Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 09
Process Characteristics of Resistance Spot Welding - Part – I

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So, we will continue look at the process characteristic of resistance spot welding. So, we looked at the various shapes of electrodes that are used for resistant spot welding right. So, type A, Type B, type C, type D, E and F and then so we also looked at the most commonly used electrodes the based on your weld geometry and then accessibility and we can choose the electrodes what we want to use it in spot welding applications.

And so for future references you can look at the standard ISO standard 5182 which actually governs the electrode dimensions and the shapes of the electrode at are commonly used for resistance spot welding. As I already explained and the most of the electrodes used in spot welding they made of copper or copper alloys, so most of the automotive industry applications that the pure copper electrodes are commonly used to make spot welds in it is galvanized material.

There are some inherent issues by using a copper or on a galvanized sheet surface because of the zinc diffusion and towards the electrode the copper material can form the bronze and our brass

formation based on the this and the galvanized sheets galvanized layer composition. So, that I mean the electrode gets deteriorate its surface characteristic over the period of the usage. So, we are not going to detail about the; those aspects will concentrate on the process main process consider the considerations as well as metallurgy.

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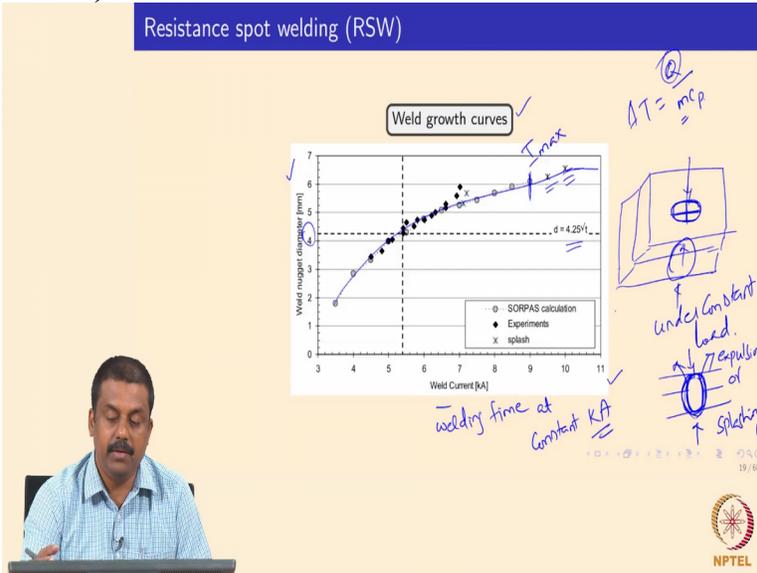
So, we will move on to the other aspect resistance spot welding with respect to the automotive industries. So, the; when you are given a material to weld a using resistance spot welding the first thing you need to do is, you need to understand the effect of the welding current on the nugget formation behavior. So, you like to see is what will be the current and the welding time so you need to use it to get the acceptable weld nugget diameter.

So, we generate what is known as weld growth curves in resistant spot welding. So, weld growth curves are nothing but you know and the relationship between the welding current you use as a function of weld nugget diameter. So, welding nugget diameter so we measure for example if we have an a sheet in wall of configuration. So, we have a two sheets one and then there is another sheet and bottom of that and then you make and weld at the middle of the plates.

So, it is actually going through the two sheets the weld nugget diameter if we say form an elliptical nugget it can be elliptical or even circular. So, we measure the diameter generally and the long axis the axis is along this direction. So, that diameter we either take it as a weld nugget diameter or you can also average it between the long and the short axis of the ellipse and identify the weld nugget diameter on the top of the either side of the surface.

So, we measure this weld nugget diameter as a function of welding current okay. So, by fixing the load constant and under constant load and we measure the weld nugget diameter as the function of welding current and we generally it follows a curve something like this and then it stabilizes. So, basically what happens when your increase in the current obviously you also weight more volumes at the interface and due to that you increase the diameter of the weld nugget generally in exponentially?

Upon up to a certain diameter and if it goes beyond that and because of the application of load you would end up expelling the liquid metal that is formed between the interfaces say for example if you have a load and if you form a liquid at the interface if you look at inside the cross-section. Upon a melting more volume then you would end up the expelling the liquid metal that is formed in between the electrodes.

For example if you look at the cross-section so you form something like this, cross sections and you are applying a load and if the diameter is increasing beyond the certain diameter and if you apply load the you would also expel the liquid material that is actually formed between these two electrodes and that situation is known as expulsion or splashing and that is not advisable case because then you will end up for making a cavity.

And because you are expelling the liquid metal that is formed at the faying interface so that happens when you are using the excessively high current and with the application of load the molten liquid is expelled forming undesirable cavities. So, we measure until the maximum current at which you have a stable nugget that is known as an IMAX the maximum current at which you know you avoid expulsion.

So, beyond that current for example in this graph I plotted the data as a function of welding current and weld nugget diameter if you look at it and see after 9 kilo amperes we observed expulsion at around 9.3 and then 10 kilo amperes. So, the 9 amperes in this case is the maximum current and which we can now form a stable nugget okay that is an IMAX. And we get the weld nugget weld growth curves as a function of welding current and we can also get welding; weld growth curves as a function of welding time at constant welding current.

So, this can also be welding time at constant welding current and constant ampere we can also develop such curves. But the most desirable or most informative in the graphs for our resistant

spot welding application is how much current you need to pass to form weld nugget the diameter of desired value. So, most of the automotive applications the guidelines the various guidelines say the acceptable weld nugget diameter is somewhere between 4 to 4 foot 4.25 square root of thickness.

So, if a weld nugget diameter for example if you have 1 millimeter thick sheet your wild nugget size must be around 4 mm okay. So, the diameter must be 4 to 4.25, so 4.25 is the guidelines given by one of the Japanese automotive manufacturer. So, they use the weld nugget diameter ideal weld nugget diameter is 4.25 times the thickness of the sheet. So, in this case for example if you have 1 millimeter thick plate the ideal weld nugget diameter should be 4.25.

So, we can identify the amperage that is required to generate such an weld nugget diameter for a given welding time. So, we apply in subsequent the applications the current of 5.2 kilo amperes for example that will give us weld nugget diameter of 4.25 mm. Now such a welding curves should be generated for a given thickness because if you change a thickness obviously mass effect right.

So, mass effect says that the temperature is divided by mc p so if you change the thickness your m also changes okay. So, then you need to change the amperage to change the Q so that will again will change your decider weld nugget diameter as well. And if you change thickness your wild the growth curve will also change because then you will also change the Q. So, for a given thickness and for a given material configuration material composition and coating configuration so we need to generate weld growth curves.

So, that is what makes this resistant spot welding is very extensive laboratory RND sensitive spotting process because for it even a small change in variation in terms of thickness the surface composition and the material composition you may have to develop well growth curves and identifying the weld nugget diameter the development has a function of welding time and welding current and we get it and most of the RnD in the labs of steelmaking units steel making companies as well as automotives companies.

And they develop such weld growth curves for a given thicknesses of a given material and even if you change a small composition for example if we change from DP 800 to DP 1000 and if you change the carbon concentration from 0.2 to 0.25 and your weld growth curves would also

change significantly. Similarly if you change thickness from 1 to 1.2 again the weld growth curve may also change and you need to identify the parameters mainly current and welding time for a given thickness combinations good.

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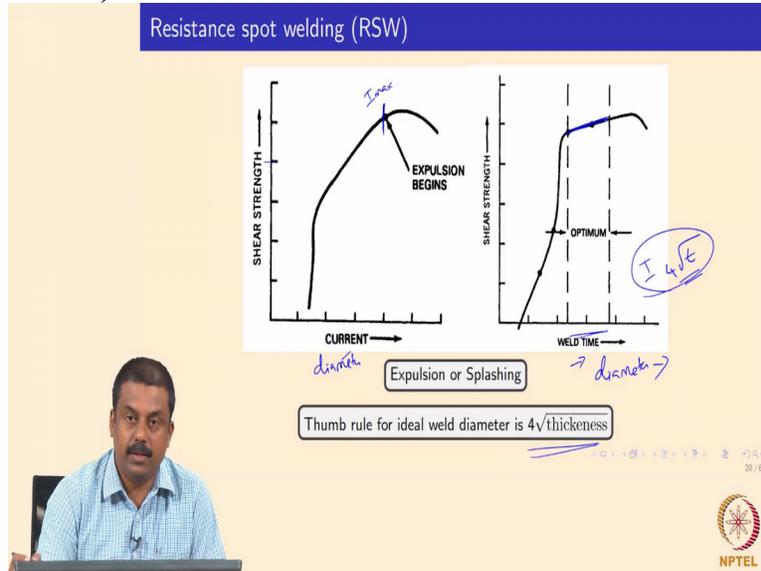
So, the weld nugget diameters it is extremely critical to determine the actual level properties for example in this graph I showed you two the axis's in x, x axis 2 values in x axis one is a current and one is welding time and as I already explained we can generate weld growth curves as a function of varying current at a constant real time or by varying real time with the constant current. So, if you look at the shear strength or the strength of the weld when you are applying in a shear load so we will come to that and we in later slides how we test the resistance spot weld for shear strength.

Right now you can assume that if you increase the diameter so you will also increase the strength significantly. So, basically the well diameter will also change as a function of current and welding time and until expression happens so upon expulsion what happens you may not have and a good nugget good solid nugget because the liquid metal that is formed this expelled because you for more volume of liquid.

So, the ideally no we need to identify the maximum they are acceptable weld nugget diameter for an acceptable strength level and this point when the current level at which the expulsion happens so just below that point in current is known as IMAX. So, IMAX always gives the maximum and the largest weld nugget diameter. So, we will identify IMAX and based on the guidelines we will

also identify the acceptable strength level and which can be you know in a thumb rule generally it is 4r times square root of thickness.

The similar behavior you can also observe as a function of welding time okay. So, we will identify the optimal range. So, generally for a given current so once you identify the IMAX and the current at which you get the weld nugget diameter of 4 by square root of thickness and we can take the current at 4 times square root of thickness. And then in that current level we can also identify at what welding time we will get an ideal the strength of the weld.

So, will again measure the shear strength as a function of welding time, we will identify the ideal current from the well growth curves and welding time as well from the constant welding a constant current experiments. So, we will fix the current in this case vary the welding time and identify at what condition you would get an ideal this strength the optimum strength okay.

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So, as I already explained the resistance spot welding is used extensively in body in white and chassis applications and if you look at the variety of components in an auto body and they are welded resistant spot welding for example in this case pillars I showed you and the side roof arc. So, these are all the dots you see over here these are all resistance spot weld. And similarly the other side various numbers and distribution of spot welds you well you see in various locations in a body white and chassis. So, imagine I mean the average car body contains somewhere around 2,000 to 5,000 spot welds.

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Resistance spot welding (RSW)
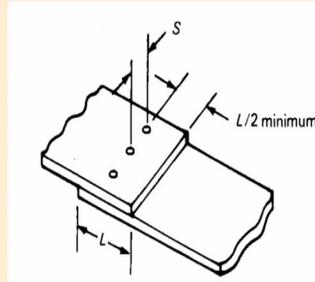
Common alloys welded with RSW
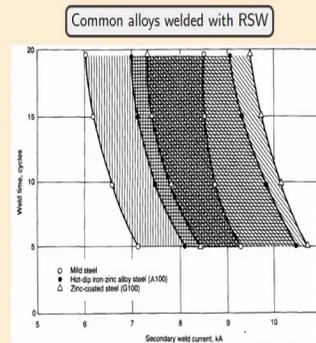
So, we look at some of the common commonly used process parameters for resistant spot welding. The current range and again so the weld growth curves for various alloys you can find it in very and in guidelines as well as in the handbooks. So, this slide shows the common weld growth curves for mild steel and a simple hot dip galvanized alloy steel and again with an iron and the electro plated steel with zinc.

So, you see in a welding time as a function of weld growth the welding current. So, ideally if you look at for a material within and zinc coated steel and you need and a slightly higher current okay than material in the mild steel because you have an bare surface over there in the mild steel without any coating. So, very time here again you need to note it, is mentioned it in cycles okay. So, it is what is cycle here is the number of the current cycles in alternating current for example if you 50 Hertz will have 50 cycles in a second right.

Alternating cycle so if it is weld time in cycle is 10 so that means that 1 by 50 times 10 so that is your time so that will be 0.2 seconds okay. So, that is will be 200 milliseconds that is your the actual reading time. So, generally we mentioned and the welding time in cycles for our fixed the frequency of the current we use, there we use 50 Hertz AC so then you mentioned 10 cycles okay. So, this similar weld growth curves can be generated for our material.

So, you see over here and the composition of these steel's are all the same but just by changing the surface characteristics and the your welding parameters change significantly. We are varying from 7 kilo amperes until close to 11 kilo amperes in order to make and given weld nugget

diameter. So, that is what this process is extremely sensitive for a change in thicknesses or surface characteristics as well as the composition of the material.

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And so when you are using a dissimilar material for instance spot welding again so there are a lot of issues in terms of surface characteristics as well as I know the weldability and so this table can be used as a guidelines. If you want to use a dissimilar material and building of similar material as well, so this is actually obtained from an ASM handbook. This shows an overview of various materials in a column first column and for example aluminum, stainless steel, brass copper.

And if you look at aluminum to aluminum spot welds it says B. B's okay reasonably good, so A is excellent and B is good C is fair D is poor and E is very poor and F t is impractical. So, for example and if you take a nickel you are trying to weld with an aluminum it is impossible to weld that know better do not try it. And so then if you have when a steel with steel and I can spot weld is much easily. You see the stainless steel for example or galvanized iron, so you will have good bet weldability by looking at the pod combination of materials we are going to use.

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Resistance spot welding (RSW) - Process consideration

So, the other important aspect you need to consider except the material composition is the process consideration. So, there are guidelines available in various literature's and open-source forums and the guidelines for automotive manufacturers. The placing of the welds with respect to your edge of your sheet as well as the thickness of the sheet and the minimum distance there should be there between two spot welds.

So, this is the most common guidelines we use for spot welds in overlap configuration. So, suppose if you are lapping distance is L and so we need to splays and the spot welds from the edge of this plate by at a distance of L by 2 that is a minimum. So, we need to do it and you can do it as close as possible. But this is a minimum distance we need to keep in overlap configuration you cannot move it along this direction.

So, the thumb rule say is that L/2 so which is the half of the overlap distance we use it when you are stacking the material.

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Resistance spot welding (RSW) - Process consideration

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

So, again this table shows the minimum dimensions for the weld nugget diameter and overlap distance. So, minimum weld spacing the S and L in a previous graphs based on the thickness of the plate okay. Suppose if you have 1 mm thick you know S that is the minimum weld spacing it must be 19, I can use it more than 19 then you have when a problem with this as partitioning and then it may affect ever a stiffness.

So, if you use the shorter than 19 that is even better but then you may also have a problem with the cooling rates and the shunt effect which will explain in a previous in next slide. So, the guidelines for a given material thickness what over lapping a distance you use and what is the minimum distance we need to have between two welds and these are standards available you can use it to optimize your weld design.

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Resistance spot welding (RSW) - Process consideration
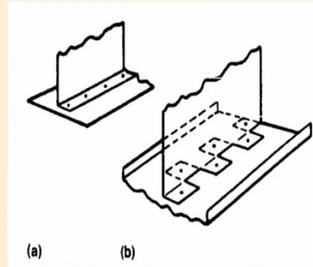
(a) Not recommended
(b) This set-up results in balanced force and minimum distortion

And again I mean if you are welding and T-joints this is an obviously not recommended we do not go into detail about and why it is not recommended obviously we need to do in a stiff analysis and yeah in kind of free body diagrams and those things and we do not want to discuss about it here. So, instead of having a spot welds made in an L configuration. It is always advisable to have such an exact configuration.

And which is much more advisable in terms of as stiffness than having a weld made in an L configuration. So, because this setup results in balanced force and minimum distortion compared to this L configuration.

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Resistance spot welding (RSW) - Process consideration
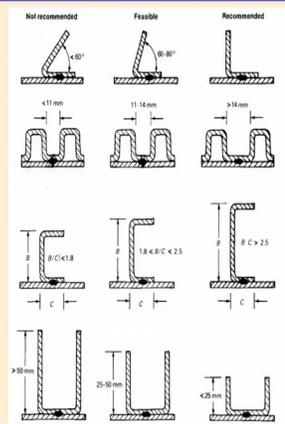
So, some of the design aspects design considerations where you have to place, who you have to place these spot welds but various designs so we can look at it in a handbook. So, one of these

designs specifications I got it from SM handbook. For example and what is not recommended for example if you have when a minimum the angle is 60 degree, it is not recommended. So, better you have L flange so that now we can have a uniform load distribution and improve its stiffness of the components you are making.

And we can also do an simple stiffness analysis to identify the actual geometry they need at which they can make a spot welds.

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So, this table again shows the information about the weld nugget diameters force weld thermal cycles current use for a given thickness. So, this is and again a guidelines this is actually for a simple zinc coated galvanized steel. The reference again I took it from my handbook so if you do not want to go to details because it is again the fundamentals are just explained. So, by if you change the welding current and welding time you can also change the weld nugged time diameter. Based on the thicknesses you can identify what current is needed for a given weld nugget size.

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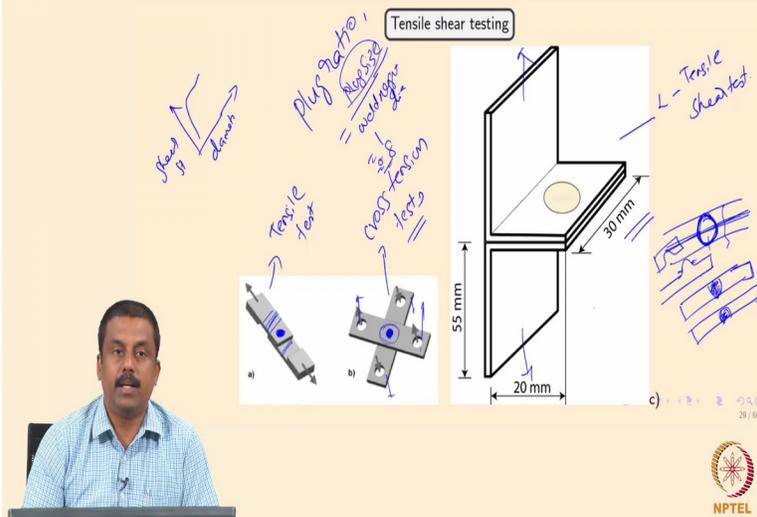
So, the most of the only the common testing methods we use is for instance spot welding they are in automotive industries to identify the weldability or the strength of the welds are in the 2 test what I explained here this is the cross tension test, this is simple tensile test and this is an L or a lap chatters or L tensile shear test okay. So, the automotive industries use generally the cross section tests or the tensile share test within L shapes geometries of the plates are welded.

And then you apply a tensile stress and so identify the strength so I will explain and in simple terms how the tests are carried out. So, in tensile test is very simple now you make and to all up joint and make a spot welds on this joint and then pull it and identify the shear strength needed to strengthen needed to pull up break the sample. Sample can break either in the weld zone or the heat affected zone or elsewhere.

So, obviously if it happens not on the weld it is a good wild and so we will also calculate other parameters other than this strength. I will come to that in a subsequent slide. So, right now what we have understand is so in the attention simple tensile stress when we make a spot weld in overlap configuration and then pull it and identify this strength as a function of either weld nugget diameter or you can also say a especially welding current which would be up to the same.

So as a function of shear strength as a function of diameter and identify as I explained sorry shear strength and there are some issues in conducting tensile stress, a tensile test in the law of lab configuration because we never know the where the load is applied only to the weld. So, you may also see material deforming and the base material is deforming and so the shear strength what you are measuring it is not exactly the strength of the weld.

So, there are some modifications and some advancement are some regulations they actually developed to identify the actual strength of the welds and then one of these such modifications we use in testing methodology by making a cross tension tensile samples. So, in this case what we do is so instead of having in a simple tensile samples. So, we make weld under two sheets in a in a cross geometry was I showed in this figure.

And then we pull the top plate in tension and again in the in the bottom plate in other direction this direction. So, in this case no we identify again the this strength and then identify the what is the maximum stress or maximum load required to break the joint again material can also in this case deform not only in the weld as well as in the surrounding regions. But then we identify apart from the strength the nugget diameter after the failure, so, that we known as what is known as a plug ratio.

So, plug ratios what we calculate is after cross tension testing is ratio between the actual weld nugget diameter over the plug size after failure okay. So, what does it indicate say for example if the weld is intact and the failure happens and elsewhere okay your weld nugget diameter is your plug size okay. So, your plug size is the same as weld nugget diameter okay and then the your plug ratio becomes one which is the most ideal conditions because your well does not fail.

So, if you look at the cross sections if the failure happens and elsewhere here you weld nugget diameter is your plug size because your plug is an intact so the crack did not happen. The material did not fail in the weld regions and your plug size after testing is the same as weld nugget diameter then the plug ratio is one. Suppose if you have one a complete interface failure okay so you have material which caused the complete interface failure.

And the weld the two plates after it cross section test it separated as it was before welding so that means that your plug ratio, so what happens here in the plug ratio is 0 right in that case your material it is so brittle after welding is causing an complete failure of the interface during the cross tension test. The plug ratio is now becoming 0 and that is the most yeah a detrimental case because your weld does not undergo any deformation. It does not actually survive your cross tension test and leading to a complete interface failure.

And you may also have a partial plug failure where you have material and you some plug is left in one plate and the other plate may have a central of cavity and you can measure the remaining

plug and identify what is your plug size upon the cross tension test and yeah you may have a say for example 0.8 the plug ratio and so the based on the guidelines say you may identify whether 0.8 is also acceptable or not okay.

We will summarize until this then we move on to the tensile share testing. So, we looked at the electrode size various shapes what we use and we move on to the process characteristic of resistance spot welding. We started from the weld growth curves. So, what is you what are the implications why we need to get the develop the weld growth curves and what is the minimum weld nugget diameter needed to get an ideal properties and what are the guidelines which actually governs the nugget diameter as a function of material thickness the compositions.

And then we will move on to the some of the design aspects what is the minimum overlap distance we need to keep and the minimum distance between two welds we need to keep and then we will move on to the actual testing of distance spot welds and the so far we looked at two types of tests a simple tensile and then cross tension test. And we looked at the plug ratios the ratio between the actual plug size remained in the in the plate after the cross tension test over the weld nugget diameter.

And if it is one that means that failure has happened elsewhere and if it is 0 you have a complete interface failure and if it is in between and you have some plug intact that is slightly better for the in terms of weldability.