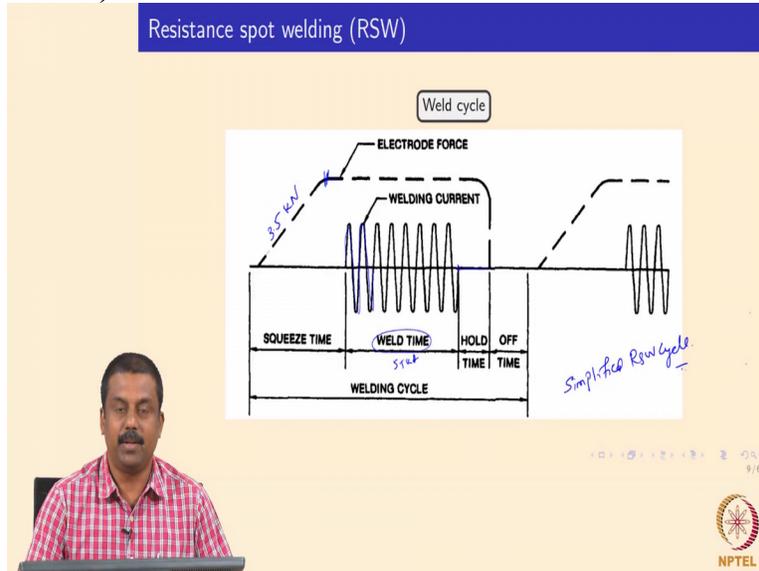


Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 08
Principles of Resistance Spot Welding (RSW)

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So, this is the simplified resistance spot welding thermal cycle but life is not that simple so we allowed to introduce some complexity to attain various modifications in terms of microstructures as well as the nugget geometry. So, we can, based on the automation of your resistance part welding equipment and we can introduce various modified weld thermal cycles during welding.

For example one such modified enhanced weld thermal cycle is shown in this diagram so we were looking at in a previous simplified case we have squeeze time where we start applying the load okay over here and then we started applying current and subsequently we stopped passing the current and then we released the load you formed the nugget. But you can introduce various heat and then thermal cycles for example in welding so we also know sometimes I like to apply a preheating thermal cycle okay.

So, that can also be introduced for example you start applying a load initially to keep the electrode faying interfaces in its position and then instead of passing full current the amperage so

we can also apply a small short pulse okay in order to preheat the your work piece your arc sheets and then upon keeping for some time we preheat pre-weld interval for example and then we can start applying the current not as in a single pulse we can also have an ramping of current where you gradually heat up the your welding sheets to a temperature of about a temperature of melting.

And then during this process you can also either apply a pulse or a constant amplitude okay. So, we will have we can have a one upslope and then we have a constant current and impulse and then we can have another down slope and doing so we can also modify the heating and then holding and then cooling a time and subsequently the rates at which these weld nuggets are heated and cooled okay.

And then at the entire weld time is determined by your up slope and then the current we apply at the constant amplitude and then a down slope okay and everything is processed we can also have a cooling time in between. So, you form a heating up and then you maintain some interval and then apply another current and subsequently you can also have an interval between applying a peak current and there are various reasons we can use these modified weld thermal cycles because we can also control the heating rate.

And we can also control the in nugget geometry and we can also control the cooling rate at which the weld nugget is formed at the interface is cooled. And then the after that you know after passing in current we can have so we can also increase the load after upon cooling and that can also control your stress development there is low stress development because we are introducing in a compressive stresses right.

So, when the transformation is happening we can also apply compressive stresses to mitigate the residual stress okay during cooling. And subsequently upon cooling to room temperature we can also apply another pulse okay and which can heat treat the whatever will micro structure that is formed micro structure is formed after the first cycle and for example if you have a fully martensitic microstructure we can also use and a temper time which is actually in which and we pass some amount of amperage to have tempering of the martensite structure that is formed upon welding.

And then yeah you can also have an ramping down load or we can also ramp up during this process if you want to change the stress state of your belt, so everything is possible under the entire cycle and I can be; completed within a second or so or even not more than a few seconds so the entire a thermal cycle of a weld nugget formation and can be altered based to our needs. For example as already explained, if you want to have a tempering of weld nuggets we apply and a small post pulsing current.

Or if you want to reduce the cooling rate at which the welds were cooled after welding and you can also do a pre heating by applying and has some small short pulsing before the application of the actual the building current. And you can also change the loads based on our need so in this case a typical cycle and we also have an increasing load when the weld nugget is cooled to mitigate the residual stress okay.

And the all of them can be used to in our favor to modify the weld thermal cycle okay. And the commercially used the risk and spot welding in nowadays they have capability to generate such an complex waveforms complex interplay between the load as well as the current which can be used to modify the micro structures to generate micro structures which are actually superior than even a base material okay.

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Resistance spot welding (RSW)

Weld cycle-enhanced

- (i) precompression force is used to set electrodes and workpieces together
- (ii) preheat is applied to reduce thermal gradients at the start of weld time or to soften coatings such as galvanized zinc coating
- (iii) forging force is used to help consolidate the weld nugget
- (iv) quench and temper times are used to produce desired weld properties in hardenable steels
- (v) postheat is used to refine weld nugget grain size and improve strength and
- (vi) current decay is used to retard cooling of aluminum alloys to help prevent cracking.

11/07

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The slide features a blue header with the text 'Resistance spot welding (RSW)'. Below the header, a yellow box contains the title 'Weld cycle-enhanced' and a list of six numbered items (i) through (vi) describing various welding techniques. In the bottom left corner of the slide, there is a small inset image of a man with a mustache, wearing a red and white checkered shirt, sitting at a desk with a laptop. In the bottom right corner, there is a small circular logo with a star-like pattern and the text 'NPTTEL' below it. The date '11/07' is also visible in the bottom right corner.

So, to summarize the weld cycle in the pre comparison forces used to send the electrodes of work pieces together okay. So, you can apply a preheat to reduce the thermal gradient at the start of the weld time or to soften coatings such as for example galvanized coating and the forging forces to help to consolidate the well nugget and the quench and temper times are used to produce a

desired microstructure. In for example high strength Steel's and advance high strength steels their cooling rates that are actually used in resistance spot welding.

We would invariably lead to the martensitic microstructure so we can use a post pulsing either to temper the martensitic microstructure or we can also re-melt the weld nugget that is formed in order to homogenize this segregation so that is also really helpful in some of the alloys which we will see in last classes how the modifying weld thermal cycle especially post pulsing would help in and changing the segregation effects in a resistance spot weld during a resistance spot welding of advance high strength steels okay.

And then for example in the post pulsing I can also be used to change the weld nugget grain size and improve the strength and toughness. So, there is also current decay okay so in a downward slope he is also used to control retard the cooling of aluminum during solidification, change the cooling rate so that you know we can avoid the cracking. If you generally the aluminum alloys are not considered for a resistance spot welding because of the various problems inherent problems that are associated with aluminum alloys.

So, similarly for stainless steel as well, stainless steels are also considered difficult and suitable candidate for resistance spot welding so generally you know if you look at to summarize you know I said explained also the enhance their thermal cycle can be used to mitigate as a fresh as well as to change the micro structures in our favor to improve the main metal properties.

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Resistance spot welding (RSW)

A typical single phase AC spot welding circuit

The diagram illustrates the electrical and mechanical components of a resistance spot welding (RSW) system. It shows a single-phase AC power source connected to a contactor, which controls the flow of current through a welding transformer. The secondary winding of the transformer is connected to two horns, which are part of an electrode holder assembly. Each electrode holder contains an electrode, and the distance between the two electrodes is labeled as 'ELECTRODE SPACING'. The 'THROAT DEPTH' is also indicated. The entire assembly is connected to a 'FLEXIBLE CONDUCTOR'.

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So, this slide shows the typical a single-phase alternating current spot welding circuit okay. So, we have a single-phase power and which is capable of producing the current of required amperage. So, the rating of the resistance spot welding machine would tell you how much on periods we can go under maximum and that will indeed determine the maximum thicknesses that can be welded by a machine. So, we have and that the power source contains a transformer an AC transformer and which is actually connected to a throttle.

And really it is an inflexible conductor a horn is connected to a flexible conductor to get the current from the transformer which is passed to the electrodes of copper. And subsequently you know when you pass a current you have a heat generation of a Joule heating. So, the components of where the power source as well as the setup is and we have an a transformer, a horn and a cantilever which is actually not only up used to pass a current as well as to apply load okay and then we have an electrode attached to the end of this horn.

And then your sheets are kept in between the electrodes and the haunt yeah so in a typical resistance spot welding cycle these horns are replaced with in a robotic arms okay the robotic arms can also control the application of load and at the moment of the electrodes with respect to the rebuilding patience.

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Resistance spot welding (RSW)

Mass effect

$$Q = I^2 Rt$$

$$\Delta T = \frac{Q}{mC_p} = \frac{I^2 Rt}{mC_p}$$

where Q is energy, I is current in Amperes, m is mass in grams and C_p is heat capacity, R is resistance in Ohms and t is time in seconds.

Handwritten notes: $R_1 + R_2 + R_3 + R_4$, C_p - Specific heat Capacity, $20-120^\circ C$

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So, the effect of thicknesses and the heating mechanism should be also considered when you are actually applying when you are using a resistant spot welding in two sheets. So, generally it is governed by the simple equation. So, this equation gives a minimum temperature rise that can be obtained for a given mass of M. Suppose if you have a thickness of a so-and-so and you can

know how much Q we need to generate for a given thickness because then you can calculate the M the mass from the density and volume.

And you can derive at the mass and then CP is the specific heat capacity okay. Suppose if you want to increase the temperature delta T okay for a given mass of material within a specific heat capacity of CP okay. So, the Q is the heat you needed to raise the temperature for example from 30 to 15 degree centigrade so how much Q you need and for a given mass of material m1 and Cp that is the minimum value.

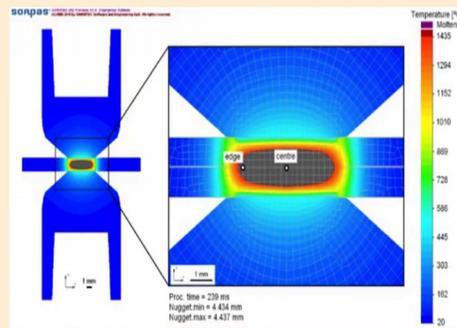
You always underestimate here because of there is some specific issues with this equation but that will give you the minimum Q needed okay to rise a temperature from say for example 30 to 15 degree centigrade and Q you already know that from $I^2 R t$ okay T is our welding time, time at which you pass a current of I right and then R is nothing but the summation of all the resistance. So, ideally you can neglect these through and if you know the R2 and R4 we can calculate the Q okay. So, for a given M mass of material Cp if you want increase the temperature from 30 to the 15 degree centigrade and we can calculate how much Q we need okay.

So, and then from there we can calculate how much amperage you typically need if you know the R4 or if you send these so much amperage you can also calculate what is the value of R4 the total resistance okay. So, that P is the mass effect I generally be considered so obviously if you want to weld thicker sections and you will have to get more Q for same increasing in temperature okay is because the Cp is a function of composition material composition.

So, we can also calculate a minimum Q needed to increase temperature from T to delta T okay. So, the other important thing I want to note down here is the unit's here amperage so it should always write and when you mention amperage in Volts and V must be in capital letters okay similarly for Ohms because these are their names ok.

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Resistance spot welding (RSW)



So, this slide shows the typical temperature evolution when you are doing resistance spot welding when the current is at the I MAX the peak current okay. So, the thickness is roughly 1 millimeter okay and you are applying a current so you see the typical distribution of the temperature. So, here the dark region denotes the molten material okay. So, it is the temperature is higher than 1500 Kelvin 1500 degree centigrade in this case centigrade okay.

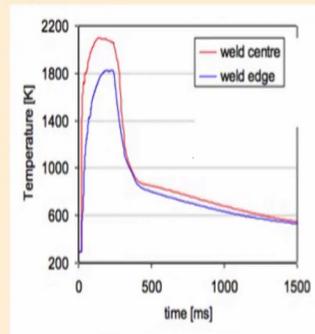
And then so you have a molten region and the temperature if you go away from the boundary between the liquid and the adjoining area decreases very drastically because of the heat transfer effective heat transfer okay. And that will lead to steep temperature gradient the temperature gradient will be extremely steep. So, you start from animating point to a room temperature and in this case if you have say one millimeter thick plate and within a millimeter.

So, there is a very steep temperature gradient always present in the resistance spot welding and so you also cool such geometry such as a heat mask and extremely rapid cooling rates. So, typically in this case you will have weld nugget sizes of about 5 millimeter in the sides roughly so this is your combined sheet thicknesses of 2 millimeter and within say 5 millimeter region so you have a weld nugget formation and then you have a heat affected zone.

And subsequently move towards the base material just by a millimeter or so. So, the temperature gradient it is extremely steep in the resistant spot welding case and so that will always trigger to a columnar or the columnar grain growth during solidification.

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Resistance spot welding (RSW)



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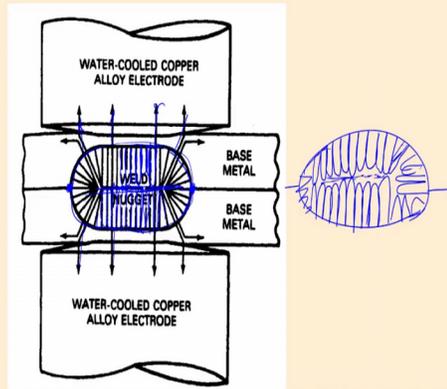


So, if you look at the temperature actual thermal cycle extracted from the previous diagram. If you look at it and say for example at the center and the edge of the weld nugget which is formed so typical well thermal cycle looks like this So weld Center and then and the weld edge which is at the efficient boundary. If you look at it the actual thermal cycle so not more than 500 milliseconds. So, within 500 milliseconds material is heated up to a temperature and as high as 2000 Kelvin something around a 1700 centigrade.

And then cool to room temperature and within a second ok so that means that your cooling rates are roughly in this case about a 1000 Kelvin per second. So, in this case even higher it is why we are cooling it in the both the regions if you look at it the melting point if you look at it over here so you have complete molten regions between the weld center and weld edge and both of them are cooled at the same cooling rates during cooling. So, this is the typical weld thermal cycles we adapt during resistance spot-welding.

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Resistance spot welding (RSW)



And there is a really explained because of the steep temperature gradients that are present in the weld during solidification and we will have weld nugget solidifying in a very columnar structure. For example you have high temperature at the weld interface because of the contact resistance right and then your solidification moment you form a liquid and subsequently if you stop the current then your weld nugget would start solidifying.

And from the nucleation from the fusion boundary and then the grains would grow in a columnar manner toward the weld centerline from the fusion boundary and they will coil as a weld centerline and this structure is not metallurgically preferred because of the very strong segregation that are developing during solidification of the columnar grains and during this process now if alloying elements preferred to segregate to liquid.

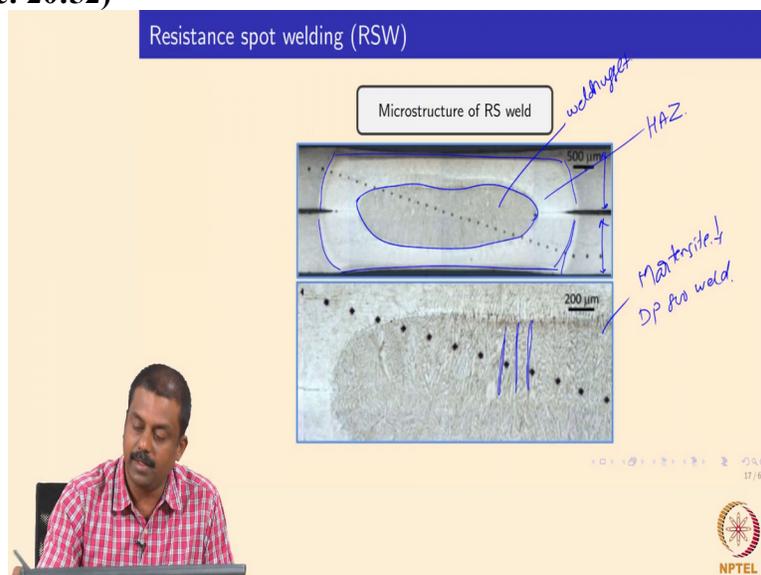
And we will end up in which ending the grain boundaries or solidification grain boundaries these boundaries as well as weld centerline ok. And because of that the this solidifying grain boundaries and the weld center line would be enriched in alloying elements by making these boundaries under weld centerline very brittle and so this structure apart from this segregation and columnar of solidification on this location.

You also have an weld boundary and you also have an open un-welded sheets so that are actually act as a stress raisers at this point. So, that may also cause some problem during loading we will see in detail the effect of the weld edges in the subsequent classes. Right now and because of the steep temperature gradient and the heat transfer that are happening by the water-cooled copper electrodes. So, you trigger a columnar solidification of you solidified liquid.

I mean the liquid is solidifying and due to that they will of and as a very strong segregation of alloying elements or the grain boundary and they will centre line. So, the typical microstructure if I can redraw again so you have a weld nugget liquid and so this is your weld center line and then you have solidification nuclear nucleating from the your fusion boundary then going towards the weld center line.

And during this process you also partition the alloying elements towards the solidifying towards the un-solidified liquid there by the liquid at the weld center line getting enriched in alloying elements. So, these are typical solidifying microstructures of the resistance spot welds.

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So, these two micro shows the actual micrographs made from my DP 800 welds. You see over here so what I see so this is 1.2 mm DP 800 sheet and they a spot welded typically and what you see over here is the we weld nugget so it is completely molten and solidify. So, this is a typical weld nugget and if you zoom in you see the columnar grain growth solidification okay towards the wild center line.

And subsequent to the weld center boundary you have a heat affected zone and in this case it is perfectly right. So, the heat affected zone is some up to this region okay. So, this is your weld nugget typically so this is your the heat affected zone and you also have the complete martensitic transformation here because of the cooling rates that actually we apply during the resistance spot welding, we do not apply but it actually cools extremely rapid rate. These black dots here is irrelevant we just hones measurements we carried out on these welds.

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Resistance spot welding (RSW)

Electrodes-ASM/ISO standards

• Standard ISO 5182 governs RSW electrodes.
• Cu and Cu alloys are commonly used.

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So, some of the electrodes that we use in the resistance part welding and we can use various geometries of the electrodes and it is all governed by the ASM/ISO standards and if you look at the typical cross sections maybe in next class I will bring in an example electrode. There are various types we can use and the most of the materials are made of copper and some copper alloys are also used.

And they alloy with copper alloy with zinc and tin sometimes are also used and predominantly the electrodes are made from pure carbon and this is a typical cross section and for example have a point A electrode, type II A electrode is in a pointed type and so this is an phase and there is a channel inside which is used to circulate the water for extract heat. And so we have various types of electrodes based on the ISO standards.

Type A is pointed and type B is dome type and you may also use of flat electrodes or eccentric electrodes and type D or truncate electrodes which is most commonly used in automotive applications or we can also use a some sort of radius electrode where you have when a pointed edge as well as some give it the concave geometry. So, the most commonly used electrodes are the type A and type B in automotive applications.

But based on the various the nugget sizes one can change the electrode shapes and we are based on these standards we can choose the electrodes and we use it okay. So, the actual standard that governs the electrode is there ISO 5182 we can refer it and then see how these electrode size and shapes can affect your nugget geometry okay. To summarize this class so we looked at the

resistance spot welding equipment and how the enhanced thermal cycle can be used to modify the weld thermal and the load cycle in our favor.

So, we can introduce a preheating cycle we can introduce and ramping up current. We can modify the heating rate to some extent we can also modify the cooling rates by changing their and down current after welding and we can also apply post pulsing to temper the microstructure if you have a fully what is a microstructure or we can also apply a pulse current in order to melt and re-solidify the solidifying solidified weld nuggets in the first place to avoid to homogenize the well nugget.

So, yeah the all possibilities are used to obtain the micro structures that are actually suitable for various applications and then we moved on to the electrode dimensions as well as the equipment that are used in resistance spot welding and we will continue look at rest for some of the features of the spot welds how we can test these spot welds and how we can change the micro structure of the spot welds by modifying the weld thermal cycles.