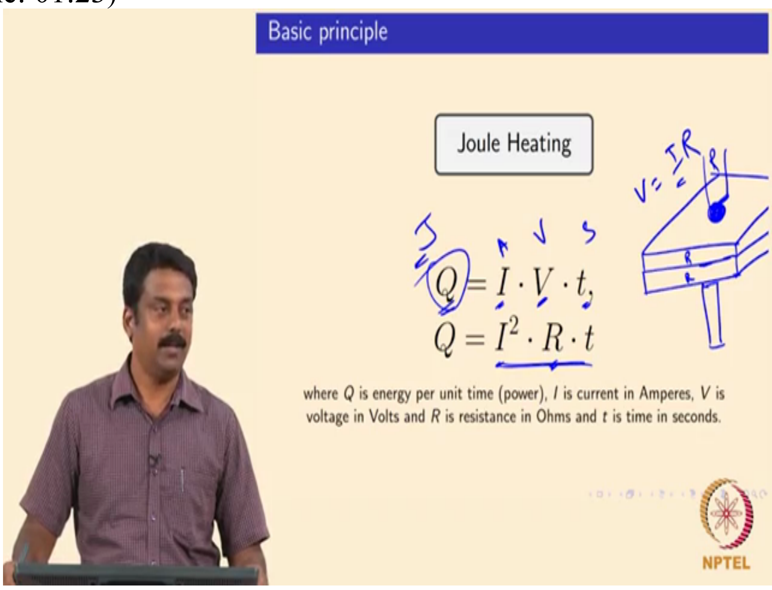
Welding Processes
Professor Murugaiyan Amirthalingam
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras
Resistance Welding - Fundamentals

So in this process so what is the basic principle in heat generation? It is resistance heating. So we will see again physics of this processes. So what is the main generation mechanism, how it is controlled and what are the factors that can influence the welding characteristics and what are the factors that influence heat generation. You said it is dual heating but there are lot of variants, factors that can influence heat generation in this process. We will see one by one, so before that there are variant, number of types of resistance heating is used in industrial welding processes.

(Refer Slide Time: 01:23)



It can be resistance spot welding, seam welding, projection welding, thermit welding, plausible welding, resistance spot welding and electric resistance welding and there are so many types but the fundamental heat generation mechanism is the same which is joule heating. So what is joule heating? The heat generated when you pass ampere of I, voltage of V or unit time of t, the heat is generated, is given by I square R I times V times t.

So it is difficult to get V all the times, it is resistance. So V is always replaced with resistance. So what is relationship? V equal to I R. Then I V, so we replace V with IR, then it becomes IR square. So you always remember, so ampere and then volt and second becomes joule. So that is from the basic definition of the ampere and volt. So you need to understand that which would generate heat. That is how we also viewed water heater. So that also used the same principle.

So here Q is the energy per unit time, time is given. If you move joules per second and second to this side, it becomes joule. Joules per second is what? It is what? So then the heat is generated in joules, it is nothing but the current square times resistance. And what is this R?

Student: Resistance.

What resistance we are talking about here?

Student: Resistance using electrode.

Electrode resistance. So imagine now I want to weld two sheets, something like this. Somewhere suppose I want to weld at the middle, so what R, what is R for this configuration? Sheet resistance, bulk resistance. That is it. So R of this and R of that will determine the heat generation. Yes or no?

Student: Sir, electrode is (())(3:52).

Say suppose you have an electrode, you use an high conductivity copper, similarly you have another electrode in the bottom. Now what are the resistance you expect in the circuit?

Student: Electrode resistance.

Electrode resistance, sheet resistance, that is it?

Student: No.

Student: Contact resistance.

Contact resistance. Okay, good answer. So where is the contact resistance here?

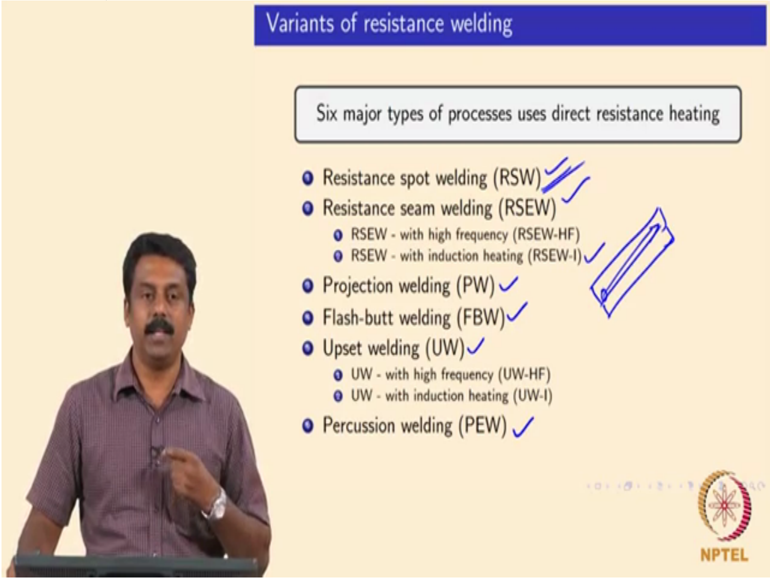
Student: Between the electrode and the plate.

Between the electrode and the plate.

Student: Sir, between the plates.

Between the plates, exactly. In this case the main resistance that dictates heat generation is the contact resistance between the plates. So before that the contact resistance can be generated in various configurations. So for example, resistance spot welding, so these are the variants of resistance welding. Various types of welds you can expect. There are six major types of probably used in direct resistance heating.

(Refer Slide Time: 04:42)



Resistance spot welding, so we use simple two electrodes to make a spot and the weld spot. Again we will see in the subsequent classes. And the resistance seam welding, so why seam welding? To make tubes. In most of the applications and tube making is done by resistance seam welding or ERW, it is called electric resistance welding, so where the sheets are folded and then we pass the current in between the interface. Interface is heated by the contact resistance and then it will not offset, to push it once the heating it is heated up and then we deform the edge to make continuous seam.

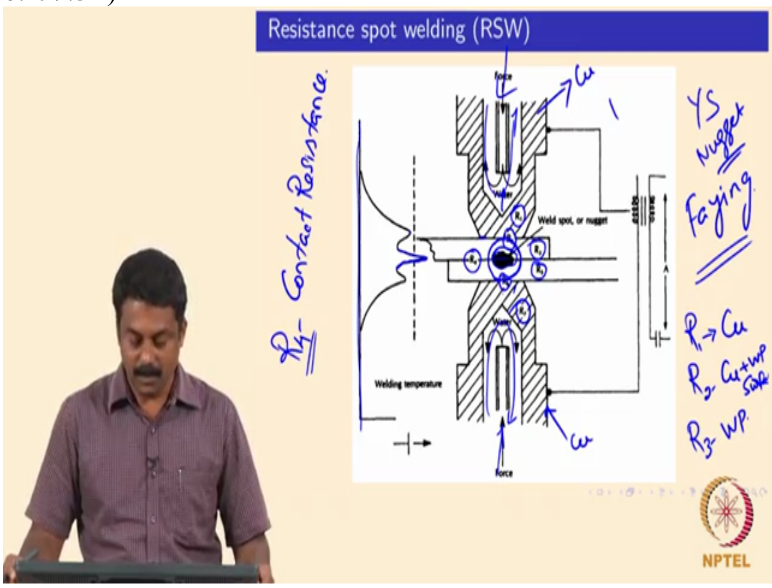
Or we can also instead of having a spot electrode, so we have two plates. And you have an electrode rolled along the interface continuously. You form a continuous seam of welding. Then electrical, that is resistance seam welding with low frequency or high frequency. Or you can also use an induction heating, you use resistance of the contact as well as the external heating mechanism. And you can also increase the heating efficiency. Or you can also do projection welding or flash-butt welding where you form an arc between the two interfaces. You melt and then subsequently do offset so the molten liquid can go away and then you can have one joint.

Or you can also do simple upset welding by resistance heating. For example, you do not melt, just heat it up to higher temperature and then upset it so that it deforms and forms a joint. Or you can also do percussion welding. So we look at all these processes in this unit. So what are the important factors that control the heat generation and what types of electrodes we use?

Why should we use this process? For what application? We all see this in this unit. So that is what we are going to see in this lesson.

So all the fundamental that governs the welding processes to make such welds, because then we can improve the weld metal property. So first process what we look at is, going to look at is resistance spot welding. It is very widely used in automotive industry, resistance spot welds. All sections they are welded with resistance spot welds.

(Refer Slide Time: 07:32)



And basically what we do in resistance spot welding is, as a simple setup it is extremely simple. So we have two electrodes, top electrode and the bottom electrode. And generally these electrodes are made with copper or copper alloys. We use copper because high conductivity and we can also extract heat from the electrode very effectively because during this process electrodes do not melt. So when you pass the currents, you keep top electrode and bottom electrode and then we attach the sheets to be welded in overlap configuration. What is overlap? Lap, so top of each other, something like this.

And then we fix the electrode at the top and bottom and then we pass the current. And during this process we will have to make sure that only the interface melts. It is not be melting the electrode. Then we have problem. We should not heat up the electrode because we are also applying a force, an axial force during this process. So in this case you make sure that temperature is not increased. So what we do? So we use copper electrode and we cool the electrode very effectively by circulating water.

So the copper electrode generally we use and then the heat can be transferred very effectively because thermal conductivity of copper is also very high. So we can pass the current and the current can be flowing through the faying interface, what is faying? It is a very nice British word, one British word. To fay means to join. So the faying interface over here and then we will have to make sure that the current flows. And during this process the current continuously flows, then you do not have an effective heat generated.

So we need to have some resistance, R. So what happens when the current actually flows? Whenever there is hindrance to the current flow, that is resistance. So that is where the charge accumulates and then the charges can interact, can collide and dissipate heat. So any moment is hindered, that means that the energy dissipated. So now in this case if the current flows from one electrode to electrode, make it positive or negative, whatever be.

And generally we use an AC current in resistance spot welding or resistance welding for very very specific regions. We will come back to that later. So imagine now we have passed an alternating current. In every cycle positive and negative is changing and sometimes the electrons can flow in this direction. Other times electrons can flow in this direction. Ultimately the flow of electrons are hindered by the various resistance in the system. So what are the resistance in the system, you can expect? Say then the current is flowing from this direction to this direction, from top to bottom.

What are the resistance we can explain, you can expect? First resistance is the resistance of the electrode itself. So in this case say R1, okay R1, R1. So generally we use high conductivity copper if we use, then R1 is very minimal. And the second resistance we would expect is the resistance between the electrode and the top of the sheet. Similarly the resistance between the bottom electrode and the bottom sheet. That means that resistance R2, say R1 is say for example copper and then R2 is between copper plus work piece surface.

So this is R2. And then what are the resistance you expect?

Student: (())(11:40).

Okay. So before that you also have the bulk resistance of the work piece itself, R3. And then you may have the resistance between the work piece, that is R4 which is the contact resistance. Which resistance will be maximum?

Student: Contact.

Obviously, the contact resistance between the two sheets. So because R1 is as small as possible, similarly the R3 based on of the sheet is not as high as R2. So maximum resistance you would expect is in between the sheets. So that is why you expect the electrons path is in direct maximum. So that is why the R4, the contact resistance can generate maximum heat. So that we can make it for our own benefit because we will have to melt the interface. The charged carriers are hindered at the interfaces, then the heat can be accumulated at the interface and that can lead to heat generation ultimately melting of the interface.

So in these four resistances the main rate controlling resistance which is actually form the weld nugget is the R4, the contact resistance. The contact resistance is not a bulk resistance, bulk resistance is a material property. Contact resistance is depending on the surface roughness and the surface condition. And then how hard you press each other, is not it? The lowered you give axially, this all influence the contact resistance. The surface conditions, for example you may do one bare sheet and another case you use coated sheet.

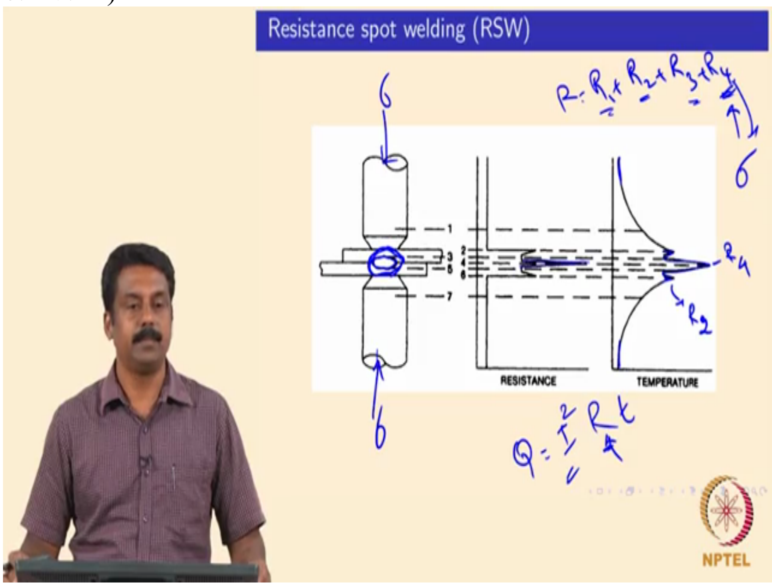
Then the contact resistance is entirely different. Similarly you use say the 2 Kilonewtons load and other case 5 Kilonewtons load which will have maximum contact resistance. So obviously 2 kilonewton, because when you increase the load, you also decrease the, or you partially deform, you reduce the surface roughness. So you are bringing close to each other, is not it? So you change the load, you also change the contact resistance. So the contact resistance, heat generation is a function of various parameters which involves the material surface roughness, material surface conditions, the load you apply.

And then that will determine the heat generation. So if you look at the temperature distribution, I put in this case in the other axis, the maximum heating would happen at the interface. So this is welding temperature as a function of distance. So you would expect somewhere other heating at the top of the surface because the R2 is also in a contact. It is not a bulk resistance. But luckily the heat whatever you form at the R2 is extracted by the water cooling. So the temperature will not reach as high as in the interface.

And similarly the R1 is minimal, the resistance of the copper if you use the copper electrode, so you will not expect any contribution from the R1 to this process. And same goes with R3, R3 also is very minimal because that is the bulk resistance of the sheet you are welding. So if you look at this entire setup, resistance spot welding, the main rate controlling resistance is the R4. The R4 leads to the heat generation accumulation at the interface and then because of that you start melting first the interface and then it will grow and you form the covering both the sheets and that is what is known as nugget, weld nugget.

We will see, it is clear, right? So how the controlled heat generation, so heat generation in resistance spot welding is actually controlled by the R4. The R4 is the contact resistance between two welding interfaces. It is clear? Good.

(Refer Slide Time: 16:24)



So this is what happens if you look at schematic again. So we have top electrode and bottom electrode and you keep two electrodes. So basically you need to apply a compulsion anode. And sheets are placed in overlap configuration. You pass the current and simultaneously you also apply a load and then you start melting at the interface and then the interface would grow and make a continuous weld joint. So now the size of the weld is determined by the thickness, and the contract resistance as well as the load you apply and the welding time.

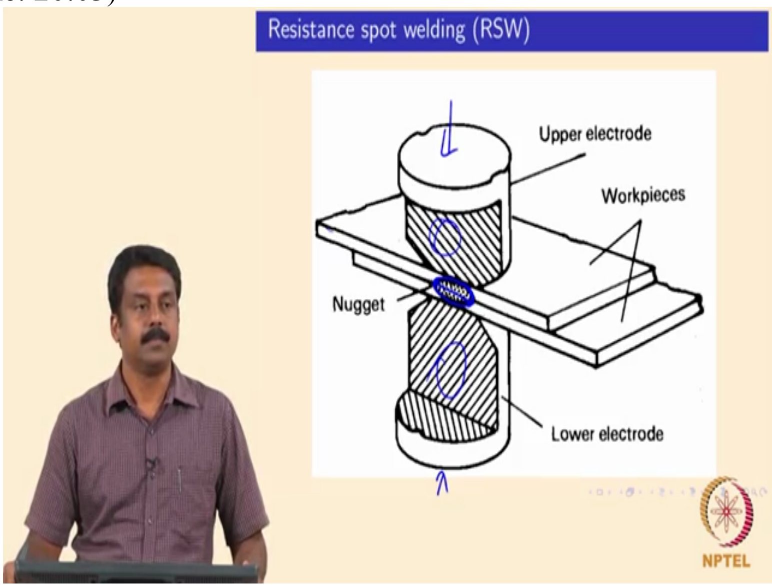
So thickness is the mass, mass effect, so Q would function of the mass effect and then the current, basically the R, R is the contact resistance. So R can be R1 plus R2 plus R3 plus R4. So you can neglect R1 and R3 and R2 also you can neglect significantly because you are extracting the heat, so the R4. The R4 is again a function of the load, as well as for a given surface conditions the R4 can only be changed by sigma by the load, how much you load apply.

Because the material is selected already, that you cannot change. For a given material the actual, the weld nugget size is determined by the current you give and then the R which is in turn determine the R4, R4 in turn determined by the load and then you have t. What is t? Time of welding, how much time you spend. So based on these three factors we can calculate the weld nugget size, so the size of the weld.

So these factors, the current, the R4, R, R4 and then in turn sigma and then welding time would determine the amount of liquid you form at the interface. So if you look at the temperature distribution, again if you look at it, so we will have maximum and the heating. So resistance you expect at the interface, therefore the maximum temperature at the interface. You have minimum heating because you have minimum resistance for the flow of current. And we also have a small variation in the temperature and this is due to R2. Sorry, this is what you do at interface, what I give R2. And this is R4.

So the main rate controlling is R4. R4 can be changed by surface condition if surface is fixed and material is given, R4 can be changed by the load. And then other factors will influence the welding is the current, and the welding time. It is clear? Good.

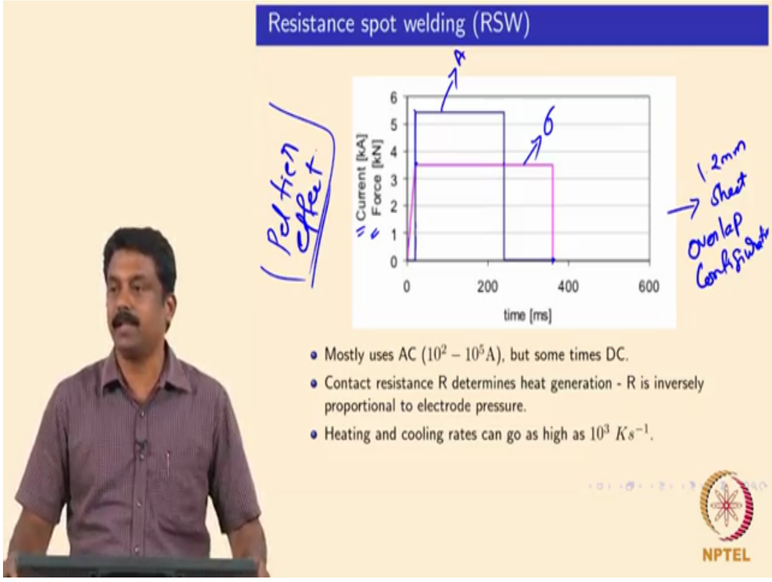
(Refer Slide Time: 20:03)



So if you look at cross-section of a typical resistance spot weld, this is how it looks like. So electrode, so we made a cross-section and parallel to the axial direction of the electrode and you have electrode, you have a cavity inside to have water circulation.

And then you place a sheet to be welded in overlap configuration and you apply a load and the current, and during this process the heat is generated at the interface and the interface would start melting and then forming a weld nugget, very beautiful weld nugget at the center of the electrode and surrounding area. It is clear? Good.

(Refer Slide Time: 20:48)



So this is the typical weld thermal cycle we follow. Weld thermal cycle I said, because we always need heat, we pass the current, and simultaneously we also apply some load. And in the conventional resistance spot weld thermal cycles you have a current versus force. Generally we have such curves, so this is done to 1.2 mm sheet in overlap configuration. So what you do is so once you have one overlap and you start first applying the load upon applying a load which is required to achieve required contact resistance, then you will start passing the current.

So for 1.2 mm sheet in this case I used 5.5 kilo amperes, kilo amperes. In conventional GMAW what is the current we use generally? Not more than 300-400 amperes. Whereas here we can go 10 kilo amperes. So in equipment what we have in our lab, that can go up to 10 kilo amperes. So in order to get a good weld diameter, good weld diameter is determined by some factors. We will see in subsequent lectures. Suppose if you want to achieve one acceptable diameter, so in this case we can go up to 5.5 kilo amperes with a load of 3.5 kilo newton.

So we apply 3.5 newton load and during this process we also apply a current of 5.5 kilo amperes and then you decrease the current, you keep the load intact for some time so that metal solidifies. Otherwise if you take it off and the liquid can separate out, so you keep the load for some time more and then ultimately you form weld nugget. And if you look at the entire weld cycle, in this case 340 milliseconds, close to 350 milliseconds, so that is a very fast process. So in this case in resistance spot welding, in most of the cases we use AC, alternating current.

In this case blue is current, pink is, that is what I said, 5.5 kilo amperes. So this is amperage and this is load. So most of the cases we use alternating current for very specific reasons. Again physics, why we use alternating current here and if you use the DC, there is the problem. So we can now assume that we use only AC, and we will see why only AC in later classes. So generally the current is from a kilo ampere to, we can go up to 10,000 kilo ampere, even much beyond that based on the equipment capability and our need.

As I said, the contact resistance determines the heat generation, so R contact resistance is inversely proportional to the load. Load increases R decreases. Why? Because we are bringing close to each other. If you are putting, if you are processing more, you are bringing place close to each other. And because of very tiny area what we look at and we also have an electrode which is effectively transferring the heat from the weld and this electrode itself is water cooled.

The cooling rates what we achieve when the weld solidifies, it can be several thousand kelvin per second. The cooling rates can be as high as 2000 kelvin per second. So entire weld you can touch in 300 milliseconds. So if you are cooling at such a high cooling rates in a steel obviously, in most cases you will get only martensitic microstructure. So weld can be very brittle. But we will have to play around with the welding parameters in such a way that we achieve a good weld metal property.

We will also touch upon some of the aspects when we study that. So you can now assume that the main characteristic of this process in this case, the heat is generated by the contact resistance which determines the heat generation the R4. And then we also apply a load and the load can change the contact resistance and then the welding time and the current would determine the weld nugget size. We use mostly alternating current, the reason is yeah, so it is known as peltier effect. For next class you can come up with the answer, so what is peltier effect?

So next class we will discuss why we use only AC. Because of this effect and then because of the effective heating, cooling done by the electrode, the cooling rates can be extremely high in thousands of kelvin per second. It is clear? Good, so we will stop with this and then we will see in the next class.