Welding Metallurgy
Prof. Pradeep K. Jha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology - Roorkee

Lecture – 25
Metallurgical Effect of Heat Flow on Welding

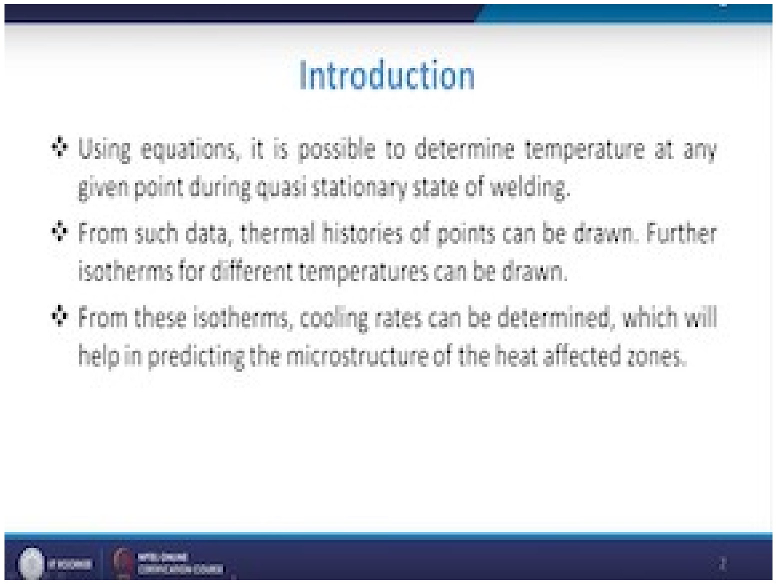
Welcome to the lecture on metallurgical effect of heat flow on welding. So far we talked about you know how you can find the temperature distribution using certain equations because you have a point heat source which is moving along certain direction and then so certainly the temperature will be highest in that locality and then you will have the temperature distribution or because of the temperature difference as you move further away you know from that point.

So accordingly you have the temperature distribution which we get and from there basically we can get a lot of idea that how you know you can predict the properties of the material. So for that we need to know the you know cooling rate which is being experienced by the material and that can be experimentally determined. So in this lecture we are going to have some discussion over that, but before that as the title suggests that metallurgical effect of heat flow.

So in this lecture we are going to basically focus on how to find you know the what kind of you know cooling rate is existing you know when we try to have the temperature distribution. So once we get that then there will be you can you know find the you know isotherms and then accordingly you can have the cooling rate determination and from there basically once you know put it or once you use those TTT or CCT diagrams and try to have the analogy between these two.

So then you can predict the microstructure you can predict the properties of the material. So as we discussed that you have the different equations and from those equations it will be possible to determine the temperature at any given point during the quasi stationary state of welding.

(Refer Slide Time: 02:54)

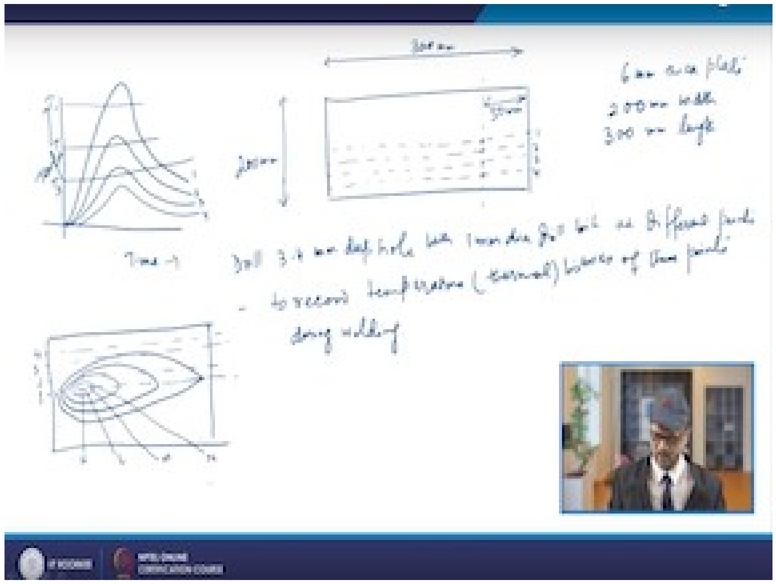


So we will get you know the temperature at any given point. Now once we have such data then we can you know the find the thermal histories of these points and then the isotherms for the different temperatures can be drawn. So you have to draw the different you know for different temperatures you have to draw the isotherms and then from there the cooling rate also can be determined which will help in predicting the microstructure of the heat affected zones.

The properties of the zone you know, this is important because the heat which is flowing so it is going to be dissipated all along in all the directions and this heat basically will alter the mechanical properties the kind of transformation which occurs in case of different materials. Especially if you talk about the ferrous based material especially steels. So in those cases you will have there will be transformations which will be occurring and that transformation can be predicted you know once you have the thermal history once you have the cooling rate.

So basically there is experimental you know determination of the cooling rate and for that we normally you know the process is that we take a 6mm thick plate. So we are taking suppose you know there is a small thickness plate that is normally taken you know a 6mm thick plate.

(Refer Slide Time: 04:45)



So we are taking basically sufficient width and you know length. So that you can establish the quasi-stationary state. So for that we say the width is taken as the 200mm and the length is taken as 300mm. So that way you can so the thickness will be very small as compared to width and length.

So you can say that you know it is quasi-stationary state. You know will be established once the you know the welding process has established through a length certain length like 50mm. So that way so your this length is you know 300mm and this length is say 200mm and the thickness is certainly as you said to be that it is 6mm. Now you know in this what we do is we are drilling the 3-4mm deep holes you know at different points. So you will be drilling these holes and what you do is from the centre so you have this line and then you will have other you know points.

So on these points what you will do is you will drill 3-4mm you know deep holes with 1mm dia so you know you will be drilling 3-4mm you know deep hole. So you know this holes are with 1 mm dia drill bit. So you know that way you can and then you will be embedding the so you will be fitting the you know the thermocouple into it. So you are drilling 3-4mm you know the deep hole with 1mm dia drill bit so at different points.

So you are marking those different points as 1 2 3 or 4 or so. So that way you will be drilling so basically you are advancing initially 50mm. So as to establish the quasi stationary state of welding and then you are drilling at these points you are drilling you know at all these points you are drilling holes. Now so and in this you are embedding the hot junction of alumel chromel you know so thermocouple in these holes.

And you know and then these are filled with so this high temperature brazing material using oxy acetylene welding. Now the other end of these thermocouples, thermocouple which is there so other end will be basically attached to the temperature recorder. So that when you are doing the welding in that case basically you are able to record the temperature histories. So basically your purpose is to record temperature history or thermal histories of these points.

So that will be you know during welding now you know the ones so when you are proceeding so you will have all these points and these points as its other end will be connected to the recorder now all these points will have different temperatures because the temperature maximum temperature will be at the centre where in in certain direction. So in this direction suppose the welding is proceeding and then you will have the different temperatures at these points.

So these points will be recorded now you will draw the you know the thermal history of the point you know along the transverse sections. We allow this is the transverse section so along the transverse section which is where you have taken the different points you will draw the thermal history. Now the thermal history basically will be looking in a certain you know pattern. Now if you look at the first point, so basically it comes like this so this will be basically the first point.

So this will be for the first point and similarly if you go for the second point so it is going like this third point will be going like this. So that way you will have the fourth point goes like this so this is the thermal history which is basically drawn after you get these temperature through the temperature recorder. Once you get the these values then you know in this axis you will have time and on this axis you will have temperature.

So as the time basically is proceeding you know so with time there will be initially you will see that the temperature has increased and then finally it is decreasing. So this kind of you know pattern will be sown and this will be you know the points 1, 2, 3, 4. So that way it for the first point it will be maximum and then you will have the you know 2nd point the 3rd point and the 4th point so accordingly the temperature basically will be decreasing

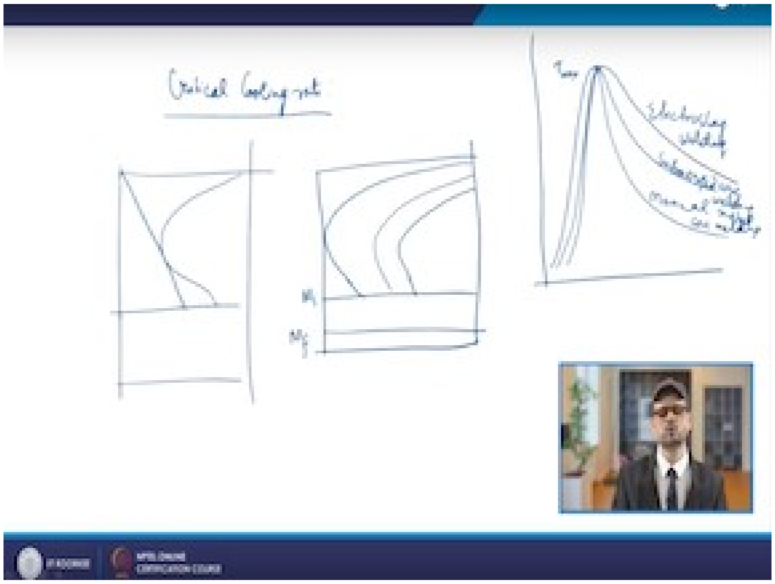
Now from these histories you can have the you know you can find so you will be having the different you know depending about the different cooling rate basically you will have the cooling rate determination in different directions. So what if you look at the same geometry in this case. Now what do you see that you will be looking at so you will have this as T1 temperature then you will have the T2 temperature T3 temperature like that.

Now accordingly you will have the you can find so what you see you can draw these you know thermal histories. So now if you look at the different point so you will have the one point here then you will have 2nd point here you will have 3rd point here then you will have 4th point here. So if you try to see the so after a certain distance we are trying to have these you know thermal history. So what we see that we are getting you know initially you have such kind of history then further you will have you know the history it will go like this.

Then you will have so such kind of you know things will be repeated. So such way now the thing is that you can have the you know determination of the cooling rate in different directions like maybe if this is the direction for the K and then you have L then you have M and N.

So basically you can have the cooling rate determination in the different directions you can have you know and based on the cooling rate basically you can further predict. So that also we will study that once you know the cooling rate, then this cooling rate basically can be utilized you know for predicting the effect of this heat flow. Because ultimately it is going to a higher temperature and then further there is decrease in the temperature just like a kind of heat treatment process. So accordingly you can have the effect of these heat flow on the structure of the material.

(Refer Slide Time: 14:39)



So it was you know so basically one of the researcher has shown that if you typically see you know shape of thermal histories for the different type of processes. What was seen that in the case of you know the electro slag welding this it was so incoming like this if the T max if this is the maximum temperature in this case and so in that case this will be your T max and this way it goes for the electro slag welding then you know behind that there was you know the submerged arc welding, so this was submerged arc welding and if you look at the manual metal arc welding.

It is further you know steeper so that will be your manual metal arc welding. So basically you know in the case of manual metal arc welding it goes even you know in a steeper manner. So the heating also is somewhat you know changed in the case of these different welding processes and also you know it also depends that depending upon the material also you will have the different level of cooling rate being established.

It will be depending upon the what will be the size of the weld or what is the thickness of the parent material because as we have understood we have seen the effect of the different parameters. So there we have seen that you know as the thickness will be changing so since it is working as a heat sink. So there will be a different effect on the you know on its ability to take the heat away from it.

So accordingly you will have its effect on the you know properties of the material cooling rate will be changed when you have a thicker material, you will have a different cooling rate, you have a higher cooling rate and that cooling rate. Basically that we can further super impose on the TTT curve that we will see and then we can predict what will be the transformation products in the case of welding. So the important points which we need to know also in such cases that we need to know about the critical cooling rate.

Because once we know the thermal history once we know the cooling rate then we basically depending upon the cooling rate as we know that if the cooling rate is established and you know based on the value of the critical cooling rate. We can further say that where how that transformation will proceed because as we know that critical cooling rate is the rate you know that is minimum cooling rate which is required for transformation of the product that is martensite.

So you can have a prediction of the formation of these products which are alike martensite in the case of the you know the sudden quenching. So what we have seen earlier so here also once you establish the you know cooling rate by finding the thermal histories then you know if that is more than the critical cooling rate.

Then you can say that you will have a martensitic you know structure formed and typically you know many times as we see if you have specimen in such a manner that it is surrounded with you know the metal or you have higher cooling that even in the case of air cooling also you will have the chance of and if you see that the cooling rate which you have achieved it is going beyond the critical cooling rate you can ensure of having martensitic structure. If the cooling rate is not you know beyond that in that case you will have to further use you know the TTT diagrams.

So as you know you see that so in the case of you know martensite formation that can be understood using that critical cooling rate. Otherwise if the cooling rate has is not up to that standard so that cooling rate you know seen by looking at the TTT curves and as we see that your TTT curve you know goes like this. So you will have the transformation start and then transformation finish.

So that we have seen so what happens that if you are you know if the cooling rate is such that it is beyond is more steep. So if your cooling rate is steep then you can have so below that you will have the Ms and Mf but you know if it goes in between the you know transformation line. So lines so you will have you know the different percentages of transformation. So if the cooling rate will be less than this critical cooling rate then certainly there will be you know pearlitic transformation from austenite.

So austenite will be transformed to pearlite and based on where it ends you will have you know the coarse pearlite formation or you have the fine pearlite formation and also you know accordingly you can predict that there will be either bainitic transformation or other otherwise we have studied about other type of transformations like the formation of bainite will be there if it is past the nose of the C curve and then we are holding here.

So now that again also depends that how you are basically managing this TTT curve because you know in the case of normal materials when your nose will be here. Suppose you will have the chance of some cooling rate that will produce martensite now when you are you know when you have lower hardenability so in this case you know with even with the higher cooling rate also there is very less that you are going into the martensitic zone.

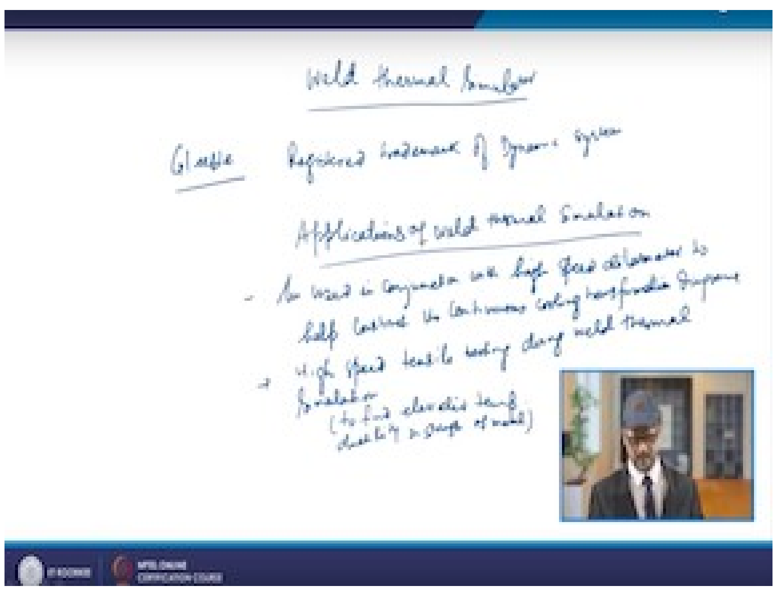
So basically you will have some pearlitic transformation so what we do is in such materials we are try to increase the Hardenability by the use of alloying elements. So these alloying elements basically will be shifting the you know these TTT curves towards the right so many a times we use the alloying elements in the filler material. So it is you know job will be because you have the transformation in a particular zone.

Now that undergoes the transformation now in that zone or you know it depends upon because anyway the material which has already alloying elements. So with those alloying elements certainly the hardenability will be changed so if you can have the alloying elements by so if you are adding the alloying elements in the weld pool. So it is you know when it is getting solidified then after that temperature say you know when it goes to the in the transformation temperature range in that case for those materials the TTT curve will be behaving differently.

So once you increase the so in those cases your you know this line this move like this. So many a times you have with even with this cooling rate also you will be able to get martensite structure. Whereas in this case you are this is just touching the nose. So basically the nose is shifting because of these alloying elements and that tends to increase the hardenability of the material and the critical cooling rate you know that value will be even lesser and even at lesser cooling rate you will be able to achieve the martensitic structures.

Now these you know the material which undergoes this thermal you know treatment that can be nowadays even you know studied or that can be seen using typical you know weld thermal simulator. So nowadays there are standard you know equipments which are available and there basically you can simulate you can have the study of that how these different you know during the welding how the temperature is varying what way you know the thermal histories are getting generated.

(Refer Slide Time: 25:01)



So for that there are weld thermal simulation and basically the thermal cycle which is experienced by the specimen that can be duplicated using these machines and you have a standard you know apparatus for that and it is known as the you know Gleeble. So this is Gleeble it is a registered trademark of the dynamic system so that way you know it is the registered trademark so in that basically for the dynamic system.

So in this what we what they do is that they keep the so you have the jaw. So in that they fix the jaw then they are heating you know the specimen using the resistance heating you know method bypassing the electric current you know through the specimen and you have the jaw which is water-cooled and it is holding that and then you have also the thermocouple which will be you know spot welded to the middle of the specimen and then you have you know accordingly you can have experience of the you know thermal history.

Though that the simulation you know how the specific thermal cycle is duplicated. So basically there are many you know applications of these weld thermal simulator. So what it can do is it can basically be used in conjunction with high-speed dilatometer, so you know to help construct the continuous cooling transformation diagrams.

So you know basically you know using that weld thermos simulator. you can use you know you can have the high speed dilatometer and then you can find the continuous you know cooling transformation diagram which will be further predict you will be able to predict the kind of micro structures you know as we have already seen that how the continuous cooling transformation curves can be used to predict the microstructure then you can have the you know high speed tensile test to you know during the welding.

So high speed tensile testing during the thermal simulation. So that will be help I mean telling us that what will be the property of the material at elevated temperatures. If you do that what will be so if you do the testing also so that we will be able to tell us that what will be its you know you know elevated temperature ductility. So to it will to find elevated temperature ductility and strength of metal okay.

Then you know we can also prepare the you know the Charpy impact you know test specimens and we can further subject the specimen to various thermal cycles and that way these you know results can be used you know for the industrial applications. So basically many a times these

instrument, which is popularly known as the Gleeble, so that is basically they are developed by Nippes and you know Savage in 1949. So in originally that was the you know original device that was developed.
And then this dynamic system you know thermo dynamic system this instrument is and this is very, so you can have the you know feel about the thermal histories then how you know when you have the welding going on. So you know for that welding specimen or so how its property will be changing. So this way you can have one understanding about the change in the properties of the materials. So that is about the you know weld thermal simulator,

However, it has also certain limitations so because you have a very extreme you know extremely high cooling rates are there doing the certain type of you know welding processes. So which you cannot reproduce you know in these processes because you have the limited you know cooling possible. So that is there then also the you know limitations are there regarding the heat losses from the surfaces.

So certainly there will be you know issues related to that but still you can certainly have a feeling about the process you can have the feeling about the thermal histories and you know proper understanding can be developed. Thank you very much.