Welding Engineering
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Module - 5
Heat flow in welding
Lecture - 1
Weld Thermal Cycle

This is the fifth module on the series of lectures based on the welding engineering. And the first lecture on the, on this fifth module which is primarily based on the heat flow in welding will be focused on the weld thermal cycle. And the heat flow of the welding we will be talking about first about the heat flow in welding and thereafter we will take up the weld thermal cycle. We know that in common conventional fusion arc welding processes, the heat is applied using suitable heat source maybe the gas flame arc or resistance, electrical resistance heating principle. And whatever heat is applied the melting is ensured to, melting is ensured of the faying surfaces to get the metallic continuity in form of the weld joint.

So, in conventional arc welding processes, where the heat developed by the arc between the consumable or non-consumable electrode, and the base material is mainly used for melting the faying surfaces of the base materials in order to get the metallic continuity. So, the metallurgical characteristics, and the kind of mechanical properties which are developed by welding by the fusion arc welding particularly in the weld joint are primarily governed by the way by which here the heat flow is taking place during the welding, because the heat during the welding effects the various metallurgical reactions which dictate the kind of metallurgical transformation and the phases which will be formed in the different quantities. And because of these variations the mechanical properties are affected significantly in the weld region and in the heat effect and the heat affected zone.

That is why it is important to look into the way by which heat flow in the welding takes place and the important aspects related to related with the flow of heat in the welding which dictate the mechanical and metallurgical characteristics of the weld joint are looked into. So, the three important aspects related to the heat flow in welding are like the over the peak temperature in its distribution, in the weld region and the heat effected zone. This is one and the second one after applying the heat when the melting has taken place the weld metal starts to solidify. So, how the cooling of the weld region and the heat affected zone is taking place after the welding that is very important. Because it affects or it governs the various metallurgical reactions which takes place in the weld region and in the heat effected zone.

Similarly, the solidification rate in the weld region is also very important which is primarily dictated by the cooling rate because the solidification structure in the weld region is governed by the rate at which it solidifies. And the solidification rate decides the, what will be the size of the grains and how the shape of the grain and what are the different metallurgical reactions which will be occurring in the weld region. So, it is important to look into the heat flow in the welding from these three aspects. One, the peak temperature and its distribution away from the weld centre towards the base metal.

The cooling rate which is experienced by the different zones in the weld region and the heat affected zone. And the third the how the solidification rate is observed, what kind of solidification rate is observed during the welding in the weld region. Because it dictates the metallurgical structure formed in the weld region and which in turn affects the mechanical properties and responses to the heat of the weld joint. So, these three aspects can be looked into easily using one very important aspect related to the heat flow in welding that is in form of the weld thermal cycle.

Weld thermal cycle indicates that when heat is applied how the temperature variation of a particular region as a function of time takes place. So, this variation in temperature as a function of time of a particular location indicates many information which may be in form of heating rate, cooling rate, soaking time and the time required for reaching a particular temperature. So, we will be talking in detail about the need of going through these aspects.

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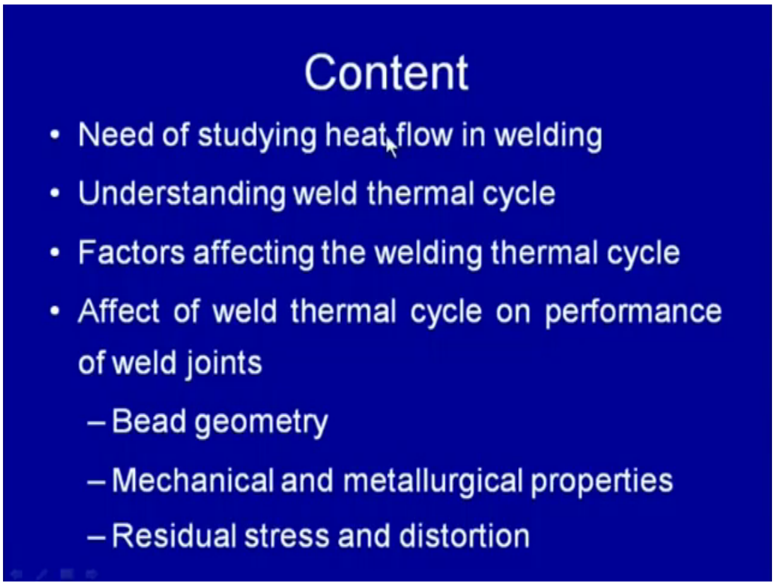

So, as far as content is concerned here the need to study the heat flow in the welding, we will be taking up first. Heat flow study is important because it affects the metallurgical transformations in the weld region and the heat effected zone which in turn affect the mechanical properties of the weld joints. And that is why it is important to go through and to understand the kind of a heat flow which takes place in the weld region and the heat affected zone. The second is the weld thermal cycle.

We need to understand how the weld thermal cycle is developed of a particular location and what are the important aspects or the parameters which can be obtained from the weld thermal cycle. And these parameters significantly affect the heat affected zone, the kind of metallurgical properties which can be obtained in the weld region and in the heat and in the weld region. And the, another then we will, we will be looking into the factors that affect the weld thermal cycle which indicates the variation in temperature as a function of time of a particular location.

So, the various factors like the heat input, preheat temperature and the thermal properties of the base material will be considered while looking into the factors affecting the weld thermal cycle. And then effect of the weld thermal cycle and the performance of the weld joint will also be seen in terms of the weld bead geometry like the cooling rate is slow then what kind of the bead will be formed, if the cooling rate is high then how the mechanical properties and metallurgical properties will be affected. And so with the variation in temperature as a function of time whether the rate of heating is high or rate of heating is slow the soaking temperature is high for longer time or it is low for shorter period or the cooling rate is low or it is very high.

Then, so these things will be affecting to the way by which the bead geometry will be developing, the mechanical and metallurgical characteristics that will be developed in the weld region and in the heat affected zone. And similarly, it will also be affecting the kind of residual stresses which will be developed in the weld region and the heat affected zone. And the development of the residual stresses lead to the many undesirable effects in form of the distortion and the change in a mechanical properties.

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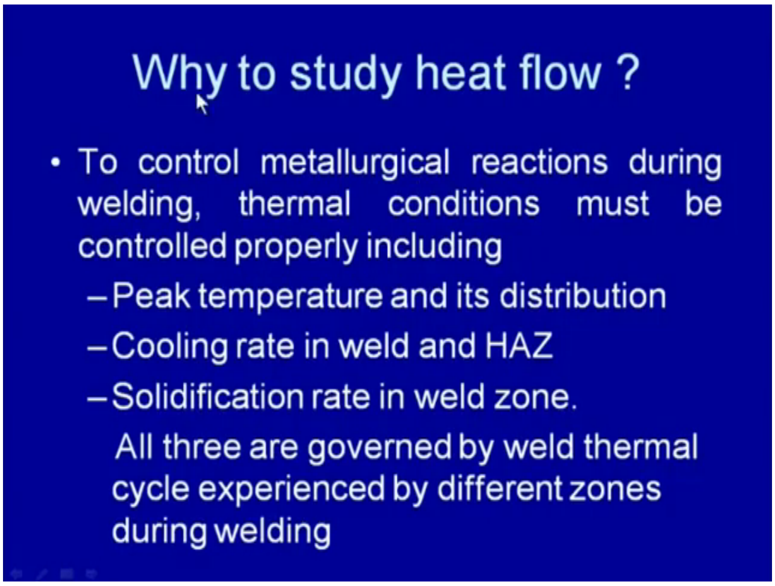

So, these things, some of these things will be covered in this presentation. We will be taking up first the need why to study the heat flow. We know that there to control the metallurgical reactions which are, which usually take place in the weld region under the heat and in the heat affected zone. Thermal conditions must be controlled carefully, so that we can have the proper peak temperature these, because these thermal conditions significantly dictate the metallurgical reactions which will be taking place in the weld region under heat affected zone.

These reactions effect the mechanical properties and that is why it is necessary to have proper control over the thermal conditions which we maybe in form of the peak temperature and the way it is distributed away from the weld region. And the cooling rate in the weld region and in the heat affected zone and the solidification rate in the weld zone. These are the three important things related with the heat flow which must be looked into to have the better control over the metallurgical reactions in the weld and heat affected zone, so that the desired combination of the mechanical properties can be obtained for a longer performance of the weld joint.

The all three, all these three aspects are governed by the weld thermal cycle which is experienced by the different zones during the welding and that is why we will be taking up first the weld thermal cycle.

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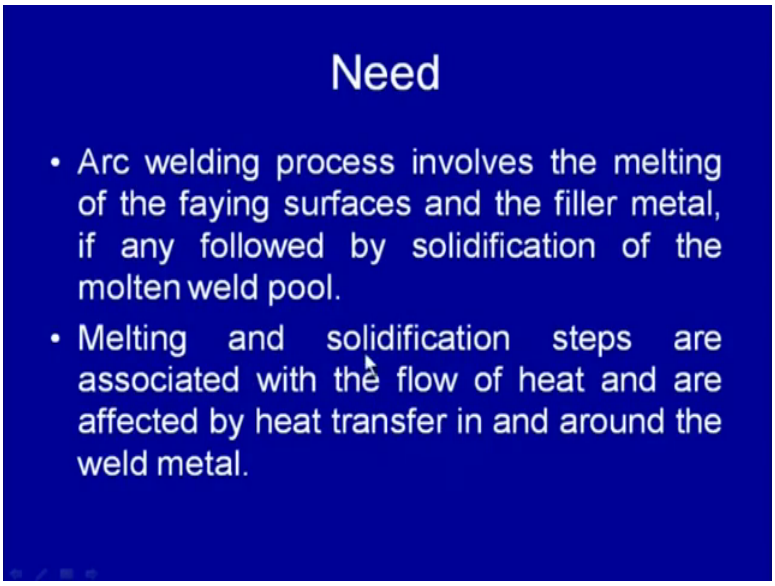

We know that arc welding processes involve the melting of the faying surfaces and the melting of the filler material and if, and it, and thereafter the solidification of the weld metal takes place. So, melting and the solidification steps are associated with the flow of the heat and are affected by the heat transfer in and around the weld metal. Means in the arc welding processes we first apply heat for melting to take place, so that the melting of the faying surfaces occur at the same time, filler metal can also melt if it is being used and once the base material and filler material are brought to the molten state solidification starts.

So, this melting as well as the solidification steps are associated with the flow of heat. The heat, the rate at which heat is being applied that effects the time required for melting as well as the amount of the material in the base material which is brought to the molten state is affected by the rate at which it is applied. And the rate at which heat is extracted effects the time required for solidification or indirectly the solidification rate. So, therefore, it becomes important to see that at what rate heat is being applied and at what rate it is being extracted after the application and melting has taken place. Not only the properties in the weld metal are affected by the rate of the heat extraction that is rate of heat flow occurring from the weld zone.

But it also heat transfer around the weld region also effects the mechanical properties and metallurgical properties because many metallurgical reactions in the heat affected zone are governed by the cooling rate experienced by the material present around the weld metal that is the heat effected zone.

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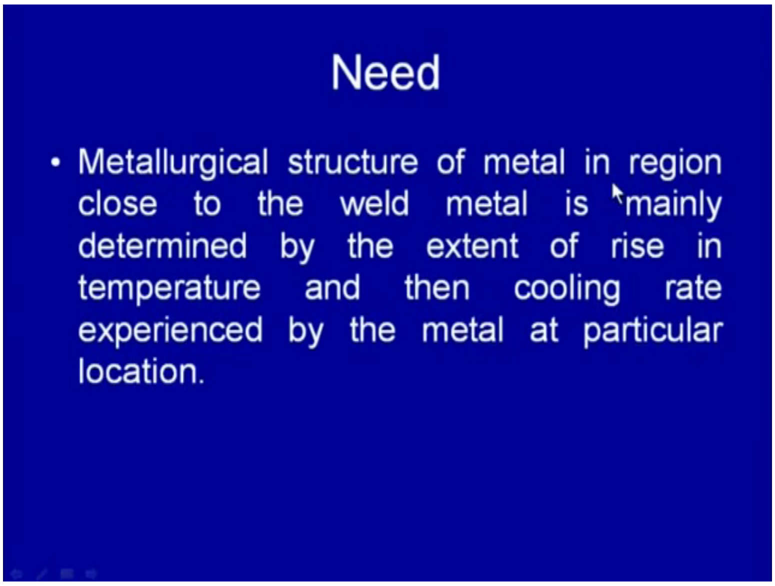

So, the metallurgical structure of the metal in a particular region close to the weld metal… So, this region is the heat effected zone is mainly determined by the extent up to which temperature rise takes place and then cooling rate experienced by the material at a particular location. So, we know that the material near the fusion boundary is subjected to the higher temperature. So, depending upon the type of metal system the higher temperature, the peak temperature up to which the properties are affected for a given material will be falling in the zone which is affected by the heat.

So, for the materials like the carbon steel or plain carbon steel all the regions away from the fusion boundary which are heated above 730 degree centigrade will be falling in the area which will be affected by the application of heat during the welding. And so it will be falling in the heat affected zone. Similarly, if the steel is hardened, quenched and tampered at 300 degree centigrade, so all the regions away from the fusion boundary which are heated above 300 degree centigrade will be falling in the region which will be affected by the application of heat.

So, that will be termed as the heat affected zone. So, all the regions where metallurgical change or the mechanical or the changes in mechanical properties are experienced in the region close to the weld metal due to the application of the heat will be falling in the heat affected zone. And this extent of effect will depend upon the kind of temperature rise which will be occurring in that region. So and thereafter, how the cooling rate and what kind of cooling rate is experienced by the metal which is falling in the heat affected zone will also be affecting to the mechanical properties. To understand this we will, we will see one diagram.

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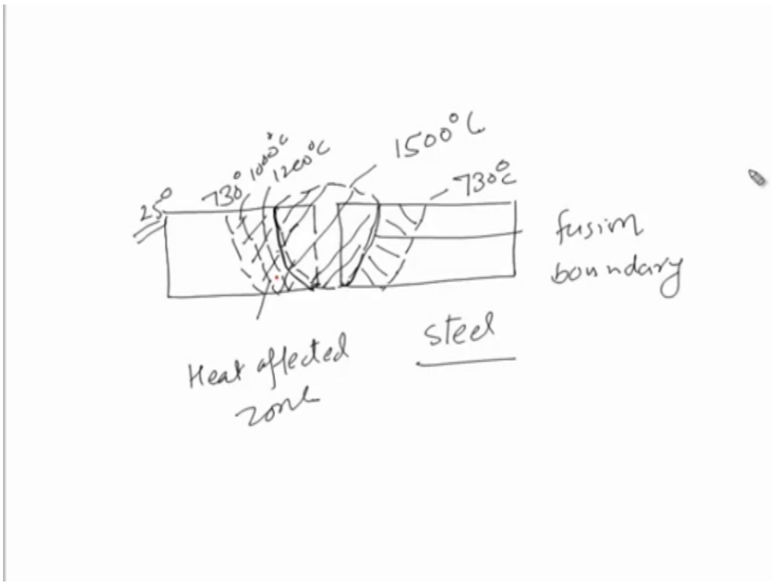

This is the base material before welding. Say, for the square butt joint. On the application of heat the melting has taken place like this and the joint is formed. So, this is the weld area which is formed by melting of the faying surfaces of the base material. So, if this is the case of steel then temperature of the weld region will be say above the 50 in 100 degree centigrade, but there will be the other regions close to this fusion boundary, we can say this is a fusion boundary. So, the regions close to the fusion boundary both the side, in both the side of the weld will be affected, will be heated to the temperature greater than 730 degree centigrade for simple carbon steel.

All the regions heated above the 730 degree centigrade will be falling in the region which will be affected by the heat metallurgically and mechanically. So, this region will be termed as heat affected zone. This will be termed as heat affected zone. So, the peak temperature… We will be, we know that the at the fusion boundary the temperature is corresponding with the melting point of the steel that is say about 1500 degree centigrade and in the weld metal zone the temperature will be higher than 1500 degree centigrade.

As we will be moving away from the fusion boundary temperature will be decreasing and at too far away temperature will be say environment corresponding to the ambient conditions 25 degree centigrade. So, there will be various zones having the different temperatures say one is 1200 degree, another is 1000 degree centigrade. So, due to the difference in these temperature values, peak temperature values all the regions will be subjected to the different kind of the metallurgical reactions. And the different kind of the micro structural properties will be obtained.

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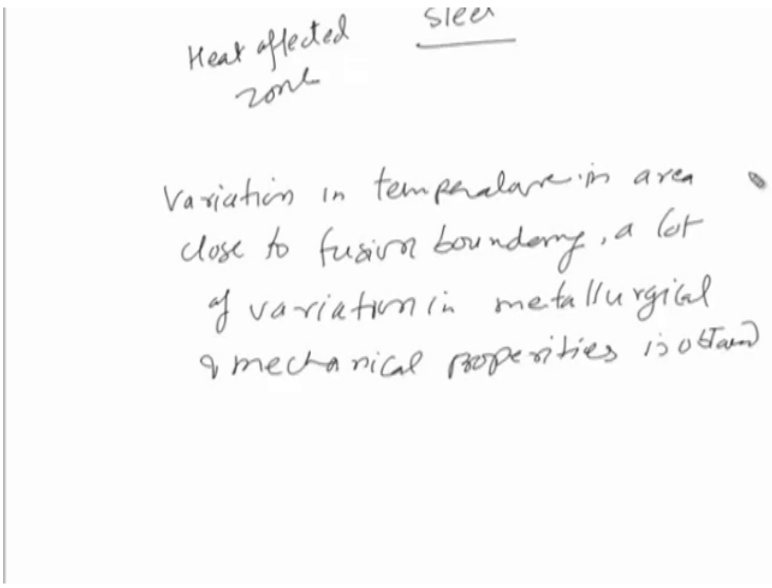

So, because of variation in temperature basically, variation in temperature in area close to fusion boundary lot of variation in metallurgical and mechanical properties is obtained. So, the peak temperature of particular location and the cooling rate which is experienced by the material in that location directly affects the metallurgical reactions and the mechanical properties of that particular location.

So, it is important to see that what is the peak temperature of particular location, how the cooling rate is taking place, what kind of cooling rate is being experienced by the material in that region to understand the way by which the application of the heat which will be affecting to the mechanical properties of the heat affected zone. Similarly, the properties in the weld region are also affected by the cooling rate as well as solidification rate experienced by the weld metal during the welding.

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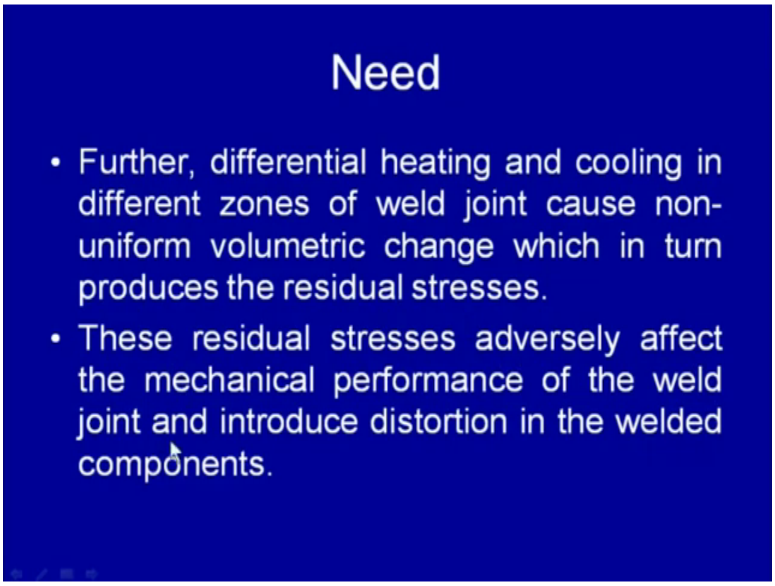

So, further during the welding we know that all the regions close to the fusion boundary are not subjected to the equal temperature. And because of this the rate of the heating and the rate of cooling experienced by the different zones become different. Areas very close to the fusion boundary will be subjected to the high rate of heating and the high rate of cooling. At the same time those which are located away will be subjected to the heating at slower rate and the cooling at the slower rate. So, because of the differential heating and the cooling to the different temperatures at and subjected to the different rate of the heating and cooling; this in turn causes the non uniform volumetric change in the different zones.

This non uniform volumetric change in the different zones leads to the development of the residual stresses which is one of the important aspect in the welding of the metal systems which are very specially sensitive to the external stresses. Especially under the tension conditions like under the fatigue loading conditions. So, these residual stresses adversely affect the mechanical performance of the weld joint and introduce the distortion in the weld, welded joint if the proper care is not taken.

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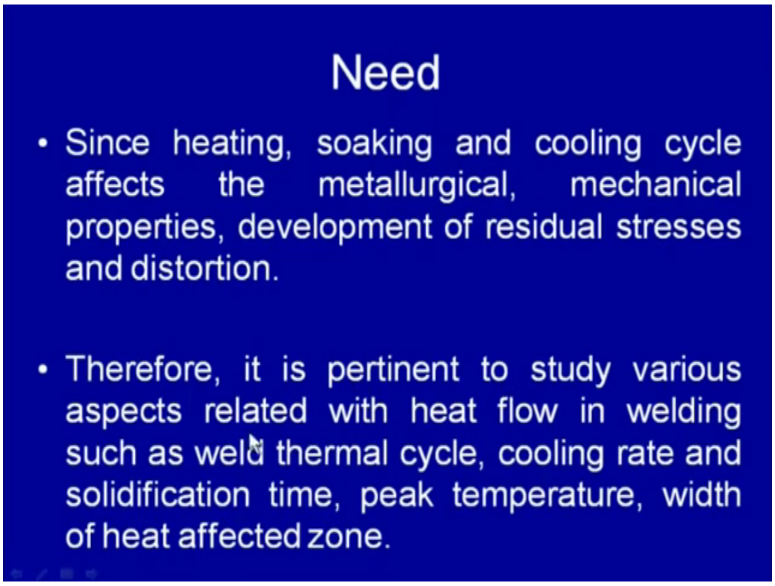

Since, the heating, soaking and the cooling cycles affect the metallurgical and the mechanical properties and also affects the development of the residual stresses, that is why it is important to look into the way by which the heating takes place, how the material is held at high temperature for different durations and what kind of the cooling cycle is experienced during the welding. Therefore, it is pertinent to study the various aspects related to the heat flow in welding like weld thermal cycle, cooling rate, solidification time, peak temperature and the width of heat affected zone. If we, now we will be look, looking into the details of the weld thermal cycle.

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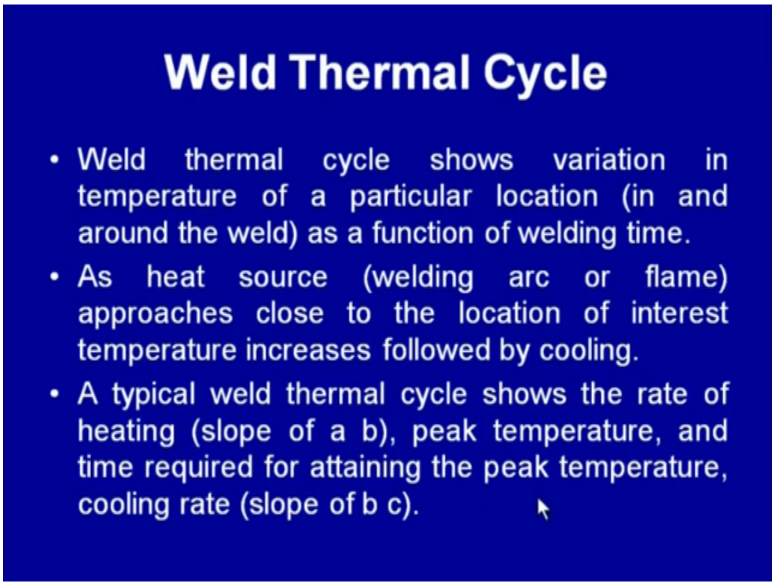

Weld thermal cycle is nothing but it shows the variation in temperature of a particular location in and around the weld, both. Whether the point is located close to the fusion boundary or within the fusion boundary means in the, in the weld region. So, the temperature variation as a function of time of a particular location is termed as the weld thermal cycle or when it is graphically represented with the y axis, with the temperature in y axis and the time in x axis we get the weld thermal cycle, so which will be showing the variation in temperature of a particular location as a function of time.

So, we know that the heat source is normally moved during the welding to join the entire length of the component. So, as the heat source is moved close to a particular location which is being considered to look into the weld thermal cycle of that particular location. So, that will be termed as the location of the interest. So, as the heat source approaches towards the point of the interest or towards the location of the interest; the temperature increases followed by the cooling.

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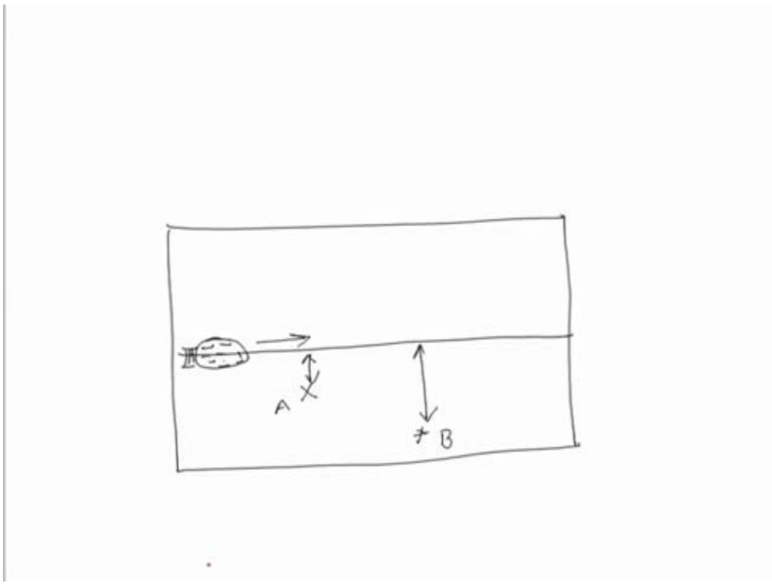

So, it means that what we are trying to say here we will see in another diagram. You say this is the top view of the two plates to be welded and they are in butting position with each other. This is the source of the heat, this is the welded portion this side and here this is the weld pool indicating the position of arc or of the flame. So, if this is the position of arc, so gradually we will be moving towards to cover the entire length of the weld. If our point of interest is A or point of interest is B, which is these are the two points of the interest, which are located at different distances from the weld centre line. One is close to the weld centre and another is slightly away from the weld centre. So, when the heat source is moved during the welding and if and when it approaches towards the point of interest then there will be continuous increase in temperature.

So, if we plot the weld thermal cycle as a function of time for point A. So, here we have time in seconds, it may be and here it is temperature. This is a schematic diagram. So, the weld thermal cycle for point A which is close to the fusion boundary as the heat source move is towards the point A and it approaches towards the point A or the location A which is close to the fusion boundary, there will be continuous increase in temperature. And this increase will continue until the heat source goes past the point of interest. As soon as it starts moving away from the point of interest, temperature will start coming down and then the cooling of the point A will start.

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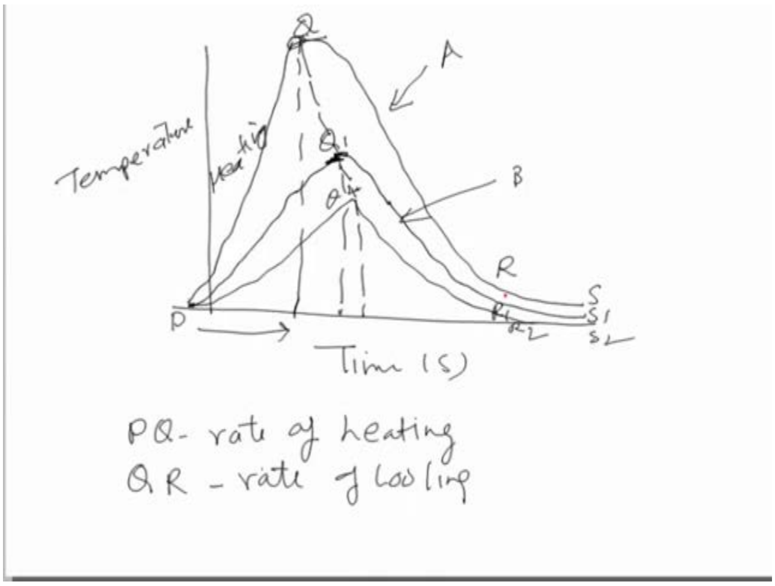

So, this is what we say the rate of heating the… the increase in temperature of a particular location when the heat source come closer to it. And as it comes closer to it there will be continuous increase in temperature. So, the, this, the slope of this heating phase, this is corresponding to the heating phase. This is the region where say we can write P Q R and S. So, in the, in the initial phase when the heat source move is, comes or approaches closer to the point of interest, the heating, there will be continuous rise in temperature during the heating phase.

This will continue in the portion P and Q. So, this is the heating phase and the slope of this line P Q will indicate. So, P Q will indicate the rate of, slope of this line will indicate the rate of heating. And then once the heat source passed means passes through the point of interest and it starts going away from the point of interest cooling starts. So, the cooling will be occurring during the portion Q R, this, the slope of this Q R will indicate the rate of cooling. This is say for the, for this weld thermal cycle is say for the location A.

So, the slope of the P Q and the slope of the Q R will indicate the heating rate and the cooling rate respectively. If we say, if we take another point which is located slightly away from the weld centre line and then for this case as the heat source approaches towards this point, we will see there will be continuous increase in temperature. But the rate of heating will be slow. That will be indicated by the somewhat this lesser slope or the smaller slope of the heating phase. So, this is say indicated by the second line. Now, the, once the heat source after approaching towards the location B, it passes away from it then cooling starts and then during the cooling phase temperature starts, will, temperature will be decreasing. So, this is P Q R S then you can say P Q 1 R 1 and S 1.

So, in the portion, in the starting the temperature is same of all the locations. So, for the location B temperature is same, at the point P and but since it is located away from the weld centre, as the heat source approaches towards this location there will be heating of this location. There will be continuous rise in temperature, but at the slower rate. That rate will be given by the P Q 1 and after being at this temperature for a short while it, temperature starts coming down. So, during the Q, Q 1 R 1 will be indicating the cooling rate being experienced by the, cooling rate experienced by the point located at the B location.

So, say if we compare these two, these two weld thermal cycles for that two locations we can see the weld thermal cycle means the temperature as a function of time is different for the different locations. The point which is very close to the fusion boundary or the weld centre line is subjected to the high rate of heating and then subjected to higher rate of cooling. And the peak temperature is also high as compared to the location if we see the weld thermal cycle of the location B that is this. The rate of heating is lower if the point is located away from the fusion boundary or the weld centre and then heating, cooling rate is also slower.

Cooling rate is also low for the point which is located away from… And the peak temperature experienced by the location B is also on the lower side. If we take another point further away then it will be further experiencing slower rates and heat, rate of heating and rate of cooling. So, if we plot say this one is a P Q 2 like R 2 S 2 like this. So, the peak temperature will be decreasing as we are moving away from the fusion boundary say for the location C.

So, one thing is clear that with the location where the point of interest is located away from the fusion boundary for the weld centre that directly effects the weld thermal cycle being experienced by that particular location. If the point is located very close to the fusion boundary or the weld centre then it will be subjected to the very high rate of the heating and the cooling and the high peak temperature. And as we move away from the weld centre then the rate of heating as well as cooling experienced by the, by the point of interest will be on the lower side. At the same time peak temperature which is experienced by that particular location will also be reduced.

There is another dimension that we can look into this diagram that is, that as we move away from the fusion boundary or the weld centre line the time required to attain the peak temperature also increases. The time attained to peak temperature is this much for the location A which is shorter than the time required to reach the peak temperature for location B and further higher for the location C. So, these are the few important points that we can understand from the weld thermal cycle during the welding that the weld thermal cycle of a particular point is directly governed by its location. Each location will have its own weld thermal cycle and the rate of heating and cooling and the peak temperature all will be on the higher side for the points or the locations which are closer to the fusion boundary, all the weld centre.

The locations which are away from the fusion boundary they will be subjected to the lower rate of heating, lower rate of cooling and the peak temperature will also be there on the lower side. But when and one more thing that if the point, when the points of the interest are located close to the weld centre or the fusion boundary then they will take the lesser time to reach the peak temperature. They will take longer time to reach the peak temperature when the point of interest is located from the, located away from the fusion boundary.

So, this is the jest of the weld, a thermal cycle which will indicate the rate of heating, peak temperature and the cooling rate experienced by the material at a particular location. One additional point that we have not touched so far that is the soak temperature and the soak time. A soak temperature is the temperature at which the properties of the material are affected by the temperature and by its holding at that particular temperature. So, any temperature can be considered as soak temperature and the time at, of exposure at that temperature will be considered as a soaking time.

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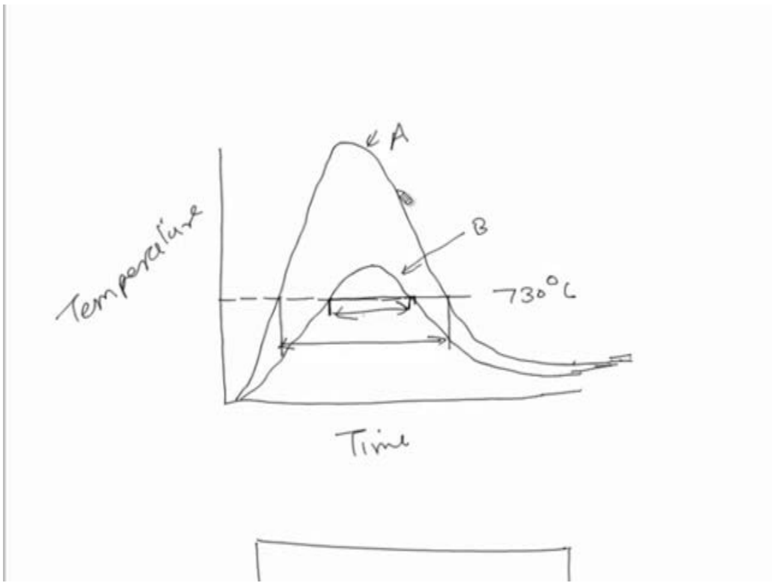

So, if we take up the temperature of any interest say, we will take up another. So, if we take this diagram showing the weld thermal cycle of the two different locations, in the x axis we have time and in y axis we have temperature. So, for location which is close to the fusion boundary will be subjected to the very high rate of heating and cooling, while those locations which are away from the weld centre will be subjected to somewhat lower rate of heating and cooling. After long time the rate of cooling will start, will tend to stabilize and the rate of cooling will be almost same for all.

The curve tend to become flat under the… The material temperature will tend to reach to the ambient condition. If we have to see the soaking time say for this steel having the temperature, critical temperature for steel is say 730 degree centigrade. So, the temperature of exposure at in the, means time of exposure at this temperature will matter a lot for the steel. So, if you have to consider soaking time then the time of exposure above this temperature of the steel will be important.

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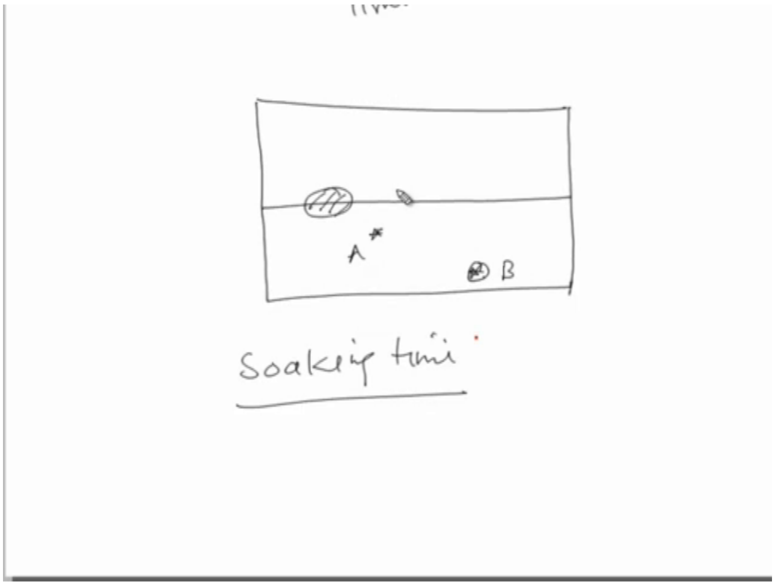

So, if we say take the weld thermal cycle corresponding to the point which is close. This is weld pool zone, this is point A and this is point B. So, weld thermal cycle for point A is this and weld thermal cycle say for point B is this. So, the exposure time for, exposure time or the soaking time for the point B will be this much which is shorter than the exposure time of the point A at the same temperature that is this. So, the time for which a particular location is exposed to a particular temperature that is termed as soaking time. Soaking time is important especially in welding because it effects the metallurgical reactions.

The kind of the end phases which are formed after the welding from the metallurgical point of view and that is why and so if we consider the soaking time is longer for the points, which are located close to the fusion boundary as compared to the case when the point, when which are located away from the fusion boundary or the weld centre. So, the locations which are away from that fusion boundary or the weld centre they will be subjected to the shorter soaking period as compared to that of the locations which are close to the fusion boundary or the weld centre line.

So, this is what we had started with as the heat source during the welding as the heat source approaches close to the location of the interest, temperature increases followed by cooling. A typical weld thermal cycle shows the rate of the heating during one phase that is fast phase that will, in diagram that will be shown in the next slide, peak temperature.

The time required for attaining the peak temperature and the cooling rate. That will be coming from the slope of the diagram.

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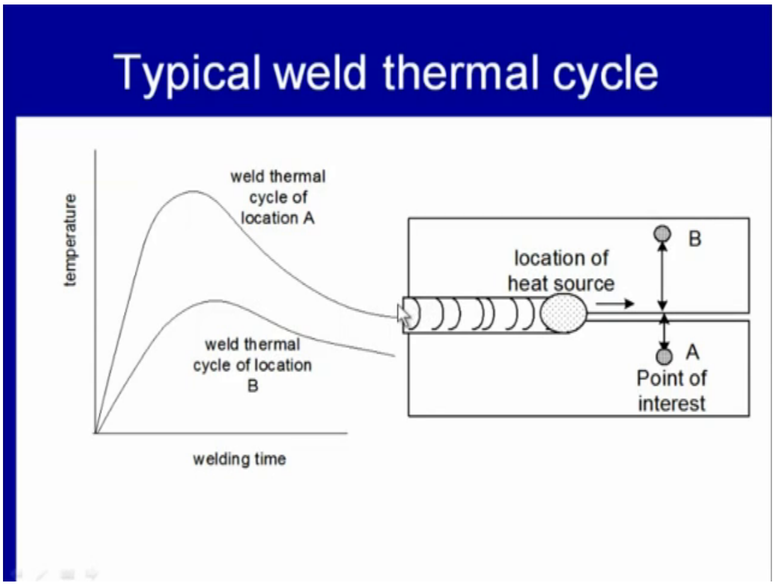

So, here this is the same what has been explained. The two sheets to be welded, this is the line along which welding is to be done. This is the location of the arc and this is the location where joint has been made. If we consider the two points which are located one close to the, means the point of interest close to the fusion boundary and away from the fusion boundary or the weld centre. So, if we draw the weld thermal cycle corresponding to these two locations, the point of interest located close to the weld centre subjected to the weld thermal cycle of this kind where heating rate is high, peak temperature is also high and the cooling rate is also high, higher as compared to the weld thermal cycle being experienced by the location B.

So, this is how we can say… So, here in the first phase this zone indicates the rate of heating, slope of this line, this is the heating phase and this is the cooling phase. So, the first phase slope of this line indicates the heating rate and slope of this line indicates the cooling rate. We can see that the slope of this line is continuously changing which is suggesting that the rate of cooling is also changing continuously. Initially it is at higher temperature cooling is high and then slope will keep on decreasing.

So, as the time passes the rate of cooling also keeps on decreasing as far as weld thermal cycle of particular location is concerned. The same thing happens at the other locations also. Since, the distance of the point of interest away from the weld centre directly affects all parameters shown in the weld thermal cycle. Therefore, each location or the each point offers the different and unique weld thermal cycle. That must be taken care of and should be understood properly to control the metallurgical properties and mechanical properties of the weld joint. In general an increase in distance from the weld centre line results in certain effects in terms of…

With the increase in distance from the weld centre line the decrease in peak temperature is observed. The decrease in rate of heating and the cooling is also observed after attaining the peak temperature with the increase in distance also the time required to attain the peak temperature increases. With the increasing distance also decreases the rate of cooling with the increase of time. Means with the increase of distance the heating and cooling rate decreases, peak temperature decreases and as with the increase of temperature also the decrease in cooling rate is experienced at a particular location.

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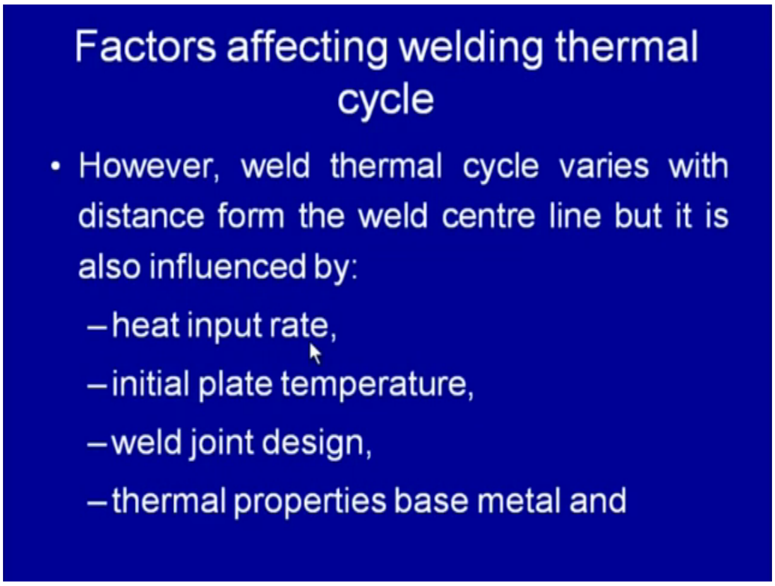

However, weld thermal cycle varies with the distance from the weld centre line, but at the same is also affected by the heat input rate. So, keeping the location of interest same if we vary the heat input rate, if we varied the initial plate temperature, if we change the joint design and if we change thermal properties of the base material then the weld thermal cycle experienced by that particular location will also be affected. So, the parameters that significantly dictate the heat or the weld thermal cycle of particular location or the heat input rate, initial plate temperature, weld joint design and thermal properties.

These points will be taken up one by one regarding their effect on the weld thermal cycle of that particular location. In general we can describe all these points in the way that an increase in heat input increases; increase in rate of heat input increases the rate of heating of the particular location. It increases the peak temperature also and it increases the cooling rate also. Now, initial plate temperature, when we increase the initial plate temperature it increases the peak temperature. It reduces the cooling rate. Weld joint design as far as thickness is concerned increase in the…

Means increase in thickness of the plate leads to the higher, the lower rate of the heating and the higher rate of the cooling at the same time the peak temperature of particular location is also reduced. Soaking time is also reduced as… The cooling rate as a function of time is also decreased. The weld thermals; thermal means thermal properties of the base material like thermal conductivity and the specific heat. The metal systems which of the higher thermal conductivity they will be leading to the lower rate of the heating, the lower peak temperatures and the high rate of the cooling as compared to the metal systems which are of the lower thermal conductivity.

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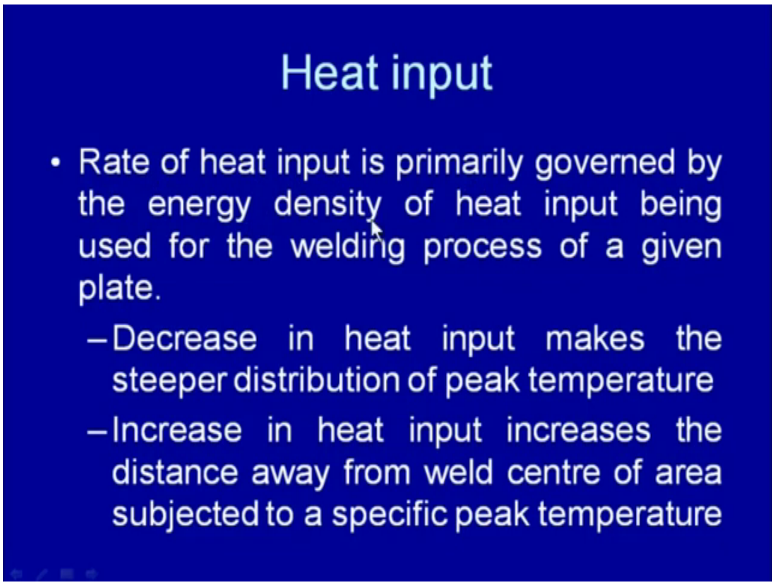

Because of this it is found difficult to melt the high thermal conductivity materials like copper and the aluminium using the conventional processes. So, we will be taking up one by one to look into the effect of the different parameters on the weld thermal cycle even of a particular location.

The rate of the heat input is primarily governed by the energy density of the heat source being used for the welding purpose. A decrease in heat input makes the steeper distribution of the peak temperature. So, if we like say, if we use the high energy density processes then the amount of the heat input is reduced to bring the faying surfaces of the butt, base material in the molten state. The reduction of the heat input will be leading to the decrease; means reduction in heat input will be causing the steeper temperature distribution.

Means the peak temperature will be of the different locations will be decreasing fast and increase in heat input increases the distance away from the weld centre of the area subjected to the specific peak temperature. Means, if we increase the heat input then the distance up to which the material is subjected to a particular temperature that increases. So, means with the increase in the heat input, the material is heated to a particular temperature to the, up to the greater distances. So, indirectly we can say that increase in heat input increases the distance up to which the material is affected by the heat application.

So, we can say the width of the heat effected zone increases with the increase in heat input. For a given preheat conditions, increase in heat input increases the soaking time at a high temperature and decreases the cooling rate. So, if the heat input is increased under the identical conditions of the preheating, the high temperature means the soaking time they stay off the material at the high temperature, at a particular high temperature that will be increasing at the same time it will be decreasing the cooling rate. So, one thing is simple that under the identical preheat conditions of the base material increase in heat input decreases the cooling rate and which in turn affects the metallurgical properties of the heat affected zone significantly.

For a given heat input if we increase the preheat temperature, if we increase in preheating decreases the cooling rate. And but it does not affect the soaking time appreciably. Means, for a given level of the heat input if we increase the preheat temperature then it decreases the cooling rate, but it does not affect the soaking time appreciably. So, as well as the welding process is concerned, effect of the welding process is concerned that we have to look into in terms of the energy density of the process. We know that the high energy density process will be supplying lesser heat to bring the material to the molten state. So, there will be, will be falling in the category of the low heat input processes.

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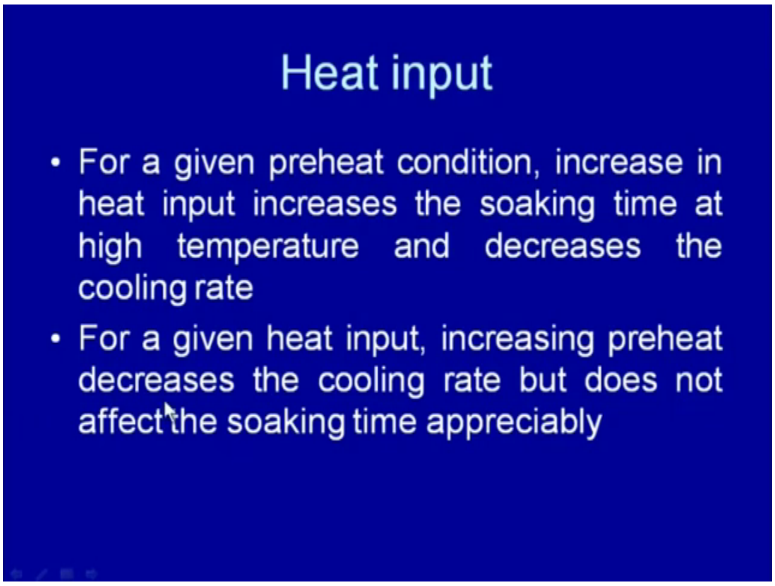

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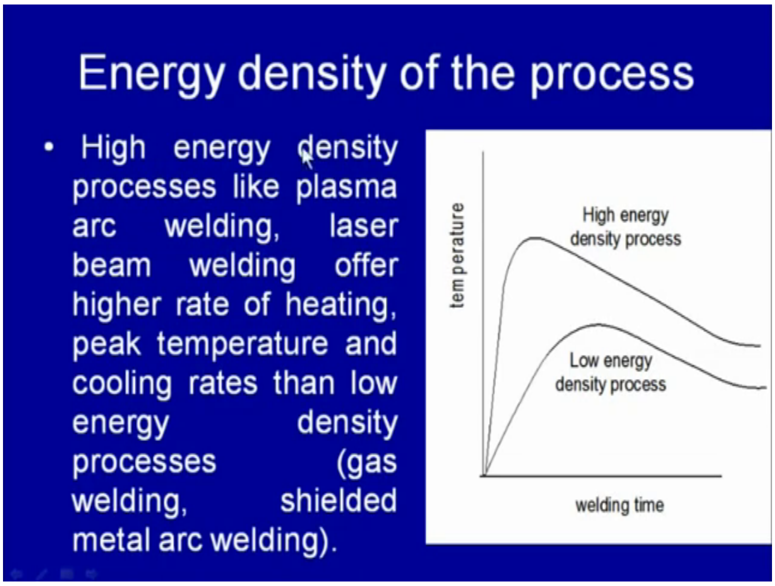

So, the high energy density processes like plasma, laser, electron laser beam offer the high rate of the heating. And so the high peak temperature and the higher cooling rate as compared to the low energy density processes. In case we know that the high energy density processes will be supplying lesser heat. So, the higher rate of the heating and the high rate of the cooling is observed because these processes will be supplying very less heat and the less heat input leads to the higher cooling rate.

At the same time the heat will not be able to get dissipated away from the faying surfaces or the fusion boundary to the base material because of the rapid application of the heat, required amount of heat for melting the faying surfaces. So, if we see the weld thermal cycle of the same material system using the two different processes low energy density process will be causing the high rate of heating, higher peak temperature and the higher cooling rate as compared to the low energy density processes like the gas welding, shielded metal arc welding.

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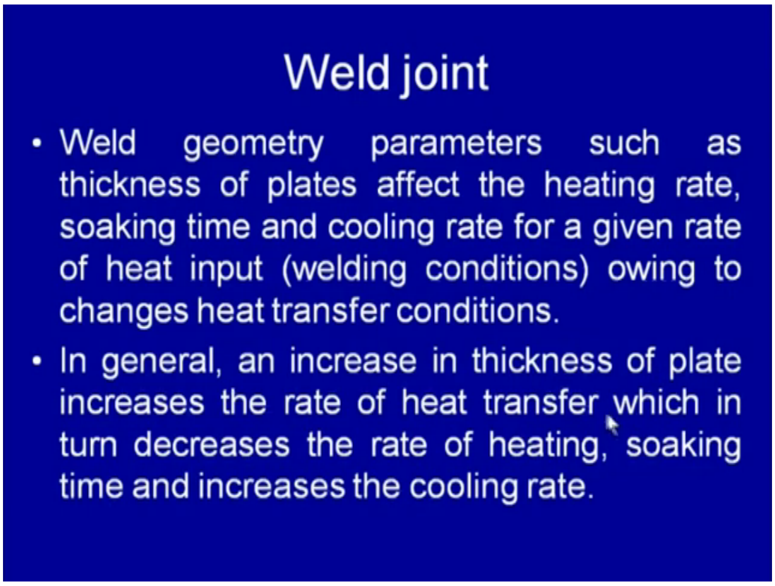

They will be causing the lower heating rate, lower peak temperature and the lower cooling rate as compared to that of, for a particular location. So, the welding process effects the weld thermal cycle of particular location for a given metal system because of, mainly because of the kind of heat input which is being supplied during the welding. And this heat input difference is observed because of the difference in the energy density associated with that particular process. Weld joint effects the weld thermal cycle mainly in the way by which the heat is heat flow away from the weld area is affected. So, if we see the weld geometry parameters such as the thickness of the plate, effect the heating rate the soaking time and the cooling rate.

We know that with the application of heat it in case of thick plates heat will be extracted and transferred away from the faying surfaces rapidly. So, the heating rate will be low, soaking time will also be low and the cooling rate will be high if the thickness of the plate is more. So, the cooling rate for a given heat input conditions. So, thickness of the plate directly effects the heating rate, soaking time and the cooling rate for the given heat input conditions during the welding. In general increase in thickness of the plate increases the rate of heat transfer away from the fusion boundary and the faying surfaces which in turn decreases the rate of heating, soaking time and increases the cooling rate.

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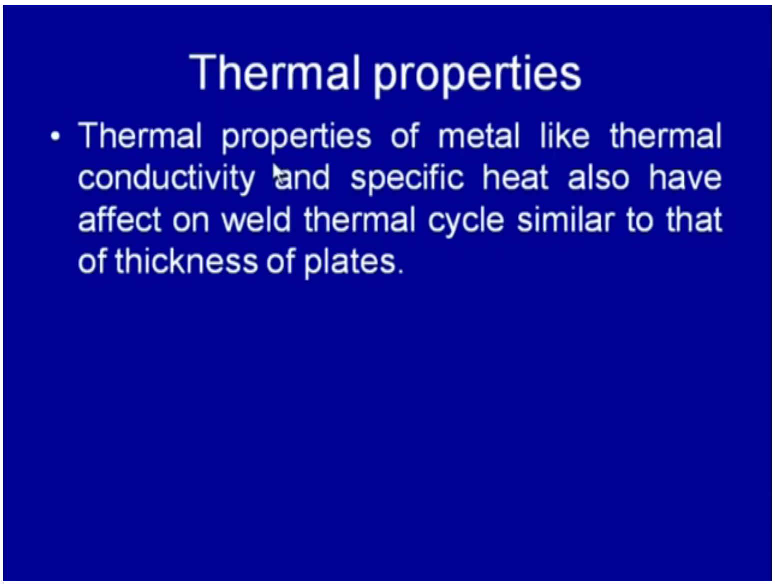

Now, thermal properties as I have said the thermal conductivity in a specific heat affect the weld thermal cycle directly. So, the metal systems which are of high thermal conductivity, they will be extracting the heat rapidly from the faying surfaces. So, will be decreasing the rate of heating, soaking time, but they will be increasing the cooling rate. And because of this many times it is observed that welding of the high thermal conductivity material becomes difficult.

Now, we will see the, another parameter that effect the weld thermal cycle significantly, that is preheat or the initial temperature of the base material during the welding. We know that increase in, reduction in preheat increases the temperature gradient means either we use low preheat temperature or no preheat then this will be resulting in the high temperature gradient.

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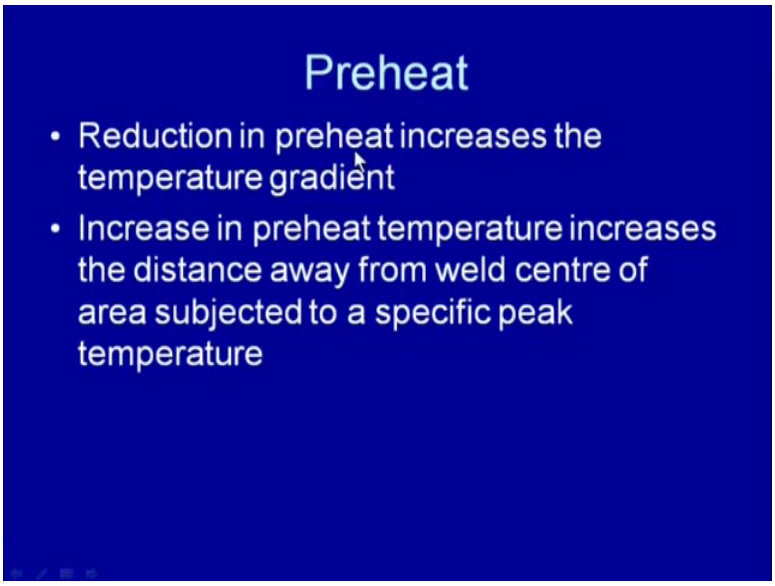

So, the temperature gradient reduces with the increase of preheat which in turn decreases the rate of cooling and because of this reduced temperature gradient many problems are reduced in terms of the distortion, residual stresses and those which are related with the sharp temperature gradient. Further, increase in temperature, preheat temperature increases the distance away from the weld centre of the area which is subjected to the peak temperature. So, if a material is preheated then the distance up to which material will be subjected to the high temperature or to a particular temperature that distance will increase.

Means, the increase in preheat will be increasing the width of the zone which will be affected by the application of heat. So, means the heat affected zone is affected, width of the heat affected zone basically increases with the increase of preheat temperature. So, if we have to see the effect of the preheat temperature and preheating of the plate reduces the rate of heating and it reduces the rate of cooling also. The reduction in the rate of heating is experienced because of the reduced rate of the heat transfer away from the faying surfaces on which heat is applied.

Because of this heat is, means the rate of heating is reduced and heat is not extracted rapidly from the faying surfaces and because of this the cooling rate is also reduced. Application of the preheat, the peak temperature of particular location increases and this also increases the soaking time or the exposure of the material above a certain temperature which can adversely affect the material properties to the great extent. So, the preheating of the plate must be done carefully, so that the desired kind of metallurgical properties can be obtained without adversely affecting the mechanical performance of the weld joint.

Now, we will see the some effect of the weld thermal cycle on the metallurgical and mechanical properties of the weld joint. Peak temperature, we know that close to the weld fusion boundary decides the width of the heat affected zone. The heating and the cooling rate effects the micro structure of the weld metal and the heat affected zone. Therefore, weld thermal cycle of the each point becomes of the great interest in the, especially in case of the structure sensitive metals like cast iron. So, structure sensitive metals are all those metal systems whose properties are… The variation in the structure and the metallurgical properties affect the properties of the material itself. So, the weld thermal cycle affects the structure and the properties of the base material.

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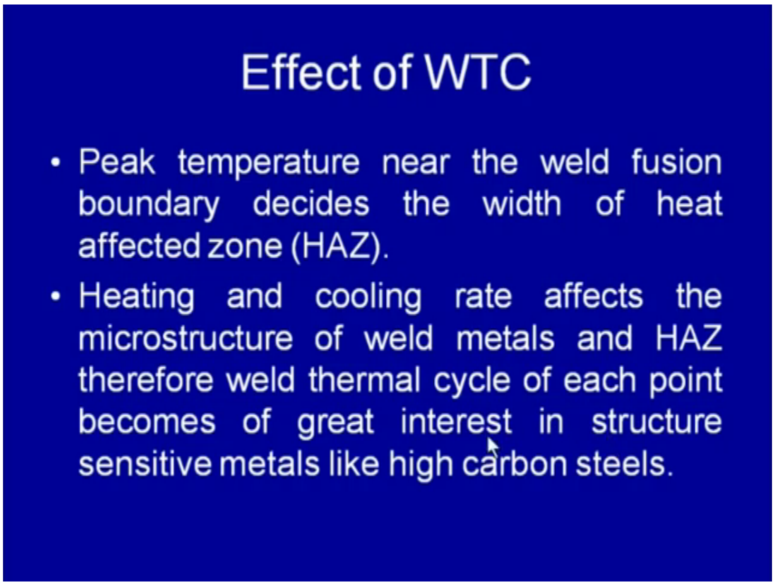

Especially of the structure sensitive materials like carbon steel, high carbon steel and the alloy steels. So, as the conclusion to summarize this presentation, in this presentation we have tried, we have talked about the need to study the heat flow in the welding. We have seen that it is important to look into the kind of the temperature variation which is experienced by the base material and the regions close to the fusion boundary because it effects the rate of heating, exposure time and the cooling rate which is experienced by the material near the weld centre line.

These variations in temperature effect the metallurgical properties and the mechanical properties. And therefore, it is important to look into the weld thermal cycle of the base materials. In coming lectures we will see that how the weld thermal cycle can affect the properties of the different metal systems. Thereafter, we will see the, how can we calculate the heating rate and heating rate, the cooling rates and the peak temperature and the solidification rate of the different locations, especially in the weld metal and in the heat effected zone.

So, thank you for your attention.