Weldability of Metals
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Lecture-23
Weldability of Q and T Steels-II

Hello, I welcome you all in this presentation related with the subject weldability of metals and we are talking about the weldability of quenched and tempered steel. In the previous presentation we have talked about the different types of the Q and T with regard to the compositions the properties and the time temperature time transformation diagram or isothermal transformation diagram.

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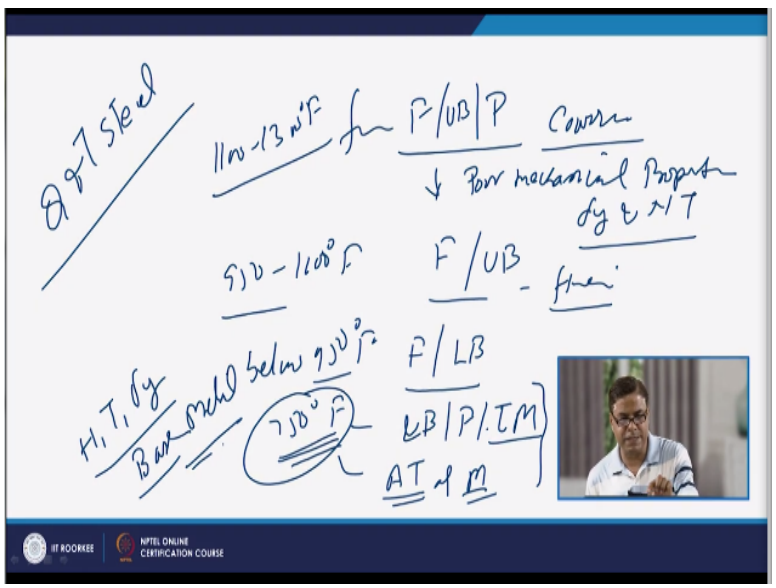

And in that one what we have seen that if the Q and T are subjected to the exposure at a high temperature say 1100 to 1300 degree Fahrenheit for long time. Then primarily it leads to the formation of the ferrite upper bainide and pearlite and these are also very coarse. So, combination of such kind of the phases leads to the reduced or the poor combination of the mechanical properties especially with regard to the yield strength and notch toughness.

On the other hand when the exposure is given at somewhat lower temperature say 950 to 1100 degree Fahrenheit primarily we get the ferrite and the upper bainide. But it is little bit finer it offers somewhat better combination of the mechanical properties on lowering down the temperature further of the exposure at constant temperature as a function of time Q and T steels leads to the ferrite and the lower bainide formation.

Like this is below 950 degree Fahrenheit and when the steel is expose to the temperature below 750 degree Fahrenheit primarily we get the lower bainide, ferrite and tempered martensite. Since the martensite is formed at a high temperature, so it experiences auto tempering of the martensite which is being formed. So, the kind of properties which are realized due to the direct exposure of Q and T steels at temperature around 750 degree Fahrenheit.

We get primarily we get the auto tempered martensite, lower bainide and some amount of the ferrite. And it offers very good combination of the mechanical properties in terms of hardness, toughness, yield strength which are similar to that of the base metal. So, these exposures are means these transformations from austenite to the other phases are primarily corresponding to the constant temperature exposure.

But these also indicate the way by which they will behave or the steel will behave when the different cooling rates are exposed.

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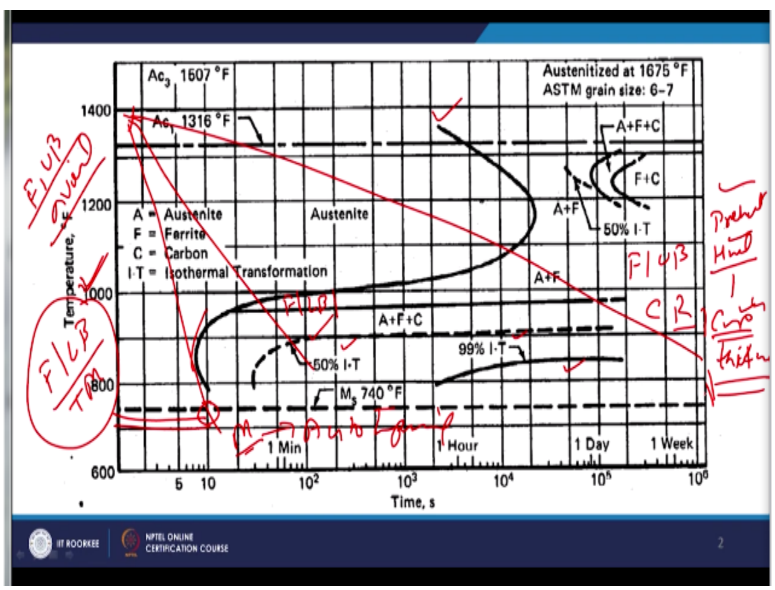

So, if we see like this is the temperature conditions say for an example of the Q and T steel in austenitic state. If the cooling rate is extremely low like this, so the temperature is decreasing as a function of time. So, this line is indicating the cooling rate, typical cooling rate say CR1, so in this case primarily will be getting the ferrite and the upper bainide. And when the cooling rate is little bit faster will be getting the ferrite maybe lower bainide which is finer in structure.

And further if we cool it very rapidly then we are going to get the martensite, since this transformation if we see is taking place at a higher temperature. So, this martensite will be subjected to the auto tempering and this is what is the benefit is. So, actually this diagram shows the transformations at constant temperature. But if we see supreme pose the cool rate lines then we can have some idea about the kind of the phases which will be formed on cooling at a different rates.

However there may be minor shifting in these lines which are indicating these start and end of the transformation. Like this is the phase transformation start line and then this is 50% transformation of the austenite into the other phases this is 99% of the transformation of austenite into the other phases. These are the different lines which are showing the start and the end of the transformation of the austenite into the other phases like it maybe like 50% transformation or 99% transformation.

So, these lines may shift a little bit when the cooling is performed when the steel is cooled continuously. So, means the particular cooling rate is imposed but by and large the kind of phases which will be formed will be like this only. There may be variation in the time required to start and end the transformation there may be little bit variation in the temperature at which these transformation start and end.

Apart from these so we can see here the formation of the ferrite upper bainide mostly we have to avoid. Because deteriorate the properties, what we mostly the ferrite, lower bainide and maybe tempered martensite, these are the kind of the phases that we are looking for. So, we need to during the welding we need to have the conditions which will promote the formation of such kind of the phases where ferrite, lower bainide and the tempered martensite is realized.

And that is why it becomes crucial to control the kind of preheat that we are using, the kind of heat input which is being applied for a given composition and for a given thickness of the steels. Because these are the 2 factors that will be governing the cooling rates as well as the temperature and the time conditions when the transformation will start composition affects the carbon equivalent directly affecting these the position of these lines start and end lines.

On the other hand the thickness preheat temperature and heat input will be governing the cooling rate condition. So, the end microstructure of the weld or of the heat affected will be influenced by preheat heat input and the composition of a steel and the kind of thickness of the plate which is being welded. And therefore we need to see the typical aspect related with the steel that is the hardenability.

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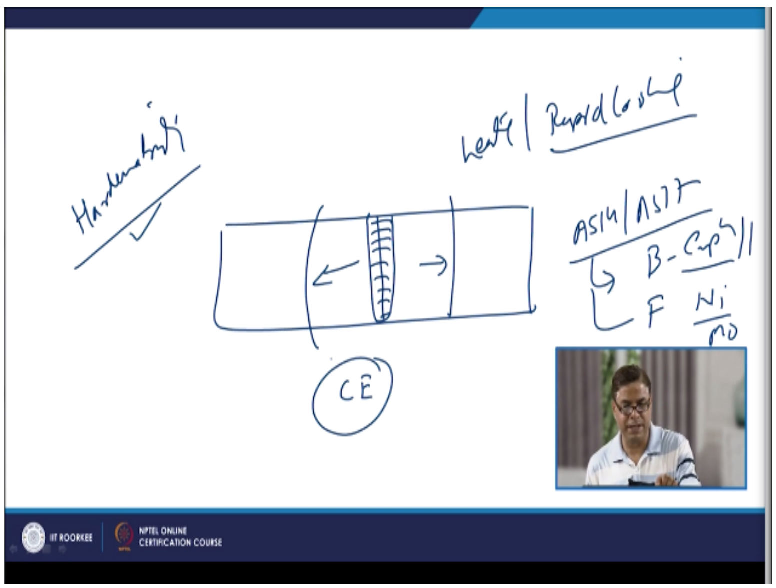

Hardenability with regard to the welding is important just to see that the distance like the heat is being applied near the fusion near the faying surfaces at the center line of the joint and the fusion is realized through the application of the heat. But at the same time some of the heat is dissipated to the base metal, so first the underlying base metal apart from the weld metal zone is subjected to the heating at a higher rate followed by rapid cooling.

So what will be the effect of rapid cooling that is what we can understand from the hardenability behavior of the material. And for that we need to see that Jominy quench and hardenability test behavior of the different metal system. So, 2 most commonly used the steels like A514 or A517 having the 2 grades like B and F which are different with regard to the composition further.

Like F is having the higher percentage of the nickel and the molybdenum while these 2 nickel is absent in the B grade and molybdenum is present in the less quantity. So, because of the compositional difference will find the different chromium, different carbon equivalents and difference in carbon equivalence will be leading to the different hardenability behavior which we can see from this diagram, what it shows.

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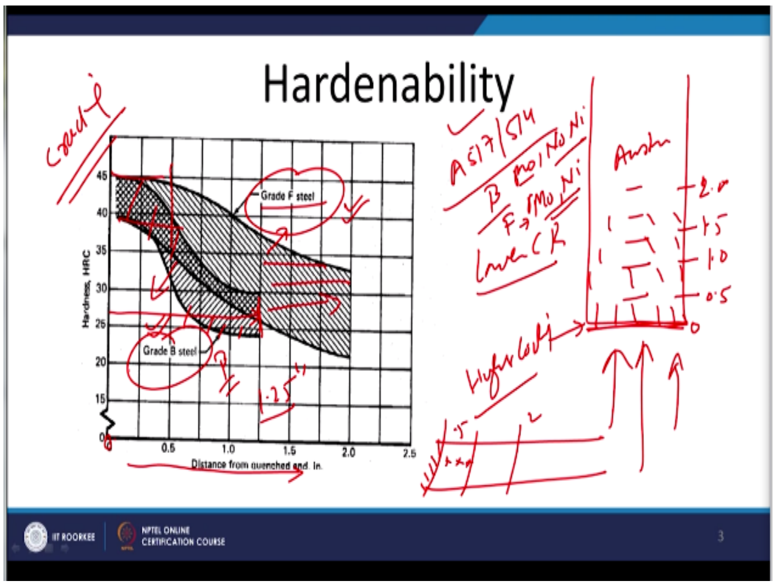

Like the hardenability curve is realized through a typical Jominy quenching test where in the system the metal is heated in the standard size up to the austenitic state and the jet of water is applied from the bottom to quench the end. So, this end which is quenched is subjected to the highest cooling and the locations which are away from the end which is being quenched they will be experiencing the lower or continuously decreasing cooling rates.

So, the kind of the transformation which will be occurring near the end which is being quenched that will be different than the other zones which are experiencing the lower cooling rate. So, as per the hardenability we will be having the different phases at different distances from the end which is being quenched and that is what we can see like this is the 0 distance from the surface and then 0.5 inch, 1 inch, 1.5 inch and 2 inch distance.

Like say for the typical A517 and A514 2 grades of the steels like B and F grade. So, if we see B grade, B grade is having the lower percentage of the molybdenum and nickel is absent. So, nickel no nickel and molybdenum is in lesser quantity as compare to that which is present in F grade where molybdenum is higher quantity and the nickel is also present in like 0.8 to 1%.

So, because of the higher percentage of the alloying elements it offers much better hardenability with this is what we can see from this diagram, what this diagram shows. So, the specimen subjected to the Jominy quench end test and the hardness distribution or the hardness value on increasing distance from the end being quenched is measured and that is plotted.

So, if we see this is the end which is being quenched and this is the increasing distance from the quenched end. So, what we can see for both grades of the steel up to say up to 0.5 inch distance the hardness of both type of the steel is almost same. But on increasing the distance further away from the 0.5 inch there is a sharp drop in the hardness of the hardness which is being realized by the B grade steel while the hardness of the F grade steel does not drop that much, steel up to say distance of 1.25 inch.

We can see that the hardness 25 HRC is realized in both grades of the steel but further if we need if this is the minimum level of hardness then we cannot use the F grade steel from the hardness point of view. While the F grade steel will be offering the higher hardness even up to the greater distance from the quenched end which is reflecting from the higher hardness which is being realized up to 1.5 and the 2 inch.

So, a higher hardness of the F grade as compare to the B grade steel of the 514 and 517 type of the steels is indicating the higher hardenability of the F grade steel as compared to the B grade steel. So, these are the if we try to relate it with the welding then we will notice that the hardness up to the 0.5 inch like this is the end it is the fusion boundary.

And thereafter there will be different zones of the heat affected zone and which will be experiencing the different cooling rates. So, if we assume that since he cooling rates are always high in the heat affected zone as well as in the weld zone. So, the distance up to which in the case of B grade steel the high hardness will be realized up to the 0.5 inch while the higher hardness will be realized in case of the F grade steel up to say 2 inch also.

So, a higher hardness of the F grade steel is not good from the welding point of view as compare to the other steels where high not very high hardness is realized. Because high hardness increases the tendency for cracking, so from the welding point of view high hardness or high hardenability steels offering higher hardness up to the greater distance is not considered to be good because it will be promoting the cracking tendency of the steels. From the welding point of view the B grade steels will be better as compared to that of the F grade steel.

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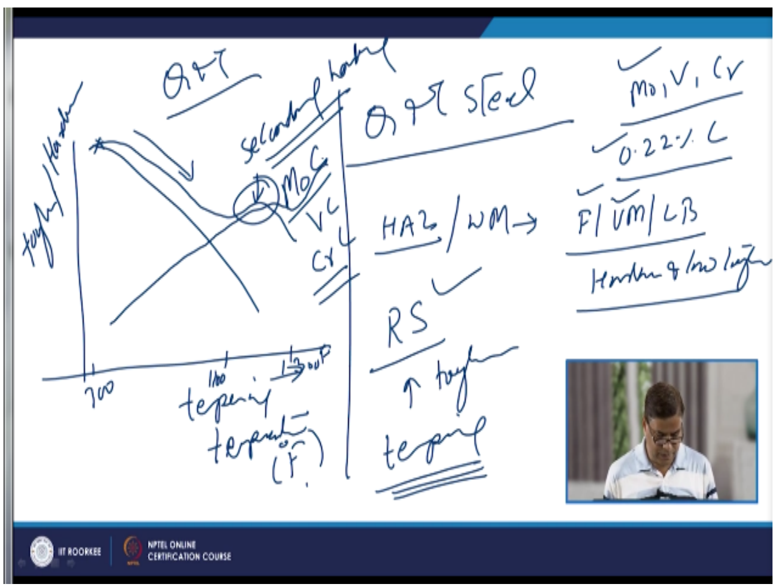

Since most of the Q and T steels having the elements like molybdenum, vanadium even chromium in little quantity apart from the carbon up to 0.22%. And when these are welded of course the heat affected zone next to the fusion boundary as well as the weld metal, these produce the ferrite or untempered martensite or the lower bainide.

So, to deal with the high hardness and low toughness situations associated with the low toughness properties related with these steels. It may be required to relive the residual stresses and induce the toughness and for that it is required to perform tempering treatment of the Q and

T steels. Normally the post weld heat treatment is not required of the weld joints of the Q and T steels.

Because after the welding in most of the cases we get the weld metal and heat affected zone properties similar to that of the base metal but if you want to relive the residual stresses and we want to improve the notch toughness of the weld metal as well as the heat affected zone. Then the post weld heat treatment in form of tempering is performed. And if we see the typical tempering curve for the Q and T which is having molybdenum, chromium and vanadium type of the elements apart from the carbon.

So, these steels show a typical behavior during the tempering as a function of the tempering temperature. So, in x axis we are having the tempering temperature and in y axis if we have the toughness and the hardness. So, hardness obviously will be reduced during the tempering and there will be improvement in the toughness.

So, the typical steels show the hardness in as welded condition in general hardness is more because of the formation of untempered martensite, ferrite and the lower bainide. So, when the steel is tempered we notice that there is a marginal increase at higher temperature of the tempering. So, like say at around 1100 to 1300 Fahrenheit tempering temperature in Fahrenheit, so say 700 Fahrenheit to 1300 Fahrenheit.

So, as the tempering temperature is increased we notice the reduction in hardness and this is attributed to the tempering of the martensite. At the same time residual stresses will be relived but when the tempering is performed of Q and T steel weld joints in the temperature range of 1100 to 1300 Fahrenheit we notice that the secondary hardening is observed. So, the drop is not continuous but the hardness drop is reversed little bit when the tempering is performed at a high temperature.

And this the rise in hardness on tempering over a particular range of the temperature from 1100 to 1300 degree Fahrenheit is attributed to the secondary hardening. Wherein the formation of the hot and stable carbides of molybdenum, vanadium and chromium carbides are formed in the steel weld joints in the weld as well as heat affected zone. So, this typical behavior of the little will gain in the hardness during the tempering is attributed to the secondary hardening.

While in case of the conventional plane carbon steel if we carry out the tempering as a function of tempering temperature there is continuous drop in the hardness. While the reverse trend just opposite trend is shown by the toughness behavior like this. So, toughness improves while the hardness comes down during the tempering of the steel weld joints.

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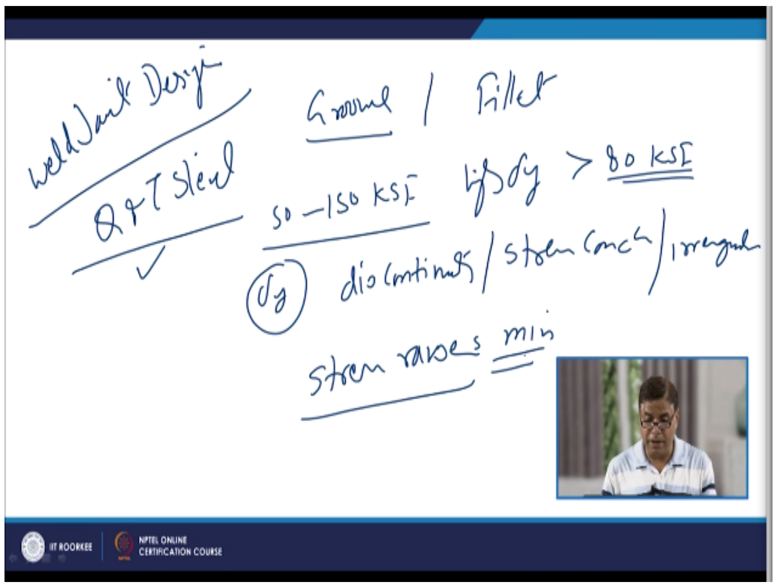

Now we will see the kind of the weld joint design which is used. So, weld joint design means there are different types of the weld joints which are used the most common one like the groove joint and the fillet weld joint. So, theoretically we can use any type of the joint for making the connections of the Q and T steels but since the Q and T steels are of the high strength like 50 to 150 KSI.

So, because of especially those high yield strength steels especially those which are of the greater than 80KSI. The joint design becomes crucial because the high yield strength metals they have the less tolerance for the discontinuities stress concentration. And irregularities if they are present in the weld joint surface, so it is more important that the weld is designed very properly for Q and T steels. So, that the stress razors or minimum or they are minimized, so for this what we can do.

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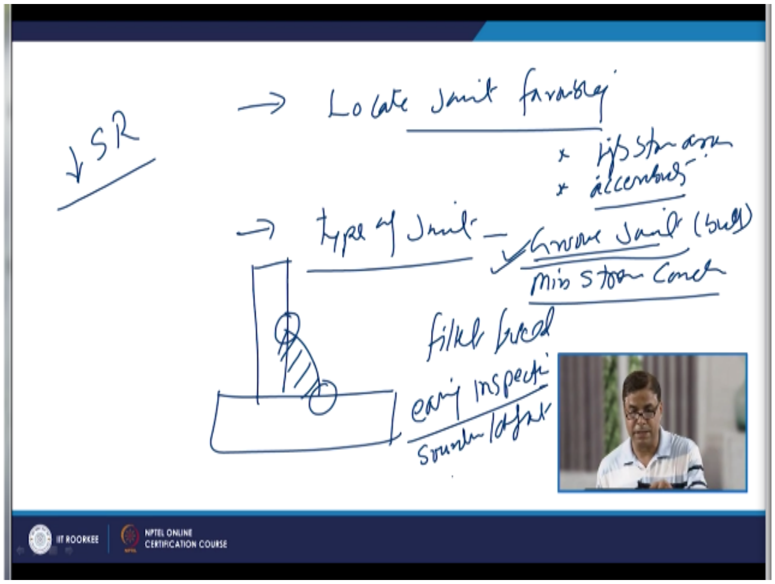

To reduce the stress razors what we can do we need to locate the joint favorably means the joint is located in such a way that it does not fall in the high stress area. Second the location is accessible for developing the weld joint if the accessibility of the weld joint location is poor than the proper control over the weld metal proper penetration will be difficult to have the good accessibility of the weld joint it should be properly located.

Then the type of the joint which is to be selected, in general for all critical applications where dynamic loading will be there in form of fatigue and in form of impact resistance. Normally the groove joint is used a groove butt joint configuration is used because it offers the minimum stress concentration especially when the toe of the weld is properly taken care of while the fillet weld offer has the inherent stress razor in it is deign like.

This is the kind of the connection which is to be made and if the fillet weld is made it will be offering the higher stress concentration at the toe of the weld. So, the fillets welds inherently offer the higher stress concentration as compare to the groove weld joints. So, for all those high stress locations and wherever the fatigue and the impact load dynamic load conditions exist groove joint is to be used as compared to that of the fillet weld joint.

One more aspect is there apart from the lower stress concentration as in case of the groove is that easy inspection of the soundness presence of defect is possible in case of the groove joint designs as compare to the fillet weld. So, lower stress concentration and the easy inspection of the developed weld joint will be more favorable for reducing the failure tendency of the weld joints of the high strength Q and T steels.

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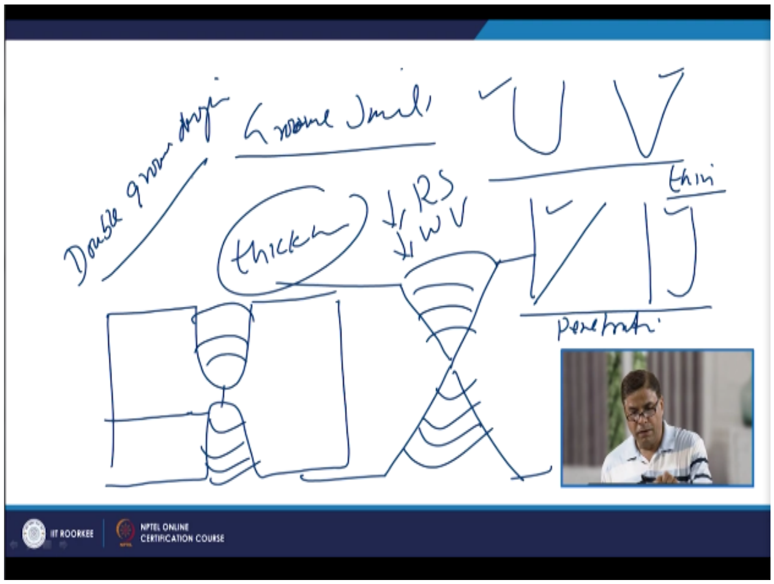

In case of the groove weld joint, groove joint designs there are various options which are possible like U joint and the V joint are most commonly used for thin plates. We prefer less to go for B weld joint and the J joint configuration because in both these cases accessibility of the route is difficult. So there are penetration issues, we are not able to penetrate and the fuse the metal properly.

So, to overcome the issues related with the lack of penetration it is normally not preferred to use the B weld and the J groove geometries while we prefer U and V joint groove joint designs. At the same time if the thickness is really for thick plates then we will be preferring the double V and the double U kind of the geometry. So, that we can neutralize the residual stress aspects.

So, in this case the joint is designed both the sides in order to neutralize the residual stress development tendency. So, for thick sections reducing the residual stresses reducing the weld volume and making the welding more cost effective and more productive suitably the double groove designs in form of like double U or double V groove joint design should be used.

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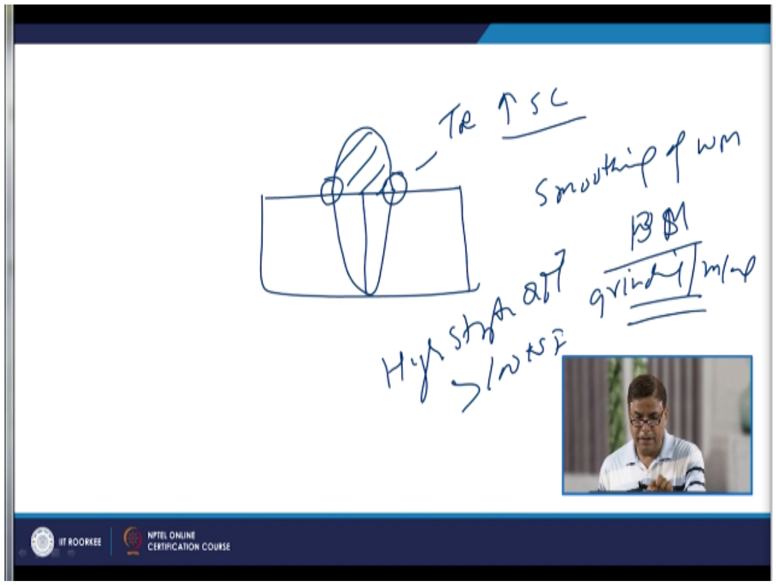

Whatever groove design we use if the weld is made improperly like this by making the weld having the toes. If the toe is offering the higher stress concentration then it will become the site of the weakness or site for the failure especially impact and the fatigue conditions. So, proper smoothening of the weld metal with the base metal must be realized through the suitable grinding and the machining processes.

So, that the stress concentration at the toe of the weld can be reduced and this is especially crucial in case of the high strength Q and T steels having the strength greater than 100 KSI.

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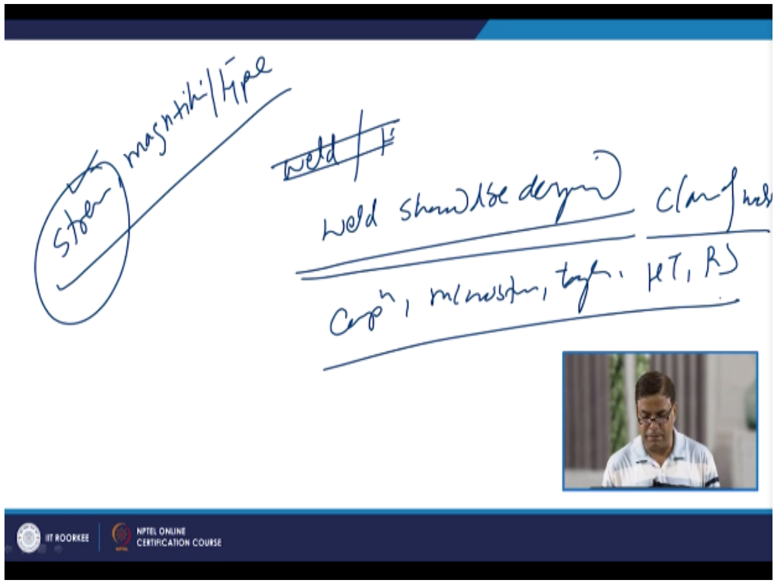

Apart from this the considering the stresses their magnitude and the type the suitable weld should be designed. So, we need to keep in mind the what kind of the stresses will be applied during the service in terms of the magnitude of the type of stresses. And keeping that in mind as per the suitable class of the weld cross sectional area should be designed.

So, that the weld joint does not experience the stresses beyond the acceptable levels and in this regard proper weld joint design becomes crucial to maintain the service stresses in the weld joints within the safe limit. So, the joint design is crucial, so that the stresses are within the safe limit apart from that other aspects like composition, micro structure, toughness the heat treatment, residual stresses all these are the secondary aspects.

The primary is that the how the weld is being designed so that the service stresses acting in weld joint is within the service stress are within the safe limit in order to offer the required life of the weld joint under the fatigue conditions. Now I will summarize this presentation, in this presentation basically I have talked about the weldability of the quenched and tempered steels.

And when these steels are tempered what kind of the hardness variation is realized and then we have seen the kind of the points we should keep in mind for designing the weld joints for Q and T steels, thank you very for your attention.