Analysis and Modelling of Welding
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Lecture - 08
Zones in a Weldment

Welcome to the lesson on Zones in a Weldment, as part of the NPTEL MOOC on Analysis and Modeling of Welding.

In this short lesson, we will be discussing the different zones of a weldment which we have been referring to in our lectures, such as fusion zone, heat affected zone, partially melted zone, etcetera. We will define them concretely, and how to arrive at their dimensions using the simulation and also, what is the way to control their widths.

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What does welding do to the material?

So, let us just look at what does a welding process do to different locations on the sample surface or the weldment.

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So, if you look at the process, what happens is that, there are points which are just below the arc or the heat source. These undergo a complete fusion, in the case of fusion welding, which is our topic. So, basically, what happens is that, you have melting, followed by solidification, and for most of the industrial alloys, you do also have things like precipitation of phases that are going to strengthen that material, for example, in the case of steel or aluminum alloys etcetera.

So, you also have precipitation, that is going to take place; and also, phase transformations, such as in the case of titanium alloys, you have transformation from BCC to HCP, as you go below the beta transit temperature. So, like this, there are, various things are going to happen for the material that is right under the heat source, and if you look at what is happening here, it is almost as if you are actually performing a mini ingot of solidification and processing, right under the arc. So, in a way, the welding is going to redo whatever we have been doing to that material right from the beginning, and for the points which are slightly away.

From the heat source, if it is slightly away, then what happens is that, they will not undergo melting, but then, they do undergo heat treatment; and, which means that, we need to keep this in mind while analyzing what would be the effect of welding on that particular material, and very often, a material is called weldable, depending upon what is happening during these processes under the weldment.

So, let us look at them little bit closely.

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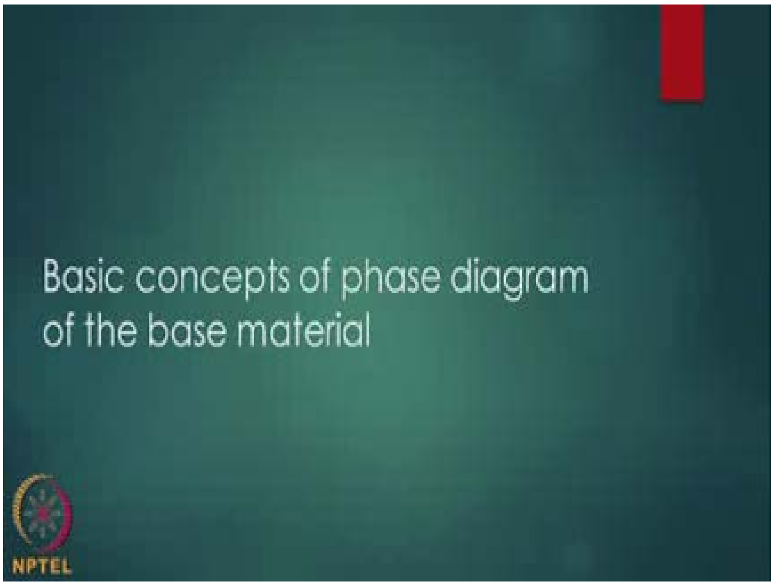

Basic concepts of phase diagram of the base material

Before we proceed further to find out the widths of different zones, and how to identify them, we need some basic concepts of phase diagram. Let us just look the phase diagram; what normally can be referred to in industrial alloys, which are very close to pure metal with alloying elements. So, we will look at that kind of a situation applicable for aluminum alloys, steels and titanium alloys, towards one end of the phase diagram. Let us look at that, to refer to those points which are referred in the calculation of the widths.

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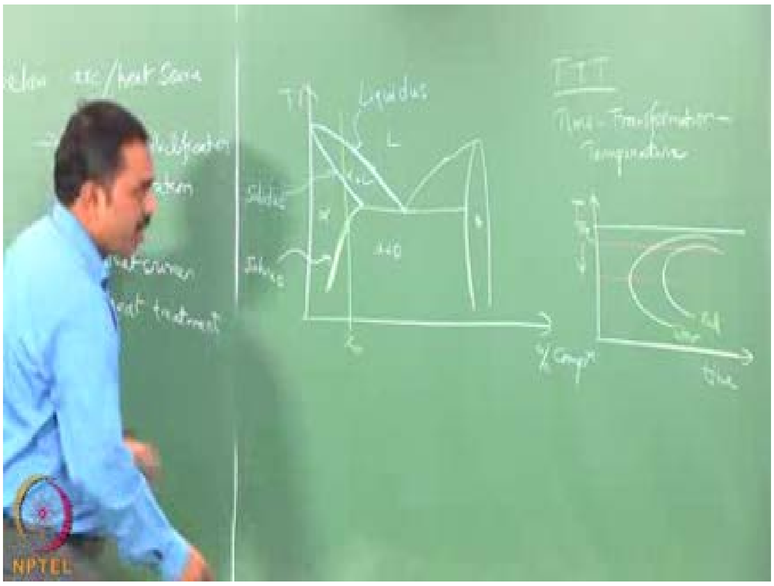

So, most of the phase diagrams for these technical alloys look like that; you have got temperature along this axis; this is a percentage composition of the element; and, you would usually have the phase diagram going like that; and, you have the phase which we are talking about, and the different zones; and you would, in the case of aluminum for example, you have a situation, aluminum alloys, you have got theta and alpha plus theta; in the case of aluminum, copper system; but, you could also modify that to be something else also.

And, above a (Refer Time: 04:06) temperature you have got liquid, and you have got alpha plus liquid. So, the reason why I am showing this schematic is that, I want to alert you to this particular point, locus of these points, which is called as liquidus. And, this zone, between which the alpha and liquid will be stable, this is called as the solidus. So, these are important, because, it is above a temperature that is known as liquidus that the material reaches fully liquid region, and that is important for us to define what is the fusion zone.

And, there is a temperature, above which the melting would start happening, and that is called as the solidus. And, there is another temperature here, which is also important for us. If this were to be initial composition, for example, there is this temperature, above which you would see that a two phase micro-structure would become single phase solution. And so, this is also going to be important for us, and this line is called as a solvus line.

For most of the alloys, you need to find out what would be the applicable phase diagram, and this is a schematic for a binary. But, such schematics can be available for even multi component alloys, when we take the most important alloying element that has to be varying, for our discussion. So, this is something basic, that we need to know from the phase diagram. And, what happens whenever you have any kind of transformation is that, there are going to be kinetics associated; that is, these transformations cannot happen instantaneously; there is some time that will be required to have these precipitates come out.

For example, in this case, the theta is to come out of alpha, and there will be certain kinetics that is involved. So, some basic concept that is required is coming under what is called as the TTT curves. These are what are called Time, Transformation, and Temperature. So, essentially, how would the variation of temperature, would cause the transformation to take place, after different amount of times that is the kind of concept that we need; and, those plots would look like this. If this, for the temperature below which the transformation is supposed to happen, then, these curves would look like that; which means that, as you go below the equilibrium temperature, at which the precipitate is supposed to come out, then, the start, the start, and end of the transformation is going to take certain amount of time.

So, let us take some temperature like this. It means that, this much of time is required for the precipitation to start, and then, the precipitation is over by that much of time beyond. And, you would see that, as you keep decreasing the temperature, you would require less and less time to start the transformation.

The reason why this happens is because, as you go below the equilibrium temperature, you have basically increased driving force, so that, you could have the precipitation taking place, and the nucleation rate also goes up, and therefore, you would have the gestation time, incubation time, required for the start of the transformation that is reduced. And, these are the concepts that are generally available in a physical metallurgy course; you could refer to any of the popular books on physical metallurgy to go in depth into this. What is applicable from this concept for welding is - what is called the CCT curves, which is a derived concept from the TTT.

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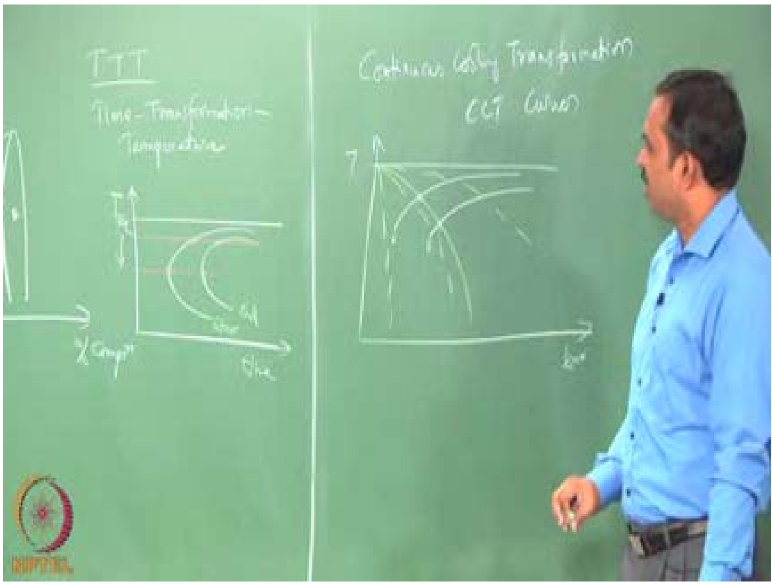

So, Continuous Cooling Transformation, CCT curves, and they look very similar, except that, they are supposed to be applicable for continuous cooling, and they look like that. So, the start and the finish are like this; and, these are to be interpreted where, if the location under the torch, slightly away from the torch, which is undergoing some heat treatment, if the temperature at that location is going to follow a particular pattern, then, it will tell you, after how much time the precipitation would start, and after how much time the precipitate would finish up.

And, depending upon the cooling rate, you could see that, it takes different amount of times. And, there could be cooling rates for which the precipitation itself is not at all possible. So, that is very high cooling rate, where actually things are going to happen. So, this concept CCT is going to help us in telling what would be the definition of heat affected zone.

So, these three concepts, that is, basic construction of a relevant phase diagram, and then, the CCT are required for us to determine the different zone widths analytically, and through a simulation. I want to alert you that, this is a simple phase diagram, but in the case of technical alloys, you may have multiple phases in the pure metal itself, as you go up in temperature. For example, in the case of steel, as well as in titanium, you do have phase transformations that are happening. And, those cut off temperatures are also going to be important. So, we will look at effects of those, as we go along, while defining the different zones.

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Dissolution versus Precipitation

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So, a word about what is called the dissolution and precipitation, I want to mention, and I would just do that by looking at a schematic, for a point that is away from the fusion zone.

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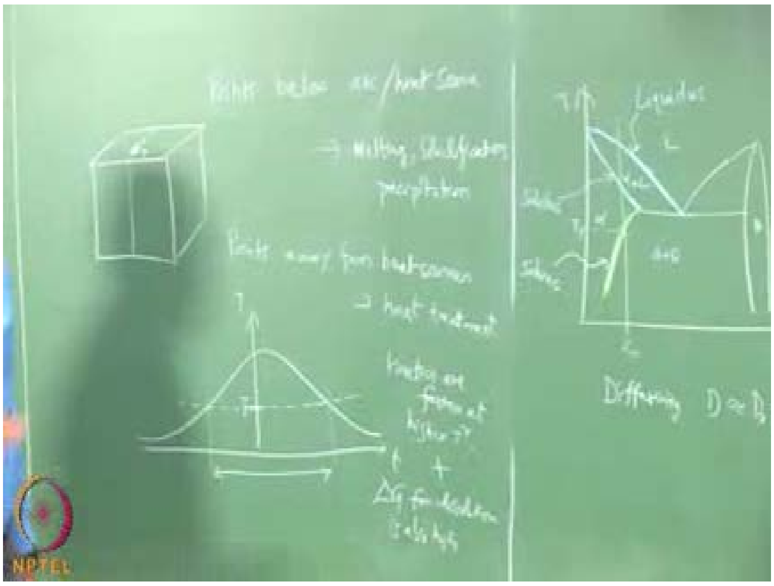

So, let us just draw where we are looking at. So, if this was the weld pool, I am looking at a particular point that is quite close to the weld pool, but not under the arc, and not so far away that the heat is not felt at all. So, if you look at that location, and see how the temperature versus time plot is going to be, I choose the origin to be where the peak is felt. So, you could have a temperature of this kind, and temperature plot would be like that. And, on this temperature axis, I can mark a critical temperature for the composition of the alloy, above which you are supposed to see that, the precipitation is supposed to dissolve. So, you would then draw that here, and this point, let me put as T 1; what I mean is this, T 1; T 1 is something like that.

For that particular alloy, x naught alloys, T 1 is the temperature above which the precipitate is not supposed to be there. And, that is the temperature here, we are saying; and, this temperature, peak temperature, may not be the melting point. So, we are talking about a point away from the fusion zone. So, what happens here is that, how much time is available for the material to dissolve the precipitate theta as I have shown here; this is the amount of time. So, it is a lot of time. And, for most of the duration in this time, the material is actually exposed to temperatures above the T 1, and above the T 1 would actually mean that, the kinetics is going to be faster. Generally, at higher temperatures, the kinetics is faster. The reason is as follows.

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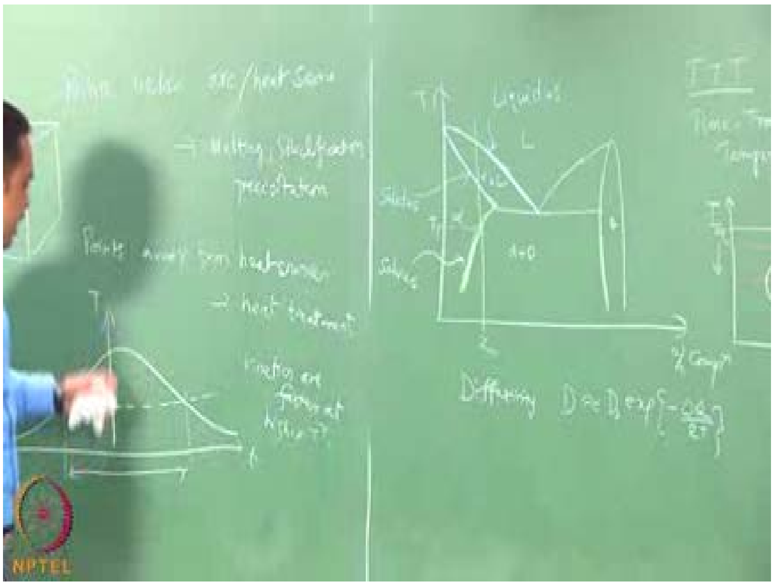

You have, usually this kinetics depending upon the diffusivity; and diffusivity is generally given in the form of the Arrhenius relationship, where the activation energy for the diffusion is given in the exponential, and the temperature at which we are looking at, is given in the T. So, you can see that, at higher temperatures, you have got basically, the denominator is large; that means, that you have got the entire number small, and that is going with the negative sign, which means that, you would have basically, division with a smaller number, giving you larger diffusivity.

So, diffusivity is high at higher temperatures. It means that, the atoms can actually go away from the precipitate to dissolve easily, when you are going above the T 1 temperature. The kinetics is not the only one factor; you also know that, as you are going above T 1, then, you are actually, equilibrium is actually demanding that you are supposed to dissolve; so, which means that, the driving force for dissolution is also high.

So, because of these two reasons, what is normally expected is that, as soon as you have a location in the weldment which is exposed to high temperatures, if there are any precipitates that are supposed to dissolve, then, the moment the temperature is going to exceed the equilibrium temperature, below which precipitate is there, above which it is supposed to dissolve, then, dissolution does happen. So, there is no argument usually that, dissolution, will it happen or not; it is taken into, taken as granted that, dissolution does happen. So, precipitate dissolution is something that, we can expect because of the thermal cycle that is experienced in the weldment.

And, precipitation, on the other hand, may not happen the same way. The reason is that, for precipitation, you have this situation that, as you are going down the temperature, that is, in this part; it is in this part that the precipitation is supposed to happen. So, I would just mark; it is in this region that, you have got dissolution; and, in this region, you have got precipitation.

So, you can see that, as the time is proceeding, you are at lower and lower temperatures, and precipitation is then dictated by certain amount of time, and the kinetics are going to be different, as you keep going down, which means that, it may be possible that precipitation is not going to be complete; you may actually end up with the single phase micro structure, even at room temperature, because precipitation has not finished.

And, which means that, between dissolution and precipitation, you can say confidently that, in welding, dissolution is generally going to finish up, but precipitation is not going to finish up. This has a consequence in the heat affected zone for the weldments. So, that is the reason why we are talking about that, and we will refer to this point, when you are looking at the widths.

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Initial microstructure of base material & changes possible

So, what are the aspects of initial micro structure that we have be bothered about these widths, these different widths. So, the initial microstructure of a weldment is going to have liked this.

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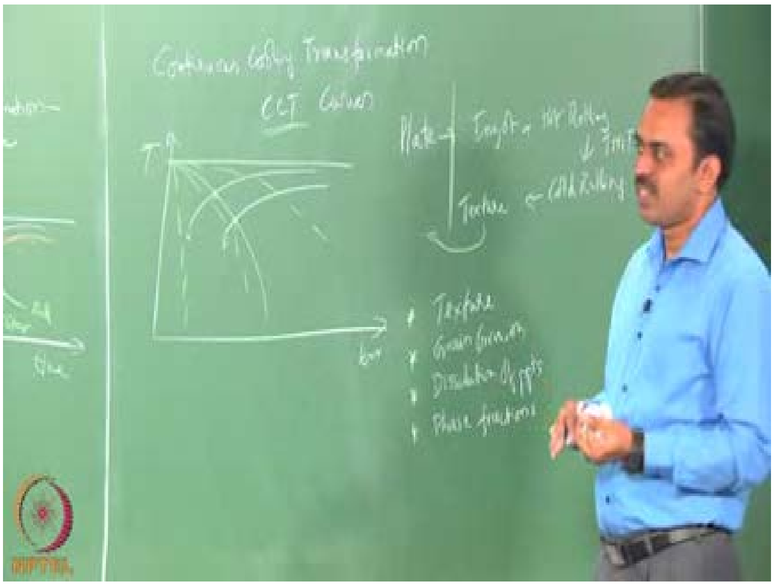

Usually, it will be a plate, that you are going to weld; and this plate usually, is going to be undergoing, initially, you have got ingot, and then, how does a plate come. So, you got a ingot, and you have got a hot rolling, and after that, you have got cold rolling, and in between, you may have also thermo-mechanical treatment, and finally, you will have a desired texture, for the optimum properties, and that is how the plate is going to be there.

Now, such a plate, for example, which you are going to then weld, implies that, you are going to superpose a thermal cycle on the top of this micro structure, which means that, the some of these things that have, are happening during the production of the plate are going to be wiped off during the heat treatment cycle. And, what are the various things that will happen? You can look at what is happening here. For example, the texture will be disturbed; things that will change; if you have a very fine grained micro structure, then, you would expect that grain growth may happen.

If you have precipitates, then dissolution of precipitation may happen; and, if you have, for example, phases, then, the phase content can change; phase fractions, in the case of, for example, dual phase steels, and alpha beta titanium alloys, you may expect that, the phase fractions of those phases may change, depending upon the welding cycle.

So, as you can see that, much of what is going on in the design of the material is going to undone during welding, and therefore, we have to understand, what is the width over which all these things will happen, so that, for that width, we can try to minimize the damage or at least, address it by a post weld heat treatment to recover back the properties. So, this is the background over which we can then build upon to see how to handle different zones.

So, some terminology of the zones and these are already mentioned to you, but let us just talk to them, talk about them briefly.

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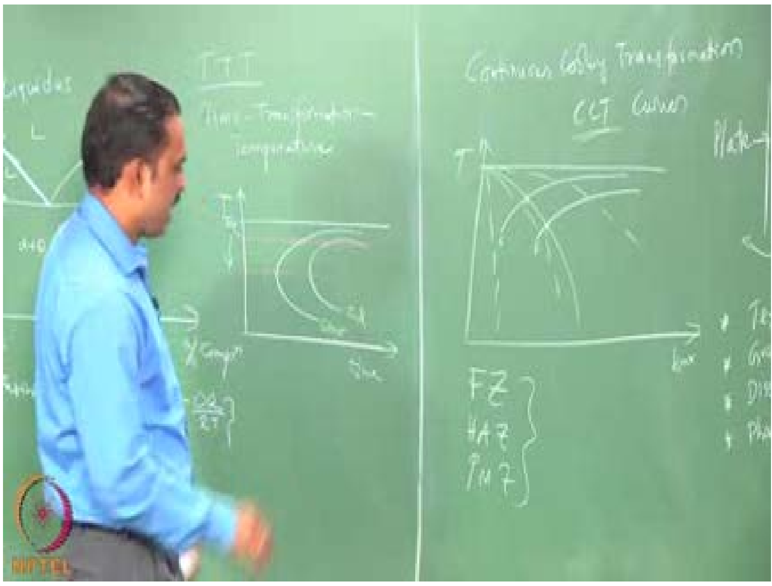

The different terms are as follows: we have got them as fusion zone, and heat affected zone, and partially melted zone. And, in the case of friction welding, you may have also thermo mechanically affected zone and so on, but in, in most of the weldments, these three zones is adequate for us to look at. And, fusion zone is what is right under the torch, which is molten; heat affected zone is slightly away from it, which is basically affected by the thermal cycle, and microstructure is actually changed a little bit on those aspects.

And, PMZ is between these two, which is basically going to experience a little bit of a melting, and that is important for alloys where cracking tendency is going to be critical. So, let us analyze these three zones by looking at how to determine them, and how to know the width. So, we will take the fusion zone first.

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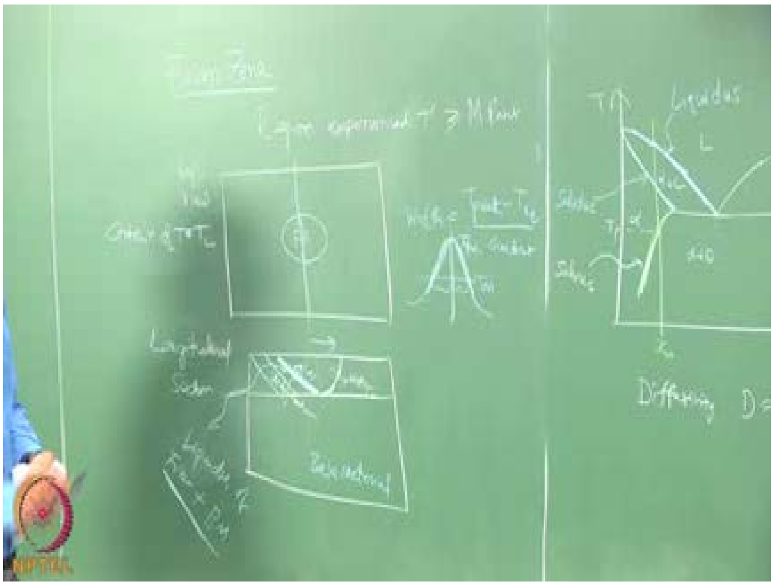

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So, let us take the fusion zone. So, the definition is that, it is that region which has experienced a temperature which is greater than or equal to the melting temperature or melting point; so, which means that, you could actually visualize the fusion zone analytically as follows. If you have the, one of the sections, let us say top view, for example, of a weldment, then, make a contour of temperature is equal to T m, then, the region enclosed by that contour is the fusion zone. In other words, that is the region where the temperature has exceeded the melting point, which means that, that is the molten region and that can be called as the fusion zone.

And, in situations where melting point is not the appropriate parameter, for example, in alloys, you normally have to refer to the liquidus, you can say that, you may use this as the fusion zone definition. So, that is, liquidus temperature can be used as a contour for the particular alloys. So, for x naught composition, you can say, this is the temperature, liquidus temperature, which can be taken for the contour, and then, you get the fusion zone. And, there is a small variation to that, which we can pay attention to, and for that, we can look at what is called the longitudinal section.

In the longitudinal section, as we have discussed earlier, you normally have possibility to see the direction of the torch velocity, and if this was a center point, then you know that this was the liquid region; and in the front of the torch is where the melting is happening, and behind the torch is where the solidification is happening. So, you could think of the fusion zone boundary as two parts; one that is ahead of the arc, and one that is behind the arc or heat source. So, there is one part here, and one part there. The reason why I am trying to show this as two halves is as follows.

In the part of the melting, usually, the alloy that you have chosen, this is the base alloy or the base material; you can look up the phase diagram to see what is the liquidus temperature for this base material, and that will become the contour for the fusion zone here, in the front. So, that is very simple. On the other hand, for the back side, there can be a variation. For example, let us say, you are using, not an autogenous or a homogenous filler kind of a welding, you are using, for example, heterogeneous filler in a welding situation which means that, the composition of the liquid zone is not the same as the base material; it has been modified.

If it was modified, for example, then, on the back side, where it is going to solidify, it is determined by the solidification temperature of the alloy which is in the melt pool, and not of the base material; and which means that, this boundary can be given by the liquidus of the alloy which is of the fusion zone. So, you can say that, this line is basically liquidus of the filler, plus the base material; it is an alloy which is a mixture of filler and base material, whereas, from the front, it is a liquidus of only the base material.

So, there could be a difference between the two. Why would anybody want to change that? Very simple; you have what is called as the freezing range, and if the freezing range of the alloy is large, I am referring to a freezing range here; this is the freezing range. The freezing range of the alloy is large, then, you normally have higher cracking tendency, and you may want to have alloying element such that, the fusion zone is having a freezing range that is very small, almost close to eutectic, and, that would mean that, the fusion zone boundary on the back end has to be changed in the definition. So, either way, experimentally it is very easy to determine that. You could actually disturb the welding torch, and take a longitudinal section, and etch it, and you normally see the disturbances causing some kind of ripples; and they can show you what was the boundary of the fusion zone on the back side.

And, if you switch off the heat source while still moving the torch, then, you can also see what is the front side of the fusion zone; and, you could use them to benchmark, what will be the shape of the fusion zone. Otherwise, if there was no complication of adding filler at all, if it is an autogeneous welding, then, simply take the liquidus temperature of the alloy, draw a contour and that would be the fusion zone. And, how would you define what is the width of the fusion zone? So, we could do that this way. The width is given by, if that was the width, then width is given by essentially, what is the peak temperature, minus what is the liquidus temperature, divided by the, what is the gradient experienced.

So, you could do it in two halves, for the rising part, and for the going down, and, assume it has been here, and this was the melting point; this is the peak. And, you can see that, widths can be taken as two halves; each half can be taken as peak minus liquidus, divided by the gradient, which will give you that width. So, one can actually use these kind of estimates to check the width for a scaling analysis.

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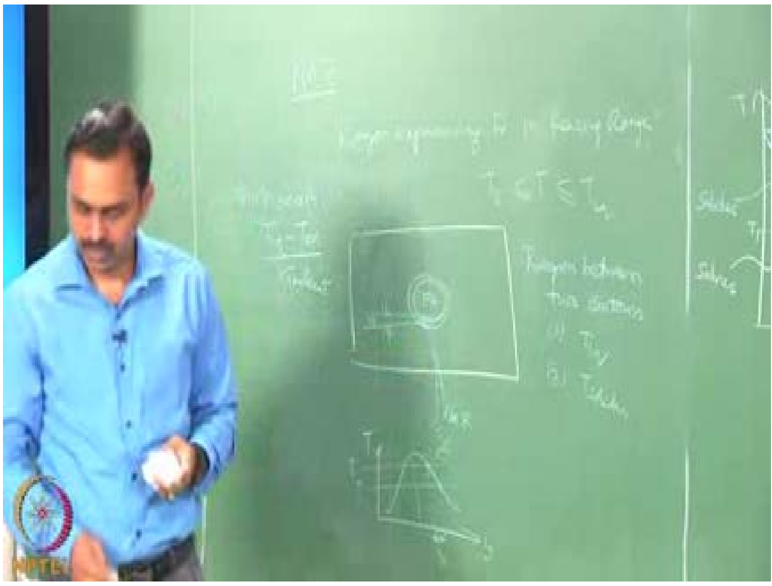

Let us now look at the partially melted zone. Partially melted zone or PMZ as it is called, is basically defined as the region that experiences temperatures, temperatures in the freezing range; that means, the solidus is less than or equal to temperature experienced less than or equal to the liquidus, which means that, what are those regions in the weldment which are experiencing a temperature given by this hashed range. So, this is a freezing range.

So, those regions are called as the freezing, partially melted zone. So, how would that would look like in a top view; you could then see that, if this was the fusion zone, then, you would have the PMZ away; this in-between that annular region is the PMZ. And, this PMZ is defined basically by two contours, unlike the fusion zone, which is by one contour. It is basically the region between two contours; first contour is basically the liquidus; second contour is the solidus.

And, these two contours would then show you, how much of the width is experiencing a temperature in the freezing range, and that freezing range is where the temperature is between the solidus and liquidus; that is why you call it partially melted zone. And, if you want to look at the width, and that is basically this width I want to know; that can be approximated. This width, PMZ width is approximately given by the difference in these two temperatures, which can be obtained from the phase diagram; so, which means that, T liquidus minus T solidus, divided by the gradient.

So, how would the temperature profile look like, along this distance y, if you were to plot temperature as a function of y, then, this is the peak temperature, and these are the liquidus and the solidus; and, I am assuming that, there is a linear plot here; and so, the width is given by this; that is a w; this is the w. So, that is given basically by looking at the difference in the two temperatures, divided by the temperature gradient, which is linearized in that particular range, and that will give you, which means that, if you are going to have issues in the welding, because of cracking, for example, due to the partially melted zone, then, you have to see what is causing that.

And, if it was, for example, the alloy which happens to have a large freezing range, you can change the alloy in the fusion zone alone by adding filler, which reduces the freezing range. You can see that the freezing range is zero for a pure metal; it is again zero for eutectic; and in between, it is varying. So, you can actually change it by changing the alloy content in the fusion zone. You can also change it by changing the gradient.

Gradient can be changed by change in the heat source or the cooling conditions, and you could then make it sharper or wider; and normally, if you make it sharper, then, the width is going to be reduced; and for extremely sharp gradients that are experienced in, for example, electron beam welding, you have basically, PMZ virtually absent. So, like that, you could actually control. So, this is how the PMZ is defined and looked at.

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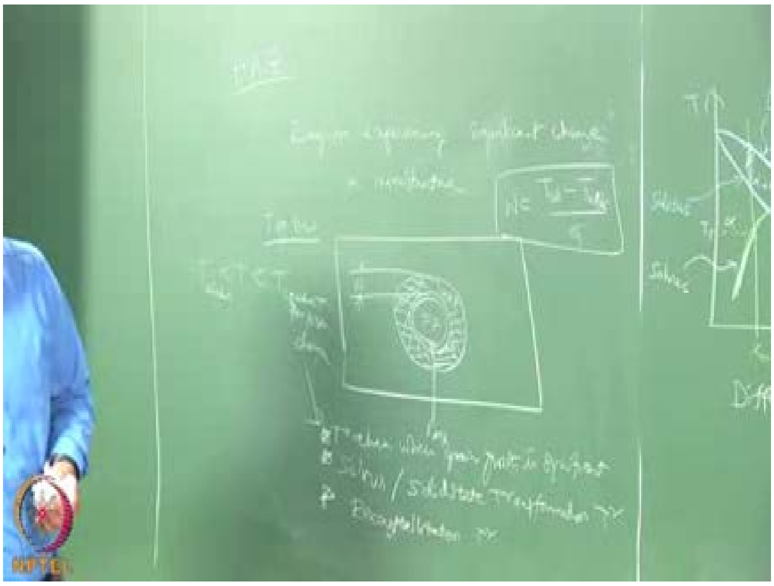

So, let us see how the heat affected zone is defined. So, heat affected zone is a bit tricky thing, because you would know what is affected by heat only when you look at the microstructure; you cannot apriori decide what would be called as a heat affected zone, because, the initial microstructure can be different for different-different welding plates, for a given alloy. So, you must always remember that, this is a bit tricky. And, the way it is defined is as follows; it is the region that is, region that is experiencing significant change in the microstructure, and of course, not fusion, because fusion zone also experiences change in microstructure, but is away from the fusion zone.

So, let us look at the top view and see what we mean by that. If this was fusion zone, and an annular region around it, we called it by the name PMZ. So, heat affected zone would be much farther away; it is also annular like the PMZ, but it is much farther away from the fusion zone, beyond the PMZ. Now, it also means that, this is a region encompassed by two contours; the first contour being the liquidus, so basically, when the temperature is between the solidus and some kind of effective temperature for microstructure change.

So, you take two contours, one contour you take for solidus, that would give you this line, this line; and, you take another contour, which is the temperature above which microstructure will change, that is this contour; and then, you see that, these are all the zone which the, heat affected zone can be referred to. And, which means that, this is the zone in which the microstructure has changed significantly. So, it is also annular like the PMZ.

Now, how do we define this temperature? The solidus temperature can be taken from the phase diagram of that material. So, that is not a problem; you can look it up. But, what about this temperature; so, this is the temperature that can be defined for a given context. Let us say, for example, a material which has no precipitates at all, like, for example, commercially pure aluminum, and you have just basically, only the grains. So, you can think of this effective temperature for microstructure change as temperature above which grain growth is significant. So, if grain growth is significant, it means that, heat affected zone is going to have coarse grains, and you want to define that by these contours, and that can be taken. And, there can be other definitions also.

For example, you could take the temperature which is, for a transition from; let us say in the case of low carbon steels, a temperature from above which you can go to austenitic microstructure. So, austenitizing temperature can be taken. In the case of titanium alloys, for example, where you can go to the BCC phase from alpha phase that can be taken. So, you can say that, solvus or solid state transformation temperature that can also be taken as a reference temperature to define what would be the heat affected zone.

In the case of microstructures which have phases, like you know the precipitates, then, it is also very simple; you can also take it as temperatures above which those precipitates will dissolve. So, that is a solvus temperature that we can take. Like this, you could define; and, in the case of a cold worked plate, then, you know that, for a cold worked plate, the microstructure, rolled microstructure can get re-crystallized at lower temperatures, with increasing amount of strain. So, you could also define that, as a temperature above which the re-crystallization can take place.

So, as you can see that, we do not have actually a single, universal definition of temperature, for what is heat affected zone, on the outer boundary, because it depends upon the material, but we do have some thumb rules for which we can use. And, this is where we can connect with what background we have looked at. So, as you can see from here, in the phase diagrams, this is a point above which you want to call it as a heat affected zone.

You can see that, whatever region is experiencing temperatures above this are fusion zone; between these two are PMZ and between these two are basically heat affected zone, and rest of it is base material. And, you would also see the region, reason why you want to call that as heat affected, because, you can see that, during the precipitation, there is a certain amount of time that is taken for precipitation. And, if it is not available because of the kind of cooling rate you have adopted in the welding situation, then, you have basically lost the precipitates.

You have lost the strength, which is typically the case of aluminum alloys, which have age hardening characteristics. The precipitates are lost, and the heat affect zone becomes very soft, and therefore, you can see that, that can be used to define the heat affected zone as basically, the temperature above which the precipitates are dissolving. The solvus temperature can be taken as a cut off. So, like this you can actually define these zones.

So, you can see now that, we have defined the fusion zone, the PMZ and the HAZ. And, once you have decided these two temperatures, the width of the HAZ can also be defined like the way we have done earlier. So, if this was the width that can also be defined like this; width is given as the T solidus minus T which is effective for the microstructural change, divided by the gradient. And, the temperature gradient within the region is also approximated as a linear.

So, what you can do to avoid heat affected zone? Very simple; we can choose an alloy in which the microstructure changes are not happening. However, that may not be in our control. So, we can actually play with gradient. So, very sharp gradients will actually make the width very small. So, which means again, for laser beam welding and electron beam welding, the thermal gradients are so large, that heat affected zone is virtually absent; whereas, for example, for low heat intensity welding processes such as GTAW or SMAW, the gradients are not that sharp; so, which means that, there is a finite width for the heat affected zone.

Like that, we can actually rationalize, and take control of the widths; and if these widths are less than that of a one grain width, then, you can basically say that, the width is not there. So, we just mentioned how to control these and these widths and I will just summarize those conditions now, in just a moment.

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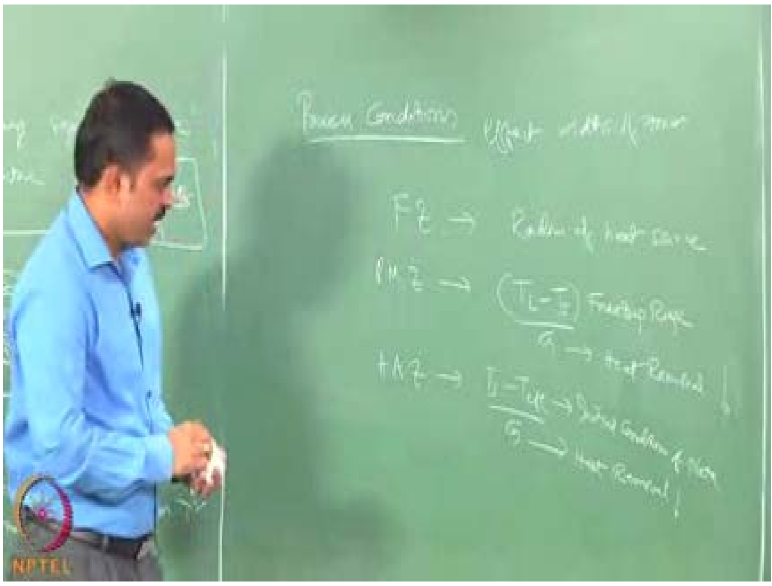

So, the process conditions that, which affect the widths of these zones are as follows. The fusion zone width is affected basically by the size of the heat source itself, because it is under the heat source, that you intend to melt the material; and you would have a wide heat source, for example, in a GTAW, and you would have a very narrow heat source in the case of electron beam welding. And accordingly, the amount of material that is molten also is going to change. So, you can say that, the fusion zone is affected basically by the radius or the size of the heat source.

What about PMZ? PMZ is affected basically by the fact that, you have got the liquidus minus the solidus; this is the range, the freezing range, by gradient; so, which means that, it is affected by what is the freezing range of the alloy. So, if the freezing range of the alloy is more, everything else kept same, then, it would have a larger PMZ. And, if you have the same alloy, but different welding processes, one welding process gives you higher gradient than the other one; then, then, the one which have higher gradient would have a lesser PMZ. So, it depends upon the gradient.

Now, how does the gradient get affected, in terms of the process parameter? Basically, it is the heat removal process. So, if you are able to remove heat much faster, then, you can actually increase the temperature gradient. So, which means that, if you have copper, water cooled copper backing plate to remove the heat from the bottom of the weldment faster, then, you will have effectively higher gradient, and you can have a lesser width of the partially melted zone. And, the same way for heat affected zone. It is dependent upon, and this is also the same width is governed, and this is also. The gradient is determined by the heat removal process and this effective temperature is coming from the initial conditions of the plate which is being joined. So, you can say that, this effective temperature depends upon the plate.

Let us take two situations; one is a cold worked plate and another is annealed plate. Then, naturally, you can see that, cold worked plate would undergo things like re-crystallization, and that would actually make a HAZ appear; and whereas an annealed plate, for example, you may have, at the most, a grain growth that will take place. And therefore, you may have very different kind of a definition for heat affected zone. So, it depends upon essentially, what is the initial condition of the plate that we are looking at. So, this is how actually we can define these various widths, and all this definitions, you can see that, we are actually coming back to the heat source or the heat removal process.

The thermal modeling has to be done properly, to be able to predict these widths or at least, rationalize the widths that you have seen in the experiments. So, if you see these widths that are going to play a role, then, naturally, you want to control them. And, of all these things, usually, you want to control only these two, because fusion zone is more or less determined by the choice of the heat source. And, if you want to control these two widths, then, you would like to do it for the following reasons. You want to handle the cracking tendency; so, that is where the PMZ is going to play a role.

And, you want to handle the strength loss in the heat affected zone, and that is where this is going to play a role. And, if you want to recover whatever loss is happened in this heat affected zone, then, you would resort to what is called as a post-weld heat treatment.

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Post Weld Heat Treatment - PWHT, post weld heat treatment is essentially a heat treatment that is done to revert the microstructural changes that are done in the heat affected zone. You can see that, you have missed the precipitation because of the cooling rate that is effective in the welding, and you want to again the, make the precipitate happen. So, you may actually resort to the post-weld heat treatment, where you may want to do isothermal heat treatment for duration such that, the precipitate actually comes and strengthens the material. It is somewhat like, I would say, whatever we designed while making the plate to get the good properties, you can redo only in the region where you have lost those properties.

However, post weld heat treatment for a very complicated weld joint may not be practicable, if there are distortion issues, and the complicated shapes are going to be critical for the application. So, there are situations where post-weld heat treatment is actually not desirable; but where it is possible, one would normally like to do this so that, after the joining is done, you again redo the heat treatment for the best properties to get the prop, the material performance that you desired, through the physical metallurgy principles.

With this, we actually close the lesson on the different zones in the weldment. We would actually see examples of how these widths are going to be affecting, and we will have a couple of problems in the tutorial, to look at the kind of numbers that we have for different processes, and different alloys for these widths.

Thank you.