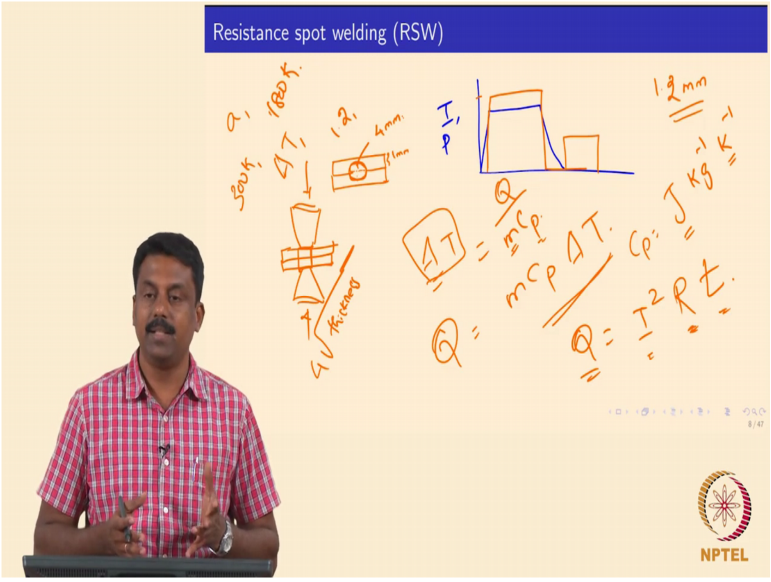
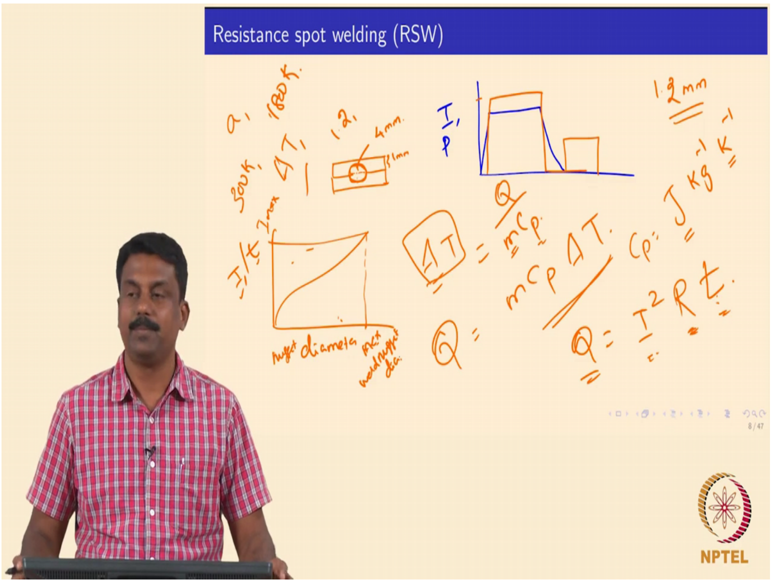
Welding Processes

Professor Murugaiyan Amirthalingam
Department of Metallurgical and Materials Engineering
Indian Institute of Technology Madras

Resistance spot welding Part 01

(Refer Slide Time: 0:26)





Okay, we will start from last class we look that the typical resistance spot welding thermal cycle right, so we looked at a simple Thermal cycle, what we are looked at it is, say for example current or you can also be load, it is also important right to keep the interfaces together, so basically cycle looks like, so will start first loading, moment we achieved are required load and then the current will also start forming okay, so load cycle will be something like this and then the current cycle.

So if you look at if you take can a red one, orange one, so then you will have a current cycle going something like that. Okay, right, so typically the current will be in few kiloamperes okay, so for its 1.2 MM thick, so why I always use 1.2 right, in your first filler why are on first heat, these are very commonly used this as an diameters for any engineering applications, especially for automotive industries right, so I picked up 1.2 which is my favourite thickness to an extent.

So 1.2 MM thick steel, we use about 4 to 8 kA based on weld nugget size what we want. Okay, so the load would be in somewhere, so around few 1000 kg newtons, newtons or kilo newtons 3 or 4 kg newtons so depends. Okay, so that is a typical current and then load the load we use and these are very simple thermal cycle. Okay, so this will do the job for us, but we always greed right, will have to modify various, for example thermal cycles, you want to introduce pre weld heating or a post weld heating and in some cases, it is important to rise in temperature more gradually or at very slow rate. Okay.

So in that case, and this simple weld thermal cycle may not give you the freedom to play around with the welding parameters, for example, heating rate, cooling rate or holding time, for example, or if you want to introduce and post weld heat it melt, you can also do it here the same weld thermal cycle, so apply an post pulsing okay, so you will have a second current pulse which can go like that, so that will give us like sort of a post weld heat it melt, so the various possibilities and can be achieved by modifying the current and the load, recycle, but we apply while doing, while applying typical weld thermal cycle okay.

So in order to achieve the typical weld thermal cycle, we also need to understand the characteristic of a material as a function of current and the load. Okay, so in characteristic by meaning the ability to melt right, say for example for a given thickness what factor determines the delta T, the change in temperature right, so for example if you want increase the temperature of material from 600 to say 1500 okay, and what you need? What you need to know? So that now you can give a certain amount of energy, so that you can reach the delta T, come on guys, do you understand my question? No, right.

So for your material, so material of A right, so this material now you are in room temperature 300 Kelvin and you will have to raise the temperature to say 1580 or we can say that an 1800 Kelvin, how do you calculate how much energy needed to achieve this increase in temperature? Delta T.

Student: specific heat capacity.

Professor: Yes exactly you need to know specific heat capacity right, so delta T would be, how do you calculate delta T? So Q is MCP delta T right, is not it, so this is the definition of specific heat capacity is not a right, the CP is, what is the unit of CP? Joule Kg per Kelvin exactly, so what do we need is? We need to know how much J goes in right, to know that I required delta T, so this will be delta T will be Q divided by MCP right, so now if you want to know how much Q you need to raise a delta T, so you need two factors, so one factor is CP, so that is the material particle parameter okay and then the other only factor which determines the heat generation or heat locate to rinse in a temperature from see our room temperature to melting point is the mass, is not it.

So, mass here, we define the mass in terms of thickness. Okay, so say for example if you have 1.2 MM thick, so we know the active volume is defined by the cylinder, cylinder diameter would be electro diameter is not it, the height of the cylinder would be the combine thicknesses of the sheet is not it, so suppose if you have 1.2 MM, so you have an electrode something like this and then you place two sheets and then bottom electrode, so you apply load is not it, so we already know that Q is I square RT exactly.

So now we need to know delta T is not it, so how do you calculate delta T? Q you can know, once you know R4 or R3 the contact resistance we can measure the Q, we know say for example given time and the given current right, suppose if you want to know how much energy is needed to rise in temperature and so and so only factor we know is M, so if M you can assume or you can calculate assuming it there is a cylinder which is actually heating up, what is height of the cylinder? The combine thickness of the sheets, so once you know the cylinder volume, you know the density of the material, you can calculate M, what is volume of cylinder? Pie R square H. Is not it, so you know R which is electrode diameter, electrode radius, H is the combine thickness, is not it.

So once you know the volume of that cylinder, you know density of the steel or any metal alloy you are using it, so then you can calculate M, so once you know the M, CP is given okay and delta T is say for example you need to rise the temperature from room temperature to melting point, then you can calculate the Q needed, so once you know the amount of Q is needed, then you can back calculate what will be the current you want to use right, so we know the contact resistance, once you know the contact resistance than as a function of time you can measure or you can get the current, it is clear.

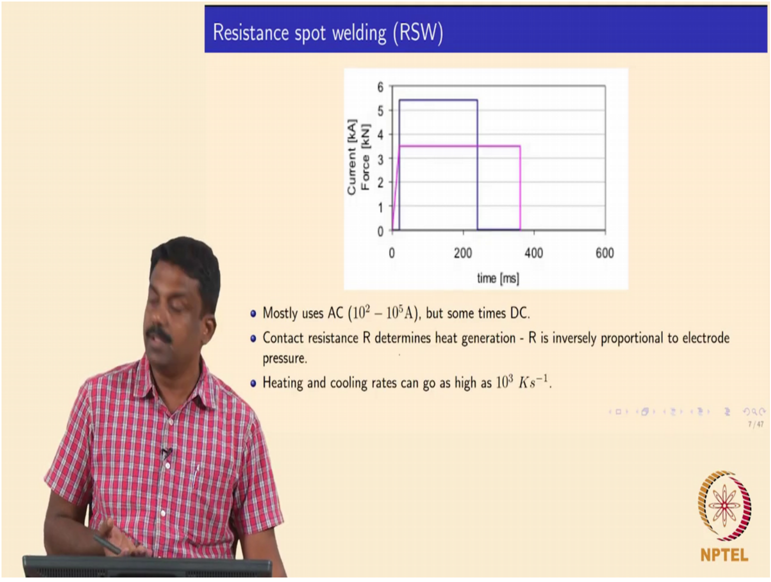
So this is how we develop the welding parameters to get diameter equal to the weld nugget diameter right, so as a thumb rule the typical weld nugget diameter is always 4 times square root of thickness. Okay, so if you are thicknesses 1 MM the weld nugget diameter is acceptable, weld nugget diameter is 4 MM okay, so 4 MM means if you take a cross-section basically, so it will be like this, is not it, so ideally you can get an average diameter, so if this is 1 MM, so you need to achieve 4 MM weld nugget diameter as this centre axis of the weld.

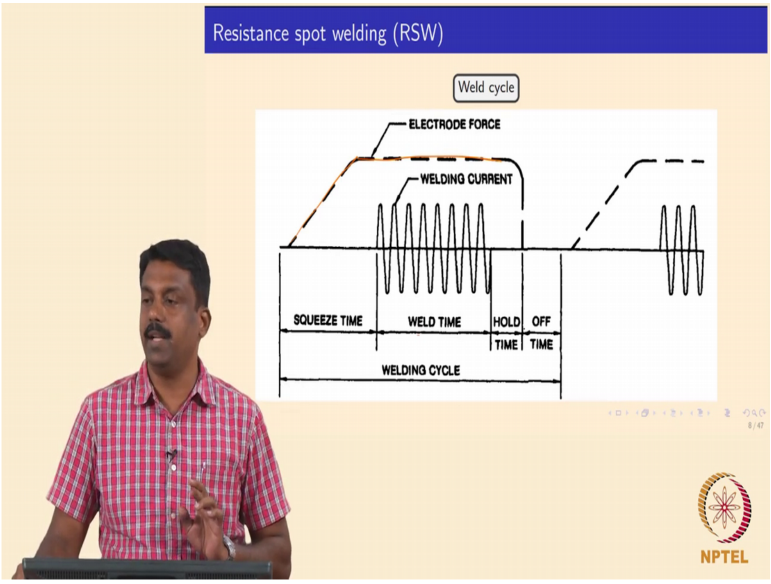
So this is the weld cross-section okay, so now we can calculate once you know the thickness, the required diameter, how much current is needed for a given time of welding is not it, so we can use our physics to calculate the welding current and time is needed to achieve a required weld diagonal diameter, it is clear, yes or no. Okay, good.

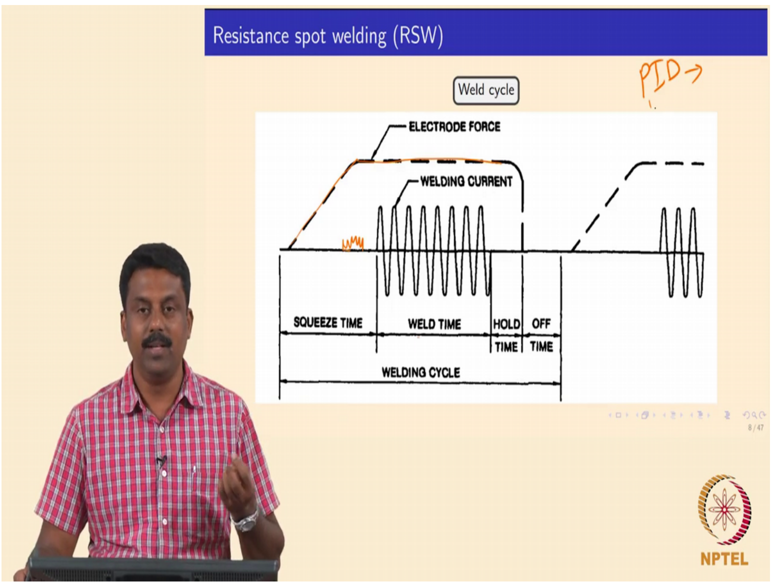
So than once you do the all the calculations, so we can also establish what you known as well growth curves okay, so well growth curve is plotted as a function of current or welding time and then weld nugget diameter I or T as a function of nugget diameter right and this is for a given thickness because if you change the thickness M changes, is not it right and then this curve will change, so obviously, so for a given thickness and given material because you change the material CP changes right, so by fixing a thickness and then CP can develop weld nugget diameter and then as a function of current and then or by fixing the time we can get the current, is not it or by fixing a current you can get the time because those two are independent variables, clear.

So we can develop the weld nugget diameter, the curve generally looks like this. Okay, so there is one current at which, so we cannot form any weld nugget because you form so much of liquid than if you are applying a load liquid get expelled, so that is the current at which the expulsion happens or splashing happens that current is known as the IMAX a current, so with this is the IMAX and this is a maximal weld nugget diameter that you can form. Okay, so we will see in detail all this concept, what I have explained in today’s class right, it is clear good, so we will move on to the slide, any questions so far from last class, no good, go ahead.

(Refer Slide Time: 11:32)







So it is the typical as weld thermal cycle in order to touch it and these are we do. Okay, so simple weld thermal cycle I showed you in previous graph, simple current and then a load, applied over a time is not it, so what do we do in a typical thermal cycle, so there is squeeze time, so load is increased. Okay, so the moment you achieved or required a welding load then you start passing the current right.

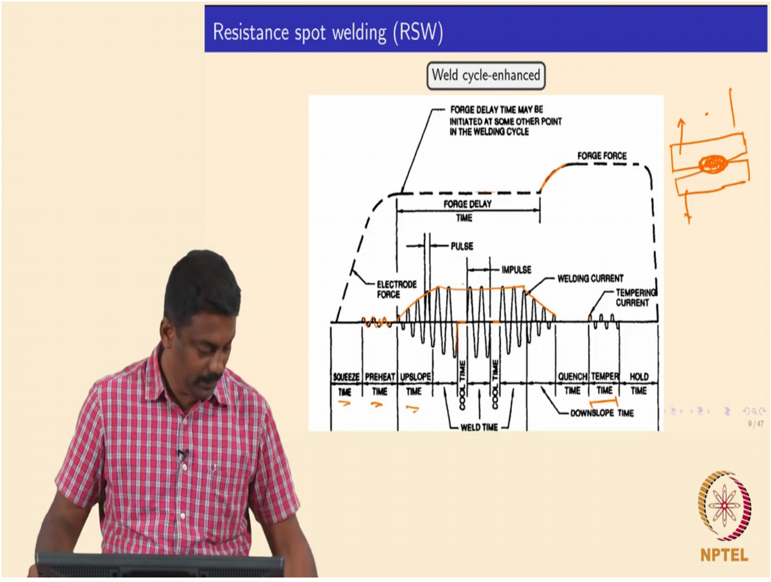
So doing this process you can keep the load constant and then upon applying in the welding current over a welding time and then you switched of the current and release the load that is it, so this simple weld thermal cycle can give us the required current needed for generating weld nugget diameter right, it is clear, so the important components of these inter weld thermal cycle is the squeeze time, weld time, hold time and of time, so entire weld thermal cycle, welding cycle would run not more than 200 ms the typical resistance spot welding right, it is clear.

But this is extremely simple, in real life such a simple weld thermal cycle we hardly use okay, so you have to introduce a lot of modifications, for example, you know that summarize, you know In a say, for example highly alloyed steel will end up getting only melting side upon cooling because the cooling rate here as I said can go 1000 Kelvins per second. Okay, so it is very difficult to achieve other grand of molten side microstructure okay, during welding.

So we may have to do a tempering treatment right, so what do we do? So we do and a second pulsing are opposed pulsing upon welding time, so that you cool to room temperature and then subsequently you add an additional pulse, so that the molten cycle in weld zone is getting pampered, okay, so we can also program that in the weld cycle itself, or you can also reduce the cooling rate by using a preheating, so instead of taking the temperature directly to room temperature, you may also have a prepulse, a pulsing before the actual welding pulse, so that is means that you are preheating the interface to our temperature of say 400°C, so that may reduce the temperature gradient and subsequently it can also reduce the cooling rate. Okay.

So in real life if you have an advanced distance spot welding equipment with a good PID control, what is PID? Yes, so the mechanics guys should know about it, so if he does not know then your problem, so these are all the professional integration and differential control, so these are input, output feedback control mechanism, so any resistance spot welding equipment would have a PID control.

(Refer Slide Time: 14:52)



To program a very complex weld thermal cycle. Okay, say it is enhance weld thermal cycle what we use, for example, so you may have a loading cycle something like, so that you have an squeeze time well the material is just squash and then you may have preheating, so preheating is achieved by applying and a small short pulse, so you may not use in a current pulse of weld thermal cycle where it will be a few kilo amperes, so you may have say 800 ampere also.

So the temperature is reached about 400 to 500°C in the interface and subsequently we can also ram up the current slowly okay, instead of filing in a or doing in a initiate ramp up to and maximum 4 to 5 kA, so you can also slowly this the current in such a way that material is also need some, reasonably slow heating rate, in order to avoid resistance stress development in the material and then during this process can also I and a weld time, maintaining it and subsequently can also slowly decrease the current such a way that you meet in a cooling rate right and you may also increase a load upon cooling, it is also beneficial because in order to mitigate the resistance stress that is forming and during welding say when a Melton side forms, so you have an tensile expansion and you can also accommodate and by applying an compressive force okay.

So in order to introduce the resistance stress development in the weld, so you may also play around in the subsequently when the weld nugget is cooling down to room temperature and you may also increase a load in such a way that you apply and a compressive force to mitigate the tensile as redeveloping in the microstructure right, it is clear, so in enhance thermal cycle, typical thermal cycle have squeeze time and then preheating time and the upslope time and then actual welding time and in this welding time also and in between a cooling time. Okay.

So there is also a possible okay, so you may also introduce our intermediate cooling, so that you do not really increase the cooling rate and significantly and then subsequently you can also change the cooling rate upon welding okay and then you have an squeeze time to give the stress, the compressive force is applied when the material is cooling down to the room temperature and then subsequently you can also apply a second sort pulse, post weld in order to heat up the weld nugget to a temperature where you expect a molten side to get pampered right, it is clear.

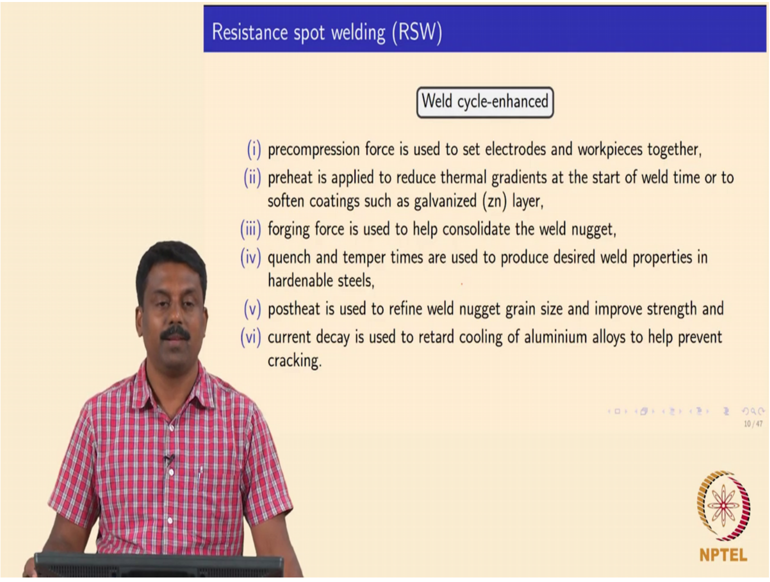
So this kind of complex weld thermal cycles are commonly used for engineering applications, so that we can mitigate the microstructure development and the stress that is developed when you are welding in envelope configuration right and in the modern resistance spot welding equipment they all of them work envelope generating such weld thermal cycles and it is extremely important because you know if you look at welding metallurgy of the automotive steels okay, so it is difficult to achieve a good mechanical properties without any post well heat treatment okay.

So is extremely important to use a post pulsing not only to temper the metallic microstructure or so homogenize the elemental segregation that is happening in the microstructure, otherwise if you look at the typical the cross-section how we often in spot weld, so this is the two sheet okay, so this is how it look like the resistance spot welding and weld nugget here, is not it the cross-section, so these are there and if you look at typical resistance spot weld you always have a notch at the weld central line, so when you are trying to pull the tensile loading, so it is like an notch and then if you have very trans segregation of a line elements at the weld center and this notch which would it as an stress concentration media and then you will end up forming a crack going towards the weld center line because weld center line is highly segregated area, that is the area where it defies at the end okay.

So you expect and a line elements segregation make the weld center line very brittle. Okay, so in order to avoid the weld center line segregation, so you may also that this post pulsing can be very helpful because this is like a heat treatment, homogeneous treatment, so after forming a weld nugget you form a subsequent pulse in such a way that you can homogenize the whatever elemental segregation happens in the weld center line, we will see in detail when you move along.

So the post pulsing can be used to modify the microstructure, to redistribute the stress so that the Mechanic properties of the weld nugget improves significantly right, it is clear, the enhanced weld on cycle is not it, good, so why is it pulsing here? Because it is alternative current. Okay, so we always use alternative current that is preferred for resistance welding okay, good.

(Refer Slide Time: 20:37)



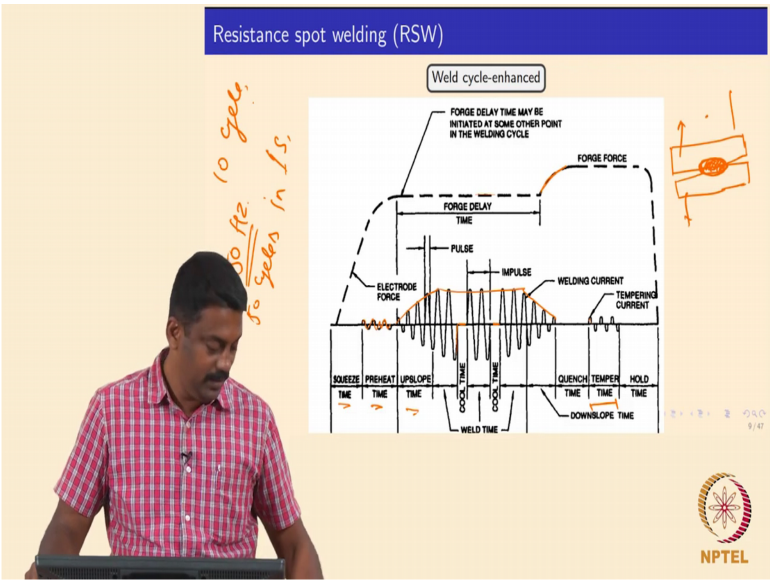
So in order to summarize the enhanced weld thermal cycle, so we can apply a precompressive force to set the electrodes, work piece together to that size squeeze time right, then we can apply preheating to reduce the thermal gradients at the start of weld time or to, for example to soften any surface coating is the right, so once you apply preheating you can also minimize the temperature gradient and then you can apply forging force to consolidate the nugget and then you apply weld thermal cycle, the actual welding time and then subsequently you can do post pulsing for quencher tempering right, it is clear and you may also play around with the current decay specially aluminium alloys to prevent hard cracking, aluminium alloys are I mean extremely notorious to weld in resistance spot welding okay, resistance spot welding of aluminium alloys and also the stainless steels, stainless steels are nightmare to weld in resistance spot welding.

So I never seen someone welded resistance spot welding of stainless steel without cracking okay, so stainless steels are reasonably good material if you are using GMAW or GTAW to weld because you can play around with the simplification patterns, simplification method, you can play around the dilutions so that you know, you can avoid hard cracking but here there is no way you can add filler. Okay, so it is all autogenous weld, so if you are doing autogenous weld and the stainless steel and aluminium alloy is you know a prone for cracking because you also apply a load okay, so compressive load becomes tensile in one axis.

So in that case, you know an aluminium alloys stainless steel, they are prone for cracking and they also have a thick oxide coating is not it, oxide layer, aluminium as well as stainless steel, so the contacts resistance can be huge. Okay, so because of this presence of oxide layer, so you may end of heating a lot right, so you need to play around with the current decay or the downslope of the current in order to you know retard the quenching of aluminium alloys which can otherwise it will do cracking okay, it is clear.

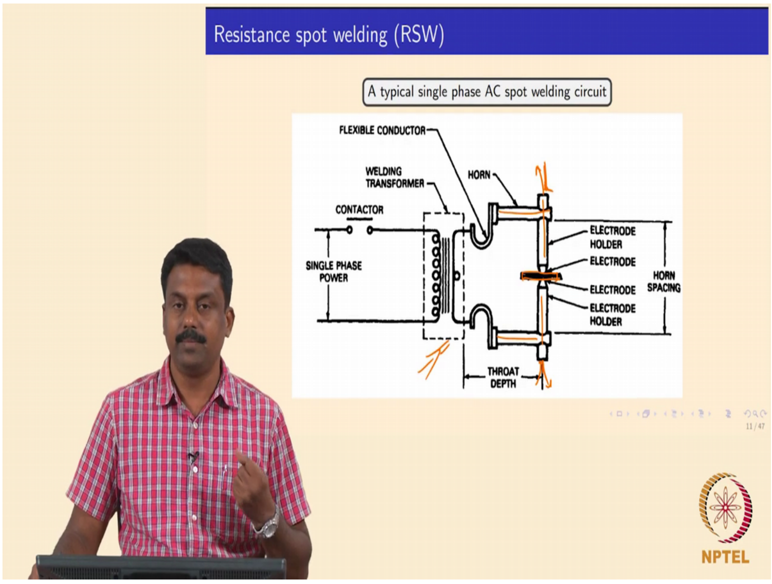
So you can play around this parameters to achieve required the weld metal properties, good, any questions on this, it is an extremely important to understand this because when you are doing resistance spot welding industrial scale you will all, so these terms are very quiet common, squeeze time, for example, post pulse time, number of pulses okay.

(Refer Slide Time: 23:37)



So we always tell the welding time in terms of cycles okay, say suppose if you tell that the 10 cycles welding time and you are raising a 50 Hz AC, so what will be the welding time? So 10 cycles means, so 50 Hz what you mean by that 50 Hz in AC, 50 cycles in 1 second, is not it, so the 10 cycles would take, come on guys 1 x 5, is not it, so 1 x 5 times that is the time required, that is the welding time. Okay, so in a, if you look at in a, you go to automotive industry what is the welding time they would say 10 cycles okay, so because the 50 Hz is a most commonly used current, so the welding time is always measured in cycles. Okay, so will set an cycles of welds, 10 cycles in 50 Hz right, it is clear, good.

(Refer Slide Time: 24:58)



So this is a typical again, schematic of the equipment, so before going to this we also have such equipment in our lab. Okay, so this is the industrial scale resistance spot weld, so what is over here? Can you see clearly in the picture okay, so this is the cantilever which also has water inlet okay, so water inlet, water outlet so that is to cool the electrode and you see here this two they are the electrodes, so now the sheet is not there, so it is placed between the electrodes right and the load is applied through this cantilever.

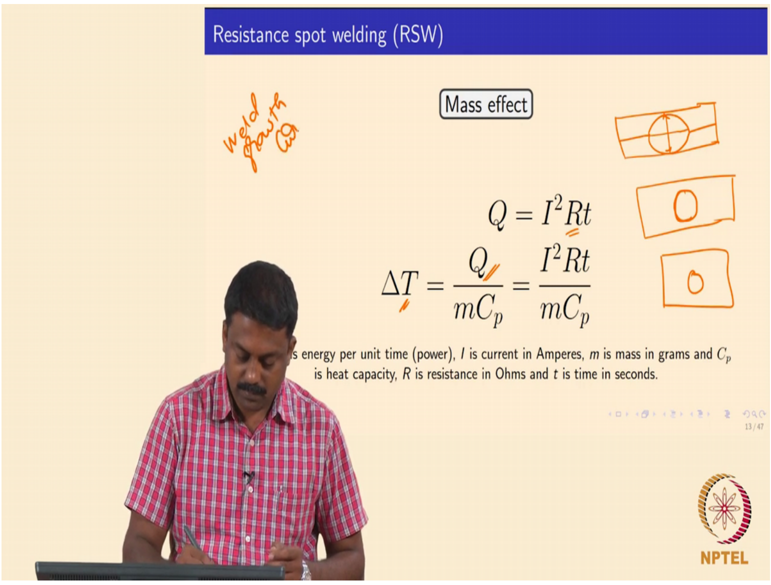
So we have some hydraulic, so these are hydraulic mechanism is not it, so these are hydraulic apply a load prepare to keep the interface in contact and subsequently the electric current is passed and then water cooled the electrodes would pass a current between the feeing interfaces and then you form weld nugget yes, it is clear. Okay, good.

So if you look at this schematic of these such setup and this is industrial scale resistance spot weld, so for example in automotive platforms and these arms would be placed by robots. Okay, so these arms will be replaced by the robots okay, so in this case in our lab, so we have simple cantilever beam is used to make a weld nugget.

So this is a typical single phase AC spot welding circuit, so we have a transformer, so in this transformer is somewhere over here okay, so and then you have a horn, the flexible conductor which is used to apply a load and this is a typical depth and this is a cantilever beam that is talking about and the water cooling goes in and comes out and then the interface, welding interface kept in between the electrodes and then while applying a load we can pass the current to form a weld nugget yes, it is a simple schematic, it is clear.

So we can around with the, so now a days this transformers circuit is also microprocessor controller okay, so we can also play around with the ramping time, cool down time, post pulsing, number of pulses okay, so load and squeezing load and then cooling load, say anything can be play, varied based on the program what we use, it is clear, good.

(Refer Slide Time: 27:47)



Okay, so this is mass effect that was talking about. Okay, so it is very important, so in order to create the amount of heat energy needed to heat up a material, so typically want to heat up from room temperature to the above melting point right, so then how do you calculate how much current you need to achieve a required weld nugget diameter, you can use a simple physics, physical law.

Student: (()) (28:17)

Professor: Yes, it is a mass of the nugget, so how do you calculate, so mass of the nugget can be calculated from the volume and the density okay, so mass we assume for example, you know the weld nugget diameter right, suppose if you want to achieve a weld nugget diameter it something like that, so I am drawing a cross-section okay, so this is a cylinder pretty form basically is not it, so once you want to know the weld nugget diameter, we call well nugget diameter and then the height of the cylinder will be the thickness, combined thickness, is not it.

Student: (()) (29:01)

Professor: Yes, that is also you can assume, is say for example you can also see, this is the set of you and this is well nugget diameter and if you look at the side view you do not see unless you are cross-section is not it, yes, because the electrode is placed somewhere here like this, from the top right, so the weld nugget diameter if you want to get a correct well nugget diameter, how much current you want to send for a given time? How do you calculate? So you know the height of the cylinder which is the combine thickness of the plate, so you want to know the diameter okay, then you solve for the cylinder volume okay and then you get M from that I once you know the M, so you can calculate Q, so once you know the Q for given welding time how much current you need, that you can calculate, is not it, so that is a simple right.

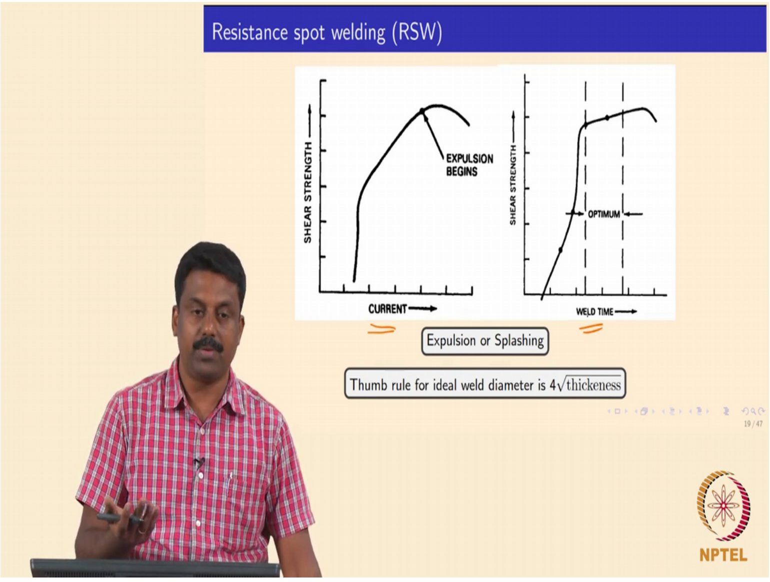
So only trick here is the R or here is made of 4 components, is not it R1, what is R1? Electrode resistance, R2? Seat resistance or the base material, bulk resistance, R3 is the contact resistance okay, the R4 is resistance between the interface and the electrode okay, so once you know the resistance basically we always assume the contact resistance is maximum, so compare to contact resistance, other resistance are negligible, so once you measure the contact resistance, so we can calculate the current required to form a given weld nugget diameter okay, yes.

Student: (()) (30:51).

Professor: R is the context reasons we can assume, only contact resistance yes, so because, see the contact resistance will be 100 times more than the bulk resistance of the plate as well as the copper electrode okay and the resistance between the electrode and the work piece it is also negligible because the heat is extracted by the water, by the cooling, that is not contributing the nugget growth okay, so only resistance that is actually controlling here is the contact resistance between the sheet, so once you know that and that can be calculated, again by using simple bridge circuit right.

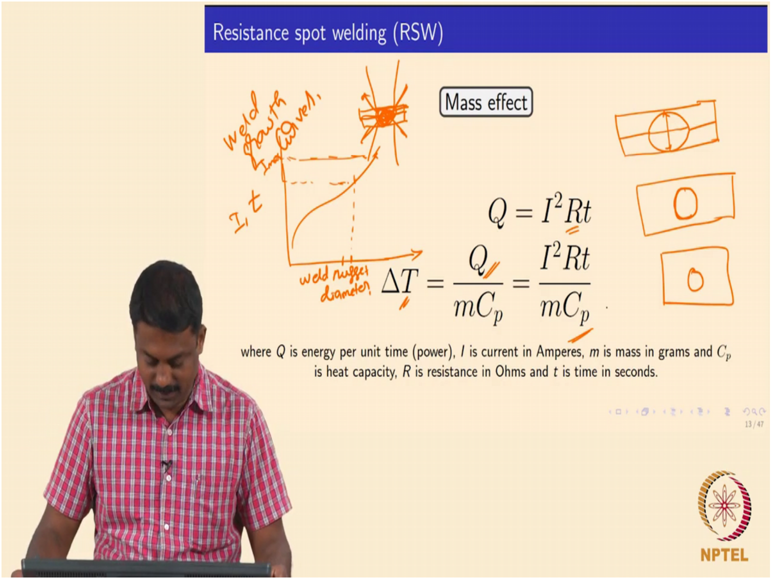
So once you know the contact resistance for a given load. Okay and then we can measure the current required for a given welding time generate a weld again diameter of so and so right, it is clear, so in experimental point of view we do not really like you know to make life easy, so we measure experimentally what you known as weld growth curves okay.

(Refer Slide Time: 32:16)



So come back to that okay, so this is the weld growth curve because you asked the question, so basically the weld growth curve is the develop as a function of current and welding time, what is the weld nugget diameter? Okay, in this case are uploaded strength, strength is proportional to weld nugget diameter. Okay.

(Refer Slide Time: 32:37)



So if you look at the weld growth curve, so you plot as a function of current or a welding time, so either with is the current and vary the welding time or you fixed the time, vary the welding current, both will lead to increase in weld nugget diameter, is not it, because I square RT whether it is fix T, vary I or fix I vary T and both will lead to change in nugget diameter. Okay, so this is typically will be like this. Okay, so there is a maximum current okay, so that is IMAX, so I really the thumb rule is to achieve an optimum strength, we always use a thumb rule of 4 times square root of thickness.

So if the thickness is 1 MM) have to would be 4 MM, so that is the typical, so why 4 MM? So because we can cover the entire cross-section okay, so that is why it is 4 MM, so if you have an a ideal, you can identify now, so what current and time is needed to achieve a weld nugget diameter of our interest, so we cannot keep on increasing a current because upon IMAX you have more liquid formed and you are applying squeeze force, the liquid will start splashing out, is not it, so you form a liquid and you are applying a compressive force.

So then if you have an electrode applying pressure and you have a sheet okay and if you start melting and if you make a large amount of liquid then you apply pressure the liquid cannot will send the load, is not it, so then it will start splashing out and this is known as exploration of splashing okay, so upon increasing current to a certain level you also splashing and then you will not form weld nugget, you will just have a cavity okay, so the IMAX is the maximum current about which the splashing occurs right.

So, generally we do not operate until IMAX, so will operate much below IMAX but will have to know why, when IMAX is happening? So these weld growth curves can be plotted as a function of time, weld concern time and the varying current, identifying when is IMAX and then we can choose weld nugget diameter which is required by the standard okay, it is clear and you can also calculate from the physics, so what I and T you will have to for a given M, CP is fixed and M is from the thickness right, it is clear, yes or no, this is simple right, the simple balance good.