Wt^3/3$.

So, R is the torsional resistance then, you have the W as the width of flat section and t is the thickness of flat section. So, once you find the torsional resistance of open section, in that case, you can have the calculation of the angular twist, because torsion creates the twist in the material, so, you can have the value of the angular twist, so, that will be $T.\frac{L}{S}.R$. So, this way, you can have the calculation of the angular twist.

So, you will have this value in radiance, this is your angular twist and you have other, as we know, you have T as the torque, then you have E_S as the modulus of elasticity in shear and you have R as the torsional resistance. So, each part of the section basically open section will be twisting to the same angle as the whole member in this case. Now, the unit angular twist that is equal to the total angular twist divided by the length L.

So, your unit angular will be the total angular twist, which we get $\frac{\theta}{L}$. So, now, once you know this unit angular twist, so, by dividing this theta with the L, so you can find the resulting shear stress on the surface. So, resulting shear stress on the surface $\tau¿\varnothing.t.E_s$. So that will be T * t/R. So, basically here the T becomes the thickness of the section.

So, you can have the shear stress which is being used and accordingly, you can have the value of the shear stresses and the unit angular twist and all that total twist, then you have also, so all these things can be computed by using these formulas and then what you do is that for the different geometries, you can have the different formulas for finding these torsional resistance like if you have the torsional resistance for, suppose a tubular shape.

So, in that case you will have the values based on the thickness or so, so, you can have the different formulas for finding that if you have a popular sections like if you have closed tubular sections, so, for a circular, in the circular form, it becomes 2 pi RQ multiplied by t. If R is the, suppose for this section if you find, if this is the R and this is t, in that case it becomes 2 pi RQt.

So, accordingly you can have these values of the torsional resistance basically being computed and the torsional resistance arc, so once you compute that, then for the different type of geometries, you can have the calculation of other different parameters which is required to be calculated that can be found out.

So this is normally the, these are the formulas which are used in the case of the static loading and there we have talked about the different type of forces, the tensile or you have the bending or maybe the torsion, so in those cases, this is how you try to calculate these torsional resistance values.

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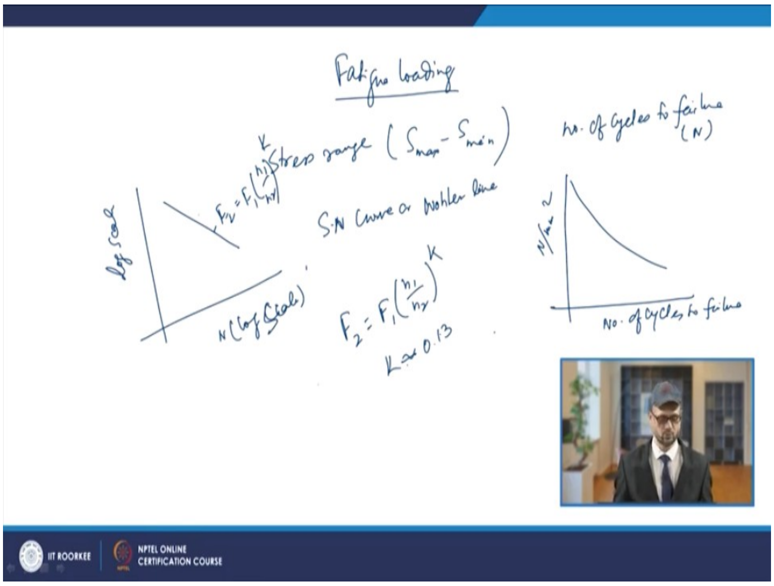

Now, if you talk about the fatigue loading cases, as we are discussed, in the case of fatigue leading, fatigue loading, if you try to determine the fatigue strength of the component of a particular material, so, in those cases, we use these S-N curve or the Wohler line. So, what we do normally that in that case, we try to test several similar specimens you are testing under the given loading conditions, and then each of these specimen will be subjected to the given cyclic stress and the number of cycles up to which it is getting fail, that is recorded.

So, in that case, you try to have these curves. Now, what we do is you will have the relation between the applied distress that your stress range, so, you will have the stress range in this case, ($S_{max} - S_{min}$) and also you will have the failure, so, that will be the number of cycle to failure. So, that is basically known as the N. So, this data is basically plotted and this is known as S-N curve or the Wohler line. So, you can have a typical S-N curve, which shows this kind of graph.

So, you will have the, this is a stress value that is in N/mm^2, and this is your number of cycles to failure. Now, in most of the cases, when you try to plot these, on the log log scale, in that case, it becomes a straight line. So, what we do is that, if you try to plot the log log plots, it will be log scale here also and that is in log scale. So, in those cases, this comes as a straight line. So, what will be happening that in these cases, once you have the log log scale.

So, accordingly, you will have the equations, which will be representing these lines, so that will be represented by the equation like $F_2 = F_1 \times (n_1/n_2)^K$. So, suppose for the stress value F_1, if the number of cycles up to which it sustains is $n_1$and for n_2, it will be F_2. So, in that case, you will have this sloping line that can be expressed in terms of this value. So, this line will be $F_2 = F_1 \times (n_1 / n_2)^K$.

So that way, you will have this equation, so, F_1 is the fatigue strength compared to, n_1 number of cycles and F_2 is for the n_2 number of cycles. F_2 is the stress that is $S_{max} - S_{min}$, so, that will be for that failing in the n_2 number of cycles. Now, this constant K will be varying and you will have the K value is normally close to 0.13, whereas its value is about 0.18 when we use the axial loading, so, tension or compressions. So, in those cases, it may go maybe up to the value of 0.18. Now, there are only one type of stress that is shown.

Now, there may be typical stress cycles, which are used in these fatigue tests.

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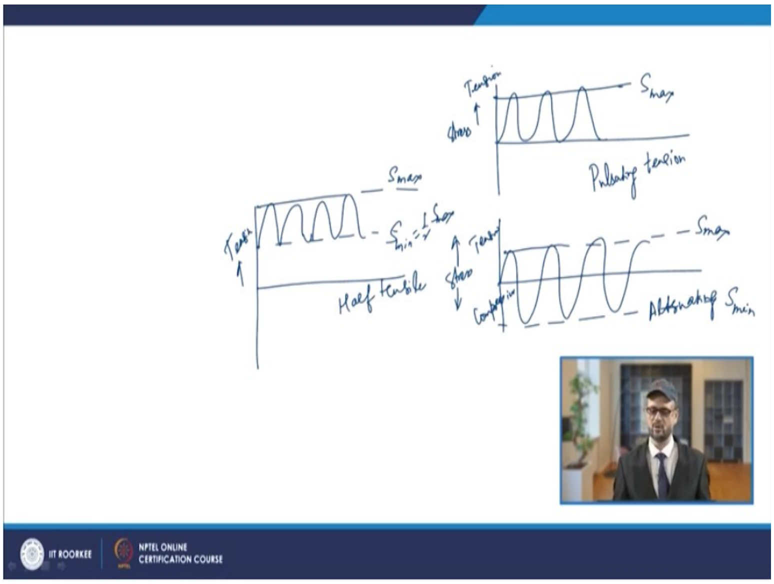

So, you will have the typical type of these stress cycles, which we use and these cycles are basically, you will have the stress cycles like, if you have this wave, this is the cycle so, you have only tension, so this is basically the tension and here in this you can take the tension on this side and you will have that is stress, so this is your S_{max}. So, this is basically the pulsating tension type of test.

Similarly, you may have the stress cycle that may be evenly on the upper and lower side. So, basically this is the example of alternating type of stress. So, this will be your S_{max} and this will be your S_{min}. Now, what we mean to say that you get the difference between the S_{max} and the S_{min}. So, S max is you have the positive value and S_{min} you have the negative value. So, here it is compression and this is your tension. So, this is your stress value, either compressive or tensile.

So, this is known as the alternative type of cycle. Then you may have also the cycles, it may be, you have some value this is S_{min} and from here, it is starting. So, basically it goes like that. This is your S_{max}, so, S_{min} basically ½ of S_{max}. So, in this case you have only tension. So, the stress is only tensile and this is known as the ½ tensile. So, you have the different type of stress cycles, which you can see my in these cases and you have 0 to tension and then you have to complete reversal also.

So, these are the different cases which is formed here in this cases, you have 0 tension here and then, in this case you have the ½ tensile. So, based on that, basically you have a diagram which is also formed and that is known as the Goodman diagram and it will be talking about the effect of the various type of stress cycle on the fatigue life. So, depending upon the different type of cycle, what will be your fatigue life, it will be talking about that and that is represented by a Goodman diagram.

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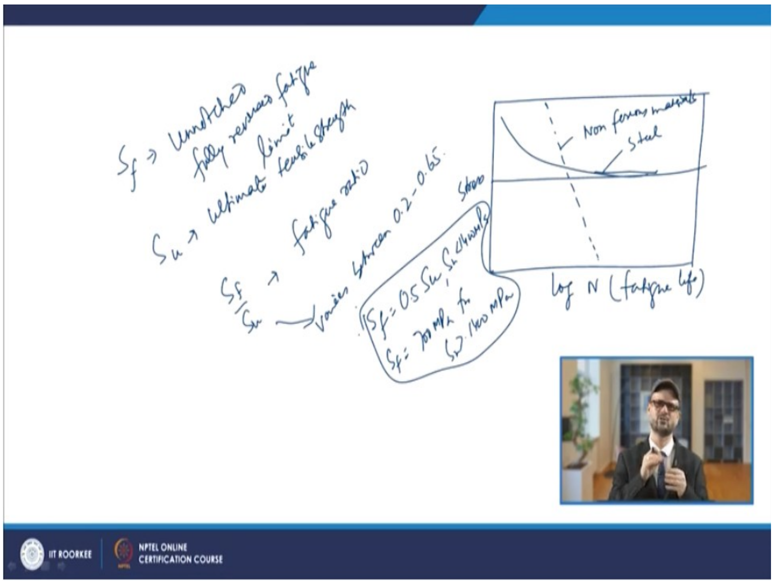

Now, if you talk about the fatigue life of the nonferrous materials, they also exhibit to the fatigue limit. So, if you try to draw the fatigue limit for the nonferrous material, so, it goes like this. So, if you find for the steel, it goes like this. But for the nonferrous materials, it will be going like that. So, this is your log N, that is your fatigue life and this is your stress. So, what you see this is for the steel and this is for the nonferrous materials.

So, they basically change and there is difference between the way they respond to the fatigue loading for the ferrous and the nonferrous materials. So, normally you have a fatigue limit which is defined. Now, normally, commonly what we do, normally we have a procedure, when we talk about the calculation of the fatigue life, then what we do is, we try to have the definition of certain parameters.

So, normally we are normally partially comparing the materials and we plot the partial, un-notched fully reverse condition that is S_f. So, we have the S_f when we are doing, in case of completely un-notched condition and we are doing the complete reversed conditions. So, S_f is the un-notched, fully reversed fatigue limit so, that is your S_f and then that we compare with the ultimate tensile strength. So, your S_u is the ultimate tensile strength.

And then we take its ratio, so S_f/ S_u , so this S_f/ S_u it is known as the fatigue ratio. Now, most of the data, which is found, suppose for any material, you can have the data for the S_f and also for S_u and when you calculate this ratio, this ratio is known as the fatigue ratio. Now, in most of the cases, this varies between 0.2 to 0.65. So, normally the general tendency is that the S_f will be increasing linearly with S_u, but that is not normally true, not very much true many a times and what has also been, some generalized equations are there.

Like S_f will be 0.5 S_u when your S_u is less than 1400 MPa and S_f will be 700 MPa for S_u is more than 1400 MPa. So, these are the relationships, by which you can have the calculation of S_f. Now, many a times we try to increase the fatigue limit of also the component and that can be done and we can check it against these findings. Now, in general it is found that the stress that is your S_m.

So, in these cases, that is when we talk about the mean stress, so in the case of the fluctuating stress, you have the, one value the mean value. So, this is detrimental, when it is tensile and beneficial when it is compressive.

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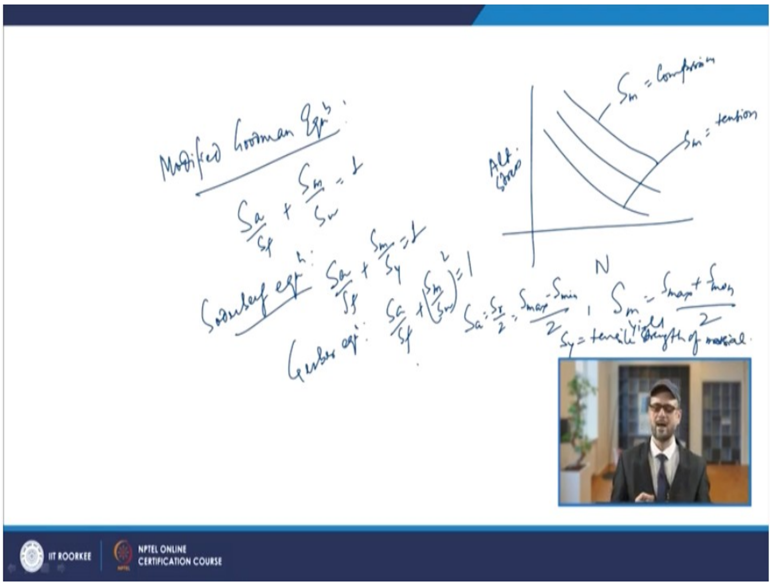

So, that is, in normal case it has been found that, if your S_m is tensile, then it is detrimental and if it is compressive, then it will be somewhat beneficial. So, that basically, what happens that you will have, that can be found out by looking at the values. Suppose you have the alternating stresses and if it is N, so what has been seen that if your curve will be, something it will go like this. So, this will be the S_m when it is in compressive mode and this is S_m when it is tension.

So, if the mean stress is in compression, then you will have the more fatigue life that is found. Now, the effect of the tensile mean stresses for different materials and situations are given by the different types of equations. So, the modified Goodman equation, so that basically tells about this different conditions like you have $S_a/S_f + S_m/S_u$ that will be 1. So, similarly, you will have the Soderberg equation. So, this equation they tell that $S_a/S_f + S_m/S_y = 1$.

Similarly, you have the Gerber equation, so this Gerber equation is $S_a/S_f + (S_m/S_u)^2 = 1$. So, this way, you have these relationships by which you can measure. So, in these cases you have S_a is basically $S_r/2$ upon 2, that is your $(S_{max} + S_{min})/2$, and then Sm is basically the mean value, so this will be $(S_{max} + S_{min})/2$. And then, if you talk about the S_y , so S_y is the tensile yield strength of the material. So these equations are used while we calculate these, while we do the analysis in fatigue loading.

So, what we see from here that if you have a completely reversed bending that is occurring, in that case, your S_m will be 0. So, that is $(S_{max} + S_{min})/2$. So, you will have, if it is completely reversed, in that case that becomes 0 and so your S_a becomes S_f, that is your fatigue endurance limit. So, this way, we try to have the analysis when we talk about the fatigue loading cases and we can correlate them, we can have the other way also the checks, you can have the study of other aspects also in the case of failure.

But, then we must be conversant with these terminologies because that will help us in analyzing these situations when we have to deal with the failure of the materials and we have to correlate it with metallurgical investigations. So, in those cases, these understandings will help us to know that. So, dear students, this is the final lecture and I hope that you have enjoyed this series of lectures for this course and I hope that you will enjoy it.

You will continue to enhance your learning levels by referring to the standard textbooks and reading more and more and hope for good exam, so that you can pass with a very good marks and all that. Thank you very much.