Welding Metallurgy
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Lecture No 59
Fatigue Loading in Welding

Welcome to the lecture on Fatigue Loading in Welding. So, we will have, in this lecture some introduction and some of the aspects will discuss about the fatigue loading and how this fatigue failure takes place and then further in our next lecture we will talk about the design features for the static as well as the fatigue loading. So, basically, you know 50% to 90% of the components, which are welded, they normally fail, under the fatigue loading.

So, most of the critical components which are there in case of welding, like you have the ships or pressure vessels or so, you will have the automotive component or aero component, all these components are subjected to the fatigue loading and then they fail under that loading. So, what happens typically in the case of fatigue loading is that a component or structure surviving a single application of load may fracture if the same load fluctuates.

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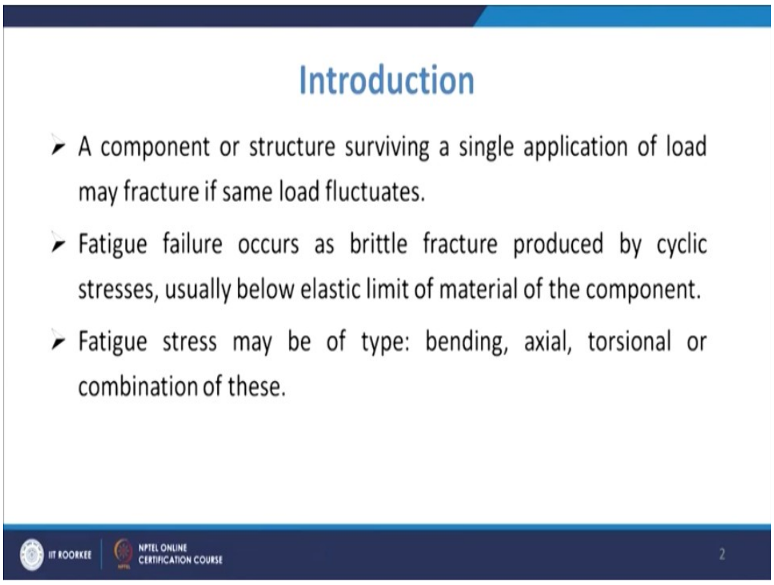

We have studied about the static loading where you have the design, you can design for safety against static load, so, you can design for strength and rigidity. However, many times, even if the specimen or the structure the component that may sustain this kind of single application of load, but, if the same load is fluctuating, then it will fail or it will fracture. So, that very much happens. Now, these fatigue failure occurs as the brittle fracture produced by cyclical stresses usually below plastic limit of the material of the component.

So, normally the stresses are cyclic in nature in these cases and, these they normally occur as the brittle fracture it means it will not give you the warning before it fails. So, normally, that is a situation under the case of fatigue loading, so, you do not have the appreciable deformation. If you have the appreciable deformation, then you can have the ways to safeguard the component, but otherwise you do not have the time. So, that usually happens in the case of brittle fracture.

So, and it will be usually below this elastic limit of the material. So many a times you have to have the understanding about the nature of the fatigue stress. So, if you talk about the fatigue stresses, they may be of different type and that will be causing the failure and that will be, normally you have the bending type or you may have the axial or your torsional or maybe the combination of these type of stresses that may be there. So, normally that will be the different types of the fatigue stresses.

So, that is what normally you have the different kind of fatigue stresses,

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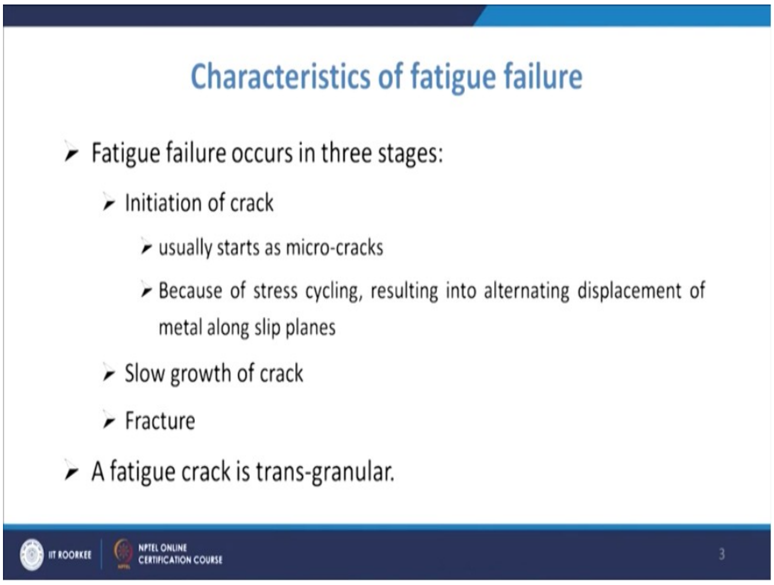

Now, if you talk about the characteristics of the fatigue failure, now fatigue failure normally occurs in 3 stages. So, first of all it will have the initiation of the crack and normally that happens as the start of the micro cracks, so micro cracks they are normally, most preferentially they will be at the surface and you might have the idea that when you have the cracks, you may have cracks, either below the surface, you may have subsurface cracks or you may have the surface cracks.

So, surface cracks are even more dangerous and they are more easily formed also. So when these micro cracks are formed at the surface. So, especially, because, the surface is subjected to the conditions when the stresses are highest at the surfaces and also here, the environmental changes are seen more prominently like, if the material is subjected to corrosive type of environment or if there is any geometry change. So, that is the most prominent observed on the surfaces.

So, you have the surfaces where the chances of these micro cracks are maximum. Now, this initiation of the crack it is thought to be because of the stress cycling. So, that will be resulting into the alternating displacement of the metal along the sleep planes. So, what will happen in that, when you have these stress cycling formation, so because of that there will be initial cracks, so that will be propagating along the sleep plane and normally sleep planes are normally at the angle of 45° to the surface.

So accordingly, if the load on this member is continuing to be the same, so in that case, as the crack dimension will be increasing, so that will be increasing the stress because as with the increase of the cross section of the dimension of the crack, your effective cross sectional area will be going on decreasing and as you know that when the effective cross sectional area will be decreasing, in that case, you will have the increase of the stress values.

And also the direction of this propagation. So there will be propagation of crack and the direction of the propagation of the cracks that is along the sleep planes. So, that is what normally happens. Once you have the initiation of the crack, then you have the growth of the crack. So, as you see that you will have the slow growth of the crack and normally these fatigue cracks, they are seem to be trans-granular in nature. So, they will be propagating within the grains.

So, rather than along the grain boundaries, they will be propagating within the grains. So, as the crack will go on propagating, so these cross sectional area that will be remaining smaller and smaller and so, your rate of crack propagation will go on increasing and when it will be increasing, the crack propagation will increase, so a stage will come when it is unable to support that applied load in that case it will fail. So, that is what normally the characteristic of the fatigue failure is, so that is how fatigue failure starts and then it culminates into the fracture.

If you talk about the fatigue failure appearances, so, you can have the, visibly, I mean, look at the microstructural appearance or the appearance at the place where the fatigue fracture has taken place.

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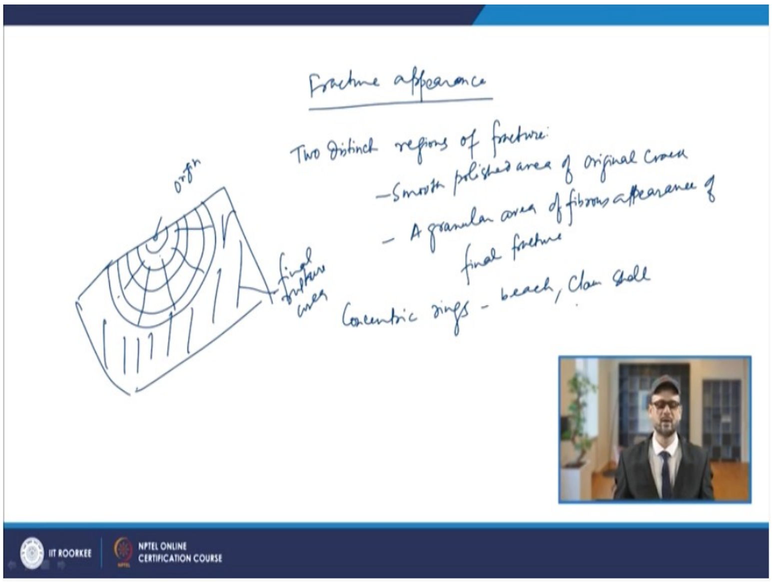

So, if you look at the fracture appearance, so, what will be happening that, because it takes time, so with time basically that fracture will come out. So as the crack is growing, so in between because of the cyclical stresses and all that the parts are rubbing against each other. So, that will be producing first of all the smooth surfaces where the failure has taken place. And also you will have the brittle type of, cleavage type of fracture that will be appearing.

And that will be normally trans-granular also, that is what we have seen. So, basically you have 2 distinct reasons, if you look at the fractured surface, you have 2 distinct regions of fracture is present in the case of the fatigue fracture. So, you will have the smooth polished area of original crack, so, wherever from the crack has originated so that subjects to maximum rubbing of the surfaces, so that leads to the formation of a polished surface.

So, you will have one reason that will be the polished area and then you will have a granular area of the reason of fibrous appearance of final fracture. So, granular area of fibrous appearance. So, these two will be the distinct results, which can be seen when fatigue fracture takes place. So, if you try to visualize how the fatigue fracture looks like, so if you try to see the fractured surface, it will be something like it has originated from here, and then it will be moving.

So, it will move like this, so you will have, this way, you will have a type of concentric lines in that case, so, you will have the origin here and then so finally in this area you will have the final rupture area is basically this one, so, this is the final rapture area. So, basically it originates from there and then you will also be able to see certain lines like this, these radial lines are basically seen. So, you will have the 2 types of lines and what you see is that if you look at this you will have the concentric rings, these are the concentric rings.

So, this concentric rings, they actually are also called the beach or clam shell or even conchoidal marks they are also known as. This basically shows the delay in this fatigue loading cycle. So these concentric rings they show that delay part. Apart from that, you have also one these radial patterns are there, these lines, they are moving towards the origin. So, basically they show that where the fracture has originated. So, by looking at the surface, you can have the idea about the origin of the initial fracture location.

So, that is how you can have the idea about the location of the fracture. Now, we also should know, if you talk about the type of fatigue fracture.

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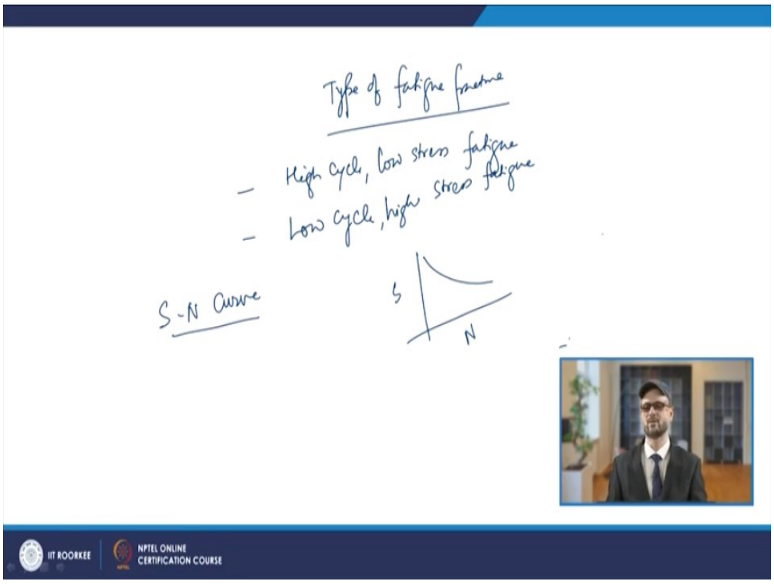

So if you look at the type of fatigue fracture, it is basically, in the case of fatigue fracture, as we have discussed you have the cyclic loading and normally you have the failing of the component in terms of the number of cycles it has sustained. So, the material is subject to load, which is a fluctuating load and it will be sustaining for a number of cycles, and then only that way you try to have the estimation of the fatigue life of the components.

So, if you talk about the fracture of the engineering materials, which are subjected to fatigue, then you have the fracture which is in, it is basically divided in two case; one is the high cycle low stress fatigue, and then opposite to it will be low cycle high stress fatigue. So, basically, high cycle low stress fatigue means stress value which is basically being applied that is low, so it goes for very large number of cycles and then it fails after subjection to very large cycles.

Whereas, in this case, the stress value is larger and so the material sustains for a very small number of cycles. So, in this case, it will be less than 10 is to the power 5 cycles and here it will go for more than million cycles more than 10 is to the power 6 cycles, something like. So, based on that, number of cycles it is subjected to, you have, the high cycle as well as the low cycle type of fatigue fracture. Now, like you have many kind of structural components, where the low cycle fatigue is the problem, typically cracks are found in the ship hull.

So, that is because of the low cycle fatigue and that is high stress fatigue. So, that way, you come across this case. So, in these cases, what happened that normally you will have the stress value high, so, correspondingly you will have the higher strains, so, basically it will be low cycle and high strain fatigue. So, that normally happens in the case of the fatigue factor. Now, what is happening that normally to determine the fatigue strength of the particular component what we do is or for particular material.

There is a curve, which talks about the fatigue life of the component and that curve basically is known as the SN curve. So, this is again one XY plot on the XY graph or XY axis and on the X axis you have the number of cycles and on the Y axis you have the stress to which it is subjected to and that basically talks about at what stress value, at certain stress value, if it is subjected to the alternating stresses, then in that case for how many cycles, the material will be sustaining.

So, you will have these values which are there, so, that curve normally is known as the SN curve. So, this is this type of curve is there. So, this will be your S and this is your N. So, that is normally nominal maximum stress that S, to which the material subjected to and this is

N and this will be basically the number of cycles and then accordingly, we have this plot and what we see that this slide will go on asymptotically, so that means that when the stress level to which the material is subjected to is very small, and below certain limit then in that case, you can see that it is going towards infinity.

So, it will go for very large number of cycles and so that way you quantize or you interpret the fatigue life of the components. So, that way you are discussing these fatigue strength of the material.

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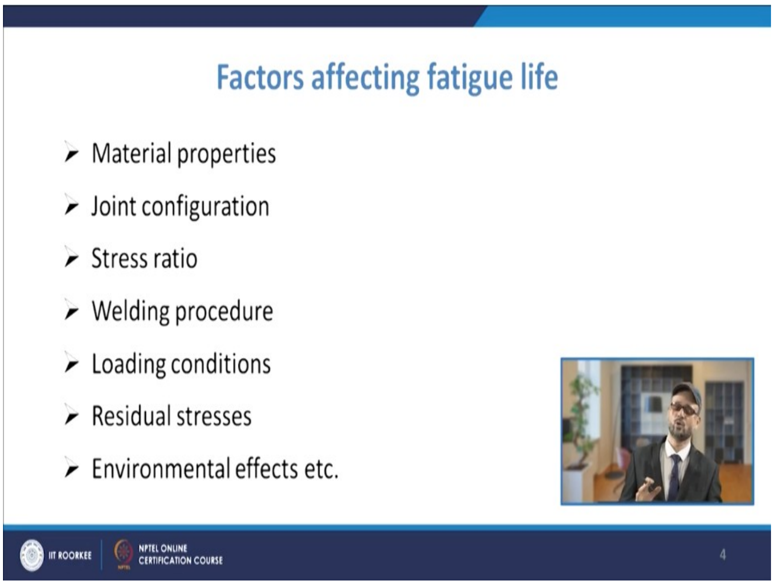

Now, we will talk about other aspects of the fatigue loading. So one more important is the factors which is affecting the fatigue life. So, there are many factors which affect the basically the fatigue life and among them you have the more important ones are like material properties, joint configuration, you have stress ratio, you have loading conditions, then, welding procedures, so, many, so, we will discuss about these things. If suppose, you have the properties, so, the materials basically have the different endurance limits.

So, there is basically a relationship between the UTS and the endurance limits.

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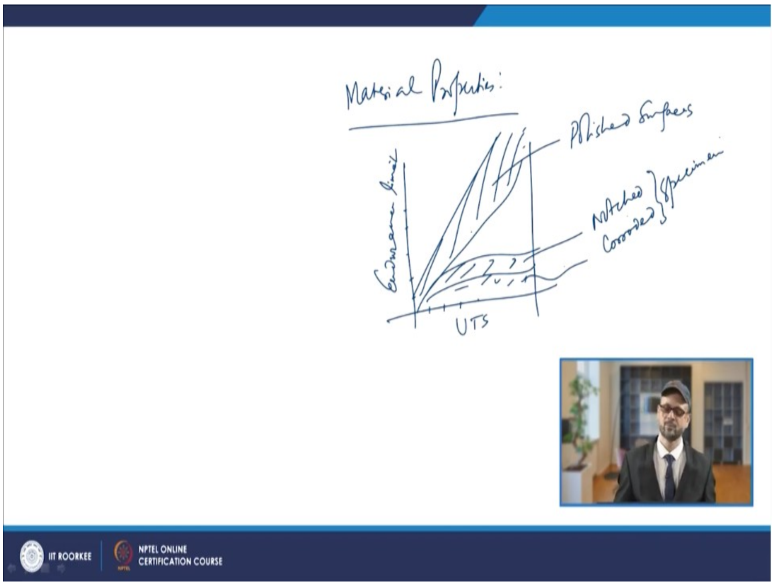

When we talk about the material properties, so what happens is that, so there is a plot, that talks about, so, on this side you have UTS and on this side you have the endurance limit. So, the graph will say that normally, for many materials, now the thing is that when we talk about the material, so, for a typical material, like for, if you talk about the property for any particular material, then the fatigue behavior will be depending upon the surface properties **so** or the surface characteristics in fact.

So, what is seen is that if you talk about the UTS and the fatigue length, then you will have is kind of behavior is there. So, normally if you look at the values, so, you will have, whatever value is here, this is here, you will have the half value. So, the endurance limit will be half of these values, and that too so you will have a region. So, basically, it will be limited nearly the half value when it is polished. And when you are having notches, in that case, it will fall into this region.

So, when you have the polished surfaces, so the endurance limit value will have the, approximately it will be about half of the UTS value, whereas when you have the notched specimen or the corroded specimen in those cases, the fatigue property of the material is getting changed. So, this is shown for steel normally and it is mostly seen that the material properties basically affects the fatigue behavior of the material. Similarly, another point is your joint configuration.

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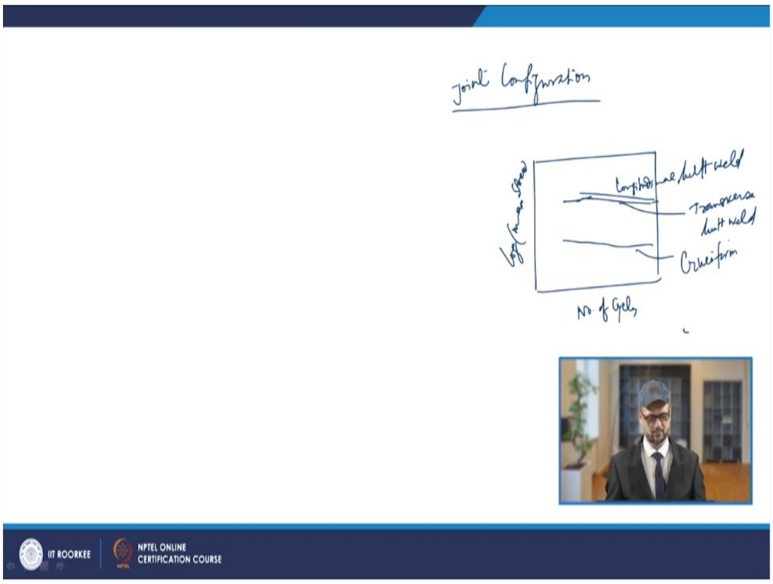

So, severity of joint, so severity of joint is basically one of the very important factor, which is important in the case of fatigue loading and the severity of the longitudinal butt weld joint is lowest because the weld is parallel to the direction of loading. So, in those cases, suppose, when you have such cases, in those cases, so, if you have the longitudinal butt weld joint and your loading is also in the longitudinal direction, in that case, you will have the it will go for maximum number of cycles.

Otherwise, as you go for other types, like you may go for transverse butt weld, or transverse attachment, or may cruciform, so, in those cases, these severity goes on increasing and that way, it is also shown by typical graphs, is basically talk about the effect of joint configuration on the fatigue strength. So, it will be log of maximum stress and then you will have the number of cycles. So, if you go for the longitudinal butt weld, so, this will be the line for longitudinal butt weld joint.

Similarly, this is the for the transverse butt weld. So, basically when you have butt welded and your load is in transverse direction, so, that way you will have the lesser life. Similarly, you may have the cruciform, so, in the case of cruciform, it goes like this. So, depending upon the type of joint also your the fatigue strength basically will be varying and that is why the joint you must know that how your component is going to be subjected to any kind of loading.

And accordingly, you can have the value of, you can have the design of this joint configuration, so, that it will continue to resist larger value of the fluctuating loads. Then, there are other factors like you have the stress ratio, so, basically what happens is that, when you have the presence of notches, so, in those cases, the value of stress is increasing. So, you have even a fatigue notch factor is defined and that notch factor is basically the ratio of fatigue limit that is un-notched to the fatigue limit notch.

And based on that, you have the sensitivity factor also defined and depending upon that, you have, it can be said that wherever these values, so, in those cases, wherever the value is becoming more, it will be more prone to fatigue failure of the component. Similarly, you have the other parameters like the welding procedures. So, many a times you can adapt to the welding procedure, which should lead to the less stress concentration.

So, like, you may go for the preheating methods, so, that will lead to less stress concentration and that basically will be decreasing the chances of hydrogen embrittlement. So, in those cases, you will have, and also the hardness of the heat affected zone, so those cases basically affect the fatigue life. You also give the post weld treatment also to increase the fatigue life. Then, you have the effects also of the loading condition and also the sequence in which the loading is taking place.

So, this way, there are many other factors which talk about these parameters which are affecting the fatigue life of the component. One of the other important factor, which is affecting, that is also the environmental effects. So under which environment the welded specimen is being used. So if it is a corrosive environment, in that case, it is more prone to the failure of the component under the fatigue loading. Then apart from that also, the presence of defects also affect the fatigue characteristic of the material.

There are different methods also for improving these fatigue life of the component and these methods, so, if you talk about the methods improving the fatigue life.

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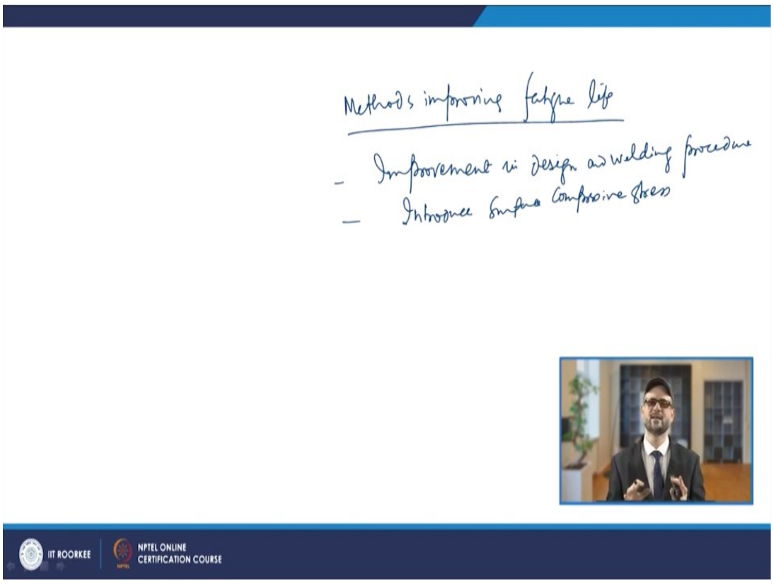

So, in that basically, you can have the improvement in the design and welding procedure. So, you can have the proper design as well as the welding procedure, which should decrease the stress emanation and then the fatigue life also. You can introduce or induce basically the surface compression. So, it is by many methods like you have the short pinning and all that, so, they basically induce the compressive stresses at the surface. So, that basically is an effective way to protect against the fatigue type of failure.

Then you have also the protection from the atmosphere, as we have a studied that many a times you have the corrosive environment will create the start of these fatigue failure. So, you can have the atmosphere free from this corrosive environment, so, those cases you have a better fatigue life. So this is about the introduction to those fatigue loading to which the weld is subjected to, when I get a, to which we must have the proper approach for safeguarding the component or the welded specimen. Thank you very much.