Weldability of Metals
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Lecture-22
Weldability of Q and T Steels-I

Hello, I welcome you all in this presentation related with the subject weldability of metals and we are talking about the weldability of steels. In the weldability of steels we have talked about the weldability of the carbon steels and high strength low alloy steels. In this presentation will be taking up the weldability of the quenched and tempered steels, so initially we will try to understand, try to know about the Q and T steels.

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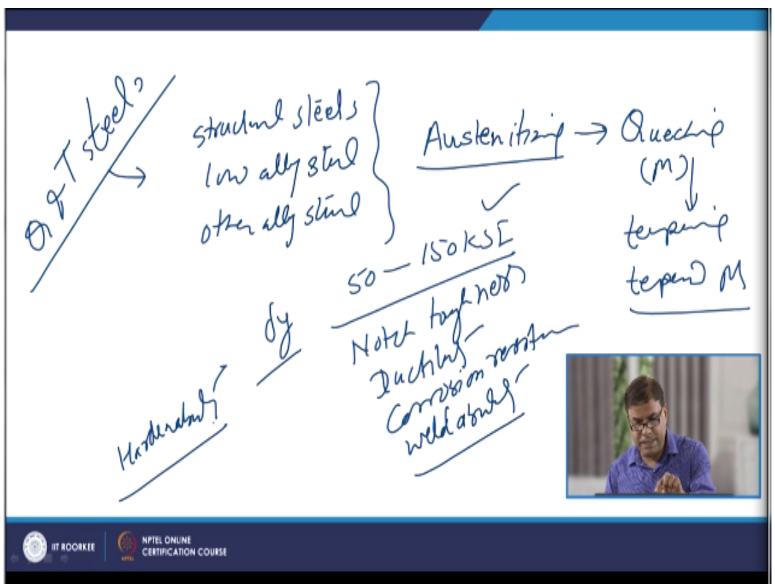

These are basically quenched and tempered steels, so these steels are basically how these are realized these can be the structural steels. These can be low alloy steels and these can be other alloy steel category. These steels are basically developed means Q and T steels can be of these categories which are developed following sequence of heat treatment involving austenitizing means we have to heat it, so that homogeneous austenite is formed followed by quenching.

So, that is involving the rapid cooling and primary goal of this quenching is to form the martensite. And thereafter the tempering is carried out at different temperatures as per the steel composition, so that the tempered martensite can be formed. And this combination results in extremely good combination of the mechanical properties like yield strength can range from 50 to 150 KSI.

Apart from the yield strength it also causes very good notch toughness, this category of a steels causes very good notch toughness, good ductility offers very good corrosion resistance and the carbon equivalent due to the low carbon content is such that the weldability is also good. But since the strength is high and the presence of alloying elements is also there in these steels. So, hardenability of the steel must be kept in mind while talking about the weldability of the Q and T steels. So, whenever these steels are welded.

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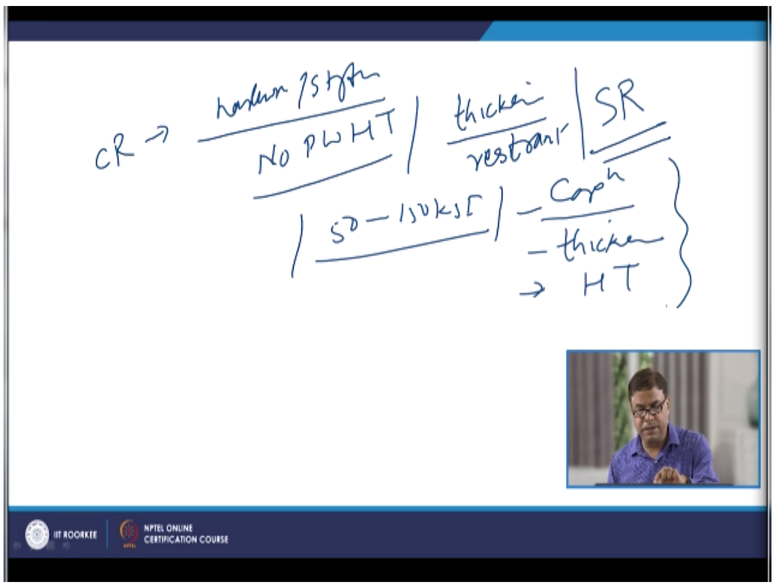

Generally the fusion welding of first the cooling rates which results in the reasonable good hardness and strength of the weldment. And that is why generally no post weld heat treatment after the welding is needed with these steels except when very thick sections are being welded. And the welding is being carried out under restrain conditions in those cases the stress reliving heat treatment is carried out.

So, that whatever residual stresses are being developed those can be taken care of as I have said these are quite high in strength ranging from 50 to 150 KSI and this strength will depend upon the kind of the composition which is there in a particular steel. The thickness of a steel plates and the kind of the heat treatment which is being given like tempering conditions or the cooling rate conditions imposed during the quenching process, so these are the general features of the Q and T steels.

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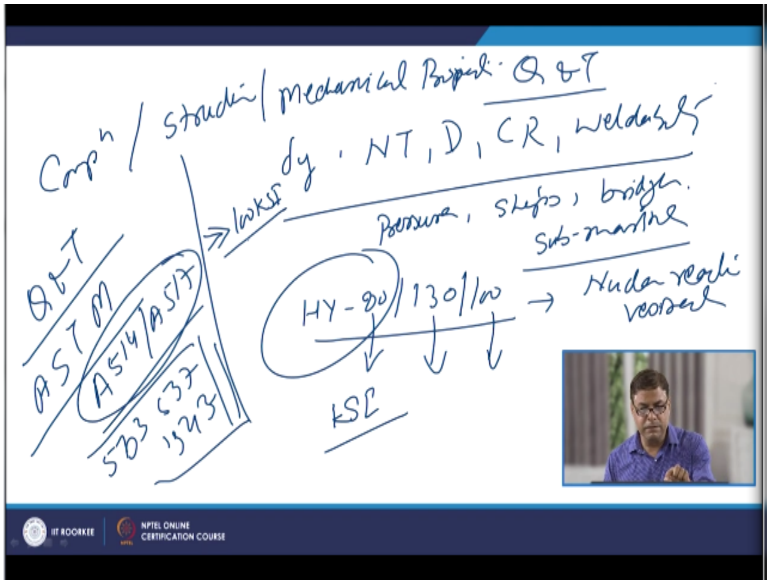

As far as the composition of the steels and the micro structure and the mechanical properties of the Q and T steels are concern. As I have said these are extremely good in terms of the yield strength, notch toughness, ductility, corrosion resistance and the weldability and that is why these found these steels find extensive application in the industry in form of like the pressure vessels , fabrication of the pressure vessel component.

The ships, the bridges, the submarine components and there are few category of the steels like HY-80, HY-130, HY-100. These are typically used in nuclear reactor vessels and here these numbers indicate the kind of the yield strength in KSI of the like HY-80 means the 80 minimum yield strength is 80 KSI of the HY80 steel and likewise for HY100 is the 100 KSI yield strength or 130 for HY130 KSI yield strength of these steels.

So, most of the Q and T steel combination or compositions are covered under the ASTM standards and one of the most commonly used steel is like A514 and another one is the 517, 514 and A517. These are the 2 most commonly used grades of the Q and T steels will talk in detail about the composition of these steels subsequently. Other steels are like 533 like 537 and 543, these are other category of the steels and they offer their own combination of the properties and the weldability.

But this type of a steel like A514 and A517 these offer the strength generally greater than the 100 KSI. So, those high strength steels need very care at very special precautions for developing the sound weld joints. So that we can perform successfully during the service, so now we will see some of the compositions of these steels.

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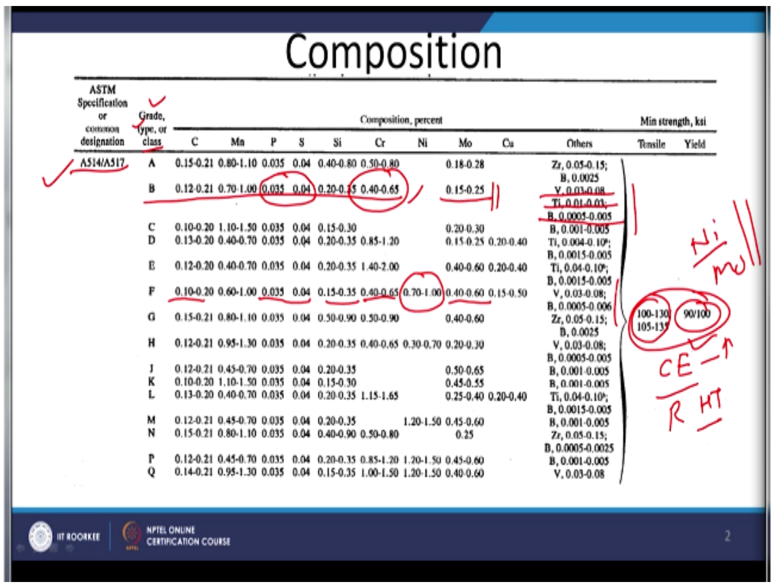

ASTM Specification or common designation	Grade, type, or class	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Others	Min strength, ksi Tensile	Yield
A514/A517	A	0.15-0.21	0.80-1.10	0.035	0.04	0.40-0.80	0.50-0.80		0.18-0.28		Zr, 0.05-0.15; B, 0.0025	100-130 105-135	90/100
	B	0.12-0.21	0.70-1.00	0.035	0.04	0.20-0.35	0.40-0.65		0.15-0.25		V, 0.03-0.08; Ti, 0.01-0.03; B, 0.0005-0.005		
	C	0.10-0.20	1.10-1.50	0.035	0.04	0.15-0.30			0.20-0.30		B, 0.001-0.005		
	D	0.13-0.20	0.40-0.70	0.035	0.04	0.20-0.35	0.85-1.20		0.15-0.25	0.20-0.40	Ti, 0.004-0.10ᵃ; B, 0.0015-0.005		
	E	0.12-0.20	0.40-0.70	0.035	0.04	0.20-0.35	1.40-2.00		0.40-0.60	0.20-0.40	Ti, 0.04-0.10ᵃ; B, 0.0015-0.005		
	F	0.10-0.20	0.60-1.00	0.035	0.04	0.15-0.35	0.40-0.65	0.70-1.00	0.40-0.60	0.15-0.50	V, 0.03-0.08; B, 0.0005-0.006		
	G	0.15-0.21	0.80-1.10	0.035	0.04	0.50-0.90	0.50-0.90		0.40-0.60		Zr, 0.05-0.15; B, 0.0025		
	H	0.12-0.21	0.95-1.30	0.035	0.04	0.20-0.35	0.40-0.65	0.30-0.70	0.20-0.30		V, 0.03-0.08; B, 0.0005-0.005		
	J	0.12-0.21	0.45-0.70	0.035	0.04	0.20-0.35			0.50-0.65		B, 0.001-0.005		
	K	0.10-0.20	1.10-1.50	0.035	0.04	0.15-0.30			0.45-0.55		B, 0.001-0.005		
	L	0.13-0.20	0.40-0.70	0.035	0.04	0.20-0.35	1.15-1.65		0.25-0.40	0.20-0.40	Ti, 0.04-0.10ᵃ; B, 0.0015-0.005		
	M	0.12-0.21	0.45-0.70	0.035	0.04	0.20-0.35		1.20-1.50	0.45-0.60		B, 0.001-0.005		
	N	0.15-0.21	0.80-1.10	0.035	0.04	0.40-0.90	0.50-0.80		0.25		Zr, 0.05-0.15; B, 0.0005-0.0025		
	P	0.12-0.21	0.45-0.70	0.035	0.04	0.20-0.35	0.85-1.20	1.20-1.50	0.45-0.60		B, 0.001-0.005		
	Q	0.14-0.21	0.95-1.30	0.035	0.04	0.15-0.35	1.00-1.50	1.20-1.50	0.40-0.60		V, 0.03-0.08		

Like this is one big grade of the Q and T steel where the category of the steels where we have the different classes like grade, type or class. Class A, B, C, D up to Q and each of these grades of the 514 or 517 steel will be having the different set of the compositions. For example like if we talk of the B grade steel having that carbon 0.1 to 0.21 manganese 0.7 to 1, phosphorus and the sulfur are very well below the acceptable maximum level silicon 0.2 to 0.35 chromium is one typical element 0.4 to 0.6.

And molybdenum is 0.15 to 0.25 and vanadium 0.03 to 0.08, titanium 0.01 to 0.03 and boron 0.0005 to 0.005. So this is one steel and just for comparison I am talking of there is another steel which is this one like grade F having the carbon 0.1 to 0.2, manganese 0.6 to 1, phosphorus and the sulfur both are below the maximum allowed limit silicon 0.1 0.5 to 0.35.

Chromium if we compare here we have again of the same level 0.4 to 0.65 as that of the B grade but this one is having additionally the nickel 0.7 to 1%. And the molybdenum percentage is ~~is~~ higher here earlier in the B grade it was 0.15 to 0.25 and here it is 0.4 to 0.6. And likewise the other concentration of the other elements, so there is additional percentage of the nickel and the molybdenum.

These elements since these are in the F grade these are the presence these are the elements which are extra as compare to that of that which has compare to those elements which are present in the B grade steels. So, extra and additional percentage of the element in F grade will be leading to the higher carbon equivalent that is why the response to the heat treatment of F grade will be completely different then what will be for the B grade.

Because of the higher carbon content, higher percentage of the alloying elements C, E for F grade will be higher than that for the E grade. And accordingly the hardenability for the F grade will be better than that of the B grade steel. So, I mean to say there are different elements which are present in different types of the 514 and 517 type of the Q and T steels. And most of these steels if we see these are of like 100 to 130 or 90 to 100 or 105 to 135.

So, this is so in general there are strength is around 100 or more than 100 KSI. So, this is like yield strength 90 to 100 and the ultimate strength is like 100 to 130 or 105 to 135.

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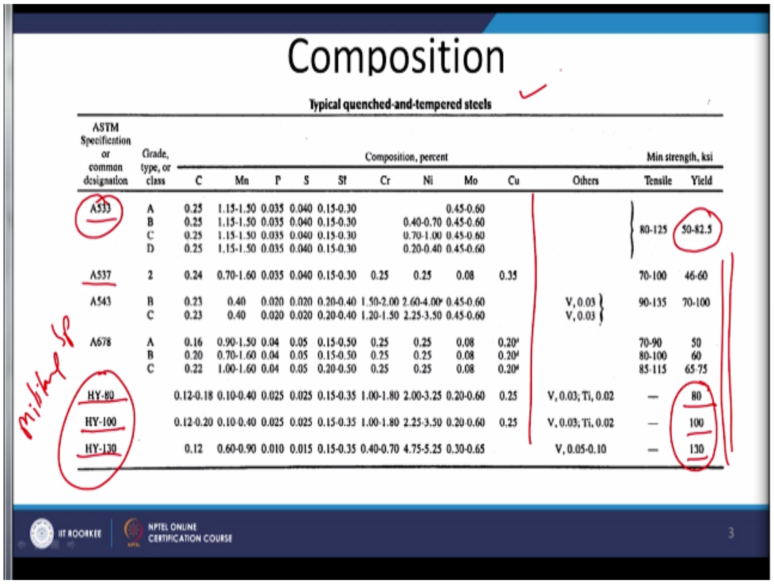

So, this is one of the most commonly used Q and T, there are other category of the Q and T steels like A533, A537. And each one will be having their, own composition and the tensile strength. So, if we see 533 steel will be having the lower yield strength as compared to 517 or 514 having the yield strength ranged of 50 to 82. And likewise others are also having the lower yield strength except these 3.

So, HY80 is having minimum 80 KSI yield strength, HY100 having the minimum 100 KSI strength yield strength and HY30 is having 130 KSI yield strength. So, these are the specially designed and covered under the military specifications while other grades are covered under the ASTM specifications. So, all these are the commonly used Q and T category of the steels.

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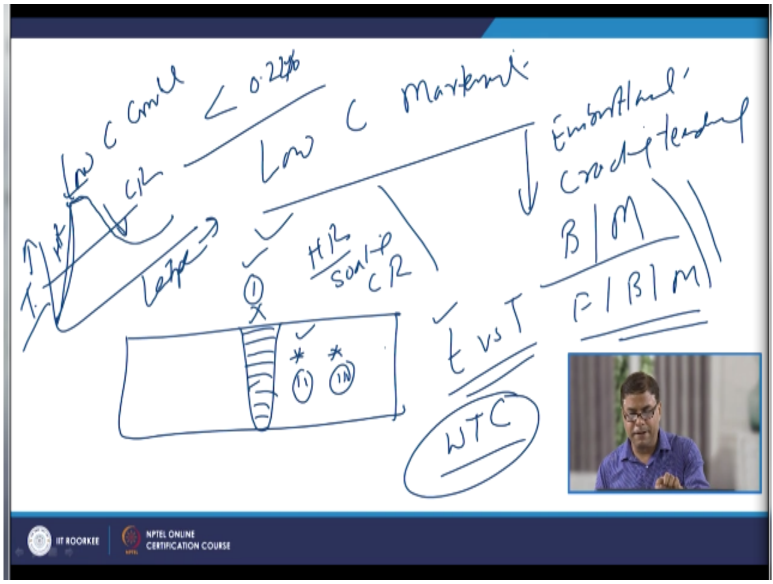

Most of these steels are actually designed to have the low carbon content which is less than 0.22%. So that whatever martensite is found that is of the low carbon martensite and it does not lead to the much of the embrittlement or increase in cracking tendency. So cracking tendency and the embrittlement tendency both are reduced because of the low carbon martensite formation.

And during the tempering that is that will be leading to the formation of the tempered martensite. So, depending upon the kind of the heat treatment given to these various category of the steels, the different types of the microstructures are produced.

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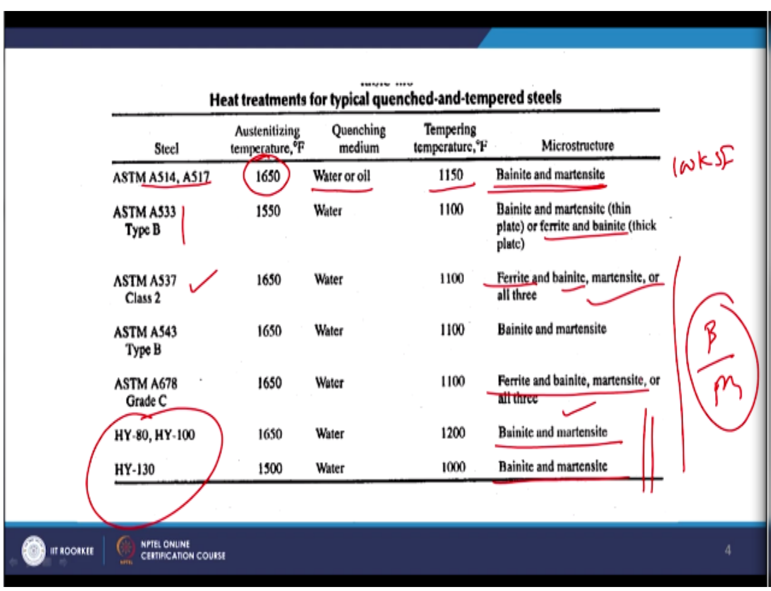

Heat treatments for typical quenched-and-tempered steels

Steel	Austenitizing temperature, °F	Quenching medium	Tempering temperature, °F	Microstructure
ASTM A514, A517	1650	Water or oil	1150	Bainite and martensite
ASTM A533 Type B	1550	Water	1100	Bainite and martensite (thin plate) or ferrite and bainite (thick plate)
ASTM A537 Class 2	1650	Water	1100	Ferrite and bainite, martensite, or all three
ASTM A543 Type B	1650	Water	1100	Bainite and martensite
ASTM A678 Grade C	1650	Water	1100	Ferrite and bainite, martensite, or all three
HY-80, HY-100	1650	Water	1200	Bainite and martensite
HY-130	1500	Water	1000	Bainite and martensite

And these microstructures will certainly be modified during the welding in the weld metal as well as the heat affected zone during the heat treatment. But what these steels have before welding that is what we can see say A514 and 517 steel when subjected to the austenitizing treatment at 1650 degree Fahrenheit followed by water quenching and then tempering at 1150 Fahrenheit this leads to the formation of the bainite and the martensite.

Find bainite-and the tempered martensite formation leads to the yield strength of the 100KSI. On the other hand the 5 A533 steel will be having the banide and martensite with thin plates and some of the amount of the ferrite and the bainite is also formed, other steels when subjected to the different types of the heat treatments they will be having the different micro structures what we can that is what we can see from the steels.

Most of the steels it will see in Q and T conditions they are suppose to have the bainite and the tempered martensite. And as per the kind of the grains size of these steels and the relative fraction of these micro constituents will be having the different combinations of the mechanical properties. So more critical in these cases where much higher yield strength is realized through the combination of the same phases by controlling the relative fraction of these micro constituents.

So primarily these have the bainite and the tempered martensite while other phases may have the ferrite and bainite or ferrite bainite and martensite mixture of all 3.

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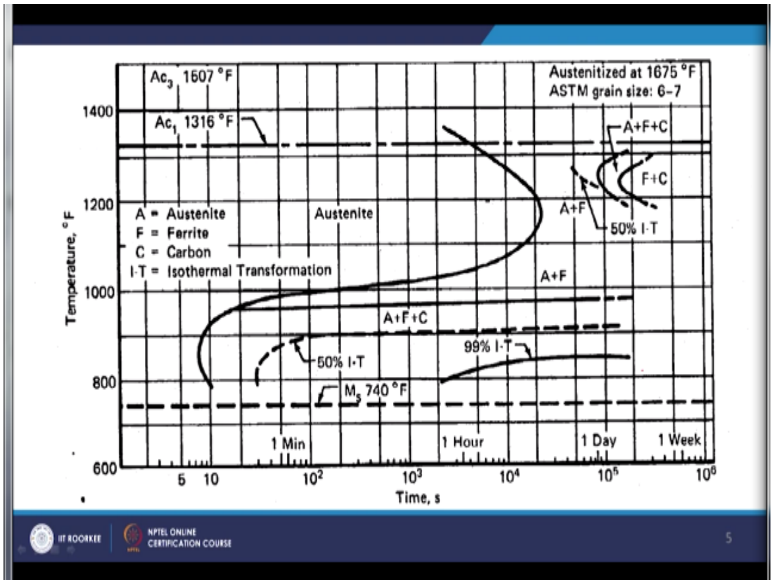

So, as per the micro constituents there will be different amount of the as per the composition and the kind of heat treatment which is being given. The steels may have the different micro constituents primarily these are design to have the bainite and martensite. But if the there are certain compositions where it can have the ferrite, bainite and the martensite. So, as per the kind of the heat treatment conditions and the tempering conditions which are being imposed.

It can have the high carbon martensite or it can have the low carbon martensite, upper bainite, lower bainite etc and which will be leading to the different combinations of the properties. Now we know that whenever welding is carried out obviously a zone which is zone where heat is applied in fusion welding is brought to the molten state. And this zone will be experiencing say this is the zone 1 will be experiencing very high rate of the heating followed by the rapid cooling.

Then there are other zones in the like the zone next to the fusion boundary that is the heat affected zone. So the different areas will be subjected to the different rate of heating rate, soaking time and the cooling rate experienced by the different zones will be different. And that is what will say the kind of the variation in temperature as a function of time that is known as weld thermal cycle.

So, a particular location the way by which it experiences the variation in temperature as a function of time that is known as weld thermal cycle which typically shows the rate of heating, maximum temperature holding at that high temperature followed by the rate of cooling. So, heating rate, soaking above particular temperature and then cooling rate, so these are the 3 aspects temperature and time, temperature on y axis and time on x axis showing the weld thermal cycles.

So, which kind of the micro structural modification will be taking place due to the welding in the weld metal heat affected zone at different locations. That is what we need to understand to see the way by which the Q and T steels will be responding to the welding or heat being applied during the welding.

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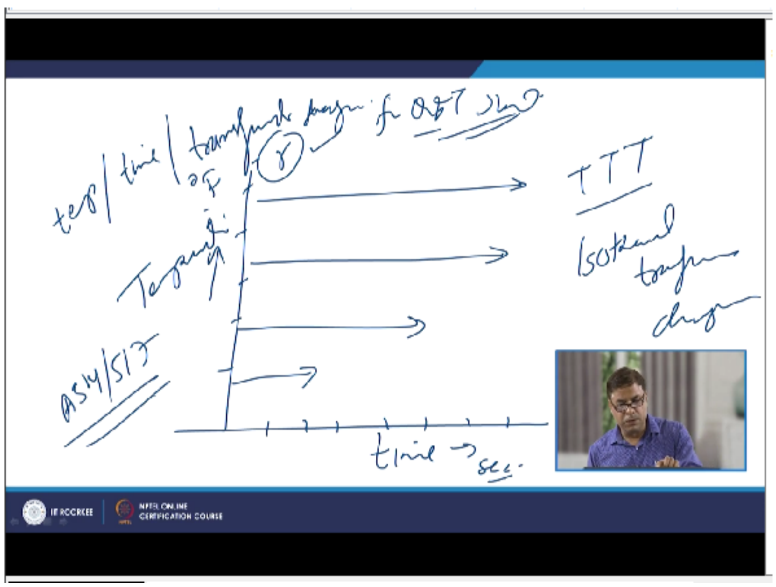

And for this purpose we need to see the temperature, time, transformation diagram for Q and T steels. So, this diagram is basically the relationship between that the way by which a particular category of steel behaves when it is held at high temperature in austenitic state as a function of time. So, in y axis if we are having the temperature and time in x axis so this will be having the time in seconds and the time in say in Fahrenheit.

And what it will be showing us as per the type of steel which we have selected it will be showing how the austenite will be transforming into the different phases when steel is held at a constant temperature as a function of time. So, this a kind of the way by which austenite transforms into the other phases is reflected by the TTT diagram or this also known as isothermal transformation diagram of a that particular type of steel.

So, for Q and T steel which is most common like A514 and 517 category, will be looking into the isothermal transformation diagram.

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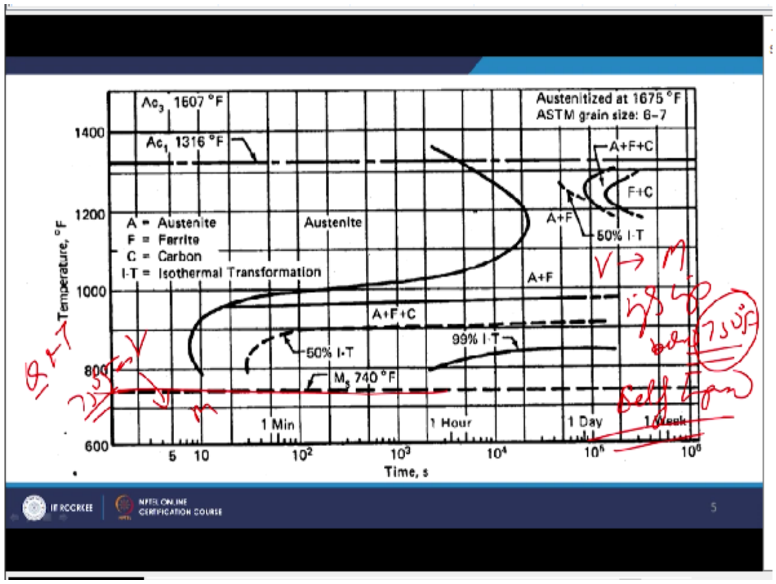

So, if we see there are 2 or 3 zones about which we can say like what happens to the steel when it is exposed constant temperature in range of 1100 degree Fahrenheit to 1300 degree Fahrenheit this is one zone. Then another zone is 950 to the 1100 Fahrenheit and what happens when steel is exposed at a temperature below 950 degree centigrade. So the responses of the Q and T steels when of the 517 or 514 type when it is given exposure at a constant temperature for longer time.

The way by which austenite transforms into the different phases that is what we can see here. So, high temperature exposure of these steels, if we see like 1100 to 1300 degree centigrade like this is the kind of zone for 1300 degree centigrade. So, what we can see here there will be formation of the ferrite there will be for formation of the pearlite or maybe martensite. Mostly ferrite and the pearlite and the bainite is formed at high temperature.

So, the formation of the upper bainite, the pearlite and the bainite in these steels leads to the reduction in the yield strength, reduction in the notch toughness and mechanical. In general mechanical properties are adversely affected when the Q and T steel is exposed for the transformation at high temperature for longer time leads to the formation of the basically the ferrite, upper bainite and this course.

This structure coarse leads to the reduction in the yield strength as well as notch toughness. If we give the exposure at somewhat lower temperature, so there is one important thing that is what we can see here in addition to this transformation like when the steel is Q and T is steel of 514 or 517 type is exposed at a high temperature we see the kind of time it takes to start the transformation that is huge.

So how much this time is you can see it is greater than 1 hour or so or even for the longer. So, transformation of austenite into the other phases will start after 1 hour or so. But when the exposure is given at lower temperature say 950 or so. Then the transformation will start like 950 to the 1100 degree Fahrenheit then it will take a starter time to start the transformation of the austenite into the other phases.

Still we get the ferrite and the upper bainite but this will be somewhat the finer in terms of the structure. So, somewhat better properties as compared to the case when we expose it at a higher temperature, so ferrite and the upper bainite. At the same time whenever the this kind of the transformation takes place this transformation involves the formation of the ferrite from the austenite with the rejection of the lot of carbon into the austenite.

And that is why we may find that the high carbon martensite on subsequent cooling may lead to the formation of the high carbon martensite. So in case when the thick plates like 25-50 mm thick plate when welded we may find a situation where no transformation of the austenite into the softer phases taken place. But whenever the austenite transforms into the ferrite the carbon is rejected into the austenite.

And that subsequently it is to the formation of the high carbon martensite, so this will be leading to the formation of the ferrite + high carbon martensite. So, the formation of soften and hard phases will be leading to the lot of heterogeneity in the structure as well as mechanical properties. And such in a kind of the phases leads to the reduction in the notch toughness of the steel.

So, when the transformation is carried out when the steel is exposed at further lower temperatures like below 950 degree centigrade. So, the transformation occurs very quickly very short time it takes to transform that is what we can see from this diagram like if the transformation occurring the steel is exposed at 950 degree centigrade. Then it will, quickly transforming into the phases.

So, the time is not much for rejection of the carbon from the austenite which is being formed into ferrite. And that is why we will see that the fine grained low carbon martensite is formed apart from the formation of the ferrite and the fine bainite or lower bainitic structure formations. So, in these cases mostly we get the ferrite the lower bainite and the low carbon martensite which offers very good combination of the mechanical properties.

And on the other hand if we see if the transformation is occurring if the steel Q and T steels is exposed to a temperature below 50 degree 750 degree Fahrenheit. Then it will be austenite will be transforming into the martensite, so this is the typical situation where austenite transforms into the martensite at high temperature just below the 750 degree Fahrenheit. And when the austenite transforms into the martensite at 750 degree centigrade, so whatever martensite is formed that is self tempered.

So auto tempering of the martensite takes place in this steels when the austenite when these steels are held for longer time below the 750 degree centigrade. So, austenite transformation to the martensite and experiences the self tempering. So this is certainly good situation and that is why we say that this kind of the steel when subjected to the welding by most of the common fusion welding process like arc welding.

Then the kind of the combination of the mechanical properties which is observed in the weld as well as heat affected zone that is as good as the base metal and that is why it does not require the post weld heat treatment. But certainly we need the post weld treatment if the welding processes are of the high heat input leading to the formation of the high carbon martensite due to the low cooling rate.

Then for those cases we need the post weld heat treatment in order to restore the properties and to relieve the residual stresses. Now I will summarize this presentation, in this presentation basically I have talked about the Q and T steels their compositions, properties, structures. And the way by which the Q and T steels will respond and to the high temperature exposure as a function of time that is what we have seen using the isothermal transformation diagram for Q and T steels, thank you for your attention.