Welding Engineering
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Module - 5
Heat flow in Welding
Lecture - 4
Peak Temperature and Solidification Rate

Continuing with the heat flow in welding, this is the 4th lecture based on this aspect of the welding, and in this presentation we will be taking up the mainly peak temperature and the solidification rate. We know that in fusion arc welding processes heat is applied for melting the faying surfaces. So, the molten metal developed by applying the heat between the faying surfaces after the solidification results in the development of the weld joint.

But, the peak temperature, which is found in the weld region, varies from the weld centre to the fusion boundary. But in any case the temperature, the peak temperature in the weld region is found greater than the melting point of the base material. But the peak temperature in the region close to the fusion boundary is found lower than the melting point.

And therefore, it becomes of the great academic and the practical important to see that, what is the peak temperature at the different distances away from the fusion boundary. Because it effects the metallurgical transformations in the region, close to the fusion boundary and these metallurgical transformations predominantly governed the mechanical properties and the other characteristics of the weld joint.

Therefore, study related with the peak temperature in the weld region as well as in the heat effected zone becomes of the great importance. Further after the application of the heat, when the cooling phase starts. The weld heat is extracted from the weld region by the conduction convection and the radiation and the gradually the heat lost from the weld region results in the solidification of the weld metal.

So, the rate at which heat is extracted from the weld region decides, the rate at which solidification will be occurring; therefore higher the solidification rate leads to the lower the solidification time. And the reduction in solidification time in general leads to the finer grained structure in the weld region. So, the refinement of the grained structure in weld region frequently leads to the better mechanical properties and better response to the heat treatment. So, these are the important aspects related with the study of the heat study based on the peak temperature and the solidification rate during the welding. So, as far as the detail content of the today this presentation is concerned.

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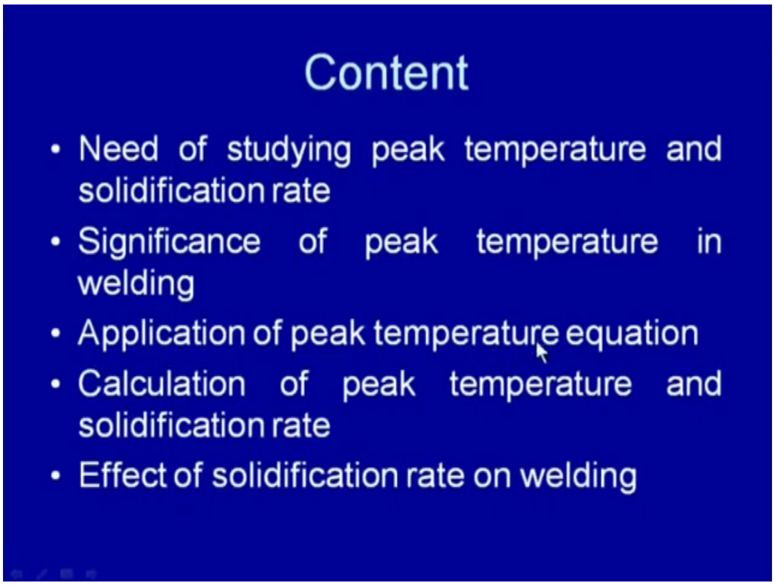

In this presentation we will be taking up the need of studying the peak temperature and the solidification rate, then we will see that how the peak temperature can affect the metallurgical and metal mechanical properties of the weld joints. So, what it is significance in respect of the soundness and the performance of the weld joint. Further how the peak temperature can be calculated and the peak temperature equations can be used for assessing the different performance parameters associated with the development of the sound weld joint. For example, peak temperature of particular application, the width of the heat effected zone or the effect of the heat input and the initial plate temperature, on the width of the heat effected zone can be calculated using these peak temperature equations. So, how can we use these peak temperature equations for the different purposes in the development of the sound weld joint.

So, the calculation of the peak temperature and the solidification rate will also be taken up with the example and we will see that if the what are the factors that affect the solidification rate during the welding, and how the variation in solidification rate can result in the difference in performance of the weld joint. So, starting with the peak temperature in the weld region, we know that when the heat is applied there are three different phases with the application of the heat and it is extraction from the weld region. And these phases involve basically, the heating zone soaking phase and the cooling zone.

So, in the heating zone temperature increases very rapidly in the region close to the faying surfaces or in the weld region and in the region close to the fusion boundary, so that is the heating phase and thereafter that temperature is maintained for some time. So, that forms the soaking time and once the heat source is passed, the heat is extracted by the low temperature base material, so the cooling take place.

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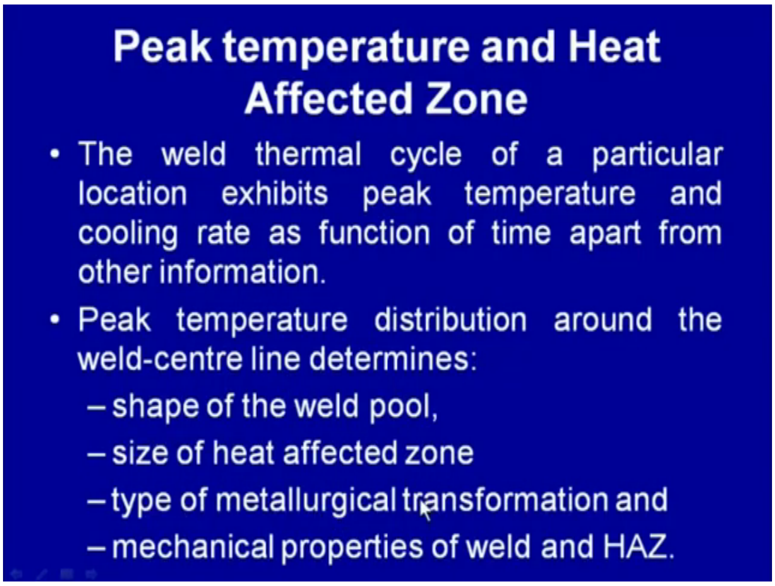

And because of this cooling from the different temperatures, we know that the cooling rate is found to be different when the cooling take place from the different peak temperatures. So, it becomes of the great importance to see that what is the peak temperature at a particular location in the region close to the fusion boundary, and then how it can affect the performance, and metallurgical reactions in the region close to the fusion boundary. We know that weld thermal cycle of a particular location exhibits.

The peak temperature and the cooling rate which vary as a function of time apart from the other information like the soaking time. And the peak temperature distribution around the weld centre line determines the shape of the weld, the size of the heat affected zone, the typical the type of the metallurgical transformation and the mechanical properties in the weld region and the heat effected zone. To understand this we will be going through the weld thermal cycle first and the way by which it can the peak temperature variation can affect, the mechanical properties of the weld region.

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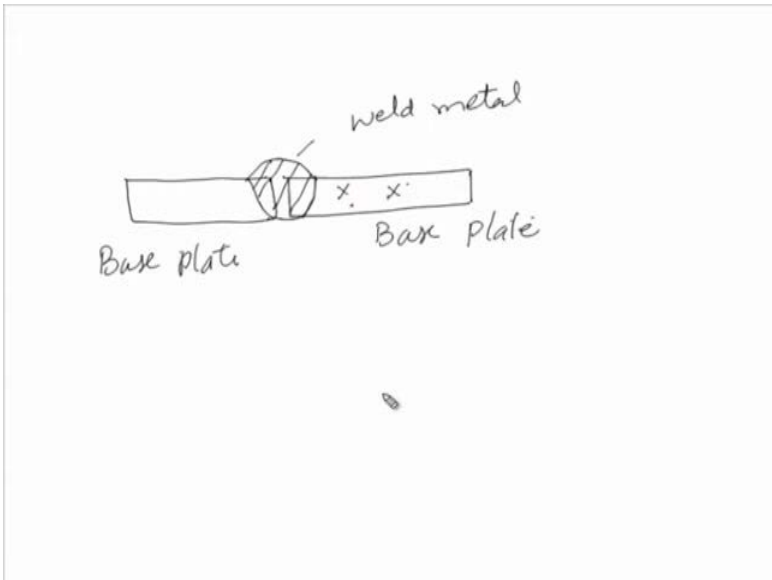

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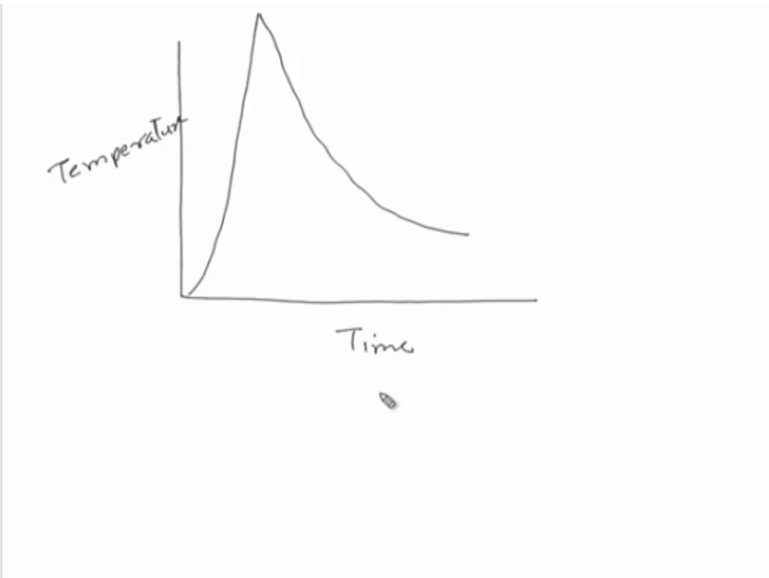

To see this say we have one, the two plates being welded by applying the heat, through the suitable heat source and after the fusion of the base material a weld is formed. So, if this is the weld region and the temperature in the weld region all will always be great than the melting point. So, here this these are the base plates and this is the weld metal and if we take the two points in the region close to the fusion boundary or in the weld region and one point in the weld zone and corresponding to these three regions if we try to see.

The variation in temperature as a function of time then in the weld region there will be sharp increase in temperature and accordingly the cooling rate will also be very fast, if you take up another points say the point one in the weld region.

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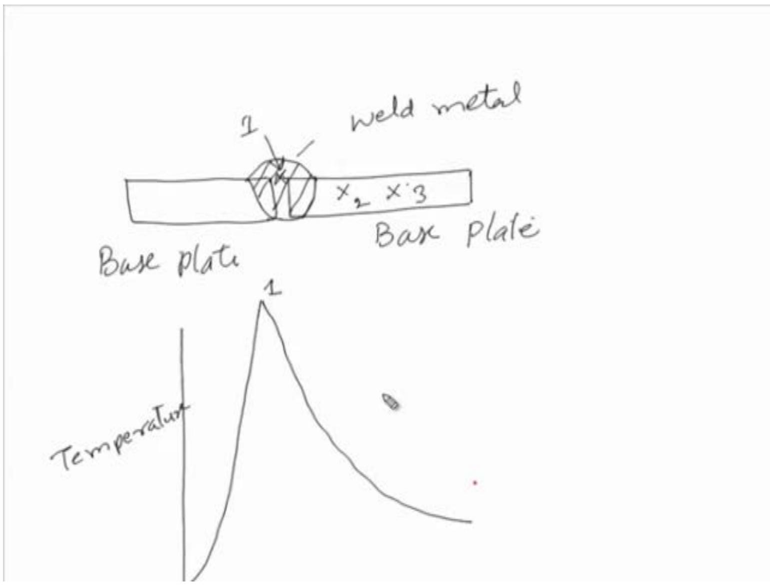

This is 1, this is 2 and 3. So, weld thermal cycle corresponding to the point 1 experiences very high peak, high heating rate and high cooling rate.

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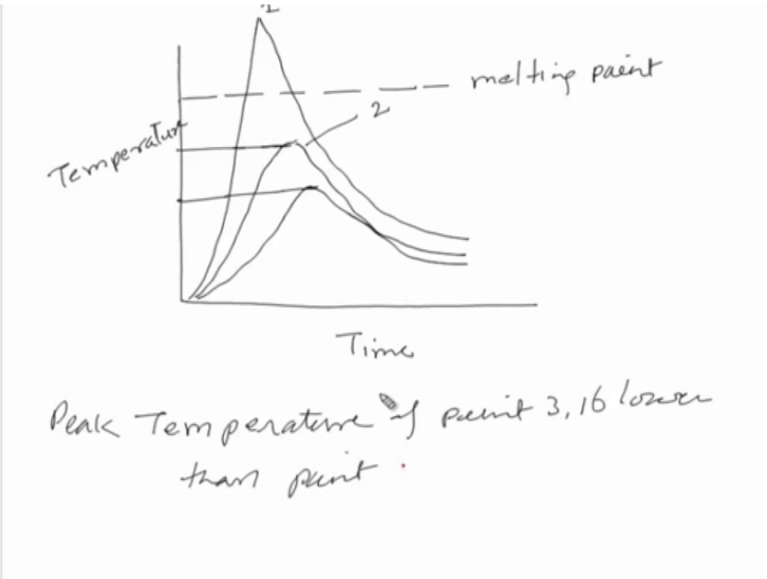

Thereafter, if we make the weld thermal cycle corresponding to the point 2, then it will be experiencing the somewhat lower peak temperature and the lower cooling rates. This is corresponding to the point 2, if we take up the weld thermal cycle corresponding to the point 3, then it will further require the lower heating rate as well as cooling rate.

So, if we see in the weld region the temperature is found greater than the melting point to facilitate the melting of the faying surfaces. So, if say this is the melting point of the base material, melting point temperature of the base material. So, in this is the above this temperature all the regions, which are falling above of this temperature will be will be forming the weld metal and melting will be taking place and after solidification that will result in the weld metal. But, if we take up the point 2 3, the point 2 subjected to the peak temperature somewhat lower than the fusion point or the melting point and point 3 further subjected to the lower temperature. So, if we see if we compare the peak temperature of point 3 is lower than the peak temperature of point 3 is lower than the point 2.

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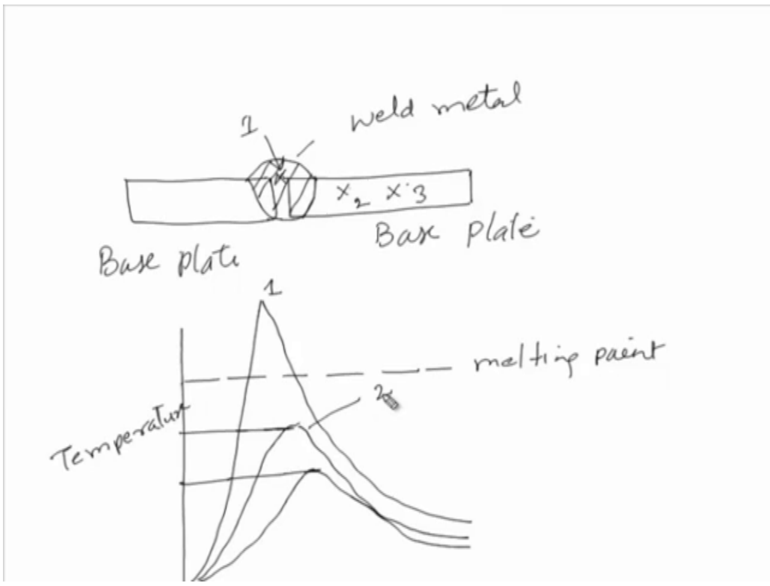

So, those regions which are subjected to the higher temperature, there will be effected by the application of heat in different way than the those regions which are subjected to somewhat lower temperature.

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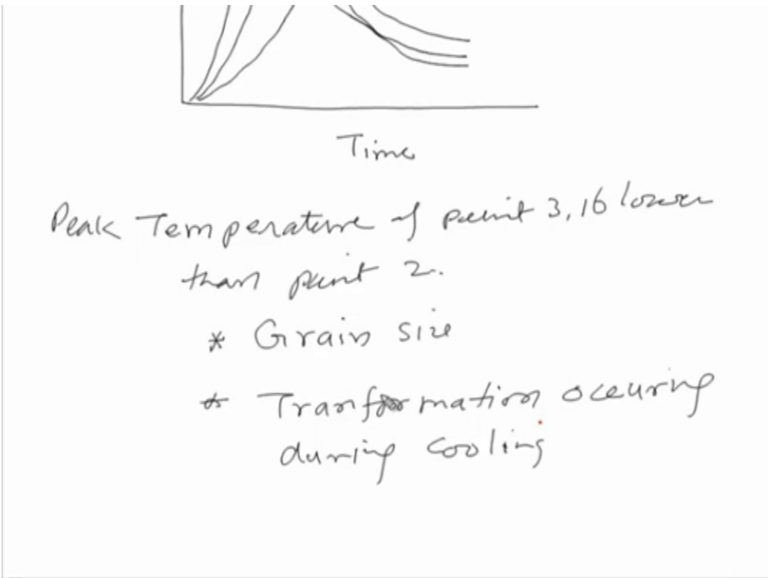

So, as far as the this effect of the peak temperature is concerned, it mainly affects the grained size in grain size and the kind of the transformation, which will be taking place of during the cooling transformation occurring. During cooling in general higher is the temperature of the metal greater will be will be the coarsening of the grains in the heat affected zone and this in turn in case of the steel will facilitate the transformation of the austenite into the martensite. So, those regions, which are subjected to the higher peak temperature results in the coarse grained structure and coarse grained structure is generally forms to the development of the martensitic transformation in case of the hard enable steels.

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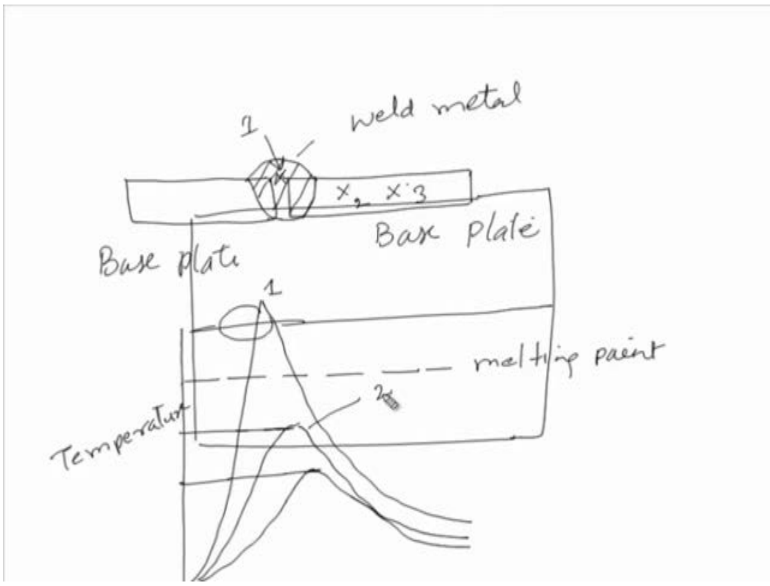

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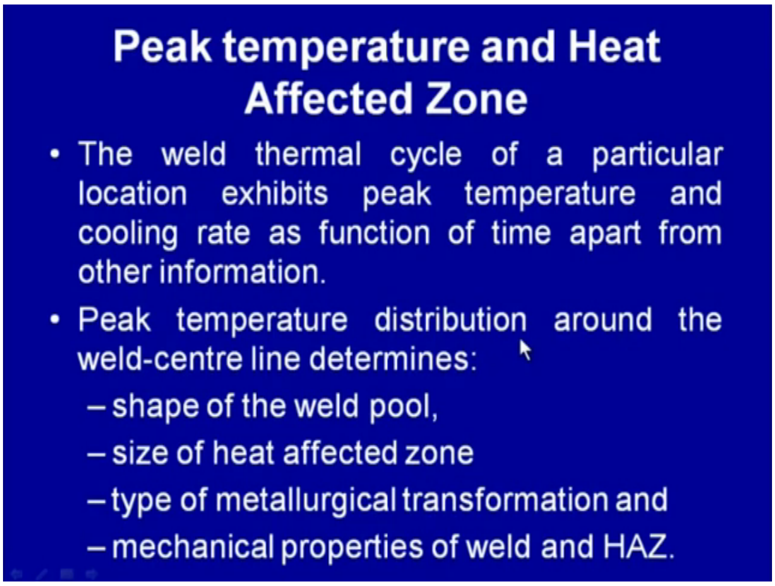

If we take up another case, where the heat if we see that the temperature variation in case of say this is the weld line. So, this is the weld pool normally, it is elliptical when the welding is done at certain speed. So, continuing with this the presentation.

If we see the peak temperature distribution around the weld centre line determines the shape of the weld pool of means, the peak temperature distribution is largely uniformed around the weld, around the heat source or along the weld centre line. Then the shape of the weld pool will be circular or close to the circular shape, if we start increasing the speed of welding then it will tend to become first oval shape and then tear drop shape.

So, because of the sharp gradient in the temperature, peak temperature away from the fusion boundary or away from the weld centre line, so the first thing is that the increased uniformity in peak temperature distribution results in the circular shape as compare to the tear drop shape. And if the temperature gradient is more than this will be resulting in the tear drop shape the weld pool.

Further if the peak temperature distribution is such that peak too high temperature is observed up to the greater distances from the fusion boundary, then this will be resulting in wider heat affected zone or the heat affected zone size will be more. Further the type of the metallurgical transformation, if the peak temperature is more than of a particular location in the heat affected zone then it will be causing the greater coarsening of the austenitic grains. And these austenitic grains are subsequently will be resulting in the martensitic transformation, but if the peak temperature is limited then it will simply result can result in the paralytic or the bainitic transformation.

And according to the kind of metallurgical reactions, which are taking place due to the variation in the peak temperature distribution mechanical properties of the weld region and the heat affected zone will be affected. For example, if the paralytic or the bainitic transformations are taking place due to the limited peak temperature in the heat affected zone, then these will result in the better mechanical properties in the weld region and the heat affected zone.

But, if the martensitic transformation occurs in then this can lead to the embrittlement and increased cracking tendency of the heat affected zone. That is why the variation in the peak temperature around the weld centre line means affects the number of characteristics related with the weld region and the heat affected zone. And this peak temperature distribution is effected by the various parameters related with the welding.

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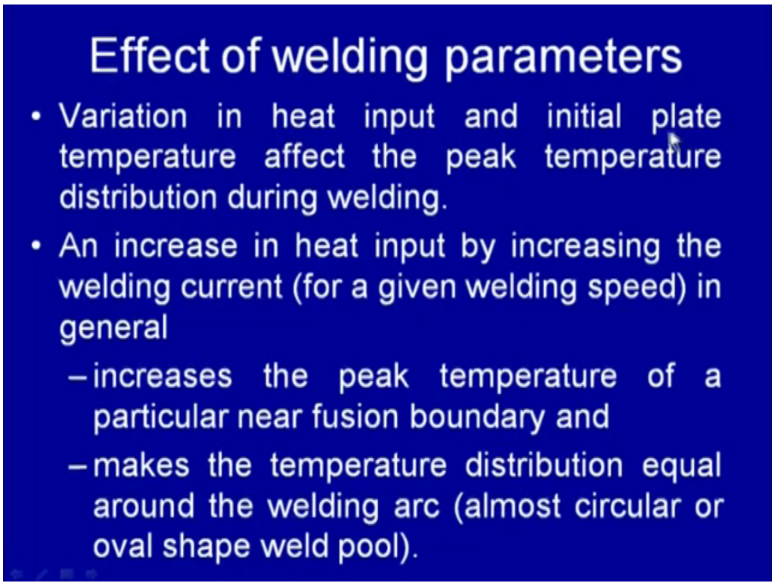

And these include mainly the heat input and the initial plate temperature. So, if the heat if we can see the individually effect of these 2 parameters, like heat input is primarily governed by the welding conditions like the welding current arc voltage and the welding speed. In general increase in welding current and the reduction in the welding speed causes, the higher heat input while higher the preheat temperature is while the initial plate temperature can be increased by preheating.

So, to see the effect of these parameters in effect of the heat input and the initial plate temperature on the peak temperature, we will we can see that an increase in the heat input by increasing the welding current or for a given welding speed or for a given welding current reduction in the welding speed increases the heat input. And this increase in heat input in general causes means, increases the peak temperature of a particular location near the fusion boundary.

But, the peak temperature distribution in the fusion boundary is not appreciably affected, this makes the temperature distribution further increase in heat input makes the temperature distribution more uniform, because of the largely uniform cooling or the slower cooling during the cooling phase. So, the increase in heat input reduces the temperature gradient and this in turn makes the weld pool almost circular or the oval shape. So, if you can see here.

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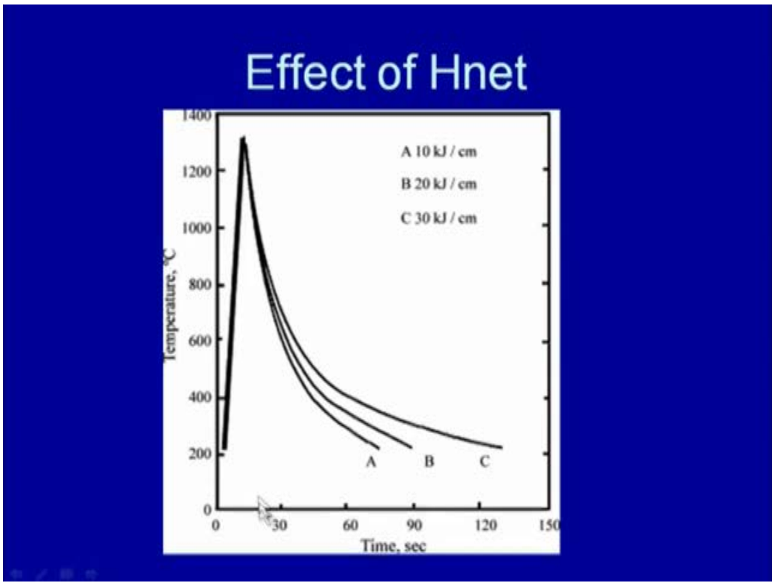

These are the different weld thermal cycles corresponding to a particular location say of the weld region corresponding to the 3 different heat inputs. For weld thermal cycle, for the curve A is corresponding to the heat input of the 10 kilo joule per centimetre and B and C accordingly for 20 and 30. This shows that the heating rate is almost same in the weld region and the temperature peak, temperature is almost same because all the things are brought to the molten state.

And thereafter the cooling rate is found to be the function of the heat input and this the variation in the slope of the cooling rates corresponding to the cooling rates in the weld thermal cycles. Developed corresponding to the different heat inputs is mainly attributed to the difference in the cooling rate, we know that higher is the heat input lower will be the cooling rate. So, this what, we can say the slope of the curve C is somewhat lower than the curve A and B. So, this the this slower cooling rate can be seen as the somewhat lesser temperature gradient as compare to that of the curve A, the another parameter that affects the peak temperature is the welding speed.

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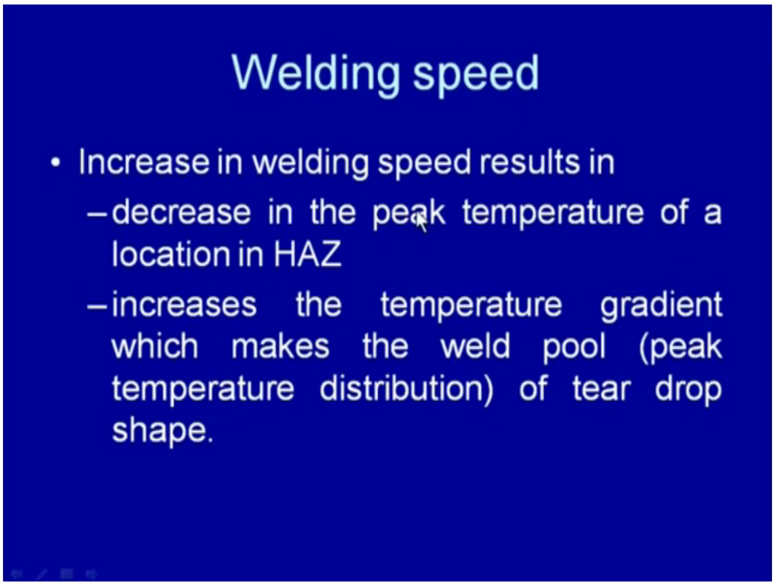

We know that, when the welding speed is increased the heat input decreases, net heat input heat decreases, but in the weld region in n case the temperature will be greater than the melting point. But, reduction it reduction in heat input in general decreases the peak temperature of any location in the heat affected zone and it increases the temperature gradient, which makes the weld pool of the tear drop shape.

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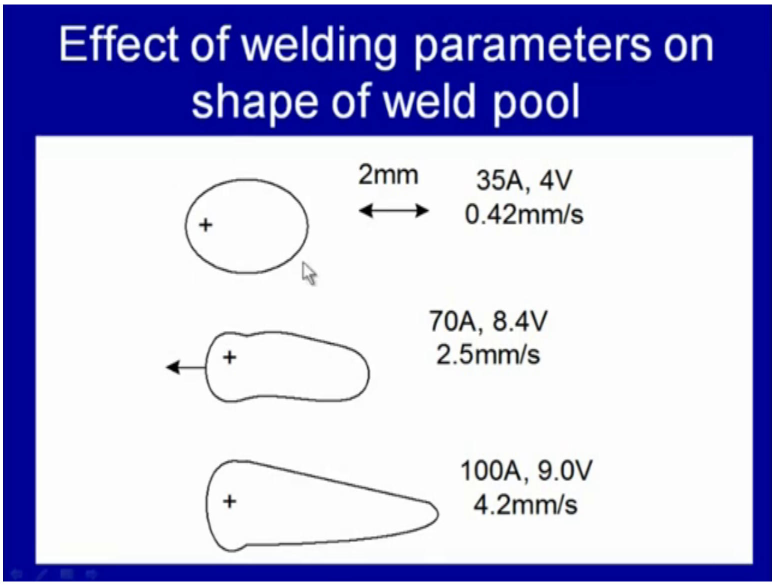

So, tear drop shape of the weld pool is mainly attributed to the increased temperature gradient and which is caused by the increased the welding speed. So, increase in welding speed results in the decrease in peak temperature of particular location and the increase in the temperature gradient, which makes the weld pool of the tear drop shape. We know that it is always beneficial to have the lower peak temperatures in the heat affected zone. So, that the adverse effects related with the weld thermal cycle in the heat affected zone or the region close to a fusion boundary can be reduced.

We can see the effect of the welding speed and the welding parameters like if we are using very low welding speed that is of say point 4 2 m m per second and the low heat input like say 25 ampere applied using. The 35 ampere current and the very low 4 volt then this will result in the largely circular shape weld pool while the use of the higher welding current. But, coupled with the higher welding speed results in the oval shape weld pool and further the tear drop shape weld pool is obtained when further higher speed is used.

So, lower is the welding speed results in the greater uniformity in the peak temperature distribution around the welding arc and this in turn results in the circular. Largely circular shape or oval shape weld pool while the higher speed results in the greater temperature gradient especially, in the trailing portion of the weld region and this in turn causes the greater the tear drop shape weld pool. And the variation in the shape of the weld pool is mainly attributed to the kind of peak temperature distribution, which is developed, because of the variation in the under the different welding conditions.

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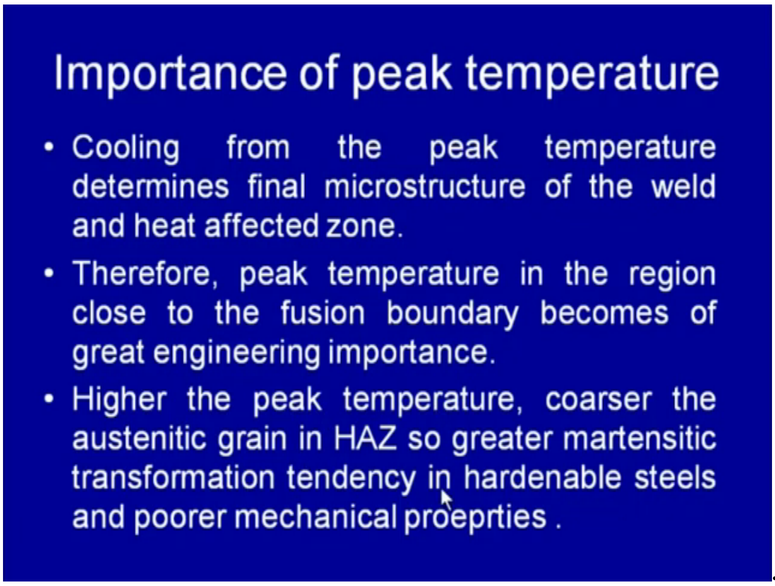

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So, a higher the welding speed means the higher at the temperature gradient, around the higher peak temperature gradient around the or the source of the heat and. Therefore, the tear drop shape weld pool is obtained, while the this temperature peak temperature distribution is more uniform in case of the lower speed and this in turn results in the circular shape weld pool.

Now, the things that have been described in brief regarding the importance of the peak temperature and need to study it and to calculate it properly, so that it can be controlled in order to avoid the adverse effects related to the peak temperature of a particular location. Here we can see that the cooling from the peak temperature determines the finer macrostructure of the weld and the heat affected zone, we know that the higher peak temperature will be the higher peak temperature results in the coarser grained structure and coarser grained structure in the weld and in the heat affected zone.

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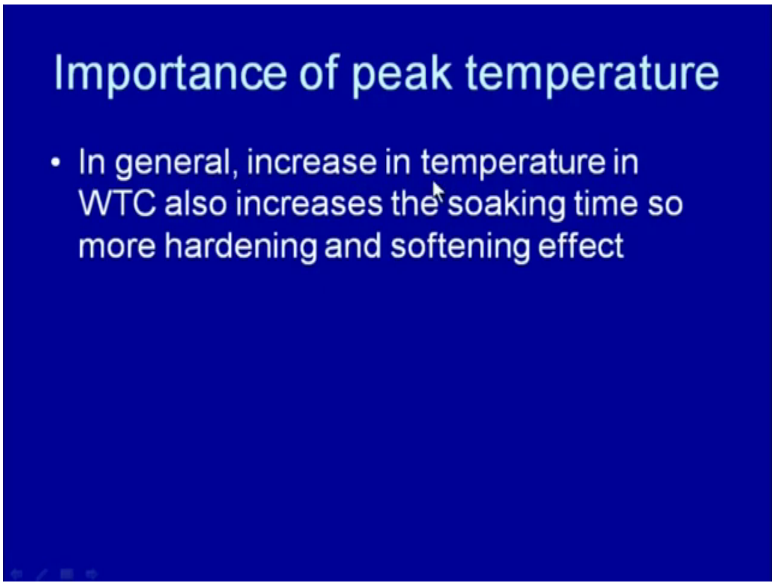

First leads to the coarser and a structure and it further increase the martensitic transformation especially, in case of the hardenable steels. Therefore the peak temperature in the region close to the fusion boundary becomes of the great importance. In general higher the peak temperature coarser the austenitic grain in the H A Z. So, the greater martensitic transformation tendency in case of the hardenable steels, which in turn leads to the poorer mechanical properties. So, in case of the hardenable steels, it becomes important to control the peak temperature, especially in regions close to the fusion boundary.

In general increase in the temperature, increase in the peak temperature in during the weld thermal cycle also increases soaking time and. So, the more hardening and the softening effect is encountered. To see this we can see, if we are interested in the peak temperature above a certain value to above the certain value, which can affect weld thermal cycle, which can affect the properties of the material

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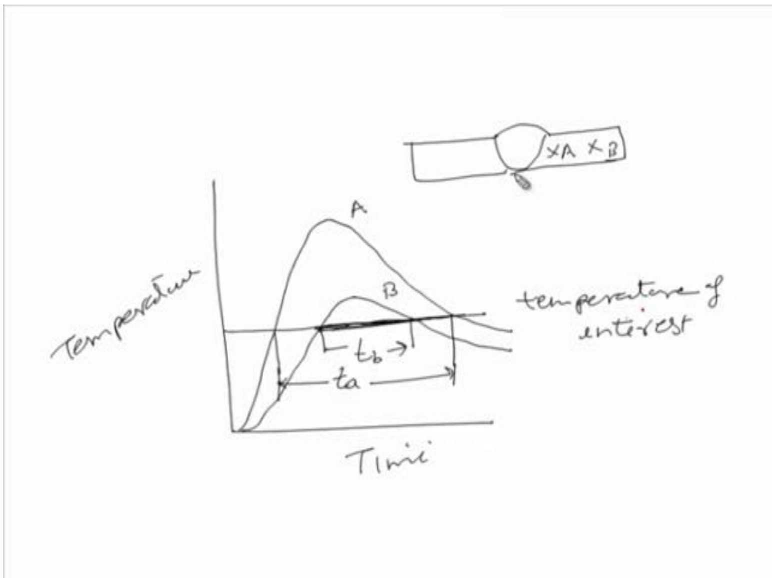

Then if say peak temperature, which is of the importance is low, this is one case and this is another case. So, if the peak temperature above these; these are the 2 weld thermal cycles corresponding to the 2 different locations say case of the weld joint one A and another B. So, weld thermal cycle corresponding to A is this and the weld thermal cycle corresponding to the B is this if the temperature of the interest, which can affect the properties of the base material is this one.

Then the soaking time corresponding to the weld soaking time, for the location B corresponding to the temperature above this temperature of the interest is just this t b, while the soaking period in case of the location A is this t a, which is much larger. So, if we see if greater is the peak temperature of particular location then it can lead to the greater soaking time for say soaking time above the given temperature of the interest. So, this is weld thermal cycle for 2 different locations from this diagram, we are trying to stress that, if that peak temperature of particular location is more than, it will increase the soaking period above the certain temperature of the interest. So, this the temperature of the interest, basically decides the soaking period above the particular temperature.

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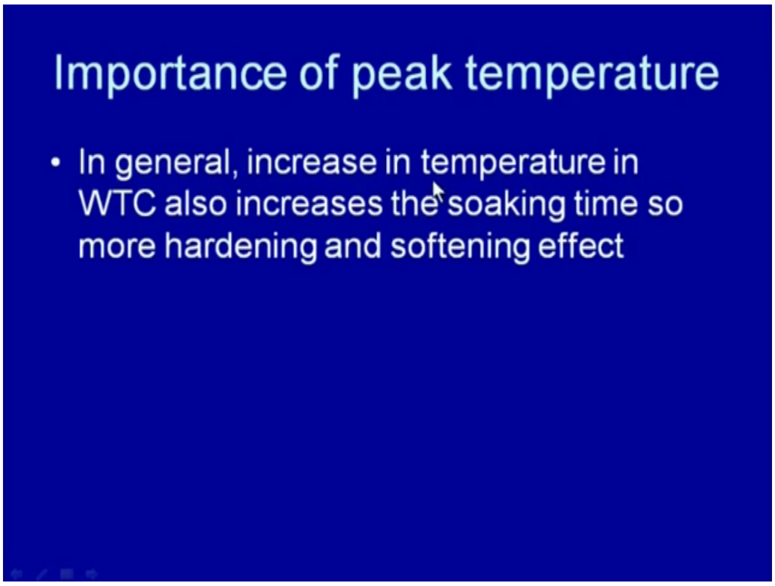

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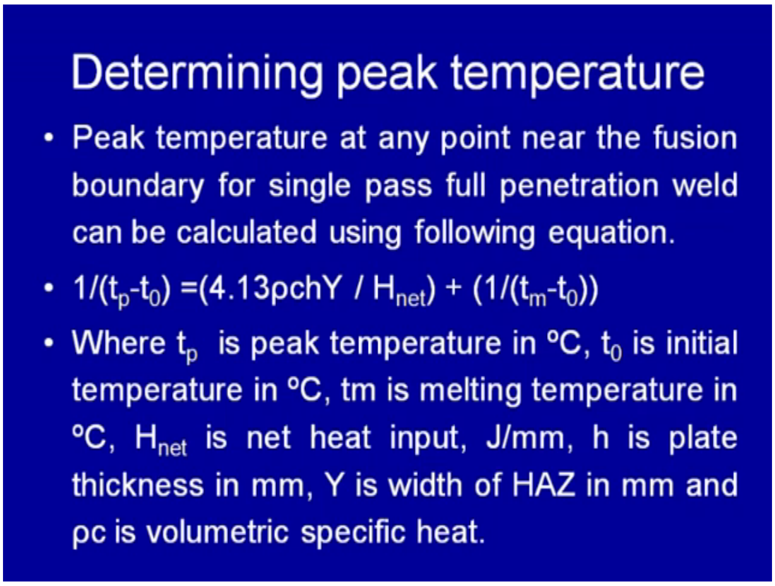

In general increase in the temperature in the weld thermal cycle also increases the soaking time and because of the increased soaking time. We can have the greater hardening effect in case of the hardenable steels and the softening effect in case of the precipitation hardenable steels, where either over edging takes place or reversion of the precipitation or the other strengthening precipitates takes place.

So, in order to determine the peak temperature, near the any at any point near the fusion boundary for a single pass full penetration weld. The following equation can be used here it involves the 1 by t p minus t naught, where t p is the peak temperature t naught is the initial plate temperature, becomes equal to the 4.13 rho c h y. So, here rho is the density C is the specific heat, h is the thickness of the plate and Y is the distance where we want to determine the peak temperature away from the fusion boundary.

And divided by H net, this is the net heat input, which is calculated from the v i by s that is the welding current and multiplied by the voltage divided by the welding speed plus 1 by t m. T m is the melting temperature of the base material and the t naught is the initial plate temperature. So, in this equation can be used to calculate the peak temperature at a location near the fusion boundary for a single point full penetration weld joint.

So, in this equation t p is the peak temperature in degree centigrade, t naught is the initial plate temperature in degree centigrade, t m is the melting point in the degree centigrade. And H net is the net heat input in joule per m m, H is the plate thickness in m m, Y is the width of the heat affected zone or the distance of the location away from the fusion boundary and rho c is the volumetric specific heat.

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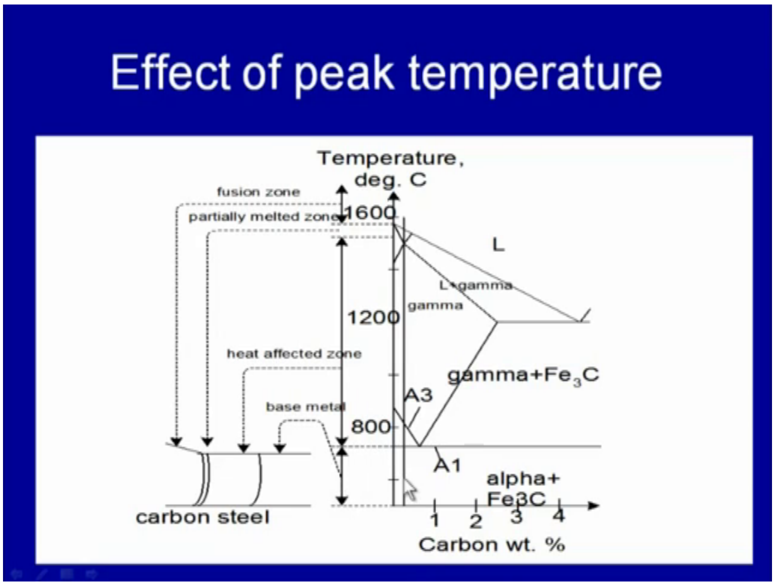

Why it is important, we know that the for pure metals for pure iron the melting takes place generally, above the 14 15 40 degree centigrade and. So, all regions falling above this will be coming in the weld region, while all the regions, which are below the lower critical temperature will be forming the base material, where no change or in the metallurgical properties of the base material take place.

So, they will be forming the base material and the regions which are above the lower critical temperature and below the melting point all those regions will be falling in the heat affected zone. So, if we see here this is the region where, which will be subjected to the temperature lower than the 730 degree centigrade and that this is the band, where the temperature of the base material will be greater than the lower critical temperature and below the solidus below the solidus temperature.

So, this is this is the portion, which will be falling in the heat affected zone and further a very narrow band can be seen here, which corresponds to the temperature zone between the liquidus and the solidus. Because this is an alloy system where the there is a range of the temperature over, which the solidification takes place. So, the liquidus temperature is one above, which everything is in solid and liquid and the solidus is the temperature below which everything is in solid state. But, those the locations, which are means this narrow band is subjected to the temperature zone between the liquidus and solidus means it will have the two phase zone. So, this two phase zone found to be sensitivity for the partial melting related problems and this is this kind of problem is mainly encountered in case of the cast irons and it is encountered less in case of the steels.

So, the all the regions in during the welding of the steels, which are subjected to the temperature below 730 degree centigrade, they will be falling in the base material and the region, which are subjected to the temperature above the lower critical temperature that is 730 degree centigrade. But, below the solidus temperature and the solidus temperature is along this line that will be the function of the carbon content in the steel.

This all this region will be falling in the heat affected zone and this narrow band will be falling in the solidification temperature range, that is zone between the liquidus and the solidus for the steel. Wider is this zone greater will be the tendency of the cracking in the partial melting zone, where one phase is found in the liquid state and the another Phase found in the solid state.

So, this the equation that has been described above is the peak temperature for which is used for determining the peak temperature of a particular location in the region close to the fusion boundary. For the weld joints developed using the single passed and the full penetration weld is made. But, above the equation can also can be used for variety of purposes, which are of the great importance for development of the sound weld joint, this equation can be used for calculation of the peak temperature at any point away from the fusion boundary.

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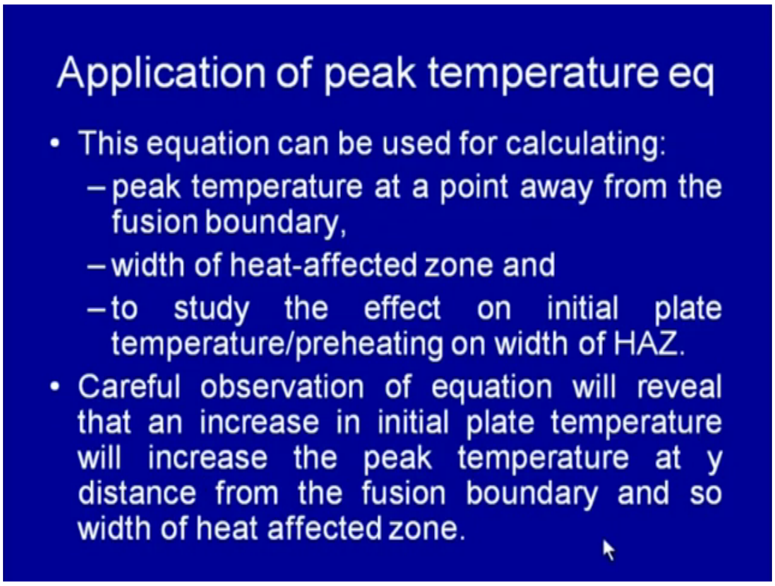

Because the temperature within the weld region is generally uniform, and varies from and the variation from the weld centre to the fusion boundary is found very less. And it is always greater than the fusion temperature or the melting point of the base material from the knowledge of the peak temperature at a particular point away from the fusion boundary. We can calculate the width of the heat affected zone or the size of the heat affected zone.

And further the above peak temperature equation can also be used to see that, how the initial plate temperature and the heat input will affect the heat affected zone or the peak temperature at a particular location. So, means to see that the variation, if we perform the preheating of the different amounts then how it will be affecting to the width of the heat affected zone. Further if we try to observe above equation carefully then this will reveal that an increase initial plate temperature will increases the peak temperature at a particular location away from the fusion boundary and alternatively. So, increase in initial plate temperature, will increase the peak temperature at a particular distance away from the fusion boundary and so, the width of heat affected zone.

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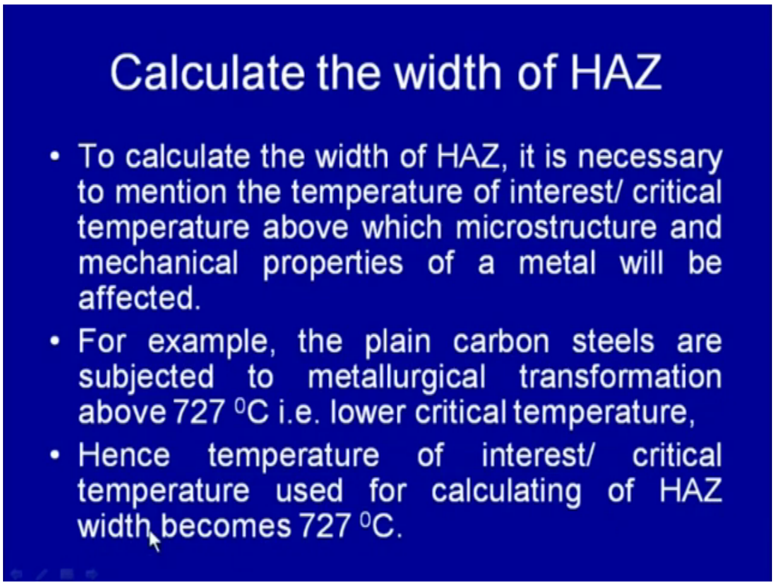

To calculate the width of the heat affected zone, it is necessary first to mention the temperature of the interest or the critical temperature above, which the properties of the base material will be affected in respect of the microstructure and mechanical properties. So, for calculation of the peak temperature, it is mandatory to identify that the temperature value. For example, in case of the plain carbon steels the temperature above, which steels are subjected to the metallurgical transformation is 727 degree centigrade, that is the lower critical temperature. So, for the plain carbon steels the temperature of interest becomes the 727 degree centigrade and this can be used for calculating the width of the heat affected zone. So, the temperature of interest or the critical temperature used for calculating the width of heat affected zone, for the simple carbon steels becomes 727, while in case.

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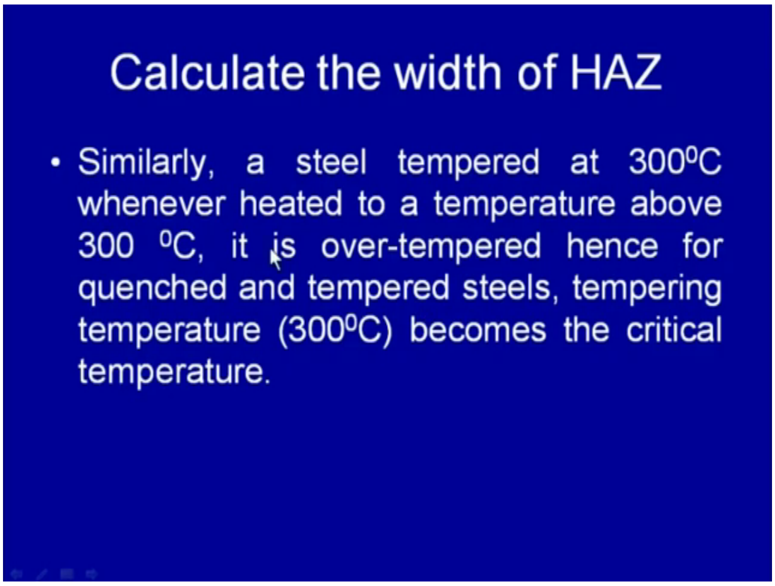

Similarly, in case of the steel which, is tempered at 300 degree centigrade whenever subjected to the temperature above 300 degree centigrade is over tempered. Hence the mechanical properties and microstructure is affected. And therefore for quenched and tempered steels, which are which have been tempered at temperature 300 degree centigrade, this temperature becomes the critical temperature. So, for the quenched and tempered steels, the tempering temperature of the steel becomes the critical temperature for calculation of the width of the heat affected zone.

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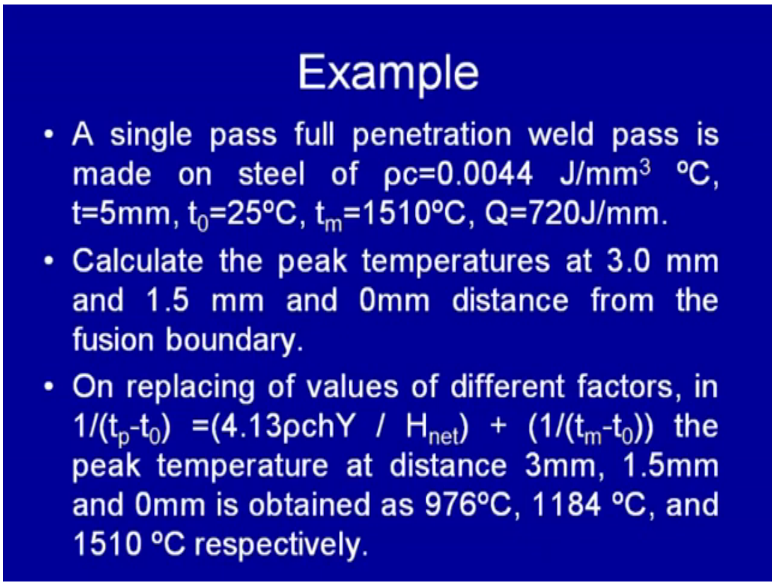

So, now, we will take up one example related with the calculation of the peak temperature, during the welding of the steel say a single passed full penetration weld is made on of the steel having the rho C of equal to 0.004044 joule per m m cube per degree centigrade. Initial plate thickness, plate thickness is 5 m m initial plate temperature 25 degree centigrade and the melting point of the steel say 15 10 degree centigrade and the net heat input is 7 20 degree centigrade.

So, if you want to calculate the peak temperature at the distance of 3 m m and 1.5 m m 0 m m distance means, on approaching towards the weld fusion boundary. First location at 3 m m distance, second 1.5 m m distance and third 0 m m distance that is at the fusion boundary. So, on placing the values of these various factors in this equation of the peak temperature or the peak temperature at a distance 3 m m is found to be 7 70 976 at 1.5 m m distance from the fusion boundary.

It is 11 84 degree centigrade and at the fusion boundary, it comes it becomes equal to the 15 10 degree centigrade. So, this suggest that on approaching towards the fusion boundary away from the base material towards the a fusion boundary. The peak temperature increases gradually and it becomes equal to the melting point at the fusion boundary. The now we will take up the things related with the solidification rate, now we know that when heat is applied the base material is brought to the molten state and the filler material is also brought to the molten state in case of the consumable arc welding processes. And during the cooling phase the heat is extracted from the weld region and the rate at which heat is extracted from the weld region, the solidification of the weld metal will be occurring at the different rate. So, depending upon the rate at which solidification occurs the weld structure and the properties of the weld metal are decided.

We know that the solidification of the weld metal takes place with the reduction in temperature of the liquid metal and the then liquid metal. Liquid to solid state transformation takes place and finally, the reduction in temperature of the solid metal up to the room temperature takes place. So, basically during the welding first the there will be a reduction in temperature of the liquid metal and then there will be the change of the phase from the liquid to the solid state. And thereafter there will be further reduction in temperature from the melting point to the room temperature.

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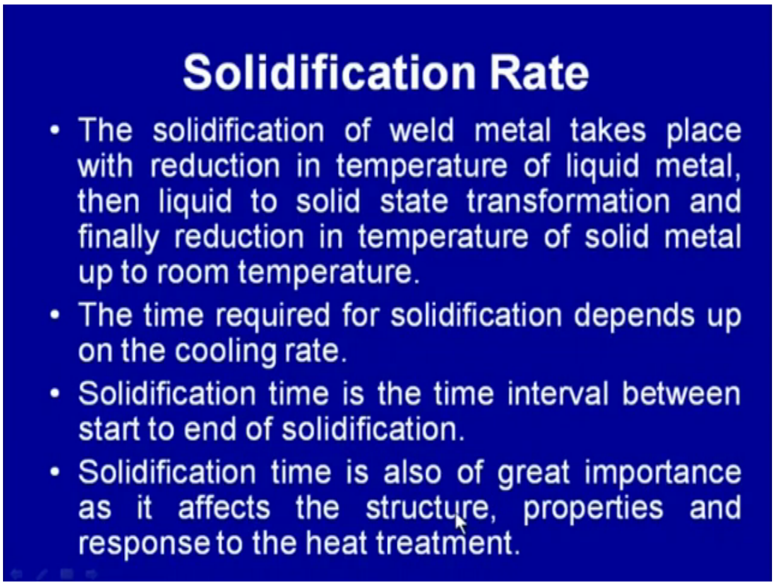

The time required for the solidification depends upon the cooling rate, in general higher is the cooling rate lesser will be the solidification time. Solidification time basically, is the time interval between the start to the end of the solidification and the solidification time is of the great importance. Because, it affects the solidification structure properties and the response to the heat treatment, we know that if the solidification time is more than every phase during the solidification will be getting enough time to grow to the large extent. And we will be resulting in the coarse grained structure and so, the coarse grained structure will be resulting in the poor mechanical properties.

And the weld zone having the coarser grain structure will be responding slowly to the heat treatment, because for heat treatment mostly, we in require the austenitizing or the solutionizing. So, the coarse grained structures respond slowly to the austenitizing and solutionizing, while in case of the higher cooling rates, when solidification time is less the finer grained structure is obtained, which in turn results in the finer or the better mechanical properties and the better response to the heat treatment.So, the solidification time of the weld metal can be calculated using the simple equation that whatever heat is available with the weld metal and the rate at which it is being extracted these is divided.

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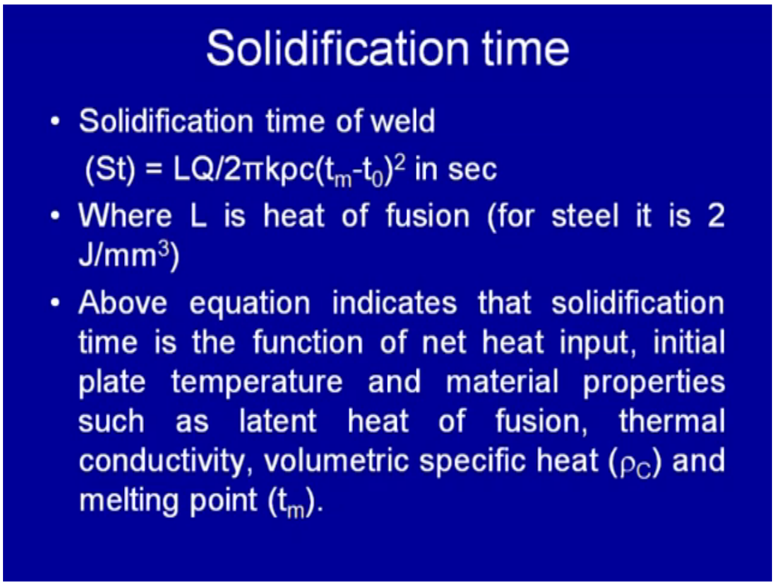

So, the latent heat of the fusion, which is available with the weld metal and the rate at, which heat is being extracted during the welding. So, basically the heat with the weld metal and the cooling rate, these 2 are used to calculate the solidification time. So, heat available with the weld metal divided by the cooling rate gives us the time directly. So, if we see this equation this is basically, the cooling rate equation for the thick plate where latent heat is divided by the cooling rate equation. In this equation the most of the parameters are same as that of the cooling rate equation, where L is the latent heat of the fusion, which is considered as a 2 joule per m m cube. Q is the net heat input, k is thermal conductivity, rho is the density since specific heat, t m is the melting point, t naught is the initial plate temperature. And this equation gives us the time in seconds, above equation suggest that, if we increase the heat input that is the q.

Then solidification time will increase or if we reduce, if we increase the initial plate temperature then this entire quantity in the denominator will decrease and the this decrease in the quantity of the in the denominator will increase the solidification time. So, so these 2 aspects can be easily, observed from this equation that increase in heat input and the increase in initial plate temperature both will increase the solidification time.

Further if we say increase in thermal conductivity, then and the increase in a specific heat this will also help in increase this will increase the rate of heat extraction and. So, the solidification time will decrease. So, above equation suggest that solidification time is a function of the heat input and the initial plate temperature and the material properties such as the latent heat of fusion thermal connectivity volumetric specific heat and the melting point.

So, from this equation, we can see that if the latent heat is high and thermal conductivity is low, volumetric specific heat is low and the melting point is low than the all these things will result in the longer. The solidification time means, greater the latent require longer solidification time, while the lower thermal conductivity, the lower specific heat and this for a given preheat, the lower the melting point will result in the greater solidification time.

So, typically, for the case of like say in tig autogenous tig weld of the steel plates of say 4 m m thickness. Generally, the solidification time of the weld metal is found lesser than the few seconds and because of the rapid solidification, the tendency of the gas entrapment and is also observed, but the high solidification rate, generally results in the finer grained structure.

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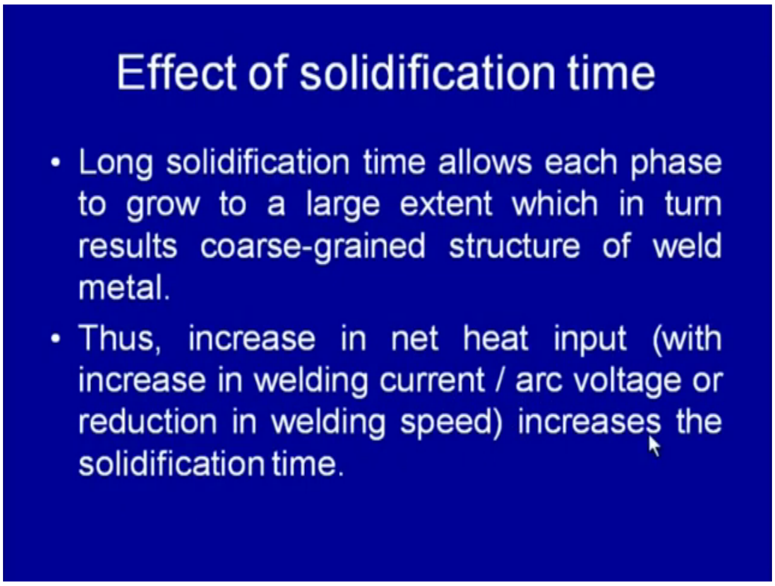

The longer solidification time allows each phase to grow to the large extent, which in turn results in the coarse grained structure of the weld metal. And thus the increase in the net heat input with the increase in the welding current or the arc voltage reduction in the welding speed, increase in the solidification time is observed.

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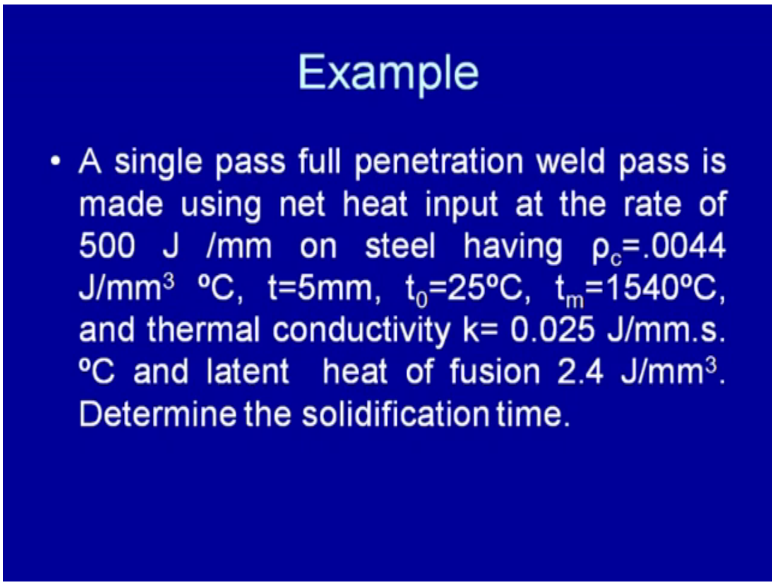

Now, we will see one example to show, that how the solidification time during the welding can be obtained. Say for one case, where the single pass full penetration weld is made using the net heat input at the rate of the 500 joule per m m on steel having the C rho C.

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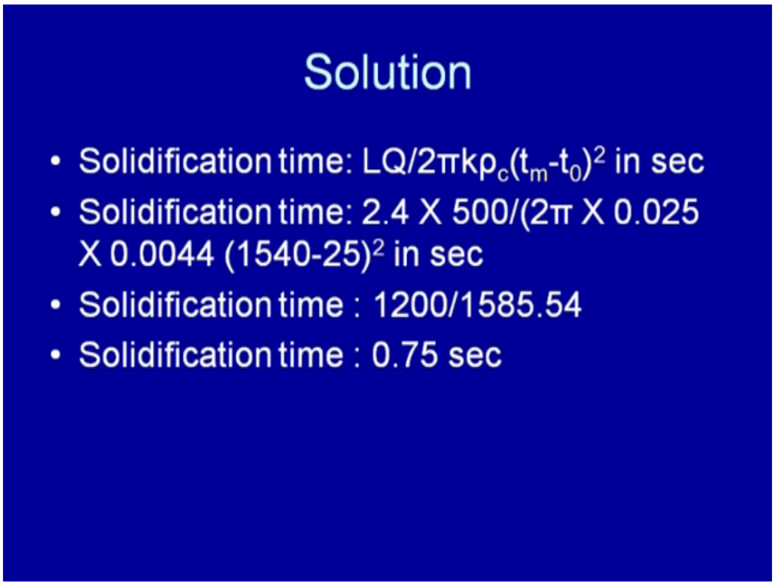

The rho is the density and C is the specific heat is of the 0.0044 joule per m m cube per degree centigrade. T is the thickness of the plate being welded, t naught is the initial plate temperature and t m is the melting point of the steel and thermal conductivity K is equal to 0.025 joule per m m per second per degree centigrade. And assuming that the latent heat of the fusion is 2.4 joule per m m cube then solidification time can be obtained.

Using the simple cooling, simple equation which shows the solidification time is equal to the L, that is the latent heat of the fusion for the material being welded. And the Q is the heat input, which is being given that is net heat input and the 2 pi in case the thermal conductivity rho C multiplied by the t m, that is melting point minus t naught is the initial plate temperature and this gives us the time in seconds.

So, on putting in the values of the different terms like solidification time can be obtained like 2.4 multiplied by 500 into divided by 2 pi multiplied by 0.025 into 0.004 15 100 40 minus 25. This gives us the solidification time on simplifying this we get the solidification time of the 0.75 seconds. So, this indicates that during the welding the solidification time is extremely small as compare to that of the costing, where the solidification time can be as high as 5 minutes 10 minutes or generally greater then 1 minute depending upon the mold material and the volume of the material in the casting and to be solidified.

But, here in case of the welding, the solidification time is extremely small due to the high cooling rate experienced by the weld metal during the welding. If we see take up the case during the typical welding.

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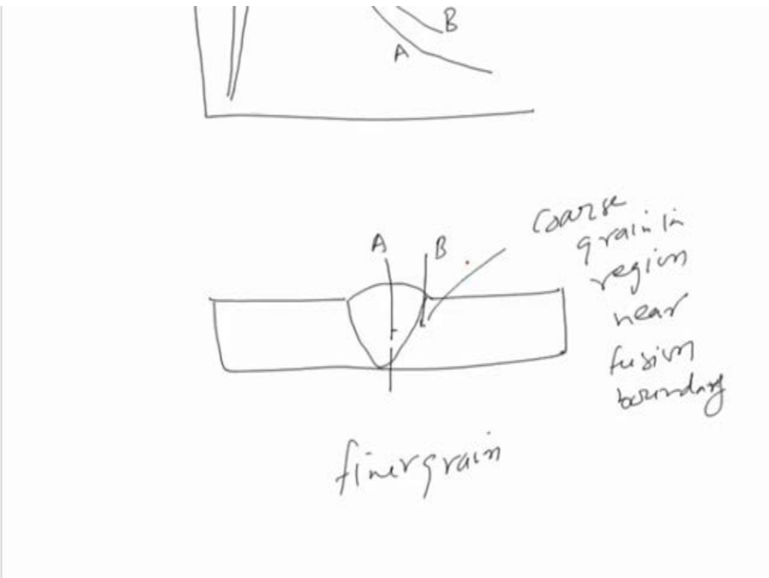

The weld the solidification rate is found to be different in the different locations of the weld region, if say this is the weld region solidifying developed by applying the heat and the solidification is taking place. Then the weld centre line the weld thermal cycle corresponding to the centre line and welds thermal cycle corresponding to the fusion boundary. So, this is a location A and this is location B. So, weld thermal cycle corresponding to the fusion boundary and the weld thermal cycle corresponding to the location A at the weld centre line are found to be different.

So, if we see both the cases, the heating rate is almost same in both the cases, but the solidification rate for the A is found to be more as compared to that of the B. So, higher the solidification rate and the weld centre results in the finer grain is structure in the weld centre and the coarse grain structure grains in the region near fusion boundary. So, this variation in the solidification rate near the weld centre and near the fusion boundary brings in the difference in the grain size varying from the fusion boundary to the weld centre. And this variation in the grain structure as far as size is concerned results in the significant variation in the mechanical properties of the weld region.

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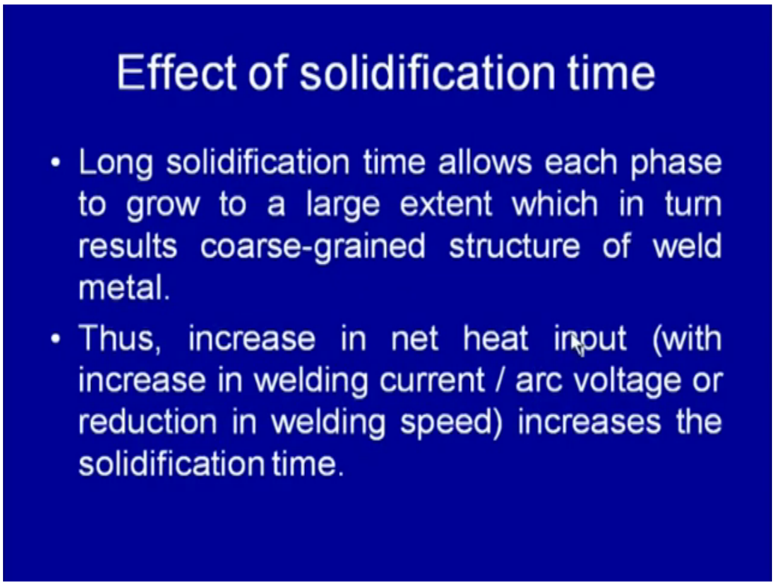

So, in general if we increase the heat input then the solidification rate is decreased in solidification rate, increases solidification time and increased solidification time results in the coarser grain structure. The similar effect is observed with the increase of the initial plate temperature, because initial increase initial plate temperature or the preheating also helps in reducing the cooling rate and reduction in cooling rate increases the solidification time and increase solidification time coarsens the grain structure.

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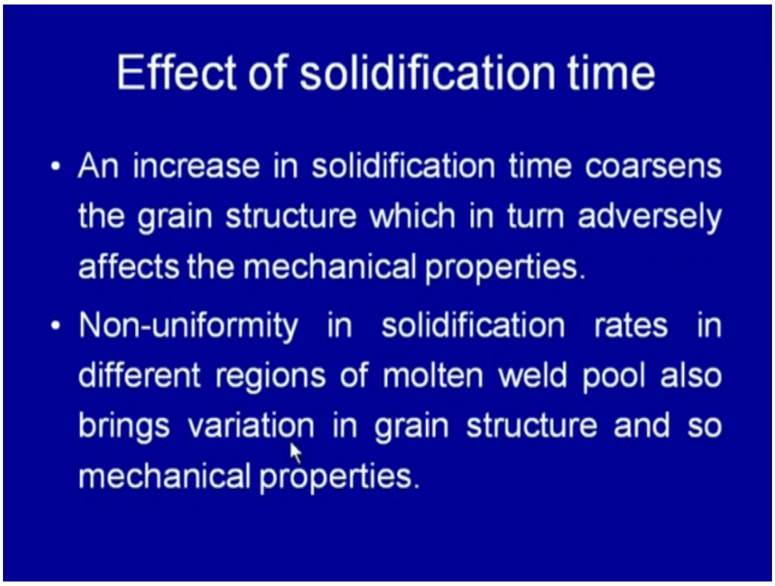

So, an increase in solidification time coarsens the grain structure, which in turns adversely affects the mechanical properties and the non-uniformity in the solidification rate in the different regions of the weld metal leads to the variation in the grain structure and so, the variation in mechanical properties. In general the weld centre results in the finer grain structure as compare to the grain structure, near the fusion boundary.

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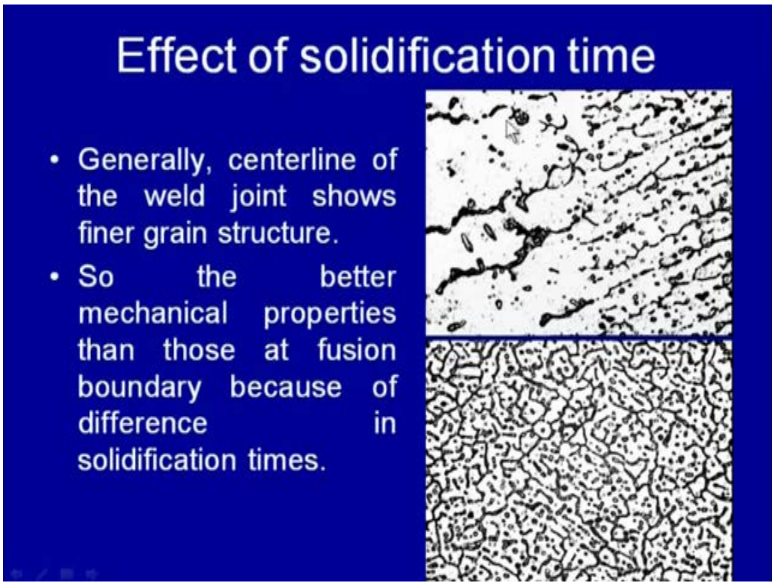

So, the weld centre of the Joint showing the finer grain structure, in this the bottom diagram here, we can say the finer and equiaxed grain structure as compare to the grain resist structure, near the fusion boundary. This is the fusion boundary of the aluminium silicon alloy system, where the coarse columnar structure can be seen near the fusion boundary. This is the fusion boundary, this is the heat affected zone and this side we can say the coarse columnar grain structures.

So, this variation in the grain structure, near the fusion boundary and at the weld centre is mainly attributed to the variation in the solidification rate. And this variation in solidification rate is due to the varying cooling conditions experienced by the weld metal near. The fusion boundary and the heat affected, near the fusion boundary and at the weld centre.

So, now I will try to summarise this presentation, in this presentation mainly we have seen the importance of the peak temperature in the heat affected zone and the method, which can be used means the equations, which can be used for calculating the peak temperature. Especially in case of the single pass weld, where through full penetration weld is made in single pass and these and what are the different ways through, which this peak temperature equation can be used for developing the sound weld joint in very effective manner.

We have also seen that what are the factors, how can we calculate the solidification time and the factors that affect the solidification time like heat input and the preheat temperature. Apart from the thermal properties of the base material being welded and the variation in solidification time in the different regions of the weld metal results in the difference in the microstructure of the weld. And which in turn results in the great variation in the properties of the weld metal varying from the weld centre to the fusion boundary.

Another important aspect related with the welding is the development of the residual stresses and the distortion, which much be controlled and these residual stresses primarily develop. Because of the variation in the weld thermal cycle being experienced by the different regions of the heat affected zone. So, varying the thermal cycle experienced by the different regions close to the fusion boundary leads to the differential expansion and contraction in, which in turn causes the great amount of the residual stress even without external load.

So, what are the residual stresses that develop in the weld region, what are the mechanisms behind the development of residual stresses in the weld region and how these residual stresses affect the performance of the welds. And what are the ways through, which we can control them that will be taken up in the presentation.

So, thank you for your attention.