Joining Technologies of Commercial Importance

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Lecture – 28
Weld Thermal Cycle

Hello, I welcome you all in this presentation. This presentation is based on the weld thermal cycle and in this presentation I will be talking about the many of the weld thermal cycle, what information can be gathered from the weld thermal cycle of particular location and why it is important to know about weld thermal cycle of a particular point and how does it desired the weld joint performance.

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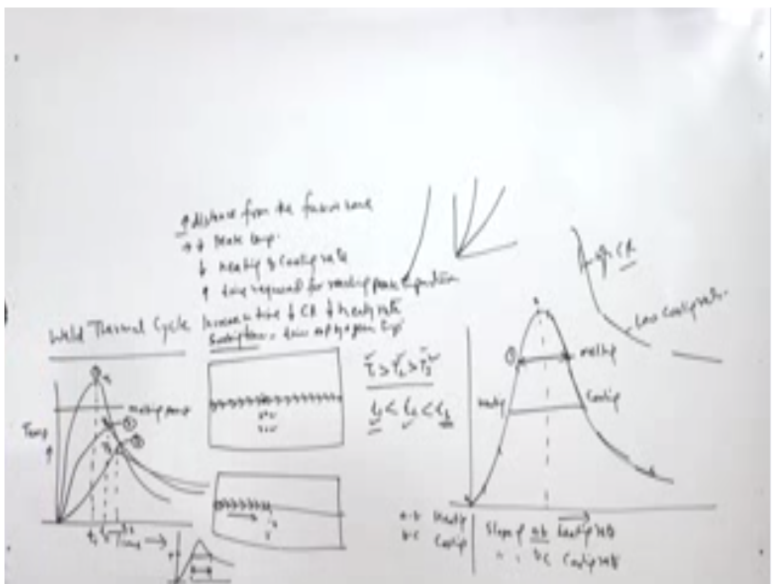

So the topic is weld thermal cycle, weather it is the fusion welding or the resistance welding whenever the external heat is supplied for the purpose of the softening of the metal like say infusion welding, the weld is made like this by applying the heat through arc or through the flame and if we see the different points, either in the weld central line like location 1 or slightly away from the weld location 2, location 3.

So say these are the three points which are located 1 at the fusion at the weld and other two are adjacent to the weld or near to the weld. So if we try to measure or try to see the variation in temperature at these 3 locations, then we will see that during the welding there is continues change in temperature of these three locations, say several figure like this, location 1, location 2 and location 3.

So as our heat sources starts moving from this point and as it approaches to these points, point 1, 2, 3. So, initially there will be heat, these points will be receiving the heats so there will be rise in temperature. So this variation in the temperature of the point 1, 2, and 3 can be plotted here in Y axis we have temperature and in X axis we have time. As a function of, you can say the welding time starting from the beginning to the end until it is completed.

So for the point 1 which is falling in weld there will be very sharp rise in temperature and then it reaches after reaching, its temperature start decreasing gradually. So, if this is the melting point then obviously the point 1 will be reaching to the fusion states or it will be melting, so this is the melting point. Then, the point 2 which is still in solid state has not been melted in course of the welding, will have the lower temperature.

So here the rise temperature will take slightly longer time and then it will be cooling slowly like this, so it will be taking here. It has taken say this much time to reach to the peak temperature, the point, this is weld thermal cycle corresponding to the point to or variation in temperature as a function of time for the point 1 which is in the weld and the point 2 goes in like for the variation in temperature as a function of time for the point 2 goes according to this here.

And if we draw it for the point 3. Then we will see like this, so what it shows, what it shows this is for point 3, so if we will see the point 1 showing the very high peak temperature and it takes very less time. For point 2, the peak temperature is somewhat lower, this is the peak temperature, T2, T1 and T3, so if you see these 3 diagrams, T1 is greater than T2, is greater than T3. Similarly, time wise also, here this is say small T1, small T2 and a small case t3.

These 3 are representing, T1 takes a minimum time, T2 longer time and further T3 further longer time, so if we will see the point at the fusion in the fusion zone will have the higher peak temperature. Maximum peak temperature or temperature will be above the melting point while point 2 will have the higher temperature than the point 3 which is away from the fusion boundary.

So this is the complete diagram. I make it one separate one here like this, so like point A to B is one regime where heating is involved and point B to C is another regime where cooling or reduction in temperature takes place, so this is the cooling regime. So these are two parts we can say as far as the weld thermal cycle of a particular location is concerned and the period between the two means, the area under this zone source the time corresponding to a particular temperature.

So this is the time period at which this temperature is held or above this temperature the time for which the temperature, this much temperature is held or if we draw another line this is that time for which it is held like this. So the gap between these two indicates the time period for which particular temperature is experienced by a particular location. What we can see A to B shows the heating and B to C shows the cooling pattern.

The slopes, if we will see here minutely, the slope is increasing here so slope is changing, so initially here the temperature when the slope is positive, the heating takes place and when the slope is negative cooling takes place and this slope can vary significantly. This slope can go like this or this slope can go like this, so the slope indicates, the slope of AB line indicates the heating rate.

Because it will be showing how much time it will take to reach a particular temperature say from room temperature to this temperature or to the peak temperature. The slope of the B indicates the heating rate while the slope from the B to C, slope of B to C, which is also changing like it is very high then it keeps on changing. So here high slope indicates the high cooling rate, somewhat low cooling rate.

So the slope basically indicates the rate of heating at a particular, in a particular segment, like this segment or this segment or this segment similarly between any period like the cooling face, between these two time while is cooling rate is too high then it will keep on decreasing, so heating as well as the cooling rate in course of the welding at a particular point keeps on changing that is what we can see from the slope of this curve.

Slop of AB shows the heating rate and slope of BC shows the cooling rate. So if we see, this is the typical weld thermal cycle and this kind of pattern is found for each point, this is what we can see. The weld thermal cycle for the point 1 shows the very high heating rate, high peak temperature and then high cooling rate also, as it reflects from the slope of the curve showing the heating and slope of the curve showing the cooling.

Similarly, for the 0.2 the slope is what lesser than that of the slope for the point 1 indicating that heating rate experienced by the 0.2 is somewhat lower and the cooling rate is also somewhat lower as it reflects from the lower slope. Similarly, the 0.3 shows that heating rate is further lower for the point 3 and similarly the cooling rate is low, so conversely what we can say here from this one that as the distance of the point increases from the weld centre line.

What we see increase in distance from the fusion zone, basically what it does, decreases the peak temperature. This is one, it decreases the heating and cooling rates with the increase in distance from the fusion zone, increases the time required for reaching peak temperature. This is what we can see that the point 3 is furthest from the fusion zone, T2 is closer and T1 is very close or in the fusion zone.

So the peak temperature is high while the peak temperature is decreasing, similarly the time required to reach the peak temperature it is minimum for the point which is very close to the fusion zone or in the fusion zone and then the time. It takes somewhat longer time to reach the peak temperature, if the point is located away from the fusion zone like this point 2 and the point 3 which is further away from the fusion zone, it takes further longer period.

So the time required to reach the peak temperature increases with the increase in distance. There is one more point related with the weld thermal cycle that as a function of time, as the time increases, the slope keeps on decreasing. This is what we can see, so increase in time basically decreases the cooling rate and also it decreases the heating rates. These are the four-point information which can be gathered from the weld thermal cycle of a particular point.

In addition to this what we can obtain that the soaking time. Soaking time is the period for which a particular point experiences the given temperature or above that temperature, soaking time is also can be obtained. Soaking time is the time experienced by a time for which a particular point experiences a given temperature, so if we see here, the temperature experienced by a particular point, say weld thermal cycling for the point 1, say this is the weld thermal cycle.

So this is the melting point so the molten metal remains above the melting temperature for this much period and if the point 2 like say if in this cycle if you want to see. Here, there is what we can see and this one if this is the weld thermal cycle for point 2, so the temperature of interest is the T, so the time for which it is above a particular temperature can be obtained from these two points.

So this time difference will tell us the temperature for which the point 2 was exposed for above a particular temperature. So basically weld thermal cycle will also be telling us the soaking period at a particular temperature. So because these are the points which are important from the effect of the weld thermal cycle on the quality of the weld joint in general and the mechanical and metallurgical properties of the weld joint in particular.

So how does it affect the properties of the weld joint and what are the different factors that effect to the weld thermal cycle that is what we will see now. So the factors affecting the weld thermal cycle. So, basically, there are three important factors which affect the weld thermal cycle. These are like the amount of the heat being supplied per unit length which is a net heat input and the second is the pre heat temperature of the base metal and third is the base metal characteristic.

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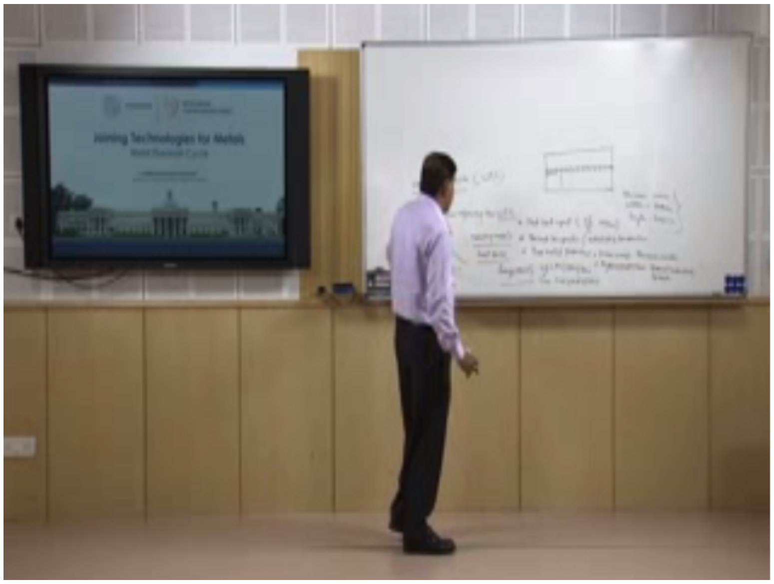

So if we will see the factors affecting the weld thermal cycle, in short we can WTC, weld thermal cycle. So basically if we take these caretaker arrangements like this is the plate of a thickness say 10 millimeter and width 50 millimeter and length 200 millimeter, say these are the dimensions, so during the welding when heat is supplied for the fusion, how fast is heat extracted that determines the weld thermal cycle at a particular point.

So few things are important like since each point experiences unique history of the temperature variation as a function of time and that is why weld thermal cycle of each point becomes unique and accordingly it affects the metallurgical and mechanical properties of the weld joints. So if you have to see this, like the factors that affect the weld thermal cycle one the main one, it is called net heat input.

Like, in case of typical fusion welding processes or in case of resistance welding process it is the amount of the heat that is delivered so heat input in that case we can say which is obtained like say in arc welding process, it is obtained like VI/S which is normally expressed in kilojoules per mm. So it is net amount of the heat being delivered per unit length. Another one is the pre-heat temperature of the base metal plates, preheat temperature or we can say initial plate temperature.

The third one the base metal properties, so basically there are two types properties that are important one is the dimensional properties which includes like thickness, width etc. and the another one the physical properties or you can say thermal properties, physical properties and these include thermal conductivity and specific heat.

These are the two important properties of the material that effect the weld thermal cycle. So we will take up all these points one by one, say weld thermal cycle goes in like this for one particular point, it goes in like this, so heat input. If the amount of heat billing, net heat input being delivered depends upon the metal being welded as per requirement. We use suitable heat source heat source or the welding process which will be self supplying the required heat, so heat source.

This basically are how much amount of it will be supplied by the heat source for the fusion purpose that in turn depends upon the energy density associated with the process. So energy density or the power density of the welding process which is like a high for laser beam welding, electron beam welding and a plasma arc welding, while it is low for like say gas welding, SMA, sealed metal arc welding or submerged arc welding.

So for this process it is low, so when the energy density associated the process is height it delivers lot of heat in very less time, so heat required for the fusion purpose is very low with the high energy density processes as compared to the low-energy density processes. So, if we have to compare the heat input what we will see that the higher is the energy density related with to the process lower will be the actual amount of heat that will be delivered for the fusion purpose. So, net heat input high or net heat input is low.

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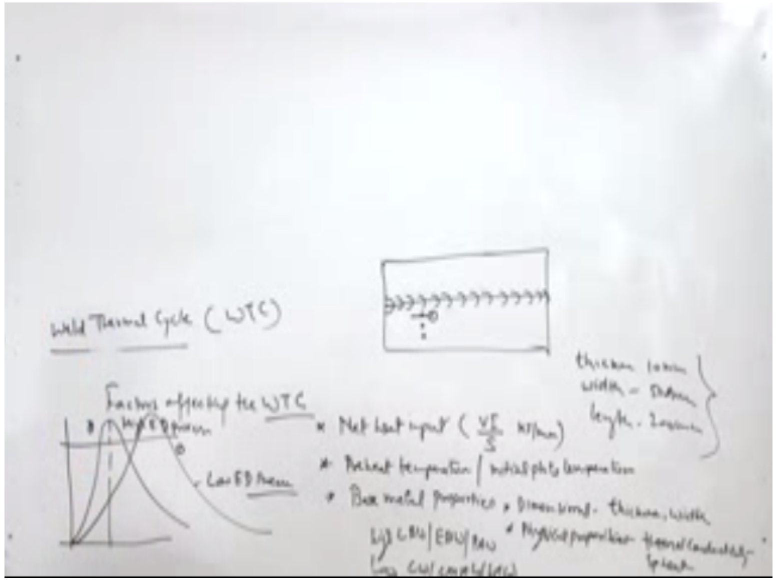

So when the heat input is low, in that case we supply very less heat to achieve the fusion or the melting of the base metal and in case of the high heat input we need to do a lot of heat for achieving the fusion. So in both the cases, in case of high heat input, the rate of the heating is so, in case of the low heat input for high energy density processes. It goes like this and for another low-energy density processes, it will be going like this.

What is the difference to, so this is a low energy density processes, like gas welding or submerged arc welding and laser beam welding or the electron beam welding. So here the peak temperature is attained in very short time, the rate of heating is high as it reflects from the low-energy density process. So, this is the rate of heating for the low-energy density process, this is the rate of heating for the high energy density processes.

If we take a particular point, this point is say here, point 1 and four which, the weld thermal cycles were developed for point 1 and for 1, for both, but the joint is made using the two different processes, one high energy density process, another low energy density process. In both the cases of course, we have to achieve the molten state but the rate of heating and the rate of cooling which is achieved in case of high-energy density processes are much higher as compared the case when the low-energy density processes are used.

So if we will see here the low-energy density processes will be offering one weld thermal cycle which will be different from the low-energy density processes for the same location in the weld joint. The point is same but when we try to see it, try to weld using the two different heat inputs, then the weld thermal cycle achieved is found to be different. If this point is farther away from the fusion boundary.

Then, we will see that in case of high-energy density processes, the peak temperature rises less, if the point is for located away from.

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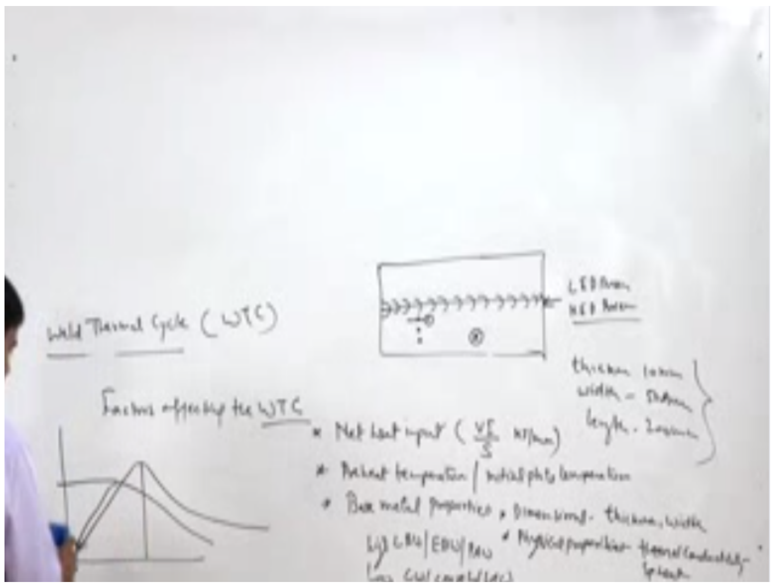

Like say here the point is this one and for this point if we will see weld thermal cycle in case when this weld is made using both low energy density process and high energy density process. High-energy density processes like laser beam so, what kind of her the thermal cycle we will getting in case of low-energy density process, will be getting higher peak temperature and then lower cooling rates.

It is possible that we may not reach to the too high peak temperature and then cooling will start like this, so the peak temperature is actually reduced because we are not delivering much of the heat, if the point is located away from the fusion boundary and it will take, in case of low-energy density process. Of course, it will take longer time but it will take a lot of heat also, so the peak temperature will be high even if the point is located away from because ability a lot of heat.

So the peak temperature increases of a particular point with the low-energy process because we need to supply lot of heat. Further it will take longer time to reach the peak temperature but the peak temperature will be high so soaking periods will be high.

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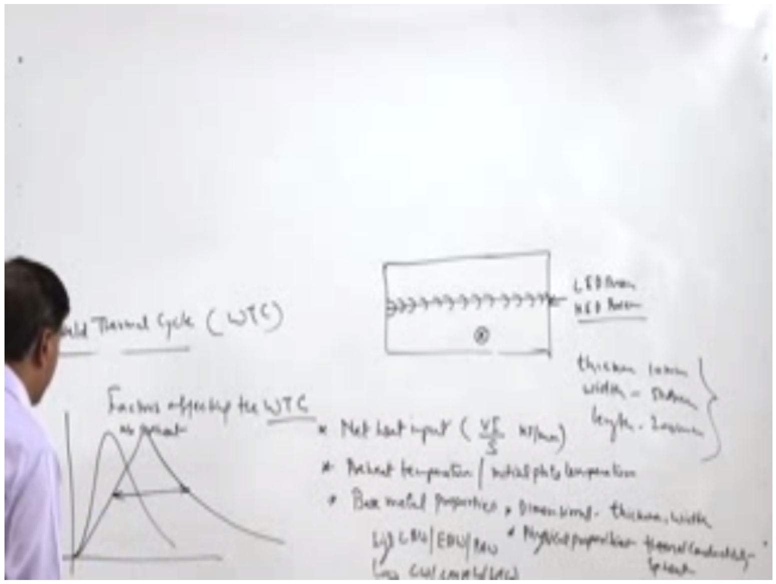

Another point is about the preheat temperature, so in case there is no preheating, the things are at room temperature, so the things will go like this, means the rate of heating is high and the rate of cooling is also high when there is no preheat and say and when the preheating is used the rate of a temperature rise, decreases, it reaches to the peak temperature and then it is starts cooling slowly.

So here the slope is low, so rate of heating is a reduced, rate of cooling is also reduced but at the same time the soaking period is increased.

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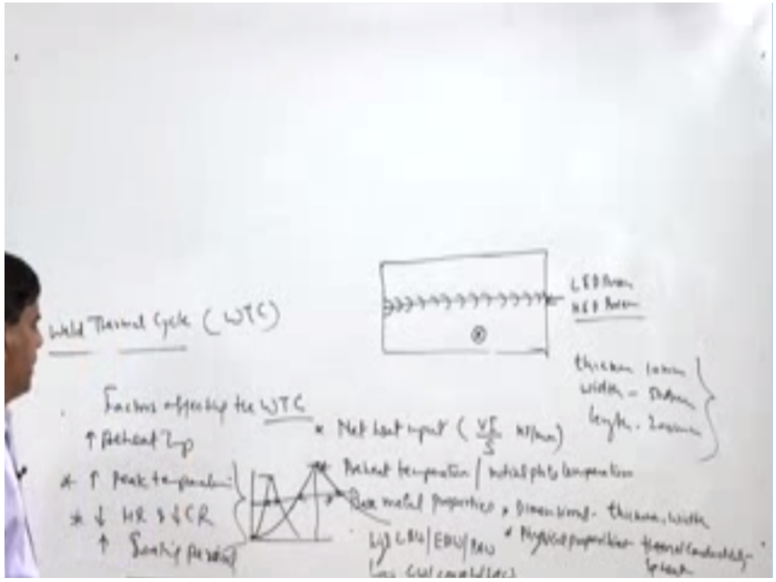

If this point is located away from, then we will see that, what we will see, with the increase in preheat, what we get, simply increase in the heat temperature what it does increases the peak temperature, if it is located away from one but at the same time it reduces the heating rate and it reduces the cooling rate. So these are the two things at the same time it will be increasing the soaking period.

Soaking period has lot of affects on the metallurgical and mechanical properties of the weld joints, that is what we will seeing subsequently, so corresponding to this one if we will see one with the no preheat and another with the high preheat, will be going like this. So peak temperature, this is with the preheat, so will have higher peak temperature then lower cooling rate, peak temperature with the no preheat.

Peak temperature is low and peak temperature is high soaking period for a given temperature, soaking period is very less and here soaking period is very large. It takes longer time to reach to the peak temperature when there is no preheat, it takes a shorter time to reach to the peak temperature, so rate of heating and cooling both are reduced.

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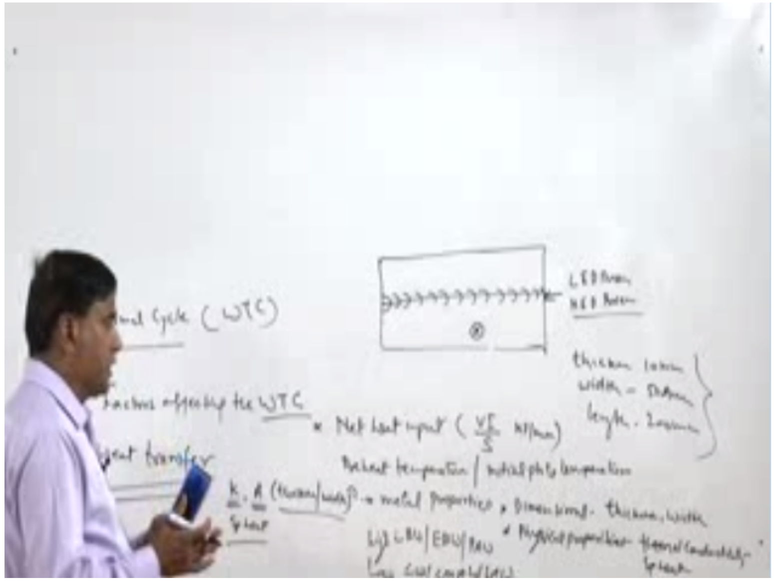

Now, we will see the effect of the base metal. The base metal has the two aspects and both are related with the heat transfer. We know that heat transfer from the fusion zone effects the rate at which heat will be extracted the from the weld area wherever heat is supplied, so are basically the thermal conductivity and the cross-sectional area affecting the heat transfer away from the area where heat is delivered during the welding like A which is influenced by the thickness of the plate and the width of the plate.

These are two factors which will be governing the in that the area available for transfer of the heat so basically the thermal conductivity area and specific heat will be determining how fast heat is transferred away from the location of the interest.

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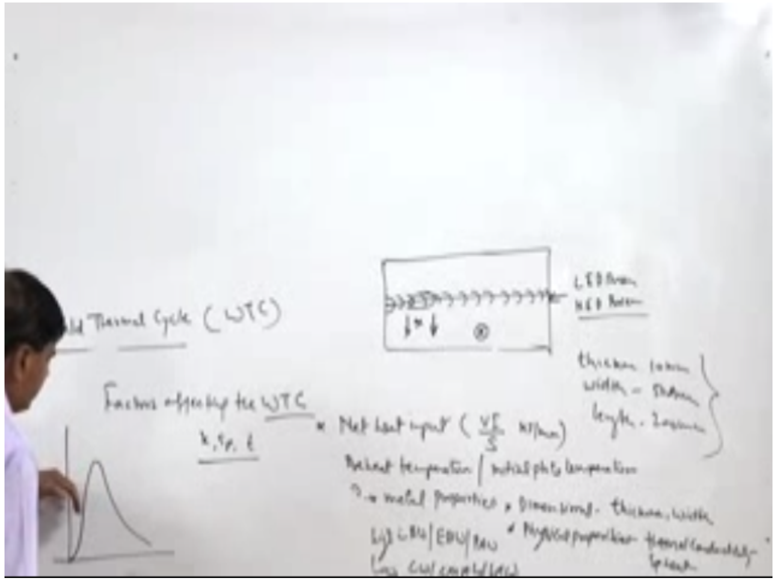

So, if with the heat is transferred rapidly from the, like heat is being delivered here and this is the point of interest then heat will be extracted, if the heat is extracted faster, and the peak temperature will be reduced, it will take longer time to reach to the peak temperature, so as far as the base metal is concerned increasing all the factors like K specific heat and the thickness. All the factors that are affecting the heat transfer rate.

They will affect the weld thermal cycle in one particular way, like say this is one for, if the heat is transferred rapidly, then what we will see that the rate of cooling will be high and the peak temperature attained will be less.

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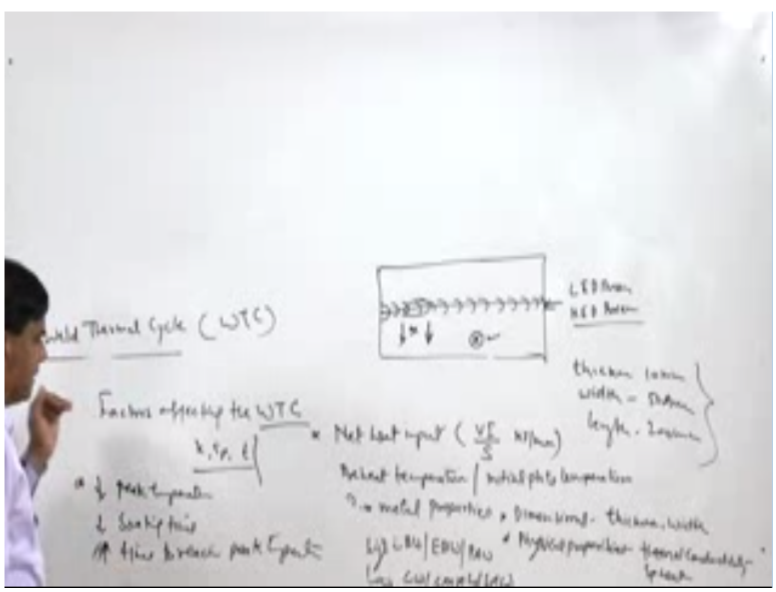

This is what we can mention for this purpose that the increasing thickness, increasing thermal conductivity for a particular point lowers the peak temperature, it reduces the soaking time above a particular temperature of that point like say the point is here so with the increase in thermal conductivity specific or the thickness of for this particular point the peak temperature will be reduced, soaking time will be reduced.

And it will increase that time to reach peak temperature, etc., like this. This is how we will see that weld thermal cycle is affected by the material properties in terms of the thickness and the thermal properties. So, what we have seen that the areas in the weld zone or next to the weld zone are affected by experience the different weld thermal cycles which means the different peak temperatures, different heating rates and cooling rates and different soaking periods above the particular temperature.

So since the heating rate, cooling rates and the soaking time determine the metallurgical structures of the weld joint and the rate of the solidification of the weld joints and therefore these factors determine the quality of the weld joints.

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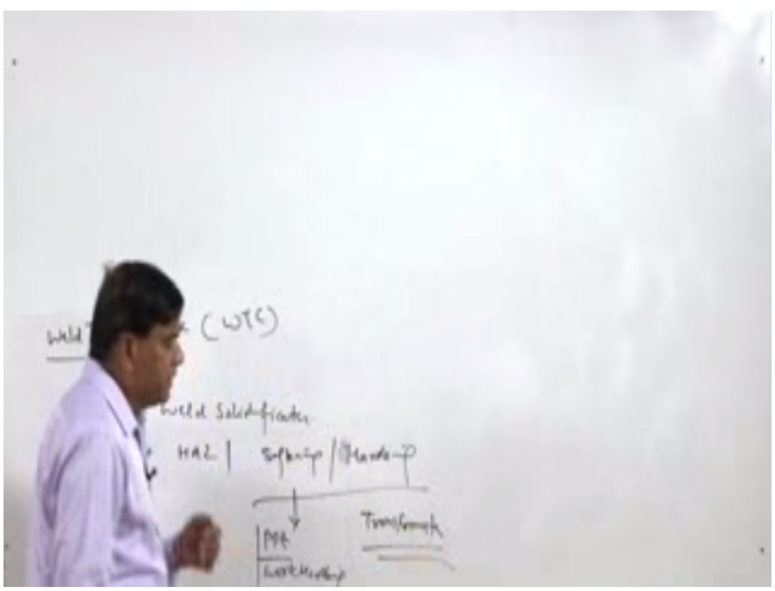

So weld thermal cycle basically affects the weld solidification which in turn determines the solidification structure whether it will be fine or course, it affects the tendency for the entrapment of the gases which in turn determines whether there will be porosity or not and it also affects the segregation tendency. Another thing is that it affects the HAZ structure and a since the heat affected zone has the different metallurgical structure as compared to the base metal.

So the properties are found to a different from the base metal. This may be different in terms of the softening or hardening, so there can be the softening of the base metal or there can be hardening also of the base metal so we need to see that depending upon the kind of metal system there can be softening or there can be hardening.

What is normally observed with the precipitation hard enabled system and work hard enabled systems basically softening is observed in case of the aluminum alloys while hardening is observed in case of the transformation hard enabled systems like steels during the welding. Depending upon the specific metallurgical aspects then maybe are the different metallurgical structures which will be governing the mechanical properties of the weld joints.

So, here now I will conclude this presentation which was related to the weld thermal cycle. We have seen the typical weld thermal cycle what are the information which can be gathered from the weld thermal cycle and that what are the different factors that affect the weld thermal cycle and why it is important to note about this. We have seen that a weld thermal cycle effect the weld metal properties and also the heat affected zone characteristics that it is why it affects the quality of the weld joint. Thank you for your attention.