Welding of Advanced High Strength Steels for Automotive Applications

Prof. Murugaiyan Amirthalingam
Materials Joining Laboratory
Department of Metallurgical and Materials Engineering
Indian Institute of Technology-Madras

Lecture - 07
Introduction to Welding Processes in Automotive Industries

So, we were looking at the microstructures of dual phase Steel and trip Steels. The heat treatments thermal cycle is actually adopt to generate microstructures of these advanced high strength steel especially dual phase steel and trip Steels. So we were looking at operating elaborately the heat treatment the role of alloying elements. Why do we add those alloying elements and what are the steps involved in generating ferritic martensitic microstructure in dual phase as well as the ferritic bainetic and retained austenitic microstructure in trip of steels.

And how the isothermal bainitic holding helps in stabilizing be retained austenitic at room temperature and then we subsequently moved to austenitic process. We look at the thermo mechanical cycles we adopt the deformation in austenitic region. And the role of alloying elements again in austenitic steel, the role of Boron, how Boron increases the hardenability because of that you know how we can generate the martensitic microstructure upon cooling from hot stamping. In case now we are moving on to next unit on welding processes.

So, if you look at the important welding processes that are actually used in automotive industry. The basic principle involved in those welding processes and what is the current state of Art in those processes in welding of advanced high strength Steels and then we want to the subsequent chapters. Before going into the actual details science behind welding processes we look at some introductions as usual.

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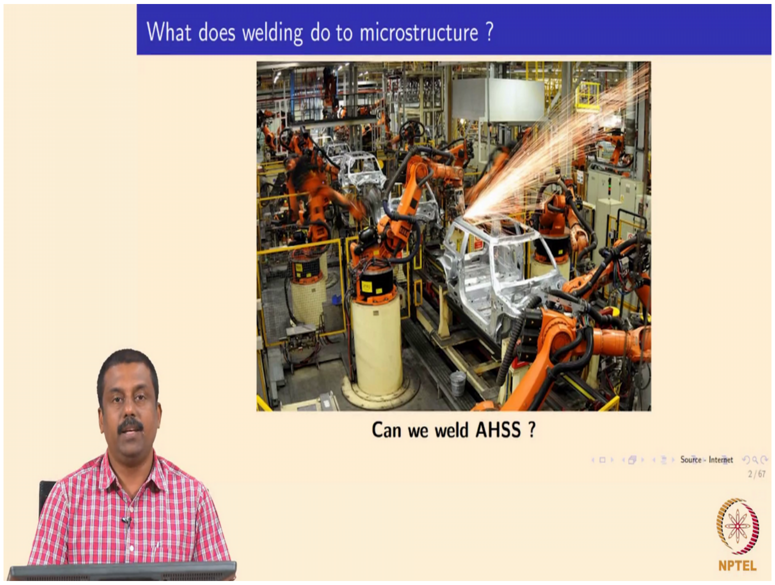

So, for example the main question that we are going to ask is what does welding do, to the microstructure ok. So, we already look that how complex the microstructure of dual phase and trip Steel. So, we have to adopt various thermo cycles to generate that beautiful microstructure which can give high strength and reasonable ductility ok. And we look at now how typical the weld thermal cycle is going to affect those microstructure can we save those microstructure so that the weld properties are equal to the base material properties if not even better than the base metal property.

So, that the big question we are going to ask now is from here onwards is can we weld advanced high strength Steels, if yes then how. If not yes then how we can improve the welding processes that such a way that we get the microstructures of welded advanced high strengths steels which are superior in terms of mechanical properties.

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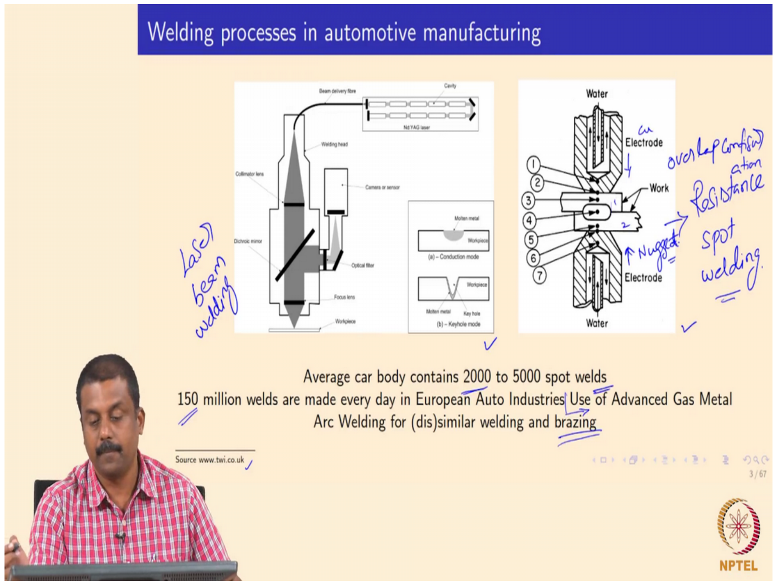

So, if you look at the important welding processes that are actually used in automotive industries. The majority of the welding in automotive industry is carried out either by laser welding or resistance spot welding. I just gave to schematics we would not go into detail about the process now but we will go in one by one. So, if you look at the images what you will see over here is the typical schematics of laser beam welding and what you see over here in right hand side is resistance spot welding.

So, in majority of welding operations in the Automotive Industries is carried out either by laser or by resistance spot welding. So, if you look at an average number of weld that represent in car body typical car body is; it can be either varying from 200, 2000 to 5000 spot welds and these welds are actually made extremely Rapid time and productivity production conditions. So, if you look at the statistics from the welding Institute of UK. By average about 150 million welds are made everyday only in European automobile industries ok.

So, trend is also moving or is coming back from the laser welding and spot welding to the advance gas metal arc welding as well. Because of light weighting also introduces complexity in terms of material thickness material composition. So, the advanced gas material are arc welding processes they are also coming up to weld especially the dissimilar joints and also some application we may also used gas metal arc brazing for welding advanced high strength Steels. But even now predominantly the welding processes that are used in Automotive industries are either Laser or resistance spot weld.

Increase in average look at an body or chassis we can find somewhere between 2000 to 5000 spot welds. And these welds are supposed to be strong and stiff throughout the life cycle of the automotive car automotive life cycle roughly is about 300000 km that is the actual mileage. So, these 5000 welds spot welds that is what you have in auto bodies should withstand such an enormous amount of workload is expected. So, we look at in an detail about this welding processes that is on the all the resistance spot welding, laser beam welding and some of the advanced gas arc welding processes that are actually getting explored to weld using advanced high strength Steel.

First we move on to the resistance spot weld, I have seen I have shown you the schematic here. So, the actual welding process is very simple what we have is two electrodes which are generally made of copper. So we keep the interfaces that are going to be welded in between two water cooled electrodes. The electrodes are water cooled ok so what you see over here is sheet1 and sheet2 it is kept top of each other and what is known as overlap joints and on overlap configuration ok. And then we applied some load, while applying load we also pass the current, current of some amperage. Show the actual value we see in the next slides.

So we pass the current and we subject the actual feeing interface to a load, compression load in this case. And while passing current material heats up in joule heating. The joule heating generated phase leads to the melting of the interface and there be a collation of the interface leading to formation of weld which is known as nugget, so well nugged is formed at the feeing interface by joule heating. So there are various 1, 2, 3 numbers that I have given here we will see in the next slide. What are these numbers means what are the various components of the typical resistance spot welding equipment.

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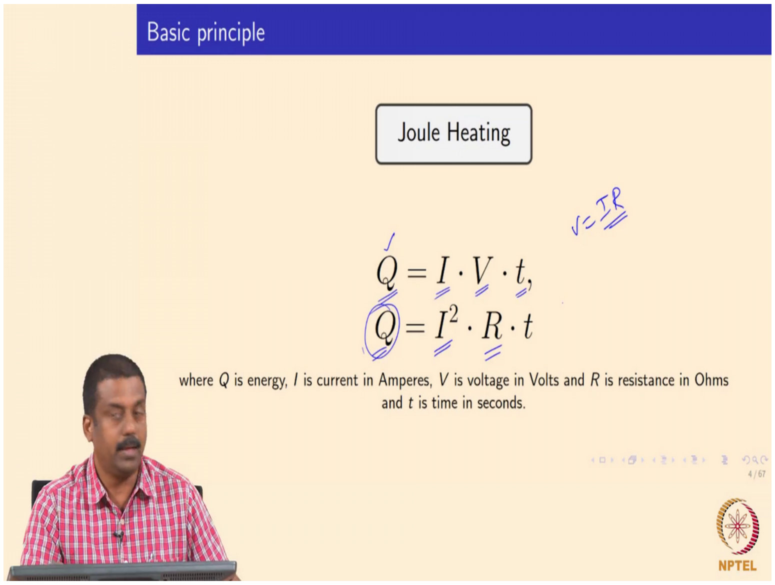

Before going to that as I really here explained resistance spot welding the main heat generation mechanism is Joule heating. In case what joule heating is the amount of heat generated is equal to the amperage the current the magnitude of current sending over a potential difference of beam. And how long we send those current over potential difference determine the heat generation. So, in this equation Q is joule and can be called as calories you are converting it. Joules are generated by passing and current of given ampere over potential difference of V volts for a given time.

So, that is the amount of heat that we want to generate in a typical resistance spot welding. So, the main rate controlling factor is or they can change this equation so V = IR, V can be replaced with IR because the IR can be measured easily. So, then the; actually heat generated in joule is I square R* t. So, this is can also be changed into watts if you take the time to other side it becomes joule per second and becomes watt then that will be I square R.

So, the main factors that are controlling the heat generation here is the R which is the resistance of the circuit and the amperage the current you pass it ok and that determines your heat generation Q, again R is not that straight forward or is not a single factor in this circuit.

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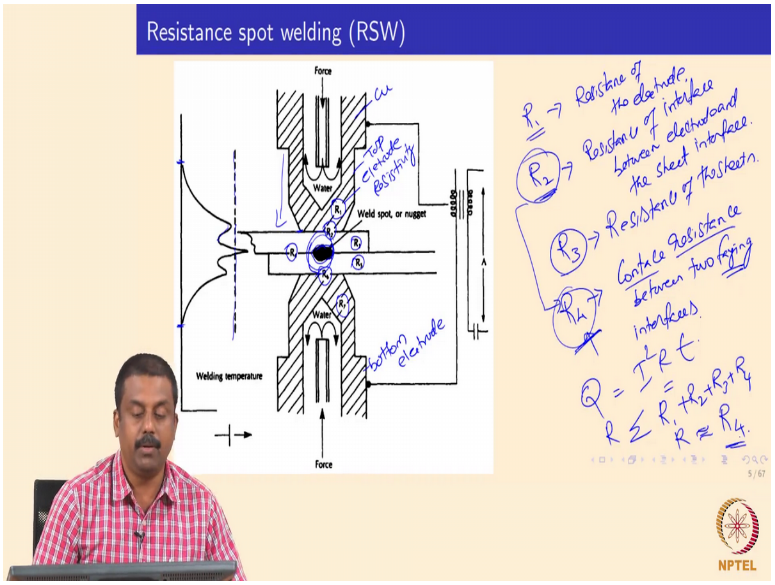

Because if you look at schematic of resistance spot welding So, there are various resistance that are present in the system ok. So, this is slightly the enlarged version of the diagram I showed you in earlier slide. We have one electrode which is copper ok this is water cool so that the electrode is not actually heated up during this process. So we have a top electrode and bottom electrode and the actual faying interface or the plates that are welded or sheets to be welded they are actually kept in overlap configuration. In between this water cooled electrode right. And if you look at the system and there are typically 4 systems present for example R1, R1 denotes the resistivity of the copper electrodes ok.

So, R1 here and this denotes the resistivity of the electrodes ok. And then we have R2. So, R2 denotes the resistance at the interface between your electrode and the sheet surface ok. So, if you write it down R1 is the resistance of the electrode R2 is the resistance of the interface between electrode and the sheet interface ok. And then we have another resistance R3 which is nothing but resistance of the sheet itself ok, R3 module over here resistance of the sheets.

And the fourth one which is actually extremely important in the resistance spot welding is the R4. The R4 is the contact resistance ok, resistance between two faying interfaces. So what is faying interfaces? Faying means welded, getting welded interfaces so that is R4. And this is known as the contact resistance and in the circuit if you look at it this system R4 is the maximum when compared to the other resistance for example R1 is negligible because we used the oxygen free high conductivity copper electrodes.

If you use them then the resistance of the electrode itself becomes very negligible and the R3 as well compare to R2 and R4 is also it is not really significant. But if you look at the actual resistance of at the contact area between two sheets on the contact area between interface and the other electrode becomes extremely significant in this circuit. So R2 and R4, R4 will be the maximum R2 will be the next ok because of increase resistance at the interface between the two sheets that are welded. We expect the maximum heat generation at the interface.

Show the contact resistance between the interface R4 determines the actual heat generation because of the increased resistance in R4 the entire heat generation is controlled by the resistivity at the interface so that is the contact resistance given by the surface roughness as well as the load we are applying to keep the interfaces intact. So there is various factors surface roughness for example the surface morphology and the oxide layer are the galvanised layer in sheets. All of them will determine your contacts resistance in the interface.

So, if you look at the previous equation what you look at Q=I square R t, so R is the summation of all the resistance R1+R2+R3+R4 ok in that you know R1, R3 is small compared to R4 and this can be roughly average to total resistance. So, roughly equal to R4. So, if you know the actual contact resistance R4 which can be measured experimentally. So, we can calculate amount of heat generated at the interface which is actually determined by the R4. So, I also given the natural temperature distribution along the curve along the schematic.

If you look at it the temperature is far away from the interface yeah because the electrode water cooled you expect no heating at all. So when the temperature move towards the interface the temperature increases and there is a peak at the interface between the electrode on the sheet that is actually determined by you R2 which is resistance between the interface on the electrode and then again the temperature decreases because you are the R3. It is now seats are not comparable with the R2 and R4.

And at the interface your temperature goes maximum given by the contact resistance between the interfaces ok. If this is the melting point for example at the interface it can go more than the melting point this leading to formation of melt at the interface and subsequently if you increase the time and the weld grows and either increase the time or current the weld grows and forming a weld nugged ok. So to sum up this slide so the actual system resistant is governed by 4 resistance value that I have given here.

R1 which is the resistance of electrode itself you can it is negligible because we use generally use the copper electrode. R2 is the resistance between the resistance of interface between electrode and the sheet and R3 which is resistance the bulk resistance of the sheets near welding and the R4 is the contact resistance between the two faying interfaces. In that R4 is the rate controlling factor for heat generation because that is the maximum compare to R4, R1 and R3 are negligible and because of that you know you have a maximum heat generation in the interface given by the increased resistance in the contact area between sheets ok. We will move on to the next slide.

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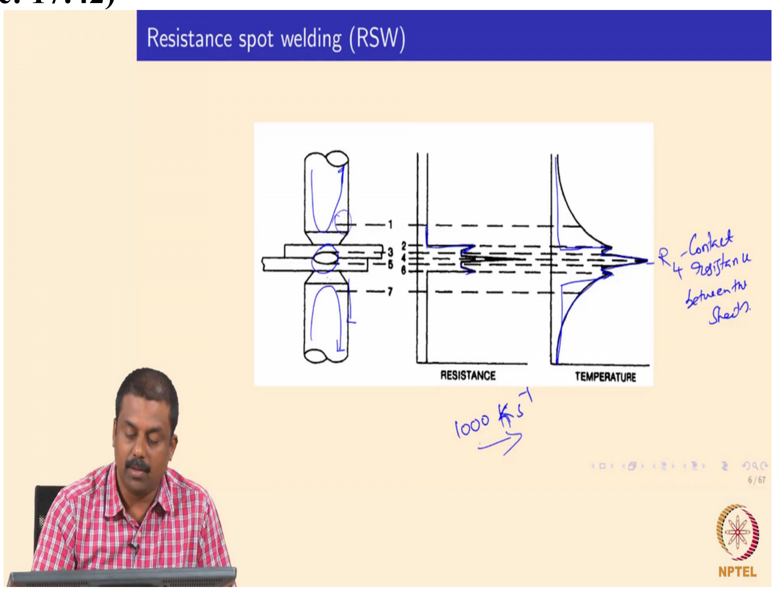

Again I just gave the schematic of the resistance and the temperature value over the cross section of the weld setup. So we are again so various numbers here one is the resistance at the area of electrode and you expect least resistance because of the copper and then interface between electrode and the sheet we have the maximum resistance increasing existence and leading to increasing temperature and if you move inside the sheets the resistance of the sheets are much lower than they interface resistance.

And you are temperature also decreases but at the interface between the two sheets your maximum resistance given by the contact resistance and the temperature increases significantly because of that and then system is symmetric right so there will be again increase in resistance at the interface between bottom electrode answer sheet. And there will be increasing resistance and increase in temperature and then if you move forward you are electrode would be related to temperature distribution.

And generally in a practical situation electrodes are not heated up because of the effective water cooling we have inside the electrode ok and due to that fact that heat is transferred in a very effective team admits that when you form a weld nugged by contact resistance of the interface and the water cooled cup electrode can extract heat extremely efficiently. So we need to make sure that the copper electrodes are cooled temperature is not increased.

So, that in real life situation is extremely sharp ok. And due to the fact that no the water cooled copper electrodes extract heat very rapidly the weld nugged that is formed during while passing the current and cools extremely fasts ok. The cooling rates all the way of the weld nugged which is actually formed at the faying interfaces can cool the; with the cooling rate as high as 1200 per second.

And it can go even higher to several 1000 killing per second as well and because of this effective cooling what we have and the copper can extract heat much more effectively rapidly as well. So, now this situation becomes extremely critical right so be the cooling rates what is not be used to over here is resistance spot welding are very rapid. So much, much more than what you need to form martensitic microstructure in advanced high strength Steel ok.

So, the microstructure of the weld nugged just because of this rapid cooling rate what we are apply during the system spot welding and leads to invariably martensitic microstructure albeit some other phases can also stabilize we will see when we look at welding metallurgy of advanced high strength Steel. But now we can say that the cooling rate what we subject the weld nuggets or in the order of few 1000 Kelvin per second and this is due to the effective water cooling water cooled copper electrodes what we actually used for welding.

So, to summarise so, the resistance at the interfaces determine the heat generation and you will have the peak temperature at the faying interfaces because of the contact resistance therefore what I explained in previous slides the contact resistance between sheets ok and the cooling rates are as high as 1000 kelvin per seconds. Because we will also make sure that the electrodes are cooled sufficiently we cannot melt the electrodes.

So we cannot heat up the electrodes. So we use water cooling channels to cool the electrodes and which can lead to effective heat extraction of the weld nugget, can lead to increasing cooling rate as high as 1000 Kelvin per second.

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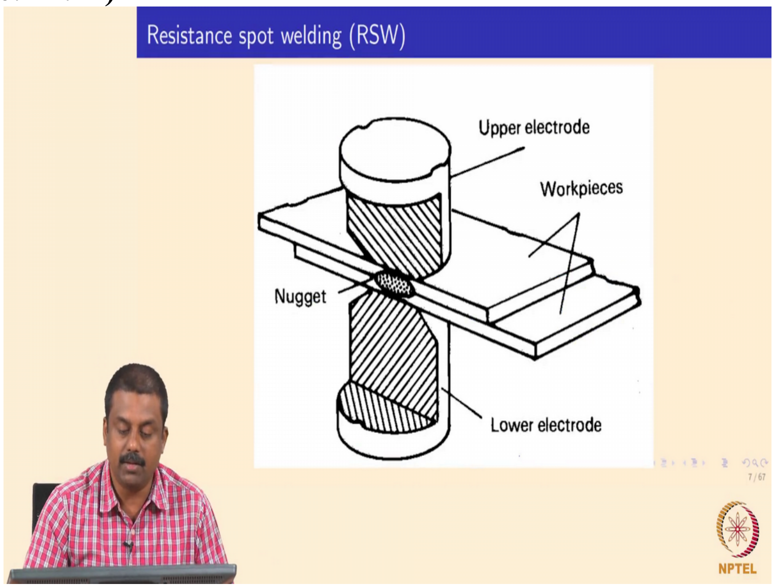

So, this is cross section view of the actual electrode on the sheet geometry this is the upper electrode and the lower electrode and this is the cross section view. Generally if you pass current ok in this direction and then we also apply some load typically current varied from say from few varied in few amperes. So roughly if you have say 1.2mm thickness plate and if you have welding 21.2 millimetre thick plate whole of configuration the amperage involved can be somewhere from 2 to 6 amperes. And similarly the loads which we are applying is also can be varied and the both the current and the load would determine the nugget geometry.

So, how the load can change because when you apply load we also change the contact area between the sheets this means right you know you will also locally change the contact resistance. Because contact resistance is determined by surface morphology the air gap between sheets so the actual contact resistance can also be varied in a way by the load you apply through the electrodes. So, we both the current as well as the lord we apply can determined your nugget formation. So, typical nugget size in the resistance spot weld elliptical.

Again that is also determined by the resistance string distribution and the deep extraction attraction again change the characteristics. Generally weld nuggets shape is elliptical what I have done over here. And it comes at the middle of the electrode in a three dimensional cross section it happens at the centre of the nuggets generally at the centre of the electrode axis. And you have a typical weld nugget in elliptical size formed and it is a three-dimensional elliptical some sort of flying saucer you can say if you look at in 3D configuration.

And if you take a cross section you see an ellipse generally you are a line axis parallel to the sheet axis and short axis perpendicular to the sheet thickness ok.

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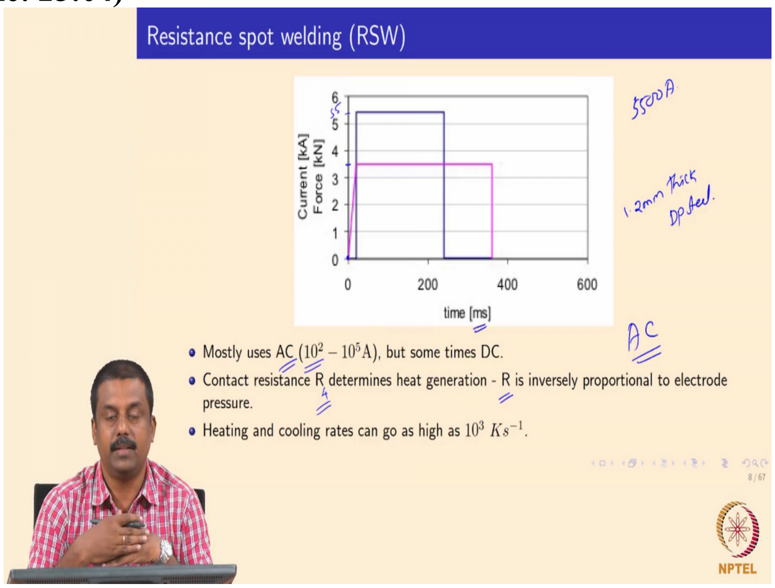

So the typical load versus current thermal cycles we apply in resistance spot welding is given in this graph. Where the blue colour shows your currents and here the purple colours shows your load axis. This is actually used to weld 1.2 mm thick DP Steel. And the current and the load can be changed based on their the size of weld nugget what we join to generate. So there are some limitations cannot keep on increasing the current because when you increase the current very high and you may also cause some explosion and we will see in next classes when you look at the weld growth curves.

So, right now you are in typical thermal cycle for welding 1.2 mm DP Steel. So we start with no current and once the plate is place between the electrodes involved configuration apply load. In this case I applied about 3.5 kilo Newton's ok. And then upon applying load we start passing the current as I applied upto 5.5 kilo amperes 5500 amperes over a very short duration ok. So, in this case after 220 milliseconds ok, so the process is extremely rapid because the entire weld thermal cycle if you look at it is completed less than 400 milliseconds.

So, that is why this process is very attractive for automotive applications because you can make weld and extremely Rapid time ok. So weld nugget if you look at it in this case it takes only 1/2 second. So, if you are make about 5000 welds you make it in few minutes. And due to this rapid welding time this resistance spot welding is very attractive in production environment and we mostly used alternative current AC current. And there is a very important reason why we prefer to use alternative current in resistance spot welding.

We see in subsequent classes why AC is preferred. The AC current is generally varied in somewhere average current in any case is in few 1000 kilo amperes. So generally it can be 2 to not more than 10 kilo amperes ok. As I have explained the contact resistance R4 which determine the heat generation the contact resistance between two sheets to faying interfaces in configuration right. R is investive preposition if you say that a proposition is higher ok. And then the R decreases that means that if you press it really hard so reduced and you also have you may induced some plasticity at the feeling interface.

So, then the resistance the surface morphology and the; your contact area becomes more coherent. So that may lead to increase in contact resistance. So as I earlier explained because of the effective heat extract extraction by the copper electrode from the faying interface the cooling rate of this process is extremely fast is extremely high. And typically the cooling rate of the weld nugget from the liquid stage is in the order of 1000 Kelvin per second ok.

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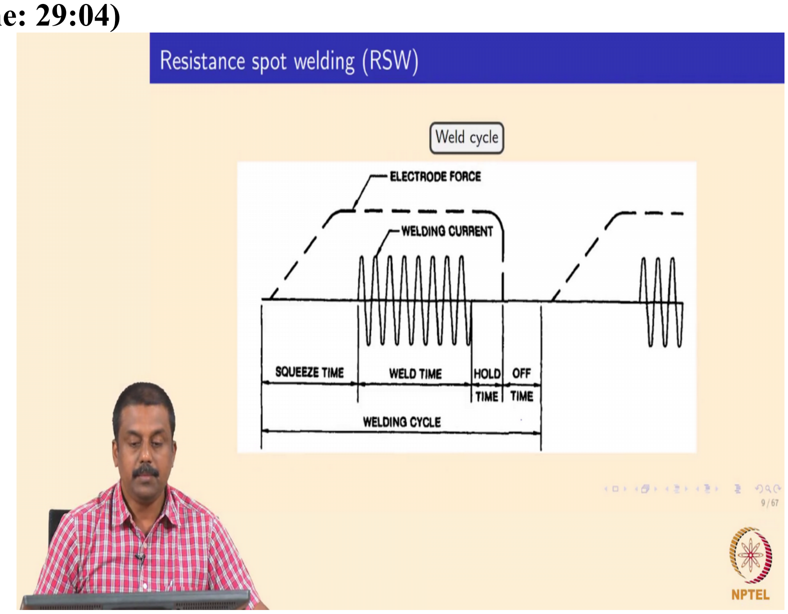

And typical current load cycle of the resistance spot welding is given in the cycle as I already explained in the previous slide in the simple line graph where we have applied load as well as current over few milliseconds schematically shown in this cycle in the slide ok. So, in a very simplified resistance spot welding cycle we have a initial scuse time where we start applying the load. In the previous case be applied load about 3.5 kilo Newton’s. So, we start applying load of say by seeing previous graph 3.5 kilo Newton’s ok.

So once you start applying finish applying 3.5 kilo Newton’s be maintained at load throughout in the weld thermal cycle and the moment you applied load there is a current. So, generally as we said we apply alternative current. We apply current over a period which is known as weld time ok. And upon applying current of previous case 3.5 kilo ampere and then we load it for some time the weld nugget will decide. During this passage of current building current we also form the weld nugget by melting the interface.

And then we upon applying current we keep it for some time so that weld nugget will solidifies and then we take it back we move to other positions and then the cycle continues and so this is a very simplified thermal cycle the RSW cycle. And this is what we shown in schematic in previous slide the weld thermal cycle can be as complex as possible because if we want to modify the solidifying microstructure we may also have to apply upward swing or various other heat treatment induced and because of the extremely rapid application of load as well as possible application of loads as well as current.

So, the entire cycle can be modified rapidly with still without compromising the productivity. That is why this process becomes very attractive we will see in subsequent slides how this modified weld thermal cycle can be subjected to in the resistance spot welding case. So, far to summarise we look that important welding process that are used in Automotive Industries and so there are three processes that are commonly used nowadays.

The first is the resistance spot welding and the laser beam welding advanced gas metal arc welding mainly to get the dissimilar. We mainly look that importance of resistance spot welding what are the process cycles the heat generation mechanism and resistance spot welding and what are the factors that control the heat generation and then we subsequently we look that RSW resistance spot welding current and load cycle in a simple way RSW cycle, thank you.