Weldability of Metals
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Lecture-19
Weldability of Carbon Steels and Welding Processes-III

Hello I welcome you all in this presentation related with the subject weldability of metals and in the previous presentation we have talked about the weldability of the carbon steels with regard to the fusion welding processes like shielded metal arc welding, submerged arc welding, gas metal arc welding gas, tungsten arc welding process.

And now in this presentation we will see the weldability aspects of the carbon steels with regard to the resistance welding and the radiation welding processes. Like laser welding and the electron beam welding process, so as far as the resistance welding processes are concerned.

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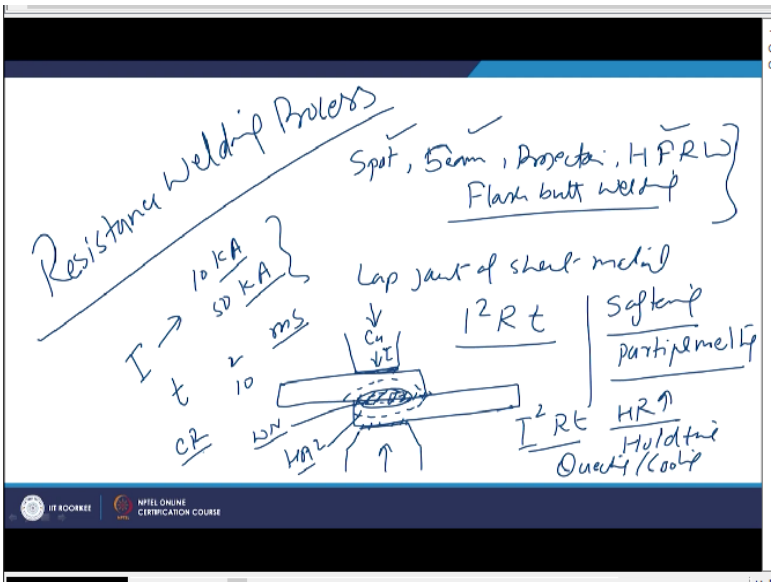

In case of the resistance welding processes, the most common welding process are like spot welding, seam welding, projection welding, and high frequency resistance and induction welding. Then we have this is called high frequency may be resistance welding and the flash welding which is mostly flash butt welding. So these are most common resistance welding processes and like the projection, seam.

And spot welding high frequency resistance welding processes are mostly used for developing the lap joints of sheet metals, while flash butt welding as name reflects is used for developing the butt joint. So, the common principle which is used in all this processes the I square are heating principle for softening or thermal softening of the components or the sheets being joined or facilitating the partial melting at the mating interface or the contacting interface.

So that the joint is developed through the consolidation and forging action in the last stage of the resistance welding process. So if we see the kind of the current values which are used in resistance welding process they are very high like 10000 ampere to 50,000 ampere. So, the values of the currents are extremely high and the time for which this current is supplied is very small it is in milliseconds. So like 2 or 10 milliseconds, so high current is supplied for a very short period say through the copper electrode in case of the spot welding the current is supplied like this.

So this is the area where the copper electrode will be contacting the upper plate and the lower plate will be contacted by the electrodes at this location. And then pressure is applied, so that the plates to be joined are in form metallic contact and once this pressure has been applied to the required level current is fed. So the current is supplied of very high magnitude for a very short period, so it generates lot of heat in very short time.

And because of this our heating rate which is used in resistance welding process is very high and thereafter the pressure is maintained. So, some hold time is there and then pressure is released joint is developed. So once the heating is over during the holding quenching or we can say the cooling of the joint interface takes place say when the current flows generation of the high heat at the interface leads to the softening initially and then partial melting for the development of the weld nugget.

So, once the heating is over the weld and the area around the weld which has absorbed some of the heat will be termed as heat affected zone. So, both weld nugget WN or heat affected zone and heat affected zone both will be cooled very rapidly So cooling rate experienced by the weld and heat affected zone will be very high.

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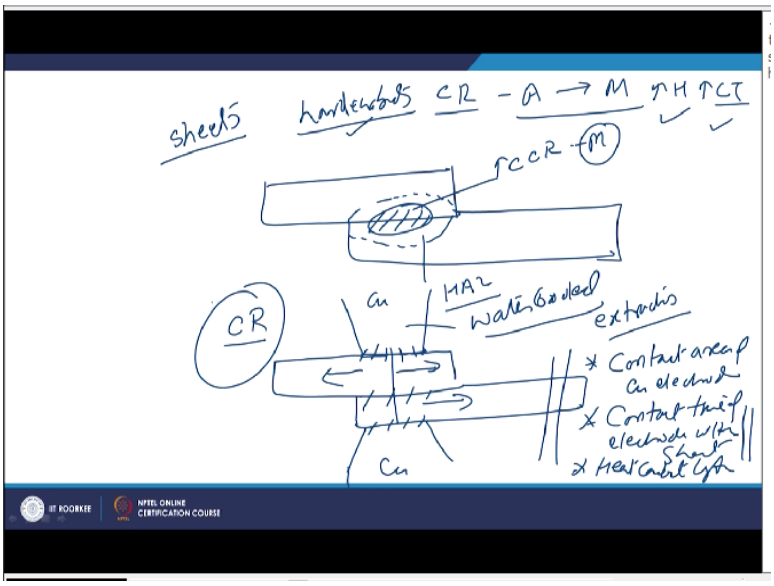

And therefore it becomes crucial that if the sheets which are being joined or having the medium or high hardenability then the cooling rate becomes crucial with regard to the austenite to martensitic transformation increase in hardness, increase in cracking tendency. So we need to be more careful with regard to the cooling rate being experienced by the weld nugget and heat affected zone during the spot welding of those steels having the some good hardenability.

Then we will see what happens when the joint is subjected to the high cooling rate like the weld nugget which has been heated to the high temperature of to the molten state and around the that zone is formed which is the heat affected zone. So, obviously because of the if the cooling rate is greater than the critical cooling rate. Then it will be leading to the martensitic transformation, both in the weld as well as heat affected zone, this will be leading to the increased hardness, increased cracking tendency of the joint.

So, now what are the factors which are governing the cooling rate being experienced by the weld and the heat affected zone once the heating is over, so for that again we have to see the same diagram this is the diagram like this. So these are the copper electrodes, copper electrodes are used, so that these can apply the pressure as well as feed the current with the minimum electrical resistance heating of the electrode itself.

So during the heating the work piece temperature will be the sheets temperature of the sheets will be increased. But since the electrode which is made of copper and is also water cooled most of the time. So that it is maintained within the same temperature limits, so water cooled copper extracts the heat rapidly from the sheet metals which have been heated during the resistance welding process.

So the contact area of the copper electrode is the one that affects the cooling rate being experienced by the weld as well as heat affected zone. Then how long the copper remains in contact of the sheet metal, so the contact time of electrode with sheet is important. Efforts are made in such a way that the electrodes are retracted or withdrawn as early as possible, so that the quenching effect can be reduced however for solid or for sound joint.

It becomes necessary that the pressure is maintained for sufficiently long time after the once the heating is over. So that proper forging action can take place, so but if the contact time is long the more heat will be extracted and the quenching will be more severe. So the contact time is another aspect then the heat conduction length the zone through which heat is lost to the base metal as per the thermal conductivity of the sheet metals.

That will also be affecting the rate which is being extracted from the weld metal as well as heat affected zone once the heating is over. So the conduction length contact time as well as the contact area of the electrodes these are the 3 factors that will be governing the cooling rate.

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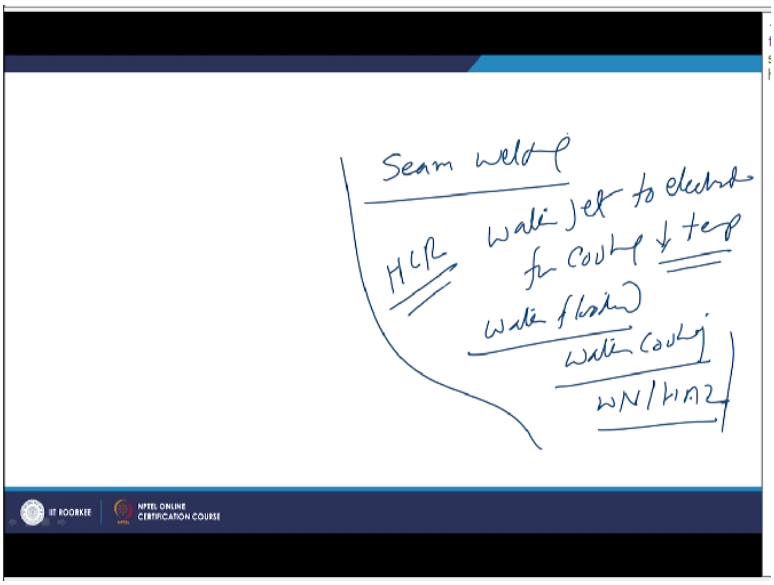

And there is another aspect related with this like in some of the welding resistance welding processes like seam welding it may be required to apply the water jet to the electrodes for cooling the electrodes, so that the electrode temperature is maintained within the safe limit. And in this process because of the water is a flooded there due to the cooling of the electrodes.

So that in turn also cools the causes the water cooling or the quenching by water of the weld nugget as well as heat affected zone. So, this the external forced cooling can also be responsible for high cooling rates during the seam welding and in the cases where we use the water jet to cool down the electrodes.

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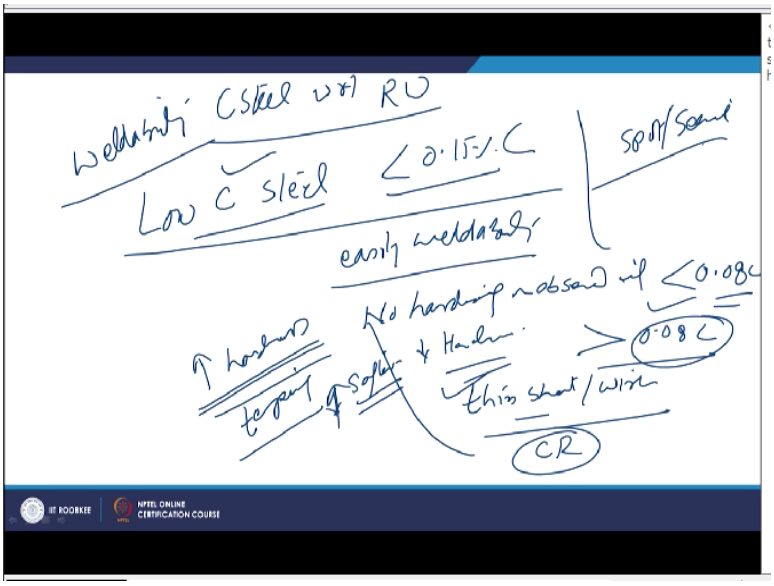

Now going by the specific metal systems the weldability of the carbon steels with respect to the resistance welding process. So, going by the specific metal systems if we see low carbon steels which normally have the carbon content less than 0.15%. But the steels usually most of the low carbon steels are easily weldable, but no hardening is observed. If the carbon content is less than 0.08 % but whenever the steel is having the carbon content greater than 0.08.

Especially very thin sheets in form of wires and sheets which will be experiencing much higher cooling rates during the resistance welding process. So these may lead to the significant increase in the hardness, so in these cases whenever the carbon content during the welding of the low carbon steels by resistance welding processes especially of very thin sheets and the very small diameter wires having the carbon content greater than 0.08% the high cooling rate will be leading to the increase in the hardness.

So, it will be more appropriate if somehow we can perform the tempering. So, that the hardness some of the softness can be induced and softness can be increased and hardness can be reduced. So this is the case when we are using the resistance welding in case of the spot welding and the seam welding processes.

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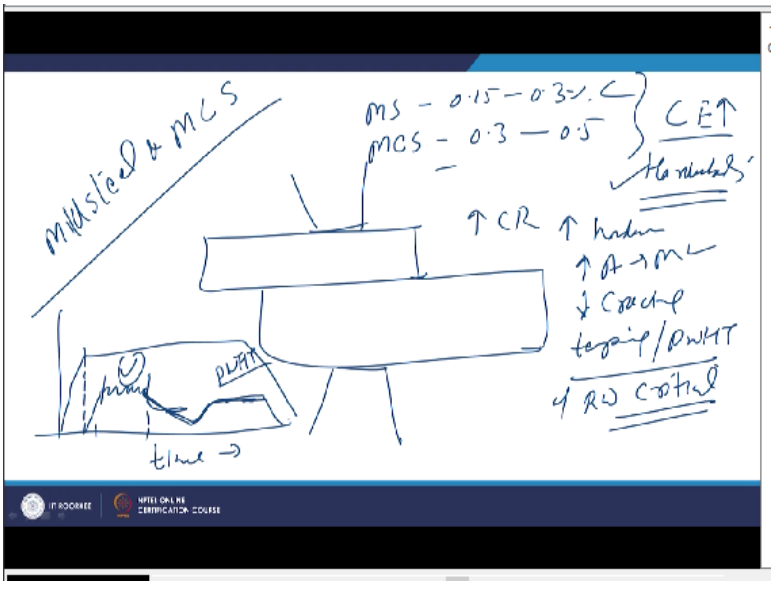

Now **we** if we talk of the mild steel and medium carbon steel, mild steel and medium carbon steels both have the carbon in range like for mild steel it is in 0.15-0.3%. And manganese content

is also high similarly medium carbon steel is 1.3-0.5%. So the carbon equivalent is high for both these and because of this there hardenability is also high. Since the high heating rate and the high cooling rate conditions being experience during the resistance.

Welding processes are such that under such high hardenability conditions medium carbon steels due to the high cooling rates will definitely be causing the increased hardness due to the austenite to the martensitic transformation tendency. So in this case in order to reduce the cracking tendency because the austenite to martensite transformation will be increasing the hardness which in turn will be increasing the crack tendencies.

So in order to reduce the cracking tendency the tempering or the post weld heat treatment of the resistance weld joints becomes very critical. And that must be done in order to avoid the cracking tendency and for this purpose what we do like this is the time and say the pressure cycle goes in like pressure is increased then pressure is held and then pressure is released as for as once the pressure is reached to the desired level.

We start supplying the current like this, so current is gradually increased then it is maintained. So, during this heating period and then once the heating is over then it can be reduced. And when the pressure is maintained, so during this period when there is no significant amount of the heat generation it will be cooling down and this cooling down will be leading to the like the current will be reduced.

And then it can be increased again little bit by certain magnitude and the current which is to be used for post heating that will depend upon the kind of thickness. And the time for which the post heat treatment is to be done the metal which is being processed. And then so this is the current the one current level is used for the welding purpose then another current level is used for the post weld heat treatment purpose. So they again electrical resistance heating is only used for the post heat treatment purpose.

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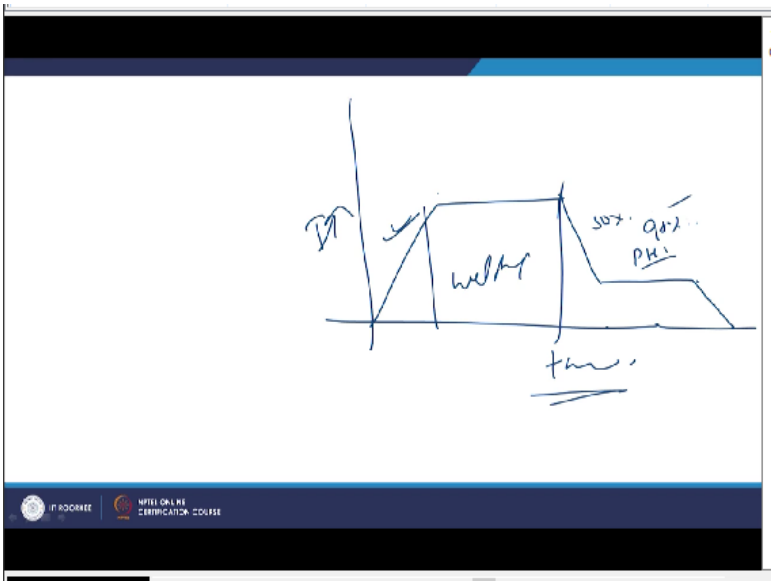

In more simplified form what we say that the current is increased then it is held. Then, so this is the welding time and then current is reduced then again the current is supplied. So, current is reduced then the current is maintained at a certain level. So, that post heat treatment can be performed and then it is again reduced. So, now this level of the current to be used may be 50%-90% of the welding current which is being used for the welding purpose.

So, this axis welding time welding current and this is the time, so basically the current is only used for the purpose of the electrical resistance heating during the post heat treatment as well as for the preheating if required. In order to control the cooling rate, so the preheating using the low current levels for some of the time has to perform the tempering and the post heat treatment of the weld metal as well as heat affected zone.

So, that the required tempering of the weld metal as well as heat affected zone can be realized to induce the softness increase the toughness reduce the cracking tendency.

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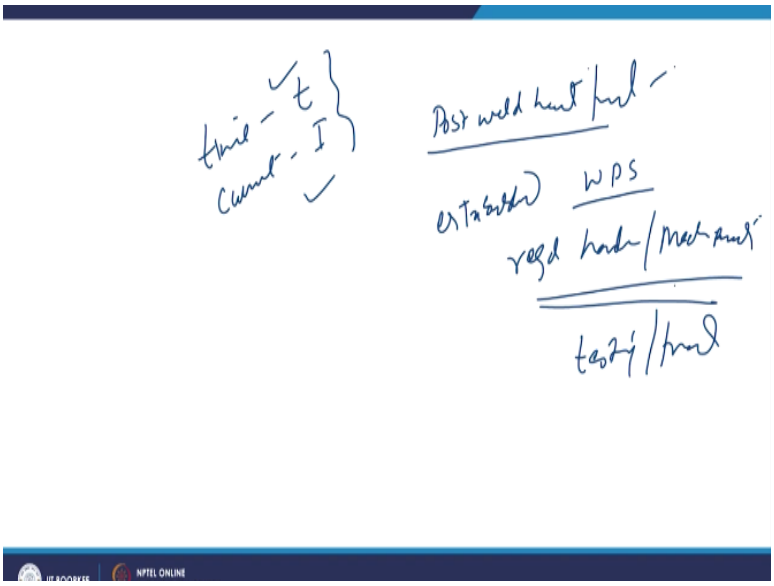

Since here the time for which current is to be supplied the current magnitude which is to be supplied. These are the 2 very crucial things for the post weld heat treatment and this must be established properly through the welding procedure specification. Welding procedure must be established through the trials, so that required hardness and the mechanical property combination can be realized.

So, through the testing and trials the suitable current and the time values for the post heat treatment are established in order to realize the required combination of the hardness and the mechanical properties desired.

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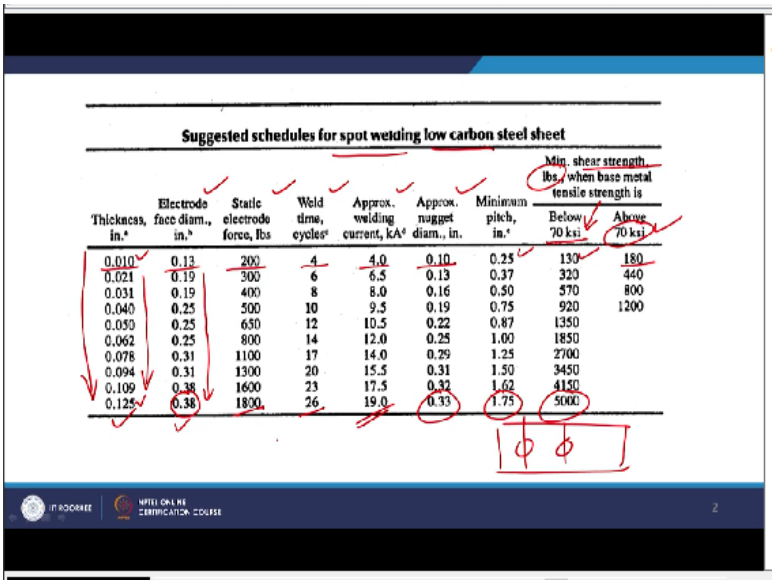

Suggested schedules for spot welding low carbon steel sheet

Thickness, in.[a]	Electrode face diam., in.[b]	Static electrode force, lbs	Weld time, cycles[c]	Approx. welding current, kA[d]	Approx. nugget diam., in.	Minimum pitch, in.[e]	Min. shear strength, lbs, when base metal tensile strength is: Below 70 ksi	Above 70 ksi
0.010	0.13	200	4	4.0	0.10	0.25	130	180
0.021	0.19	300	6	6.5	0.13	0.37	320	440
0.031	0.19	400	8	8.0	0.16	0.50	570	800
0.040	0.25	500	10	9.5	0.19	0.75	920	1200
0.050	0.25	650	12	10.5	0.22	0.87	1350	
0.062	0.25	800	14	12.0	0.25	1.00	1850	
0.078	0.31	1100	17	14.0	0.29	1.25	2700	
0.094	0.31	1300	20	15.5	0.31	1.50	3450	
0.109	0.38	1600	23	17.5	0.32	1.62	4150	
0.125	0.38	1800	26	19.0	0.33	1.75	5000	

Now here if you see this is showing the sheets of the different thicknesses or increasing thickness like 0.01 inch in thickness to the 0.1-5inch. And say for 0.1 inch sheet thickness to be joined the electrode diameter in inch will be of 0.1 3inch electrode pressure to be applied is 200 lbs. And the time for which current will be supplied is the 4 cycle.

Then approximate welding current magnitude is 4000 ampere or 4 kilo ampere and the nugget diameter which is realized is 0.1inch. And the minimum pitch for developing the spot welds like one spot and another spots. So, the minimum pitch is 0.25 inch and the kind of the joint strength that we get minimum shear strength that we get that will depend upon the base metal.

The base metal having the tensile strength less than 70 KSI the joint minimum joint shear strength in the lbs is 130 while in case of the base metal having the tensile strength greater than 70 KSI it will offer the minimum shear strength in lbs is 180. So if we see increase in the thickness of the sheet to be joined by the spot welding of the low carbon steel. There is increasing requirement of the diameter of the electrode to be used say 0.125 it is 0.38 inch.

And the force which is to be applied is also increasing 18 lbs, weld cycle time is also longer. So, that's efficient heat can be generated to facilitate the softening as well as the interfacial pasture melting of the 26 cycles. Welding current is also increased it is also required to increase the current 19000 ampere or 19 kilo ampere. Approximate nugget diameter is 0.33 inch minimum pitch is 1.75 inch.

And the strength of the 5000 pounds is realized when we are working with the 0.125 inch sheet thickness for the spot welding. So, these are some of the typical values but there may be requirement of adjustments at as per the exact composition with regard to the electrode diameter, force, time, the quilting current and requirement of the nugget diameter. So, nugget diameter and the shear strength is required that will be given by the applications.

And as per the metal thickness and the composition of the metal it may be required to adjust the suitable combination of the welding parameters. So, that we have the required the mechanical properties of the joint, so this was for the low carbon steel if we compare it so, with the seam

welding because earlier one was the spot welding, so seam welding uses higher value of the current for longer period.

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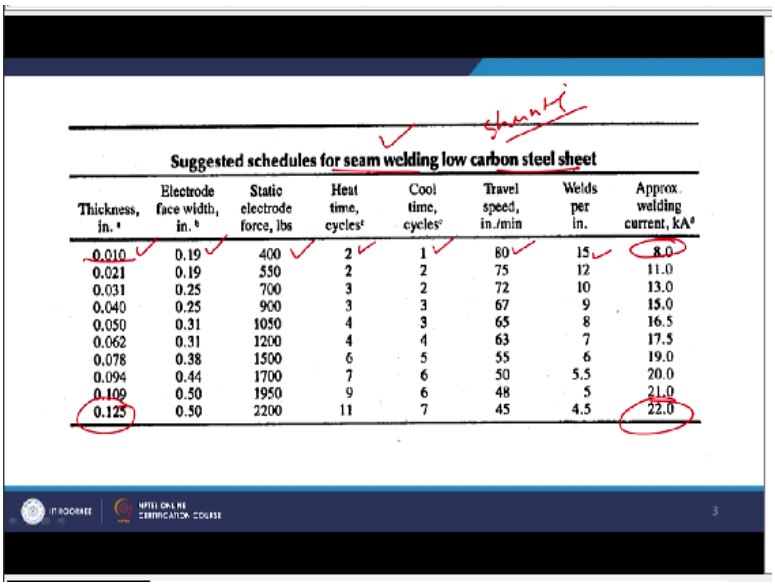

Because lot of current is passed to the shunting effect and the heating is reduced, so for say in this case earlier the current value was of the 4000 ampere 0.1inch thickness. So, this what we can see here for 0.01 inch thickness the current value was 4000 ampere. Now if we see the current value for seam welding for low carbon steel in case of the 0.01 inch is the 8000 ampere.

So, we need higher current setting for the same thickness when seam welding is performed to take care of the shunting effect. So, that the required amount of heat can be generated the because in case of seam welding and the electrode in form of the wheel is used. So, the phase width of the wheel is like 0.1 inch the force is 400 lbs heating cycle time is 2 cycle. Cooling cycle time is 1 cycle travel speed is 80 inch per minute.

And the number of welds per inch is 15, so while in case of the thick plates like 0.1 inch the value of current is for the 22 kilo ampere and likewise other parameters will also be high.

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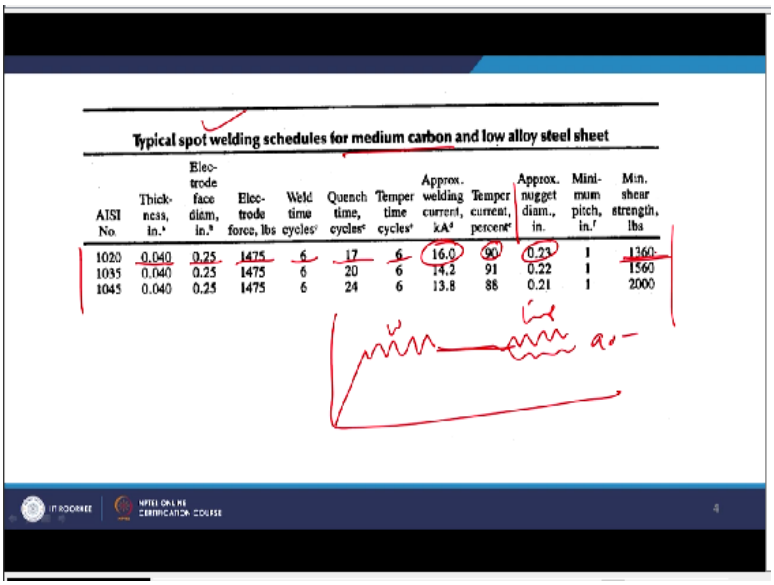

As compared to the low carbon steel if we see and medium carbon is as compared to the low carbon steels for a spot welding and the seam welding. If we see spot welding of the medium carbon steel for these 4 types of the medium carbon steels and the mild steel like 1020 for 0.04 inch. The electrode phase diameter is the 0.25 electrode force is much higher like 1475 lbs weld cycle time is 6 cycles.

Quenching cycle time 17 cycles temper cycle time is the 6 cycles, so here now we can see clearly like when the current is passed like this. Then quenching is there for sometime then current is again passed for some time, so the welding and the tempering and in between it will be held. So, during which the quenching will be happening, so and the tempering current percentage.

If you see the welding current 16 ampere and the tempering current tempering is performed using somewhat lower level of current say 90% of the welding current. Approximate nugget diameter is 0.2 inch and the minimum shear strength which is realized is the 1360 ampere. So, these were the weldability aspects of the low carbon steel mild steel and medium carbon steels and the typical parameters.

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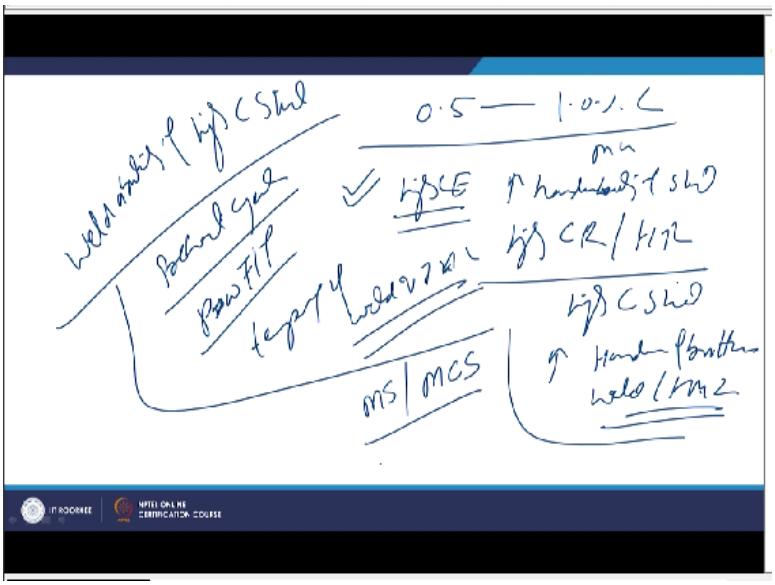

So, which are used now if we see the weldability of the high carbon steel. High carbon steel actually has the carbon content in the range of 0.5-1%. So, such a high level of the carbon content coupled with the manganese leads to the very high carbon equivalent. High carbon equivalent causes significant increase in the hardenabiltiy of the steel and the high cooling rate.

And high heating rate combination of both these in case of the high carbon steels leads to the significant increase in the hardness and brittleness of the weld and the heat affected zone which is developed. And therefore it becomes very crucial to precisely develop the preheat cycle. And the post PWHT cycles, so that the proper tempering of the weld and heat affected zone can be realized.

Mostly the high carbon steels are not welded by the resistance welding process because the weld joints really offer very low toughness, low ductility and the metals are also of the high strength. So, mostly these are not subjected to the resistance welding but if at all the welding procedures are to be developed for high carbon steels. Then general methodology is same which is used for the medium carbon steel and the mild steel, as far as the medium carbon steel and the mild steel welding is concerned.

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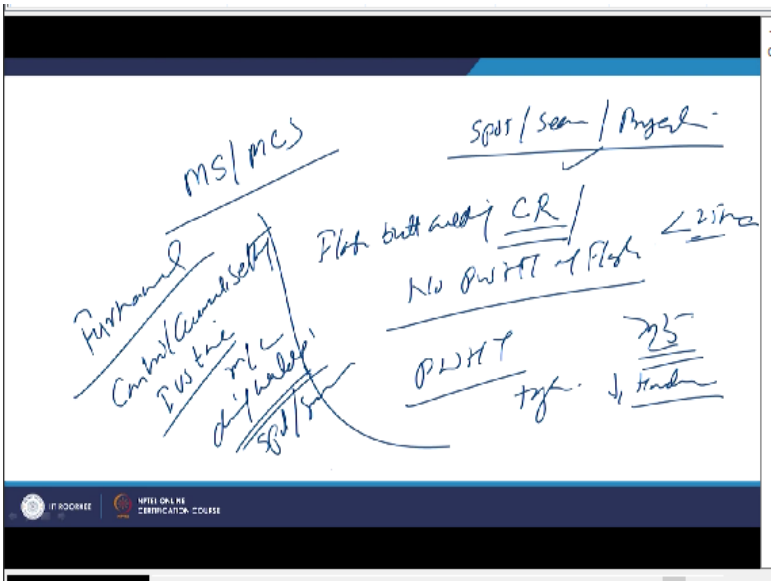

In case of the mild steel and the medium carbon steel the issues are more problematic with the spot welding, seam welding, projection welding. But as far as the flash butt welding is concerned the cooling rate is not that high or is not that problematic as a in case of the spot and the seam welding. So, it does not require so no PWHT of the flash but weld joints is needed.

If the diameter of the section is less than 25 mm but of course if the diameter of section is greater than 25 mm then we have to perform PWHT. So, that the required toughness can be induce hardness can be reduced in order to avoid any embrittlement and the cracking tendency. Now so for this heat treatment purpose we may use furnace or we may use the controlled current setting where current verses time is properly controlled in the machine itself during the welding.

So, that during the welding by the spot welding, seam welding or projection welding, so that they put necessary PWHT of the weld joints can be realized in order to induce the required combination of the properties. Now will summarize this presentation, in this presentation basically I have talked about the weldability of the carbon steels with respect to the resistance welding processes like spot welding, seam welding and flash butt welding process, thank you for your attention.