Theory of Production Processes
Dr. Pradeep Kumar Jha
Department of Mechanical Engineering
Indian Institute of Technology, Roorkee

Lecture - 43
Metallurgy of Fusion Welds

Welcome to the lecture on metallurgy of fusion welds. So, in the last lecture we discussed about the heat flow in fusion wheels. So, how the heat flows, the heat I saw thorns how they are generated then the speed depending upon the speed of the welding process you will have the different isotherms.

Now, we will discuss about the basic metallurgy of fusion wheels. Now, what happens that because of as we discussed in that class also in that lecture that because of the imposition of the heat and because of the thermal conditions the changes in a structure is observed. So, the metallurgical structure from point to point will be varying and because of that you will have also the consequential variation in the mechanical properties, because mechanical properties in turn is dependent upon the macro structure.

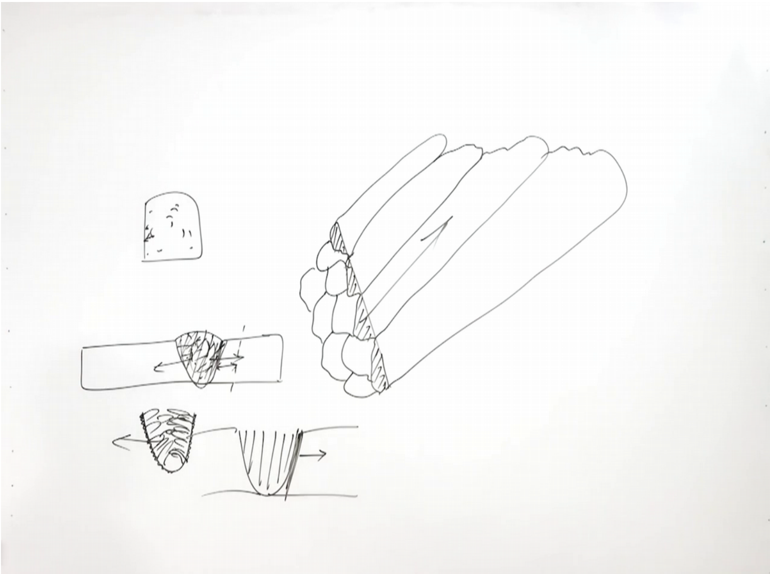
So, what whatever type of microstructure is formed that will be indicative of the type of mechanical properties you can expect, now the thing is that as we discussed that there are cooling as well as heating. So, there will be heating first and then there will be cooling. So, because of that you will have a zone which is subjected to this heating and cooling and there will be formation of different type of microstructure, there will be structural changes or micro structural changes and a zone will be there where this effect is basically observed. Now, this zone how much will be the width of this zone up to what distance this its effect can be seen it is basically dependent upon the heat input per unit time welding velocity and physical properties of the work material.

So, these are the parameters which basically effect like you have, what is the heat input per unit time it may be more or less then velocity welding velocity it is more or less if it is welding velocity is less then and the more spread will be I mean transverse spread will be to the you know isotherms and similarly if it is speed is more then it will be less you know spread in the width direction you will have the isotherms. Then you have different physical properties of the work material that also you know dictates what will be the, you know you know ultimately extent of the heat affected zone.

So, these properties are basically like you have melting point of the material or you have the thermal diffusivity of the material. So, this way they affects the these heat affected zones.

Now, weld bent can be divided into 3 basically distinct zones and if you look at the zone from the point where the welding takes place

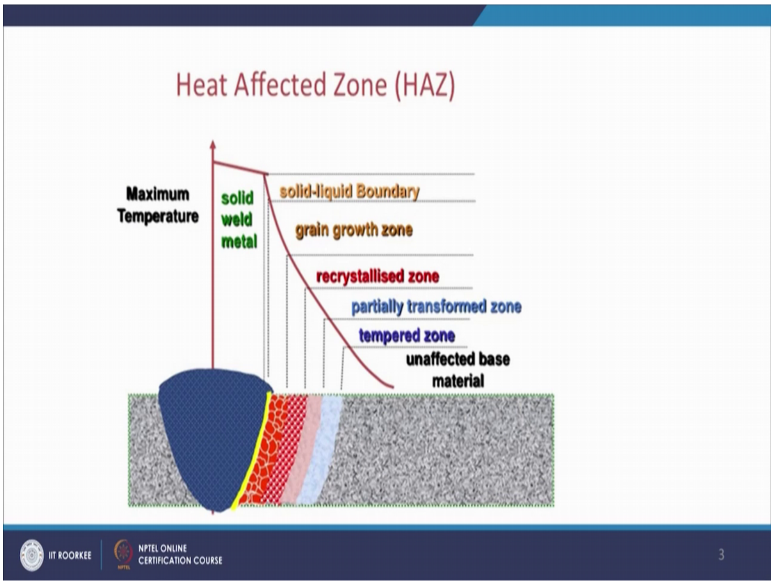
(Refer Slide Time: 04:00)



So, suppose you have this is the basically weld bent. So, here the welding takes place here you have the fusion zone.

Now, the thing is that you will have 3 distinct zones, weld metal zone. So, weld metal zone is the zone where there is welding takes place, then you have h a z, h a z is heat affected zone a zone which is basically affected because of the heats. That is heat affected zone and the rest part will be basically the unaffected base metal zone. So, this way you have 3 distinct zones, if you look at the pictures in a more clear manner you can see here that you will have as you see that this is the weld metal zone this is the zone where you have maximum temperature.

(Refer Slide Time: 04:53)



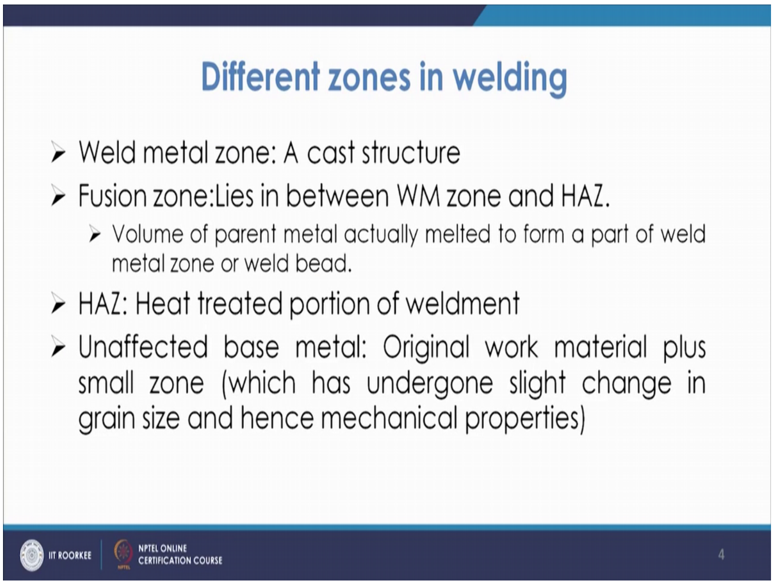
So, here there is fusion of the metal then you have this is so this is getting solidified this portion was earlier liquid and this is basically cast.

So, it is like a casting or solidified portion of the weld, welded specimen which basically converted into liquid by application of heat and then this basically is after solidification you get this structure. So, that is known as solid weld metal and that is known as weld metal zone. Similarly, you have if you look at from here you have this zone as you see there will be a grain growth zone, you will have a recrystallized zone, you will have partially transformed zone, tempered zone all these zones here you see the effect of this thermal treatment which is experienced by this material. So, that is known as a heat affected zone and then next comes a zone which is unaffected base material where you do not see appreciable change in the structure of the material.

So, that is known as unaffected base material. So, that again depends what is the temperature rise in that area, if the temperature rise is not enough to promote any kind of change of transformation then that zone tells, is told as the unaffected base material zone and all the zone where there has been effect because of the temperature or thermal you know cycling they are known as the heat affected zones. And then you have a zone which is basically solidified which is a caste type of structure having that is known as the weld metal zone.

Now, if you come to next you have as we know that you have different zones in welding.

(Refer Slide Time: 07:13)



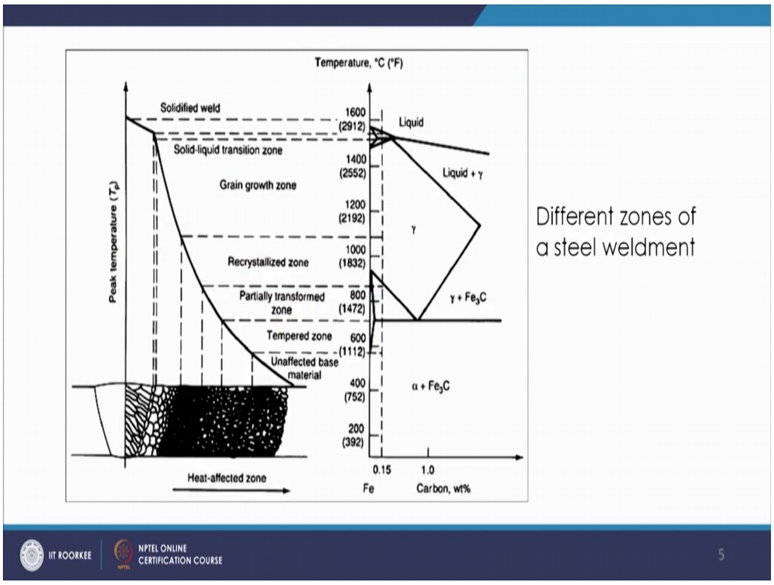
The zone that is weld metal zone is having a caste structure, after the weld meeting metal zone you have a fusion zone. So, this zone basically is lying in between weld metal zone and heat affected zone. So, once the weld metal zone finishes then you have the onset of the heat affected zone, but in between you have a demarcation or a zone which is that is known as fusion boundary zone.

Now, in this the volume of the parent metal that is basically melted to form the part of weld metal zone or weld beat. So, that will be part of weld bead and this zone is normally known as the fusion zone. So, basically that becomes sometimes very narrow and in that case we also call it as fusion line many a times. So, that is fusion zone or fusion line, that we will discuss later then you have heat affected zone.

Now, heat affected zone is the heat treated portion of the weld bent. So, that portion which as we have seen is subjected to the heat treatment that is heat affected zone, then rest is as we discussed that you have unaffected base metal. So, it is the original work material plus small zone which has undergone slight change in grain size and hence the mechanical property.

So, this way you have different zones in the welding. So, if we try to see the different microstructures how the there is change in the microstructure then we can refer to this figure.

(Refer Slide Time: 09:12)



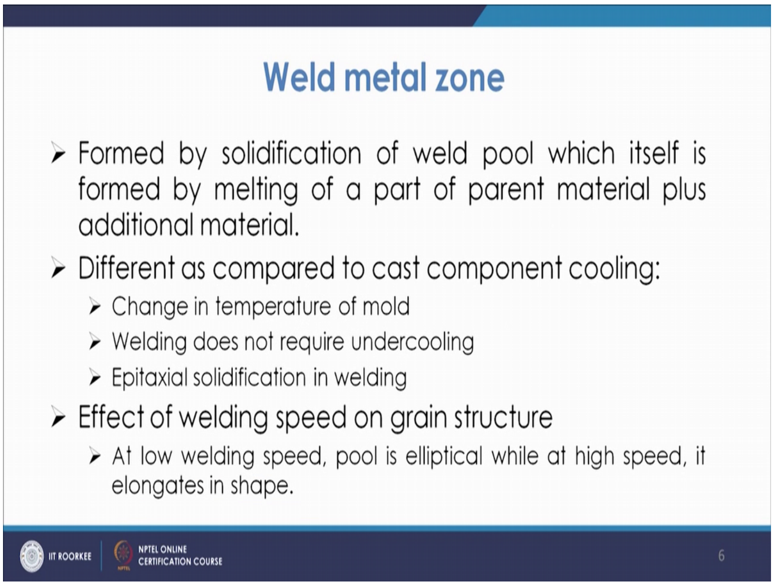
This figure talks about the different zones of a steel weld bent. So, it is for a low carbon steel weld and in that if you look at the different zones as you see that you have, this is the weld metal zone which is at this temperature which is around the liquidus temperature and even little higher. So, here the middle assembly liquid and then has got solidified. So, that is the solidified weld in this zone and then you have this zone as the solid liquid transition zone here.

So, that is what it is as you see that. So, as you see the fusion line of fusion zone it will be around this line, then you have this joint further after this zone you will have a zone that is known as a grain growth zone. So, this joint will be somewhere close to 1000 100 from there it will be up to this temperature.

So, this will be on the higher side you will have the zone that is known as the grain growth zone. Then after grain growth zone you will have the zone which is subject to for the lower value then the grain growth zone and that is known as recrystallized zone. So, here you will have the refinement of the grain occurring. So, that is also known as grain refines zone, then you have the partially transformed zone which is seen in this near the upper critical temperature up to the lower critical temperature that is the partially transformed zone, then after that you have a tempered zone and then as you go below the 600 or 550 degree centigrade where this temperature is not exceeded below above that degree then that is the untransformed base metal zone.

So, by looking at the different points if you map all these reasons to the different temperatures you can have the idea of the different zones which are formed in a steel weld bent.

(Refer Slide Time: 11:38)



Now, coming to the weld metal zone. So, weld metal zone as we discuss, discussed that it is a zone where you have the liquid metal available and that basically is solidified. So, you have the formation of this weld metal zone by a weld pool itself and this is formed by melting of a part of parent material plus additional material. So, as we discuss that here you will have this is the filler material as well as some part of the parent material is also melted so that is your weld metal zone. Now, once we fill this part with the with the application of heat then it slowly as it loses the heat to the surrounding metal as well as to the surroundings then in that case the cooling starts, now then solidification starts.

So, then it is a case of solidification, but then there are certain basic differences between the mechanism of solidification in the case of welding and in the case of normal casting. So, as you know that in the case of normal casting you have the mold which is at some temperature, in that case you have certainly there is change in the temperature of the mold in this case, you do not have mold you have the adjacent you know liquid metal itself. So, it is in contact with that and then there from the solidification has to start.

So, in that case now what happens that in normal casting in the normal casting case when the liquid metal is poured now when it touches this point at this point the under cooling is experienced. So, there will be as we have discussed that there is free energy concept based on that you will have the under cooling and then the solidification starts by the mechanism of nucleation and then further growth.

Now, in the case of this welding what happens that you have as we discussed that some part of the parent metal is also melted. So, what happens once this portion is there in this part some part is melted whereas, some part is not melted, now when some part is not melted then those part is basically acting as the existing nuclei. So, from there you will have the growth. So, you will have the presence of these as the existing nuclei and then from there the growth starts.

So, the nucleation barrier which is there in the case of normal solidification that is not the case in this case because you have heterogeneous nucleation sites and these un unmelted partly melted grains they act as the nucleation centers and from there the solidification starts. So, the solidification starts in this fashion and also you here from also in this fashion. So, it will move and this way the solidification will proceed, now the thing is that the wherever you have the solid liquid interface in that case perpendicular to that will be the you know direction where you have maximum heat transfer.

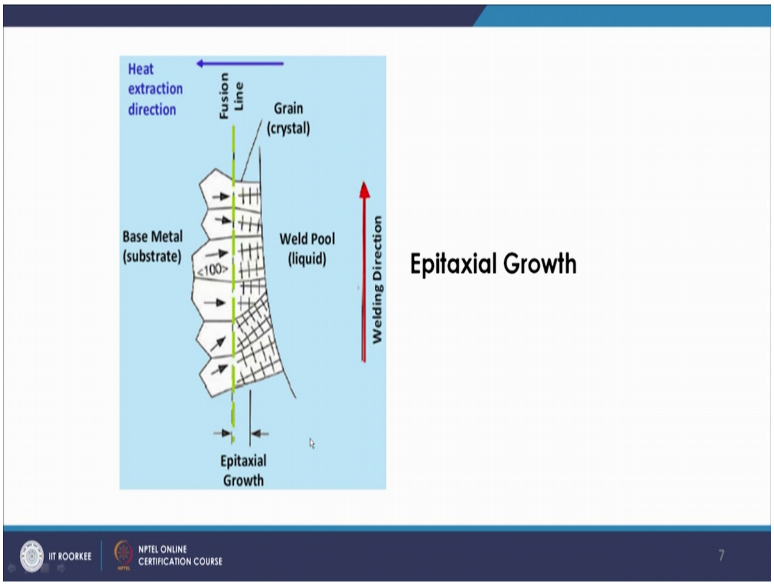
So, as we know that if the heat transfer is in this n then your growth is in the opposition that is why grains grow in that direction, then grains also have a favourable direction to grow. So, basically what happens that you will have 2 cases one is that you will have the interface and 2 perpendicular to it there will be automatic growth of the grains because of the effective heat transfer in particular direction then you will have the preferred grain growth directions.

So, basically what happens those grain growth direction which are parallel to this particular direction of heat flow, I mean in that case that is the predominant direction of grain growth otherwise they are pinched off. So, that way you will have the formation of what kind of grain growth. So, that is basically just based on that, also you have.

So, now the thing is that such kind of grain growth where you have already an existence of partially melted grain which acts as the nuclei. Now, when the solidification occurs from that particular grain then that is known as epitaxial type of solidification in the welding. So, and the growth is also known as epitaxial growth. So, that is normally encountered in case of welding process.

Now, if your speed is low then the pool is electrically elliptical whereas, at high speed it will be elongated in the shape.

(Refer Slide Time: 17:46)



So, if you look at this figure it talks about the epitaxial growth as we see that you have the, this is the weld pool and in this what happens that this is the welding direction.

Now, the thing is that this is the base metal. So, now, from here the metal will grow in a particular direction. So, you will have this is the weld pool, now in this weld pool now from here the metals will grow and this is the place this is a fusion line and this is the partly melted. So, this basically acts as the nucleation points and from there these are these are the points where the growth starts and they will grow in this direction. So, that heat extraction direction is from here to this side this side and that is why growth of the grains is in the opposite direction. So, this way your, when the growth of the grain is from a partially melted grain which is already available on the of the parent metal part, then is known as the epitaxial type of grain growth and this is a typical characteristics of the you know welding process.

Now, the thing is that we discussed there are 2 aspects one is basically that you have the predominant direction of the heat flow. So, growth will be in the opposite direction and there will be the preferred direction of the growth of the grains. So, they actually try to grow in certain direction, now because of that when these two are basically parallel then in that case the grain grows otherwise they are pinched off. So, that is known as a type of competitive type of growth.

So, ultimately that this competitive growth concept is there effective in the case of welding and then that is how you see that you have the formation of the grains. So, what we see is that if you have this is as the fusion line and if suppose this is how your grains are there and these are the partially melted ones which act as the nuclei. So, from here it will move like this and now this will be like that similarly like this like that. So, this way your growth of grains move in that direction and this side you have a edges. So, this way you will have formation of edges that on this side and these are the fusion line.

So, that type of growth which is occurring that is known as the epitaxial type of growth in the case of welding now the next zone which is of interest is the fusion boundary zone. So, as we discussed that you have zone which is weld metal zone which is completely melted and then gets cast gets solidified and then on the one side another side you have a zone which is basically heat affected zone, where the microstructure is affected because of the thermal treatment of the material. So, in that case that is known as heat affected zone now in that. So, in between the weld deposit and the heat affected zone you have a joint that is known as fusion boundary zone, now this zone sometimes it is very sharp. So, this is also known as fusion line.

Now, what happens basically at the fusion line or fusion zone, now as you see that you have the composition which is changing from parent metal to that of more or less uniform weld deposits. So, as you see that this side you have. So, this side you have the weld deposit this is a weld deposit that is weld metal and this side you have the heat affected zone.

Now, in between there is a line that as you discuss this is the there is compositional change. So, one side you have parent matter, you have different microstructures or so and you have the uniform well deposit. So, basically the demarcation between the 2 is known as the fusion line or fusion zone. Then the thickness of this zone basically will be varying between about 50 to 100 microns for a manual weld with the coated electrodes. So, it has been seen that if you use the normal manual welding where you use the coated electrode in that case the width of this zone was seen as the around 50 to 100 microns.

Now, when we talk about the other type of material. So, now, that is for a low carbon steel you know weld where the freezing zone is not so high, now when you have the freezing range higher for the alloys alloys with for larger freezing range. Now, in those cases there may be partial melting that may take place in the h i z which is adjacent to the weld deposit. So, that is that is a basically problem in the case of these higher freezing range alloys.

Now, this h i z where the partial melting takes place. So, this is a occurring immediately as I said to the weld deposit and there will be some of the liquid pockets. So, that will be formed. So, that will be a continuous type of you know phase with the world matter it will be for me. So, you do not have a if a visible type of fusion zone you will see you will have you will see that this because the melting takes place in a range of temperatures.

So, what happens that you will see that there will be personally melting this zone itself and this is not considered to be a desirable you know case or situation and in this fashion whichever alloys behave or similar or you can say that for the material with large freezing ranges that is why they are said that they are very difficult to be welded in that cases. So, they are difficult to fusion weld.

So, exception is the cast iron, but normally what we see is that you have the zone which is basically because of this phenomenon which we discussed that you have the melting and with that basically makes this fills the gap between the fusion zone and the weld metal. So, because of that it is said that it is not very very desirable kind of situation and that is why they are not considered to be a good welded, weldable you know material then you have the. So, first is weld metal zone, then you have the heat affected zone then you have the zone of unchanged base material.

Now, unchanged base material in that you have peak temperature is normally going about 550 degree centigrade. So, that is your zone of unchanged base material, now in this case normally there is not much of the structural changes, but there may be certain effects of a heating and residual stresses and that may and dynamic strain is the aging is normally seen in such cases and that makes the situations or the phases brittle in many census.

So, that is the trait of these you know zones which is unaffected based materials we are you will not see the much of the change much of the considerable change in the structure, rather there will be some variation in the properties and there may be some such type of discernible exchanges like maybe some brittleness may be seen in such cases.

So, that is about the you know basic metallurgy of fusion welded zones and we will talk about the heat affected zone which is the most important zone in the, when we talk about the metallurgy of fusion welded zone. Then in the next lecture we will talk about the you know heat affected zones in detail in the different zones in the heat affected zone sub zones which are important.

Thank you very much.