Welding Processes

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Resistance spot welding Part - 02

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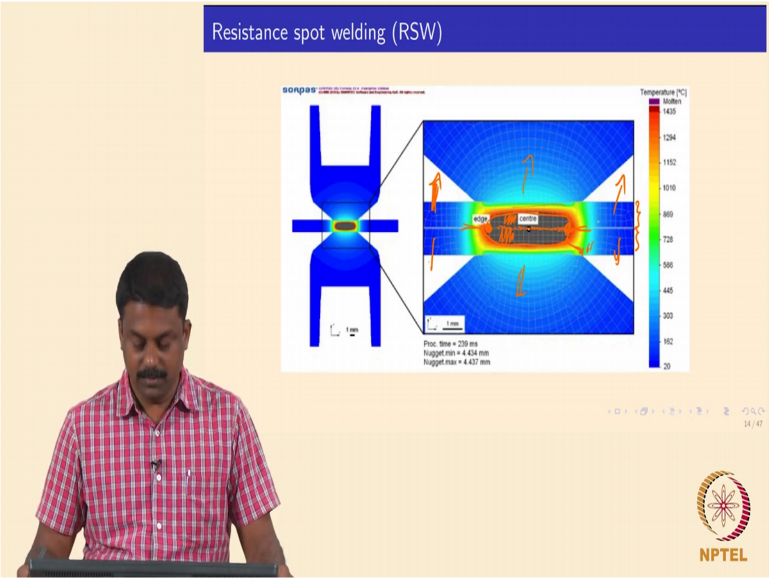

So if you look at a temperature distribution, temperature gradient in resistance spot welding the temperature gradient is extremely high. Okay, so therefore heat of the dead zone is a very, very low. Okay, very small, so why because of the effective heat transfer in the process right, if you look at, this is the cross-section, FEM simulation which we carried out and other point is very difficult to measure the temperature by experiments okay, if you attach a thermocouple it is very difficult to get the temperature, why? Because the, you are passing a current, if you attach a thermocouple that will also influence the temperature measurements.

Parameter, how do you measure? Because the weld is not exposed okay, so the weld is contine, you will be measuring only the surface between the electrode and the sample okay, so that is always its cool, is not it, so the best way is to stimulate for a given condition and physics is well established. Okay, whatever talked about I square R, that is it, so once you know precisely the contact resistance everything can be calculated, so trick is to get the contact resistance okay, so once you know the contact resistance I square RT and then Q by MCP, that is it.

So then we can solve for heat transfer, conduction and then convection radiation, you can solve for it, than we know exactly temperature distribution in the weld nuggets it. Okay, so then we can get exact temperature distribution from room temperature while applying whatever thermal cycle, enhance thermal cycle or the other thermal cycle, yes, it is clear, so this is the typical weld thermal cycle you get, so again, this is 1.2 MM sorry because I like 1.2 MM okay, so this 1.2 MM thick a plate.

So if you look at the average distribution, so the maximum you can go, so this is again the cross-section, so this is the cross-section of the electrode, the entire cross-section and this is a center, so now if you look at the temperature distribution, so you form a fusion boundary, so where below which you have heat affected zone and about which you have a weld centerline okay, so the nugget we form, generally it is an optical shape okay, so but, so you will have something like this and can, so the splashing happens, so for example the is the fusion boundary extends to the surface of the plate, so then you will have splashing, is not it, it is clear.

So if you look at the, so this is the temperature distribution and you already reached to a close to room temperature, somewhere about the 1 MM from the fusion boundary okay, so already from say 1400 C you reach to room temperature within a 1 MM distance, so the temperature gradient is extremely high and due to that, you minimize the heat affected zone significantly, but the problem is not due to heat affected zone in resistance spot welding, but problem is cause of the weld centerline segregation.

Suppose if you solidify this nugget, the solid education would happen in a columnar manner right, so you will have a grand growth happening like this from the fusion boundary, they grow likely this and if you look at this growth, so obviously the liquid which solidifies the end is at the middle at the weld centerline, is not it, so that is the region its highest temperature you expect, so that is region solidifies at the end, so the alloying elements which are partitioning from the solidifying solid to liquid would all enrich the weld centerline right.

So that is the brittle region in this weld nugget because of the enrichment of align element, so now if you are after welding, if you apply a load, say for example tensile load are shaded load, so you already have an interface which is not join here, so this is like a notch, is not it, instead I take a notch and you pull plates apart in engineering application, for example apply a load okay, and then you expect the stress concentration to happen at this region, is not it and then if you have a very brittle weld centerline the crack would open continue and then the weld will fail completely.

So now trick is to avoid such a failure, so that is why we use the post weld thermal cycle. Okay, so that we can homogenize or you change the microstructure in this regions, so that you know we the RST crack propagation from the age of the fusion boundary to the well central, it is clear, so this slide shows the temperature distribution, we always say the temperature gradients is very high, extremely high because of the effective heat transfer from the weld to the electrode, so you would expect maximum temperature gradient leading to minimize of heat affected zone okay, so if you are moving say even from 1 MM from the fusion boundary, material would be in room temperature, it is clear, good, so you look at a thermal cycle, so for example I showed you one at a center and one at the edge.

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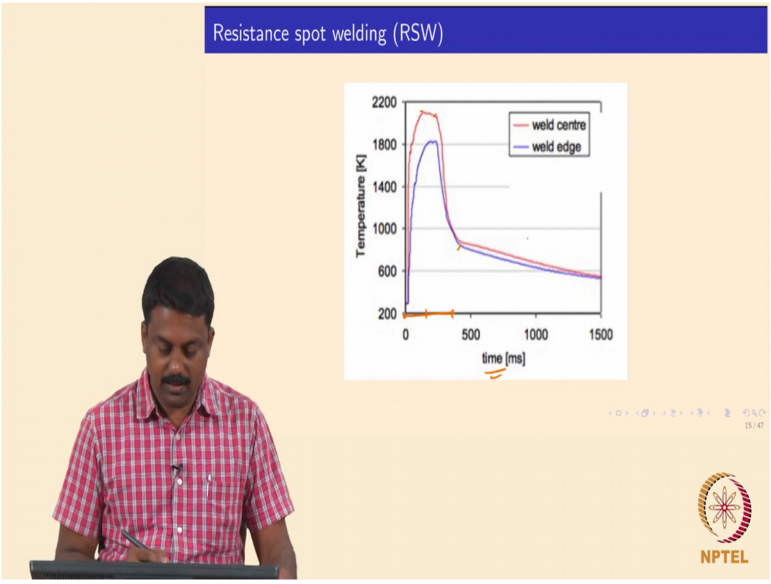

You see the time. Okay, so it is hardly 400 ms, is not it, so the metal is heated up to a temperature at the center SIS 1800°C, 2000 Calvin, let imagine metal is heated up from say a room temperature 2000 Calvin in 100 ms, it is extremely fast heating as well as the cooling rate. Okay, so within no time at battle is cool from a melting point to room temperature. Okay, so the heating rate and cooling rate can be SIS 1000 to 2000 Calvin per sec, in this case even 4000 Calvin per sec.

So this is the actual predicted thermal cycle for weld, I showed you in a previous graph, so the entire weld thermal cycle can be completed within of a second right, so the weld is form, that is it, so this is what makes this process very attractive or the production, where you have to make 5000 welds in 2minutes okay, so will have a 4 or 5 robots okay and then they would do all the jobs within 2 minutes the entire searches welding right, so because of such a fast heating and cooling use and even we if we apply a short pulsing subsequently it does not take more than 100 seconds extra right, so the entire process can be completed in extremely rapid pace, yes, it is clear, good.

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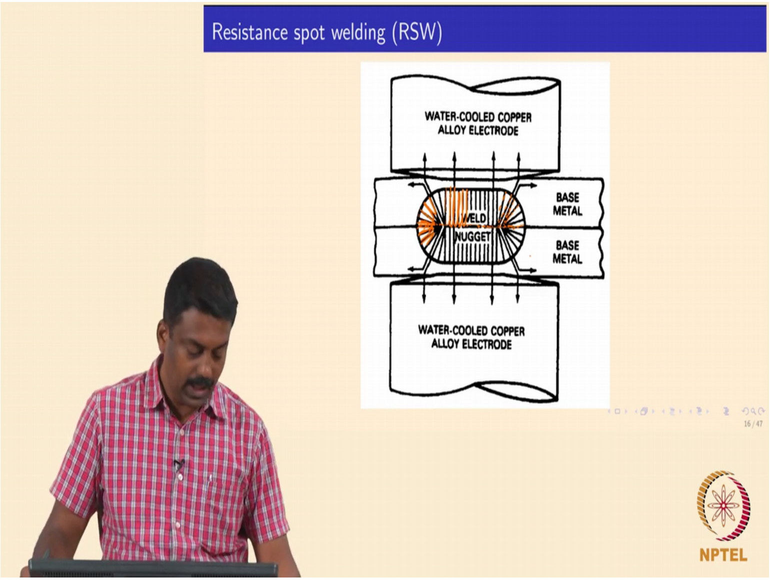

So if you look at this schematic of the weld nugget which is actually formed, so you always have a columnar growth from the fusion boundary, so this is again the base material and the copper electrodes, so if it is liquid then you have a columnar growth which is formed from the solidification, from the fusion boundary and inner steel or even in aluminium alloys, so you always have segregation at the liquid which is left and solidify right, so this weld nugget the weld central is last solidifying region, is where all the alloying elements which are segregating to the untransformed, unsolidifying liquid would enrich the regions and the weld centerline and also at the solidification primary grand boundaries right, it is clear.

So unless you do a some magic, so this weld is going to be very brittle. Okay, so as such for a say a low carbon steel or a simple sale we do not have any problem because segregation is not that significant, so the moment you increase alloying of elements okay, so you will end up making a well brittle because of the segregation at the weld centerline, due to this solidification pattern, you always have a columnar growth, a growing from the fusion boundary towards weld centerline okay.

So that is how you extract the heat, is not it, so you will have a very strip end temperature gradient and then the weld solidifies from the fusion boundary towards weld centerline, it is clear, yes or no, so apart from that you also apply a load right, it is clear, so that will also influence the surface that are developing during solidification right, is clear, so the both will influence the cracking in some alloys.

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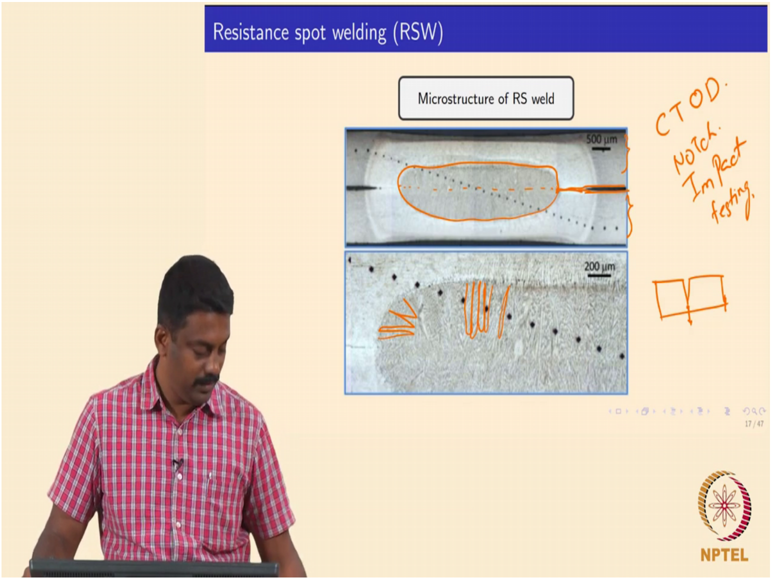

So this is a typical microstructure of resistance spot welding okay, so whatever I explain, so this is the cross-section, you see that notch, can you see that, so this is the top and this is the bottom plate and have a beautiful weld nugget. Okay, so again, this is 1.2 MM, so weld nugget is typically is about 4 MM weld nugget the diameter, so it is the cross-section, so this is completely molten and then if you look at actual microstructure you have a column growth, is not it, you see that, it is not very clear, but you can see that the growth has happened and here and if you look at here, so that is what I talked about.

So this is like a simple CTOD, sample, is not it, what is CTOD? Impact, impact is what you called, heard you make impact feasting sample, notch, how does it look like? Notch impact sample, is not it, something like this, so you will have stress concentration leading to a failure and if you look at the structure, it is exactly like that, so you will have a notch right and then a segregation at the centerline and this is potentially very vulnerable structure right.

So because a stress concentration at the notch or at the fusion boundary can be very huge, but you will have to make sure that this weld is intact, otherwise when you make a car then you hear something, so when you are weld is broken, it could hear, good, any questions so far, good, will move on.

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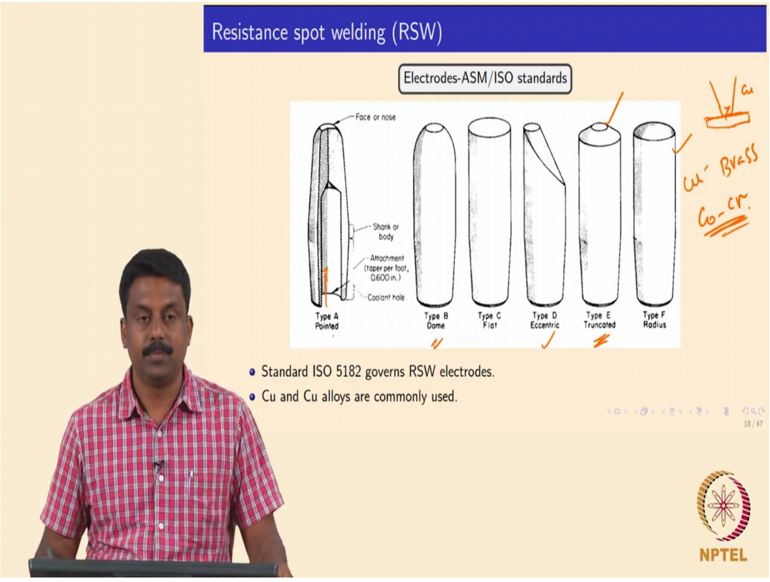

So the electrodes, in types of electrodes what we use? So there are about 6 in fact 7. Nowadays, so most commonly used electrodes are shown in this figure, so if you look at the cross-section of the electrode. I will bring next class that electrode you can also look at it, so the most commonly used electrodes are the type E and then type B, so based on the needs we can choose okay and we can also change the electrode diameter from top to bottom, that is also very useful, so for some reasons we can also change the electrode diameter from top to bottom that will see subsequent classes.

But as of now most commonly used electrode types are listed here, so if you look at the cross-section, so this is the channel for water, so water goes in there to cool the electrode okay, so this is the phase, so you may have type A, it is pointed type or a dome type, so in our lab what we have is a dome type electrode okay, so if you look at the, so something like this, okay, so you may also have truncated type, this is also commonly used electrode okay, so a flat or you also have some concave radius, so it is also useful some eccentric electrodes.

So this is all covered by the standard ISO, standard 5182 which is, which actually go the electrode selection, the electrode material, so most commonly used the material for making electrode is copper or copper alloys, so obvious reason is it has to have a good electric conductivity also thermal conductivity, so that the heat can be extracted very effectively right, from the fraying interface, the electrodes would not melt okay, so if you have electrode is melting then you have a problem and electrodes should also with stand large number of weld thermal cycles.

Okay, so when you use copper and you are welding in a galvanized heat, so what will happen? So most likely the zinc would defuse to copper than what will happen? So you have an electrode on top and you have a material which is galvanized if a zinc defuses to copper, you will form brass, is not it, so it is a big problem, so welding of automotive steels especially and the steel is galvanized, so the electrode surface vase-out because the moment you form brass, it also change the resistivity locally and you also increase the hardness and the layer becomes very brittle, so you will end up changing the weld nugget diameter, even if use you the same current, same welding time after 1000 welds, the weld nugget diameter will increase.

So you can lead to splashing, if you are operating it close to IMAX right, so the electrode one out is a big problem because of this of copper and copper alloys, if are welding zinc coated steel, so there are various development has happened in the material, so for example, people started using even rareth addition, so adding a yttrium oxide okay, or zirconium oxide to copper to make it by about a metallurgy route, so obviously these oxides enhance the electrode conductivity okay.

So they can improve electrode conductivity, so that we can avoid, we can increase or we can improve the mechanical properties of this electrodes okay, so people thought about replacing the convental copper with rareth added the electrodes, copper electrodes or even internally replacing copper with the other super materials, for example cobalt chrome okay, so you can also achieve reasonably good thermal unrelated conductivity by these cobalt chrome alloys and these alloys have very good ice temperature properties, good, so these are the common type of electrodes we use okay, so most commonly we use type E and type A good.

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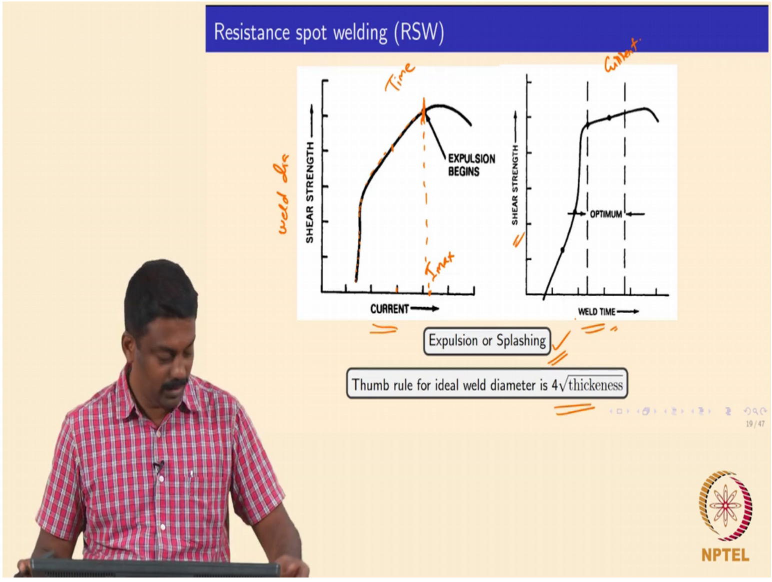

So as I said the thumb rule for ideal weld nugget diameter is 4 times the square root of thickness and it is also governed by the automotive industry, sometimes it will be 4.2 times the thickness okay, so does not matter, so the idea diameter is 4 times square root of thickness, so in order to achieve required diameter and we have to generate what is known as weld growth of curve, so what explain to introduction. Okay, the weld growth curve is extremely significant to achieve, to arrive at required weld nugget diameter and this is also influenced by the mass, the M okay, in turn, mass is influenced by the thickness, as well as the CP, specific heat capacity.

So if you change the chemistry slightly, if you change the thickness slightly weld growth curve changes okay, so that makes this process extremely instable for you know a small change in processing condition, so if thickness is change from 0.1 MM to 1.4 MM, you cannot use the same current at same welding time, you will have to invent the welding current, the welding time required for welding for the change in thickness. Okay, so the welding process parameter what you develop it is extremely unique to a given thickness for a material, because M changes, is not it.

So obviously M change, even if we keep a CP change then IRT changes okay, so to developing a welding process parameters for resistance spot welding is a very laborious experiment, suppose if you want to use a material, you are developing a steel for an application, so you will have to generate such a weld growth curve for varying thicknesses and then give that to a customer, so that the customer can choose a welding parameter for thickness what is using in area, he may use a different thicknesses in different parts, so then the same welding parameter cannot be used right.

So how do we generate such the welding parameters? So we get the weld nugget diameter measured as a function of current, by fixing the time constant or as a function weld time by fixing the current constant okay, generally this strength is a proportional to the a weld nugget diameter, diameter is higher that means, that thing is higher until the expulsion, so what is expulsion? So this is the maximum current that which the liquid is expelled right, so there is expulsions, the IMAX in this case this is IMAX, is not it, now so we can generate such a growth curves value change the current or a given time, unless weld nugget diameter. Okay, so once becomes IMAX obviously and you start of expelling building the liquid which is that in between the welding electrode and then distance decreases because you will have a cavity, the liquid is going out okay.

So that is the IMAX what you have and you can identify, so now suppose if you want to get a 4 square root of thickness, you can identify say suppose this current would give me the diameter of 4 square root of thickness okay and this is to identify the current required, so once you identify the current, so you can also vary time, is not it, so time for a given current would also change the weld nugget diameter because I square RT, Q is a function of current and then time because context resistance is fixed as long as load is fixed, is not it.

So you can also get weld nugget time generated for a given current and identify the optimum weld time required generate a nugget diameter of your interest, it is clear, so you will have to identify the IMAX, so the IMAX is the maximum current above which expulsion or splashing occurs, so expulsion and splashing they mean the same, so IMAX is a maximum current above which expulsion or splashing happens. Okay, it is clear, this graph is clear right, yes or no, quickly will move on.

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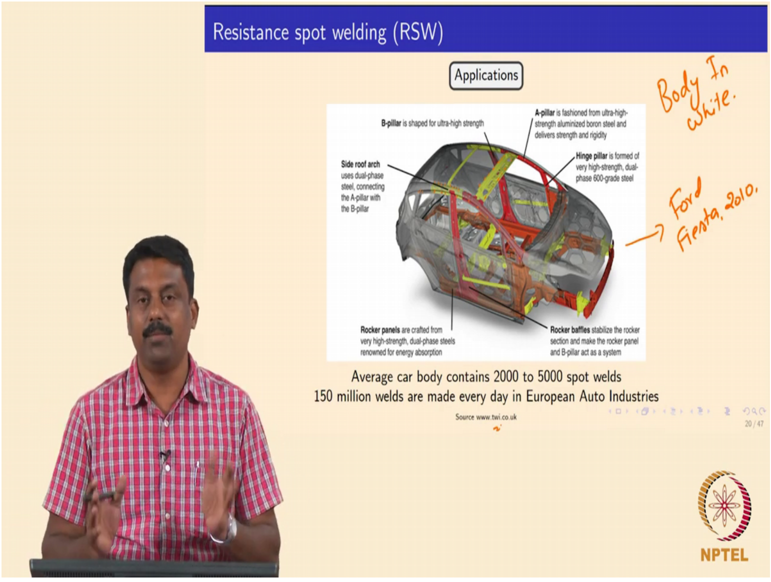

So applications, so I just put one example, so this is I think Ford Fiesta okay, so I think it is 2010 model I remember correctly, so if you look at this season a body in white, what is body in white which? It is not human body. It is a car body okay, it is called body in white and then if you look at the parts, so all these the pillars, you see the black dot, these are all welds, resistance spot welds. Okay, so these flanges, the pillars and the all the parts are all joined, the resistance spot weld okay, you see the dots here, whatever it is difficult to see okay.

So in a typical car, automotive, car you have about 2000 to 5000 spot welds. Okay, so number of welds you make per day in India it will run around a few crores okay, so this strategy it took it from TWI, the welding Institute of London, so in Europe alone we make about 15 crores welds every day, the similar amount you will also see in India as well. Okay, so the number of welds, resistance spot welds made in a day it is huge, enormous okay, so we will have to make sure that by obtaining good welding procedure, so these welds can withstand the life cycle of automotive vehicle right.

So, in typical if cycle, life of an automotive is 300,000 km, 3 lakh km okay, so the weld should be intact, so weld breaks when the monkey jumps then you have a problem. Okay, so then is a welding engineer, as a welding scientists and we have a problem in will have to solve that, by nature resistance what welding is one of the worst geometry, you can generate okay, so because of the weld segregation the notch effect, so this is the worst thing you can have, but will have to live with that, so we have to identify the weld thermal cycle is kinky was input mechanical properties.

Okay, it is always welders job. Okay, so steel, metalogics who are developing steel, they always curses the welders because they would generate such a beautiful microstructure, you know with all the properties, you know they want strength, the ductility, toughness, ultimately he have to weld otherwise you cannot make a car, so they always tell us okay, you guys always destroy such a beautiful microstructure okay, so, but that is how will do it, but still a demand is the weld should never fail okay, so weld should never fail, the fail would always happen except weld, anywhere else except the weld.

So you know we have such a challenging and geometry, we can make a weld with can which stand the demanding load cycles. Okay, so that is the challenge, so we can work on, so we see in and how we can improve? How can achieve required mechanical properties the welds, resistance spot welds, without going much in details about the microstructure okay, it is good.

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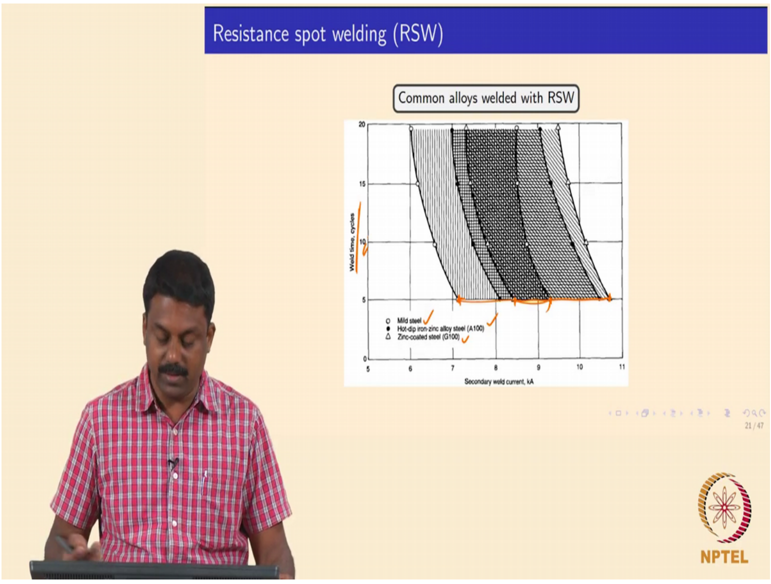

So this is common thermal cycles, we use it for the alloys like for example, mild steel, the zinc coated, at deep zinc coated in the electrode galvanize material, if you look at compiling the bar sheet, you always need to have higher current, is not it for zinc coated steel, so in this case, the mild steel is operated between these regions. Okay, so and then, this is for a electrode zinc coated, so you will have to soften the galvanize layer, so you need to pass a ramping current so that you soften the this zinc coating layer and you also by doing so increase the weld time in cycle.

You see that weld time in cycles, so you never give well time in resistance spot weld in seconds, you always mentions the cycles okay, so for example if a 10 cycles means, so it will be 200 ms, milliseconds okay, it is clear, so we generate such a curve. Okay, so the one weld growth curve what I am showing here as a function of current and then time, so we can also generate the window in which you can operate for a given comparison and the thickness.

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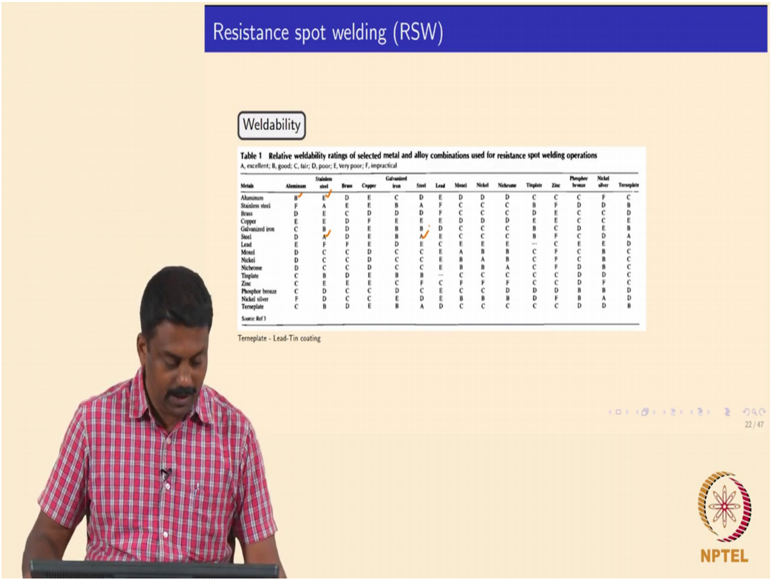

And this table shows the compatibility, the weldability and this I took it from Handbook and this is very important, supposing future if you want to know that can I weld aluminium to steel, it is very difficult, do not try okay, can I do steel, steel okay, you can do. Okay, so you can chose by looking at this table telling us what, whether I can weld, I say for example aluminium to aluminium its B okay, so we need to get an enhance in weld thermal cycle, so that you can design the weld okay.

Aluminium to stainless steel, never try okay, impossible I will challenge, I will bet you, I can even recommend for Noble prize, if you generate a weld a aluminium, stainless steel without any crack okay, so the most preferred in the A, so the A will be steel to stainless steel respectively. Okay and steel to steel lights every nice, happy okay and if you go beyond led and zinc any things like that, it is very difficult for you get a good weld the diameter okay, so you can refer this table, so it has read the in Handbook, so that you can identify the weldability for wearing interfaces.

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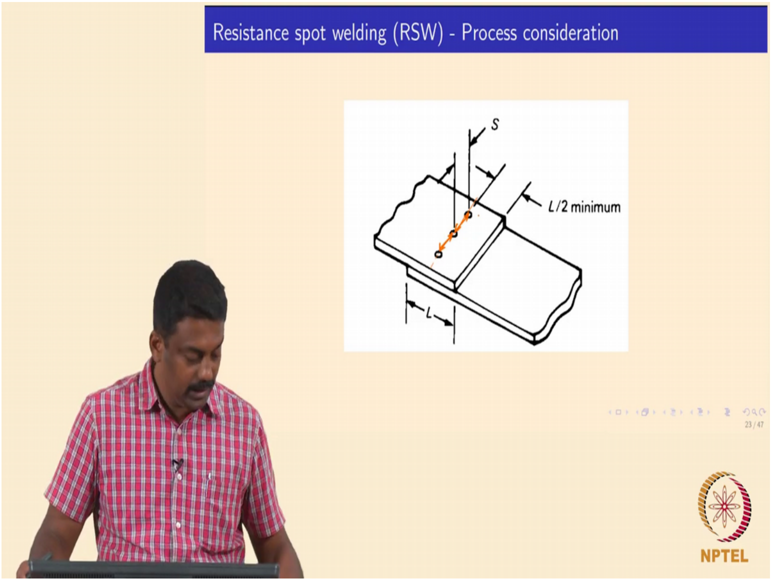

Okay, so other important considerations apart from current and time, so what will have to consider is the geometry okay, so geometry of the weld the one of the important factors you need to consider, here is the distance between the weld. Okay, so for example if you have an overlapping distance of L, where exactly you will place the weld? So you will always place the weld at half distance between the L, so this is the overlapping distance, so L by 2 you place the weld and then the distance between the weld is extremely important okay.

Because that is going to determine the path of the electric current. Okay, so the S and L by 2 generally we have an well-placed in overlap configuration, for a half a distance between the overlap and the S is the distance between two welds and this is very critical, yes, so why it is very critical? Okay will get back to that next class, as of now you can assume that the S is also very critical, if you keep it very close then you may also have a current passed through the previously weld nugget. Okay.

Suppose if you are welding it in this case, so if you are keeping a very close, so instead of the current passing through this location, it finds another easy way because this is a solid junction now, there is no contact resistance, is not it, you already made a weld nugget, so the current would follow the easiest path, it would start flowing, it start reheating the already formed weld nugget okay, it is clear, so instead of that, you know instead of making weld here you will end up heating the weld nugget here, previously weld nugget, so that is why the S very critical, the minimum distance between two welds.

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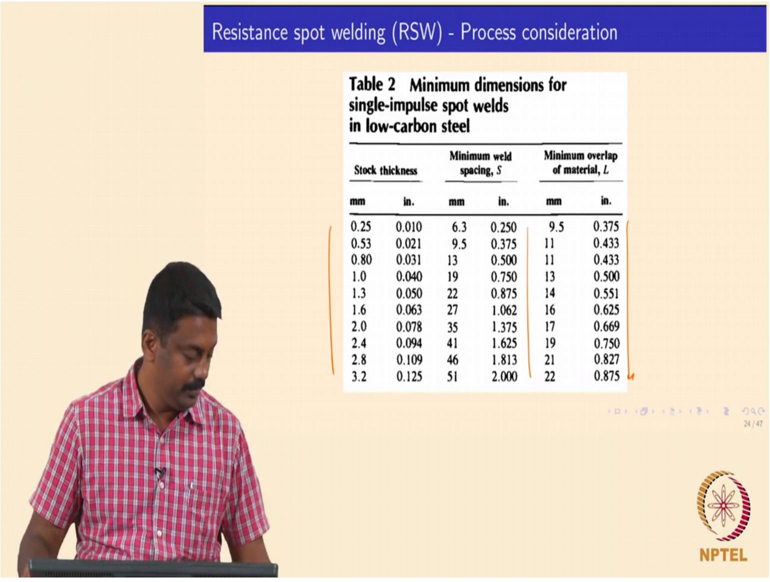

Table 2 Minimum dimensions for single-impulse spot welds in low-carbon steel

Stock thickness		Minimum weld spacing, S		Minimum overlap of material, L	
mm	in.	mm	in.	mm	in.
0.25	0.010	6.3	0.250	9.5	0.375
0.53	0.021	9.5	0.375	11	0.433
0.80	0.031	13	0.500	11	0.433
1.0	0.040	19	0.750	13	0.500
1.3	0.050	22	0.875	14	0.551
1.6	0.063	27	1.062	16	0.625
2.0	0.078	35	1.375	17	0.669
2.4	0.094	41	1.625	19	0.750
2.8	0.109	46	1.813	21	0.827
3.2	0.125	51	2.000	22	0.875

Okay, there are some get data you can find it out. Okay, so these are all already established the parameters for low carbon steel as functional of thickness, so what is the minimum S you need? What is minimum overlap distance you need to have? Okay and these are all alkylated best on the fact that you know an electrical resistance and the contact resistance would be maintained at the faying interface and yes no need to concentrate on this, this I just so you to see these are important okay.

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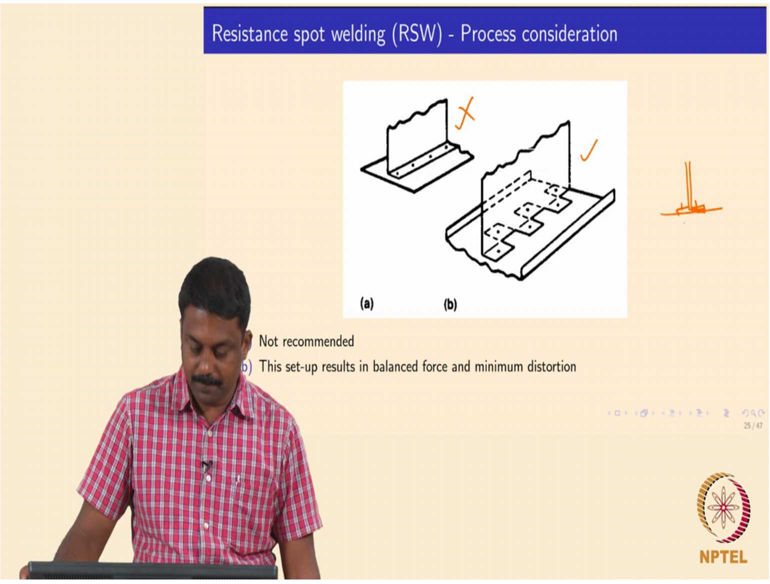

And then another geometric considerations when you are doing spot welds, it is never advisable to do such a weld because obviously the low distribution. I will be extremely bad in this case if you are doing welding, it is always advisable to an zigzag welds and this will be much stronger geometrically than a structure like this here, is not it, so this zigzag spot weld would result in balance force and minimal distortion, is not it, it is obvious, so that is why when you are welding it, not it advisable to weld in its configuration, so we always go to weld this configuration yes, so this is the balance force as well as minimal distortion.

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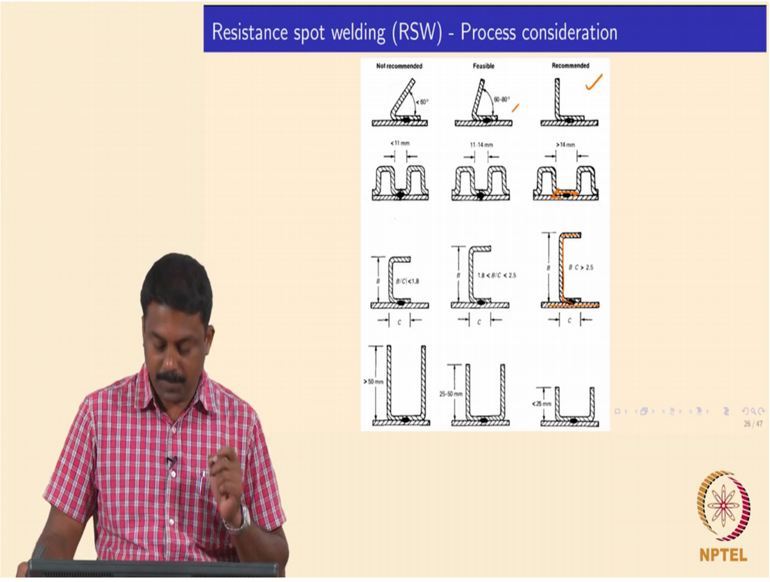

So some of the geometrical considerations because here load distribution is very important right, so you can look at, say for example, if you are having a very short L angle, it is not recommended. Okay, you can do it, but ideally you should do in a L flange okay, so similarly instead of having in a weld like this and you can have a longer distance and you can also have a lot of geometrical considerations. Okay, the structural analyses is extremely important in resistance spot weld and the all the automotive components, they optimize the structural low distribution and then the identify where exactly you will have to place the weld nugget okay.

So you cannot, just like that you choose a point and weld because the load distribution is a function of geometry of your components, so the structural analyses is they do it for components and identify the location where it is ideal for this spot weld to be there, otherwise you will end up, not balancing the force and you act or you induce lot of stress partition to the weld nugget and weld is prone for failure right, it is clear.

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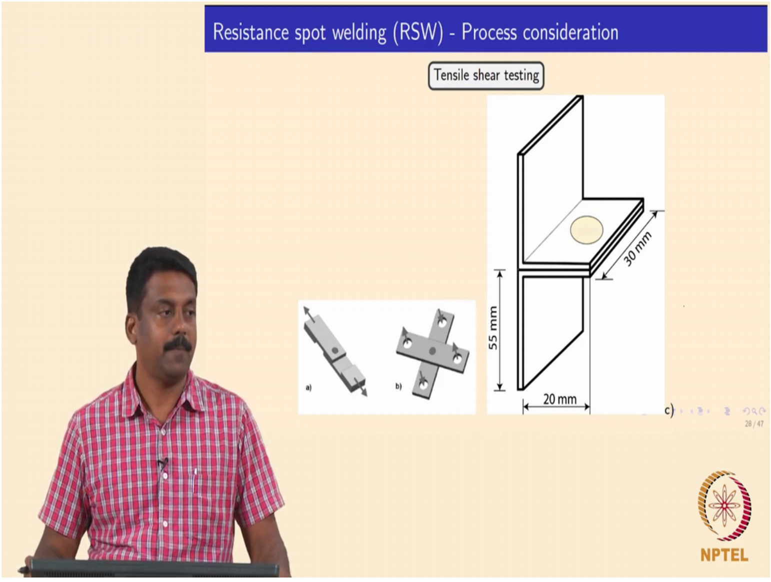

So will also look at the testing, so how we can quantify the weld gets, maybe a next class. Okay, good, any questions so far, yes or no, so will look that in this class weld thermal cycle, simpler thermal cycle, enhance weld thermal cycle and then mass effect, the effect of thickness and then looked at the weld growth curves, IMAX and then will look at the temperature distribution, temperature gradient right, so cooling rates right, the width of the weld nugget and then the heat of the dead zone and we also looked at some geometrical considerations, the L and S. Okay, will look at in next class how we can test and what are the testing methods we use to quantify the mechanics properties of this spot welds right, good.