Weldability of Metals
Prof. D K Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-24
Weldability of Q and T Steels-III

Hello, I welcome you all in this presentation related with the subject weldability of metals and we are talking about the weldability of the quenched and tempered steels. We have talked about the chemical composition and the properties of the quenched and tempered steels. In the previous presentation we have talked about the hardenability behavior tempering curve of the Q and T steels.

And the kind of the points that we have to keep in mind while designing the weld joints for the Q and T steels. Since these steels of the high yield strength, so we need to avoid the residual stresses as well as the stress concentration in the weld joints. So, the proper care has to be given at that weld joint design stage. So, that unnecessary the stress results from the weldments can be reduced just as a quick review of the things.

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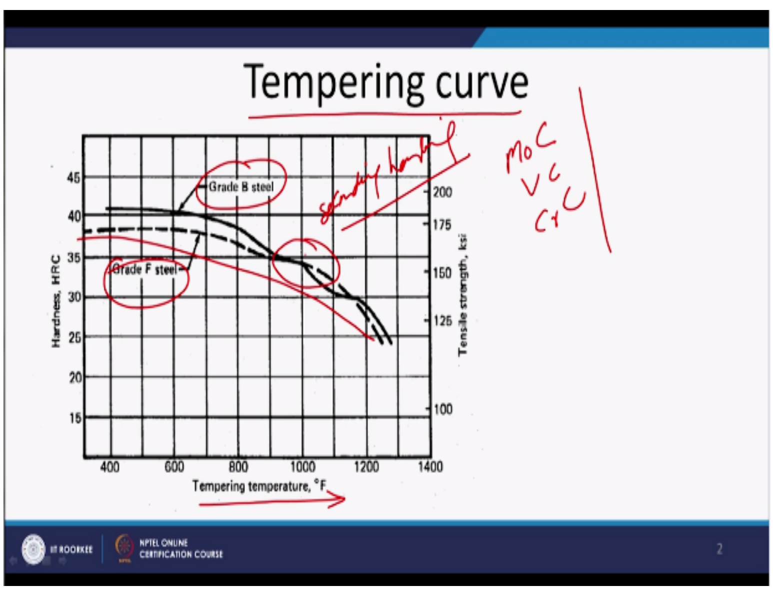

That we talked about the tempering behavior of the Q and T steels and wherein we have seen that as the tempering temperature is increased there is a reduction in the hardness which is realized, that is what we can see. But at somewhere like 1000 to 700 degree Fahrenheit we notice that a little bit arrest of the drop in hardness or increase in hardness is observed and this is attributed to the secondary hardening of the steel primarily due to the molybdenum, vanadium and chromium carbide formations.

Since these elements are already there in both these steels there is one more aspect that the drop in hardness of the F grade steel is faster than the B grade steels. While the secondary hardening behavior is same in both the category of the steels.

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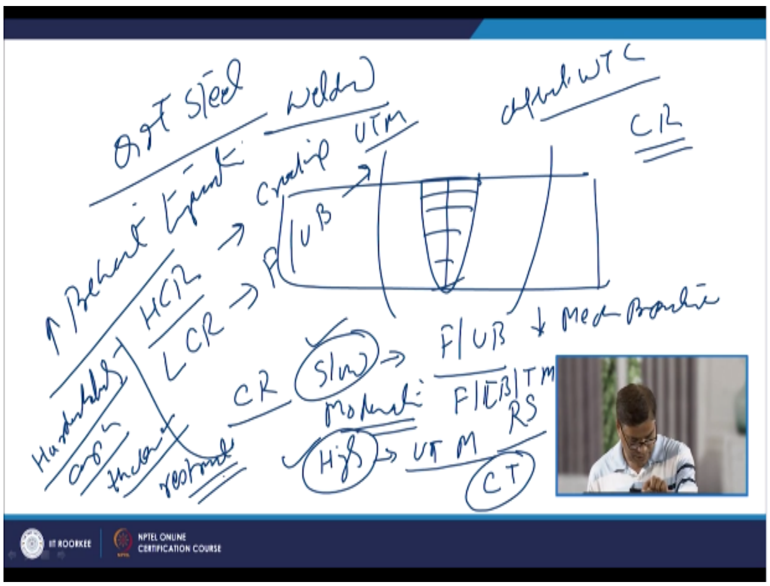

Now we have seen that when the Q and T steels are welded or when welding is performed you know the weld metal as well as the heat affected zone say this is weld metal and the heat affected zone . These will be experiencing the different weld thermal cycles in the different zones and the kind of cooling rate which is experienced in these cases.

That is found sufficient for the formation of the martensite as well as the upper bainide sometimes the lower bainide and the ferrite. But what we need to do is like if the cooling rate is unfavorable, cooling rate is very slow then it will be leading to the formation of the ferrite and the upper bainide only which lowers the mechanical properties significantly.

So, there is deterioration mechanical properties in terms of notch toughness and yield strength. When the cooling rate is extremely high then it will be leading to the formation of the untempered martensite is formed. So, development of the residual stresses in combination with the formation of untempered martensite will be increasing the cracking tendency.

So, increased cracking tendency will be leading to the defeat of the purpose like the weld joint is being made with the defects. So, neither too high cooling rate nor too low cooling rate is needed during the welding and that is why moderate cooling rates need to be used. So, that we get the ferrite, bainide a lower bainide and maybe tempered auto tempered martensite. So, that we have the reasonable combination of the yield strength toughness and unnecessary residual stresses are also not developed which will be increasing the cracking tendency.

And the embrittlement tendency is also reduced, so neither too high or nor too low cooling rates need to be used during the welding. So, what we can do for this purpose, we have to avoid the excessive high preheat, preheating is needed. So, optimum preheat is to be used, if the preheating rate is less preheating temperature and interpass temperature during the welding is less of the Q and T steels.

Then low preheat temperature will be leading to the high cooling rate and that maybe increasing the tendency for cracking due to the formation of the untempered martensite. On the other hand if preheating temperature is very high then high preheat temperature will be leading to the very low cooling rate. And low cooling rate again will be leading to the formation of the ferrite upper bainide and these will be deteriorating mechanical properties in terms of the reduced and notch toughness and the yield strength.

So, and optimum preheat temperature is to be used, so that should be carefully controlled enlight of the hardenability as dictated by the composition of the steel thickness of the plate being welded and the kind of restrained conditions which are being used. So, that unnecessary cracking tendency can be reduced and the required set of the properties in the weld joint can be realized.

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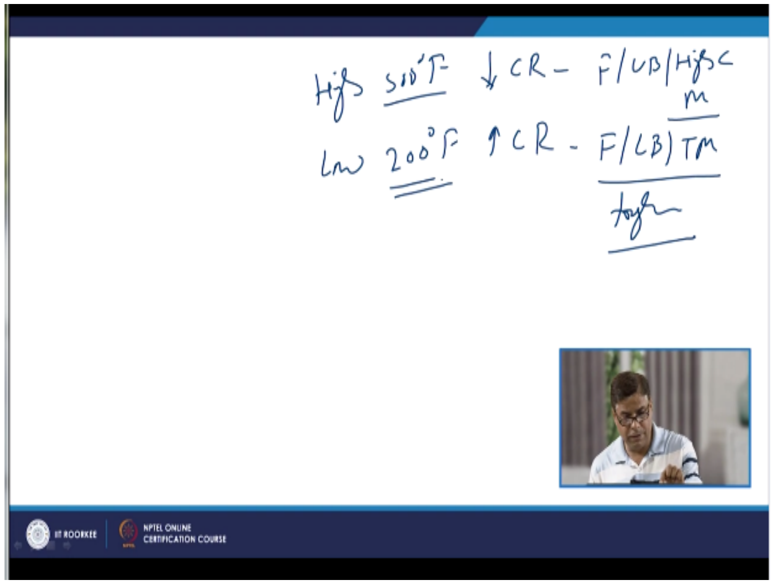

And therefore the different value of the preheat is used say too high preheat temperature say 500 Fahrenheit will be lowering down the cooling rate which will be leading to the formation of the ferrite upper bainide and maybe a high carbon martensite. On the other hand low cooling rate will be leading to the like say 200 Fahrenheit, so this 200 Fahrenheit will be leading to the reasonable cooling rate and good combination of the ferrite lower bainide and the maybe tempered martensite.

And so will be getting the much better toughness in when the moderate preheat temperature is used as compared to the case when the very high preheat temperature is used.

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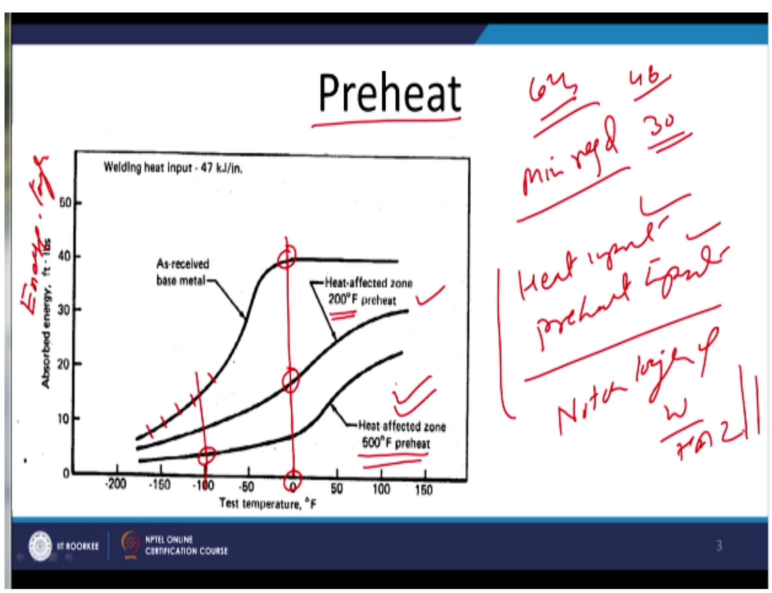

So, if we see this kind of the comparison the way by which the preheat temperature affects the toughness in terms of the energy absorbed. This is basically indicating the notch toughness of the Q and T steel weld joints when the base metal toughness behavior as a function of test temperature this is like the variation in toughness as a function of temperature.

If we take any temperature of the impact test like this, so the base metal will be offering very high energy absorbed high toughness while the heat affected zone expose to the heat affected zone of the weld joints given preheating of the 200 degree Fahrenheit upper somewhat better somewhat impact resistance in terms of the energy absorbed as compared to the case when the preheat of the 500 Fahrenheit is used.

So, what we can see here in all the cases there is a drop in the energy absorbed with a reduction in temperature but this kind of drop is more severe when the preheat temperature is high especially the regard to the impact resistance of the heat affected zone. So, many times the heat input during the welding and the preheat temperatures are identified considering the toughness or notch toughness of the weld as well as heat affected zone.

So, **so** the preheat temperature and the heat input are identified or established during the welding procedure specification that means the heat input and the preheat temperature are established in such a way that weld joint in the heat affected zone and the weld metal is having the minimum required toughness for given application. This can vary it maybe in terms of like 30 units or it may be 48 units or 64 units.

So, **so** as per the application the minimum required toughness can very or can change significantly. So, accordingly the heat input for a given welding process and the preheat temperatures need to be identified. So, a higher preheat temperatures are not good especially with regard to the preheat especially with regard to the impact resistance of the heat affected zone and the weld metal.

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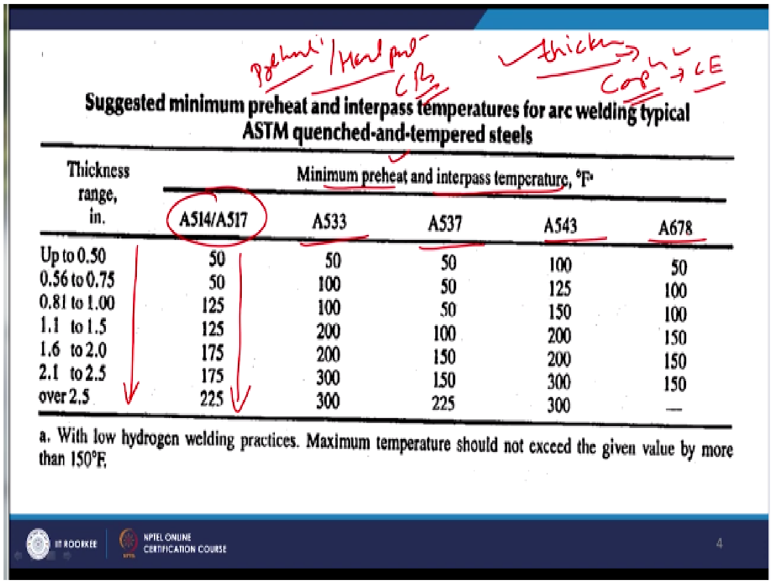

Suggested minimum preheat and interpass temperatures for arc welding typical ASTM quenched-and-tempered steels

Thickness range, in.	Minimum preheat and interpass temperature, °F[a]				
	A514/A517	A533	A537	A543	A678
Up to 0.50	50	50	50	100	50
0.56 to 0.75	50	100	50	125	100
0.81 to 1.00	125	100	50	150	100
1.1 to 1.5	125	200	100	200	150
1.6 to 2.0	175	200	150	200	150
2.1 to 2.5	175	300	150	300	150
over 2.5	225	300	225	300	—

a. With low hydrogen welding practices. Maximum temperature should not exceed the given value by more than 150°F.

Now we will see so keeping the things in mind especially the thickness of the plate which will be determining the rate at which heat is being extracted from the weld as well as heat affected zone. So, the thickness and the kind of composition different steels having the different alloying concentrations and that in turn will be affecting the carbon equivalent.

So, the conditions under which the particular kind of the phase transformation which is taking place that will also be changing. And therefore we find that the minimum preheat or interpass temperatures are found to very significantly with the change of the thickness of the plate which is to be welded. Like say these the most common series of the Q and T steel is A514 and A517 and we can notice that with the increase in thickness of the plate to be welded.

There is continuous increase in the temperature which is to be used for the preheat and likewise for the different steels. There are different values of the minimum preheat temperature which means these preheat temperatures need to be established enlight of the application for a given thickness and for a given type of the steel. So, that the preheat temperature and the heat input combination offer us the required cooling rate.

So, that we have the desired set of the micro structural features to obtain the required combination of the mechanical properties in terms of the yield strength and the toughness or the notch toughness. So, these are the preheat and interpass temperatures for the most commonly used Q and T steels.

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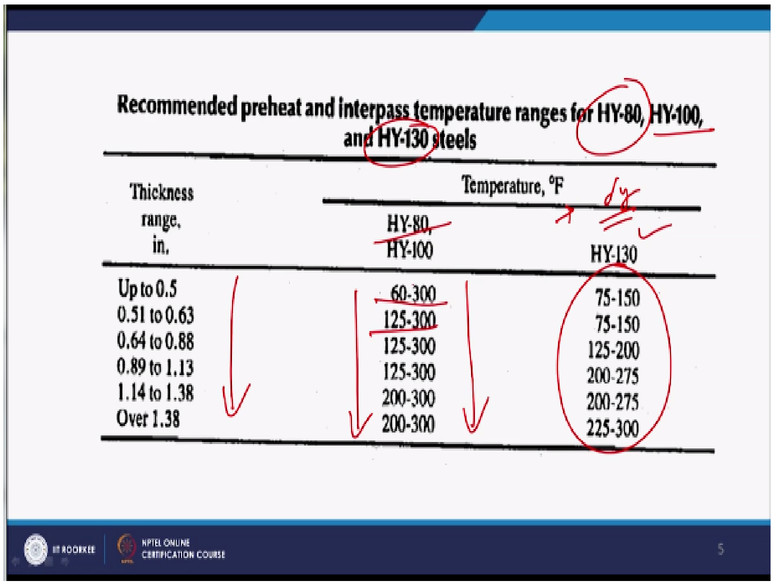

And in the next slide we have few more the preheat and interpass temperatures for HY80, HY100 and HY 130 steels. And what we notice that in this case also with increase in thickness of the plate required preheat temperature is also increased. So, almost similar kind of the preheat temperatures are there for HY80 and HY100 like up to 0.5 inch it is 60 to 300 Fahrenheit then 125 to 300.

So, depending upon the thickness and depending upon the welding process the kind of the temperatures which are used been mentioned here. And what it shows that the minimum preheat and interpass temperatures will be increasing with the increase in thickness of the plate while the higher preheat and higher interpass temperatures are used for Hy130. It will be offering us much higher yield strength as compared to that of the Hy80 and Hy100 type of the steel, so a proper combination of the preheat at the heat input is needed.

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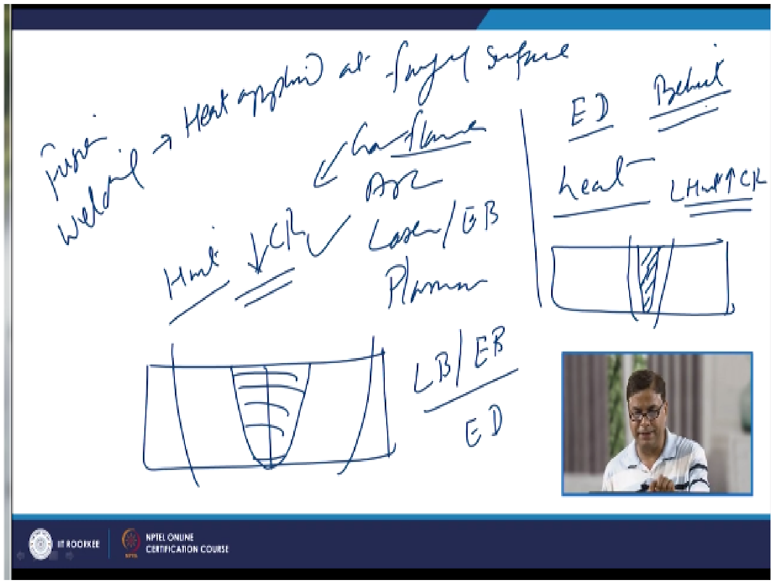

Now we know that for welding or for fusion welding heat is applied at the faying surfaces using suitable heat source which maybe in form of like gas flame, it maybe arc, it maybe radiations like laser and electron beam. So, or it may be plasma, so suitable heat sources used to apply the heat since the energy density associated with each of the welding process is different, so the amount of heat to be supplied by these processes for bringing the faying surfaces of the plates to be welded that will also be different.

Like low energy density process like gas welding it will be require to supply more amount of heat. So, the weld metal fused size is more heat affected zone size is more and because of the high heat input we get the lower cooling rates. On the other hand the laser beam and electron beam welding processes they offer very high energy density.

So, very less heat is required to be supply to bring the faying surfaces to the molten state and very limited heat affected zone is formed due to the less heat supply. And we know that the cooling rate and the heat input are inversely related. So, the lower heat input leads to the higher cooling rate, so the cooling rate and the heat input are very closely related. And now this will be affecting our choice for preheat temperature. So, as per the welding process to be used the preheat temperature may change significantly.

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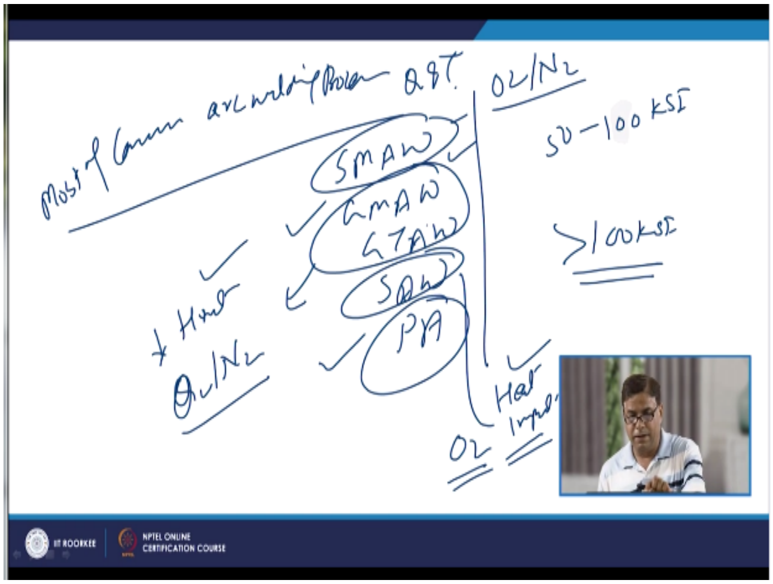

Now we will be talking about the processes which are available like most of common arc welding processes can be used for welding of the Q and T steels like SMAW, GMAW, GTAW, SAW, PAW all these can be used for welding of all types of steels having the strengths from 50 to 100KSI. But when this is the very general statement but when the steel strength is greater than 100KSI we would like to use those good quality welding processes which offers the lesser heat input.

So, that the heat affected zone being formed is limited at the same time the oxygen, oxygen, nitrogen concentration in the weld is also less. So, the through proper protection of the shielding gases in case of the GMAW, GTAW and the plasma arc welding process helps us to develop the good quality weld joints with the less heat input and gases present in form of oxygen and nitrogen in the weld metal are also reduced.

So, the Q and T steels of high yield strength or yield strength greater than 100KSI are mostly preferred to be welded by GMAW, GTAW and the PAW process. While other processes like SMAW offers the higher concentration of the oxygen and nitrogen in the weld metal. So, there are lot of discontinuities in the weld metals since these Q and T steels are of the high yield strength.

So, they have less tolerance to the discontinuities and therefore they promote the failure tendency . And likewise the SAW of also offers the higher concentration of the oxygen as well as the heat input which is provided by the SAW is also on the higher side. So, it results in the this weld is continuities due to the oxygen present or the presence of the flux inclusions or the wider heat affected zone due to the higher heat input. So, we prefer to weld the high yield strength Q and T steels by GMA, GTAW and the PAW processes.

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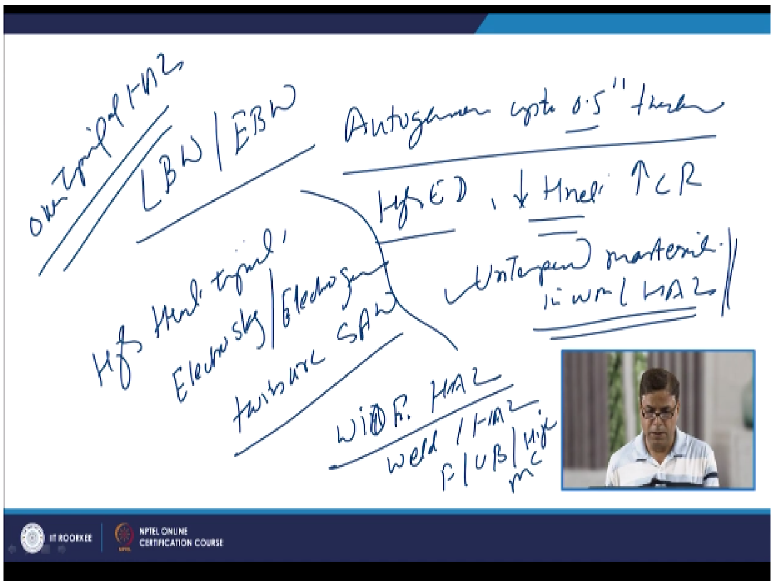

We can use the laser beam welding and electron beam welding for autogenous means direct welding, no filler autogenous welding up to 0.5 inch thickness of the Q and T steels. Since the both these processes are of the very high energy density, so they will supply very less heat for realizing the fusion of the faying surfaces to develop the joint, cooling rate is extremely high.

And because of the high cooling rate mostly we with this processes we get the untempered martensite both in weld metal as well as heat affected zones. So, we need to be careful about the embrittlement associated with the untempered martensite. But if we use on the other hand if we use very high heat input processes like electro slack and electro gas welding or twin arc SAW process.

Then very high heat input will be leading to the very wide heat affected zone, wide Hz and unfavorable structure both in the weld and the heat affected zone which maybe in form of like ferrite upper bainide or very high carbon martensite. And if since the steel is the Q and T steel, so over tempering of the heat affected zone is also caused by the welding processes which are of the high heat input.

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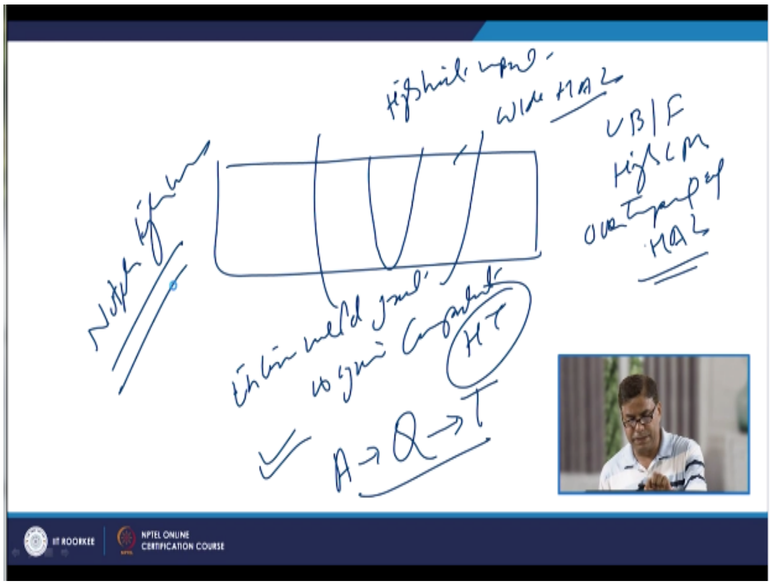

So, in order to overcome the issues related with the weld joints made using the high heat input processes like wide Hz upper bainide, ferrite and high carbon martensite or even over tempering of the Hz . It is required that entire weld joint is given complete heat treatment again what it involves austenitizing of the weldment followed by quenching then tempering.

So, that the properties in the base in the weld as well as heat affected zone can be homogenized and the properties can be restored. So, the adverse effects related with the high heat input associated with the electro slack, electro gas and the submerged arc welding processes can be reduced. So, the complete heat treatment of such type of the weld joints are is needed, so that especially the notch toughness can be restored apart from maintaining the required combination of the properties.

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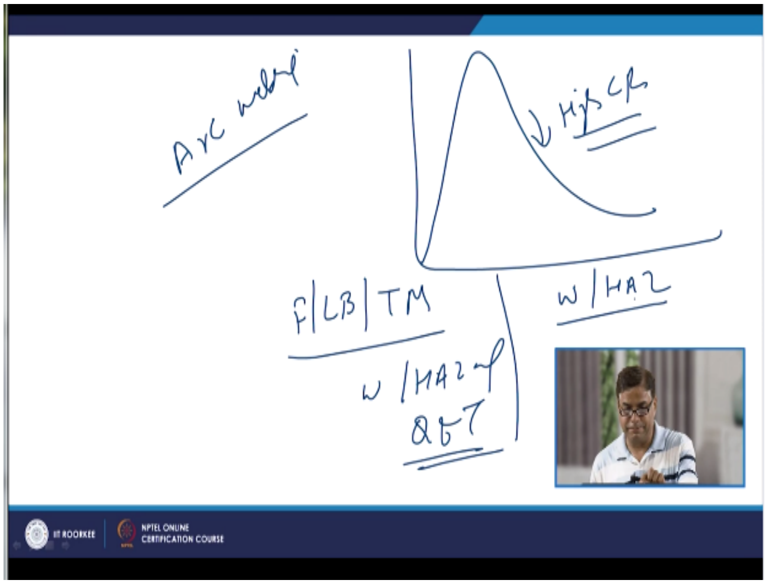

Otherwise in most of the arc welding processes the kind of weld thermal cycle which is realized in the weld as well as heat affected zone it is such that cooling rate is high enough to form the ferrite, lower bainide and the tempered martensite auto tempered martensite in the weld as well as heat affected zone of the Q and T steel weldments. And that is why the mechanical properties of the weld and as well as Hz of the Q and T steels are similar to that of the base metal.

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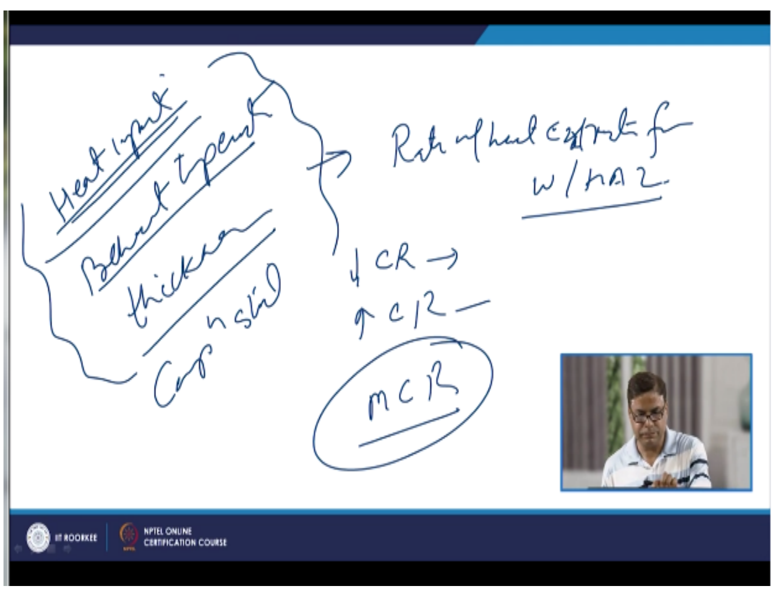

Now we will see the heat input related aspect, heat input and the preheat temperature and the thickness of the plate. These are the 3 aspects which are seen together because a combination of these 3 will be determining the rate at which rate of heat extraction from the weld as well as heat affected zone. So, what we have seen earlier that if the cooling rate is very low then we get the unfavorable structure.

Similarly if we have very high cooling rate then again we get the cracking tendency due to the formation of untempered martensite. So, we need to have the moderate cooling rate and the moderate cooling rate can be realized by having proper consideration to the heat input, preheat temperature and thickness for a given composition of the steel.

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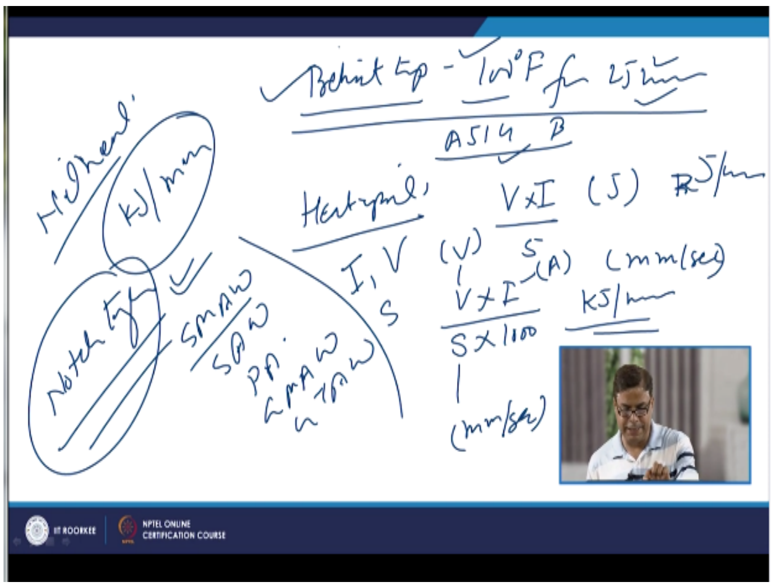

So, **so** we have to fix up at least one thing like preheat temperature is fixed say 100 Fahrenheit for a 25mm thick plate. Then for this preheat inverse for this thickness of the plate of a given steels say A514 B grade steel. Then we need to establish the heat input for the process which is being selected and heat input how can we choose now for all those arc welding processes heat input is obtained through the voltage into current gives us the power of arc or in the joule.

And if we divide it the welding is speed then we get welding speed mm/second then we get the joule/mm net heat input in joule/mm. If we want normally the heat input is expressed in kilo joule/mm, so we will be dividing it V*I/welding speed/1000. So, this will be giving us the voltage V is the voltage that is arc voltage a is the I is the current in ampere and S is the welding speed in mm/second if it is in mm/minute then we need to multiply 60.

So, this is what will be giving us kilo joule/mm, so for a given welding process whether it is SMAW or SAW or PAW GMAW or GTAW whatever the processes will be using particular value of the current and the voltage and the arc will be travelling at a particular speed. So, for those various combinations we need to see that our kilo joule /mm net heat input this is called net heat input does not cross the specified value.

So, through the welding procedure specification for a given preheat during the weld of plate of given thickness of the given composition we try to identify the heat input. So, that we are able to have the required notch toughness, most of the heat inputs are given with reference to the notch toughness value that the combination of the welding parameters, preheat temperature for a given thickness of plate of a given composition will be offering us this much minimum notch toughness.

Because most of the steels during the welding, experiencing drop in toughness that is why notch toughness is considered as an important criteria. While there is another set of the steels in the Q and T category where the more drop in the yield strength takes place. So, in that case yield strength of the weld joint is taken as a qualifying criteria for deciding or determining the preheat temperature, heat input as well as for a given thickness of the plate of the given steel.

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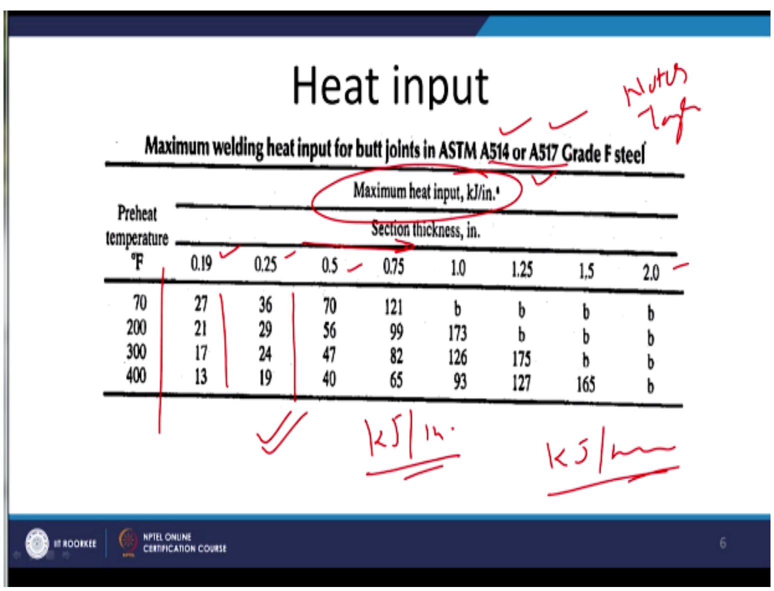

Now we will see there are the different preheat temperatures different heat input values for developing the weld joints or butt joints of the A514 and A517 steels like what we can see here this is the preheat temperature. And the kind of the section thicknesses 0.9 to 0.25, 0.5 to 2 inch and the maximum heat input which is allowed. So, that we this is the maximum heat input in kilo joule/inch.

So, we can obtain in kilo joule/mm which is most commonly used by dividing these values with the 25. So, this is giving us the value of the maximum heat input which will be giving us the acceptable range of the notch toughness. So, this is for this is the kind of heat input data which can be used as a guideline for welding of the A514 and A517 steel.

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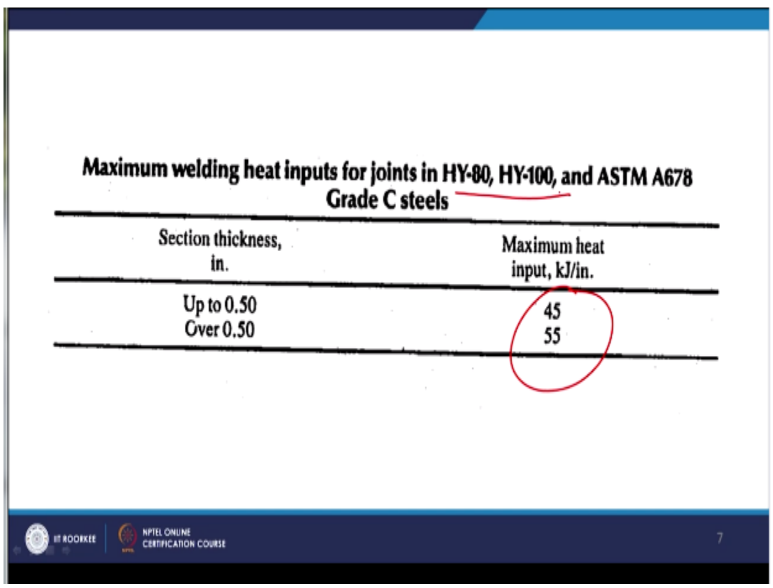

This is the kind of the heat input for maximum heat input for the welding of the Hy80 and Hy100 steel. Now I will summarize this presentation, in this presentation basically I have talked about the way by which welding processes will be affecting the weld joint characteristics of the Q and T steels and the way by which we should select the preheat temperature for developing the weld joints of the Q and T steels. So, that we can realize that required combination of the properties, thank you for your attention.