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

Lecture - 28
Constitutional Supercooling

Welcome to the lecture on Constitutional Supercooling. So this is about the you know discussion about how you know in the liquid depending upon the thermal gradient line there will be observation of certain undercooling and because of that you will have the formation of different type of microstructure you will have depending upon you know because we have seen the cases of solute segregation.

Now depending upon its extent and depending upon the extent of, you know, the convection dominated diffusion or limited you know diffusion in liquid sometimes you know no diffusion in solids. So you will have we have seen that there are different cases and if you talk about you know the solid redistribution in the case of you know when there is no solid diffusion then in that case you will have different you know severity.

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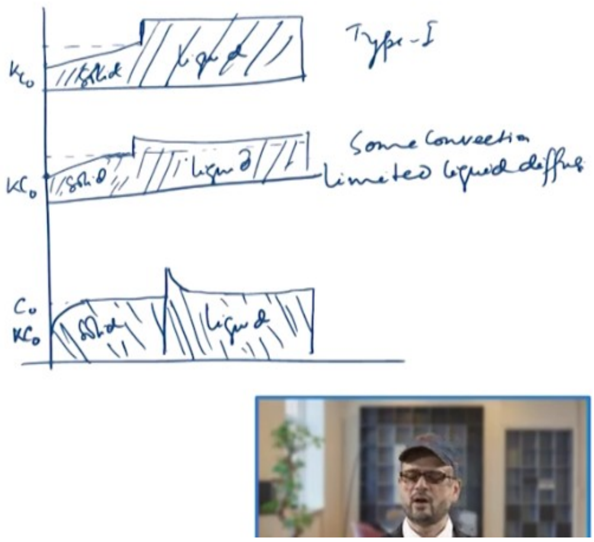

And what we have seen is that in those cases when you have complete liquid diffusion or mixing in those cases your solute redistribution will be going like you know you have in the solid you will have start from k_{c_0} k_{C0} and then it will move to C_0 so that there is and then from here you know there is complete liquid you know diffusion. So your profile goes like this and this is your liquid and this is your solid.

So this is solid and this is liquid this is for known as the Type I cases where there is you know complete liquid diffusion. Now if you have a limited liquid diffusion in those cases what you see is that from k_{c_0} this is your k_{c_0} that is you know for the solid. So then from here you will have coming up and then there will be some so at this point so you have limited liquid diffusion so there will be some pile up.

And then you know your difference goes like this. So this is your C_0 and there will be some increase in these cases and so it goes like this so this is your solid and similarly this is your liquid. Now when you have the limited liquid diffusion also and there is no convection in this case there is some convection and you have limited liquid diffusion and when you have even no convection and you have limited liquid diffusion in those cases as you have seen you have initial transients felt.

And so in those cases your you know you have this is as k_{c_0} from here you have initial transients which is observed so there you come to C_0 and that move so that comes in the solid and then in the case of liquid again further you will have this drop so that way it goes into so this will be your liquid so this is your solid and similarly this is your liquid. So that way you know your depending upon the concentration of the solute you see these boundary lines how they move like.

Now based on that you know now we will talk about the different solidification modes and also a phenomena known as the Constitutional Supercooling.

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Introduction

- During the solidification of a pure metal the S/L interface is usually planar., unless severe thermal undercooling is imposed.
- During the solidification of an alloy, mode of solidification can be planar, cellular, or dendritic depending on the solidification condition and the material system involved.
- Four basic types of the S/L interface morphology are observed during the solidification: planar, cellular, columnar dendritic, and equiaxed dendritic.

So what we see that during the solidification of pure metal the solid liquid interface is usually planar. So when we talk about the solidification of pure metals in that case the interface moves in a planar way unless severe thermal under cooling is imposed. Now when we do the solidification of alloys then the mode of solidification can be planar cellular or dendritic depending upon the solidification condition you know and the material system involved.

So what type of material system is there how much is the value of k or how you know what is the freezing range you know situations so depending upon that so that is the material system involved and on that basis you have you know four basic types of solid liquid interface morphology are observed during the solidification. One is planar, second is a cellular, third is columnar dendritic and forth is equiaxed dendritic.

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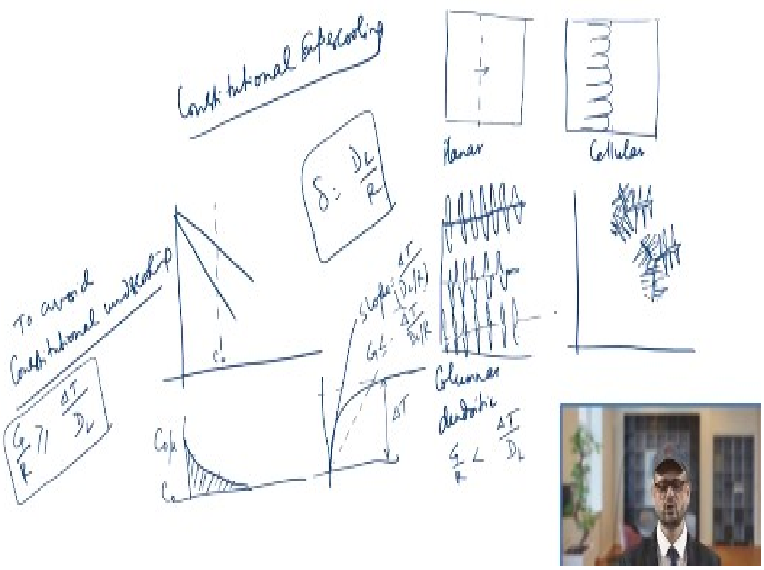

So if you look at the planar so as it is very much clear that when you have the planar interface your interface will be move in a plane manner so this way has to move. So this side you have solid and this interface will move and that is known as the planar you know plane front solidification also it is known as then you have the you know cellular. So in the case of cellular what is happening that you will have the conditions like this it will be moving.

So this way you know so this is the case of you know so you will have a front which is there which is moving and that is you know so this is a case that is planar and this is cellular. Now further you know you will have depending upon the severity case you will have the columnar dendritic structure. So in that case the structure is something like this you will have the dendritic structure, but you have a columnar you know structure.

So this way it will be going like so this way you will have these dendrites which will be seen and then they will be having this columnar you know growth of spikes you know all along. So and you primarily you see that these so depending upon the undercooling observe that we will study you will have you know such kind of you know structure this is seen so that is known as columnar dendritic structure.

So then next a severity is furthermore in those cases you have the equiaxed type of a dendritic structure. So this is your columnar dendritic then you have the equiaxed dendritic so in those cases you have structures like so here you have you will have these dendrites you know appearing, but then ultimately you will have you know these also in the in the terms of you know equiaxed structure.

So you will have here it is in the form of a column and here it is basically you know growth in all the direction. So that way this kind of structure which you get you will have the equiaxed you know this is you know equiaxed dendritic mode of solidification. So that basically you know this is because of the phenomena which is basically nothing, but the undercooling which is experienced in the liquid portion ahead of the solidification front or the interface.

And because of the you know cooling conditions and because of the properties of the material this cooling is experienced undercooling is experience and there the crystals are formed the solidification occurs and on that basis you know this type of because of that you know these kind of structures are likely to be formed. So you know for that there is a theory which is proposed that is the Constitutional Supercooling.

So this is you know proposed by Chalmers and coworkers. So and then you will have also the breaking down of the solid-liquid you know planar interface during solidification, So that is so one is your constitutional supercooling that is and also you have the interfacial stability you know interface stability theory that is also given by the Mullins and all that. So there are two aspects one is the thermodynamic aspect and another is the kinetic and heat transfer aspect.

So we will talk about the Constitutional Supercooling you know in this lecture and basically that is by which we will try to understand that how you know these dendritic structures are developed in the case of you know materials or maybe cellular or them columnar dendritic and equiaxed dendriic type of structures depending upon the different conditions how you get you know this kind of structures.

So if you know look at the you know the case of I mean that is in a phase diagram if you see so if you suppose we have already seen that in the case of you know phase diagram what we see is that when you are talking about this situation. Now as we have seen that you have one increase in the solute segregation at the interface and then that basically will have a you know a trend that how that you know is formed.

So suppose this is your C_0 so now you know C_0/k so you will have the segregation that is happening from $C_0/$ k to C_0. So that is you know this is because of the buildup you know you have no diffusion in the solid in those cases as we have studied in our third case. So in those cases this will be you know solute rich boundary. So now in those cases what is happening that because of this you will have the change in the you know liquidus line.

So as the concentration of solute is high and the it is you know decreasing and coming to the C_0 that is your in the domain when it is liquid. So in those cases you will have so because of that if you look at the you know line so if you look at the liquidus line it will be you know changing so because of this you will have you know change in the liquidus line like this. Now because of this if your, you know, if your tangent line goes like this if this is your you know thermal gradient line.

So this is you know the slope that is your $\Delta T/D_L/R$ so that is your slope of the you know tangent. Now this is slope now if this is the you know slope and your you know and if the slope of the thermal gradient line so that if you are you know cooling in such a manner that if your actual slope is you know going like this and this slope basically$=\Delta T/D_L/R$. So we have already talked about these values.

So if now in this case the slope which you are getting this slope G this is $< \Delta T/D_L/R$. So what is happening that you know so the G/R that is if you look at this G/R is $<\Delta T/ DL$. Now in these cases what is happening that what we see that this region basically so this is your you know this is ΔT. Now if you have to avoid these you know constitutional under cooling this region this shaded region is basically experiencing you know the undercooling in these cases.

Now if you have to avoid you know now why if it is you know facing if it is experiencing the undercooling in such case in that case there will be crystallization which will be starting. Now this basically condition that is you if you have to avoid this to avoid this constitutional undercooling. So as we see that this difference in the concentration is achieved because of the you know limited diffusion and for that since there is you know there is a region which is form that is known as the that that experiences undercooling.

So that is why this principle is or this region is known as constitutionally under cool region and for avoiding that you know your condition should be G/ R has to be > or=or=$\Delta T/D_L$. If it is < than that in that case you will have the region which is formed that is you know constitutional under cool and there the solidification will occur and this D_L/R basically is nothing, but the Δ.

So based on that only you are finding this $\Delta T/D_L/R$ so that is your slope of this so this will be ΔT and your Δform that is your D_L/R. So based on that only this condition so your delta is nothing, but this D_L/R. So once you have the if there is a small you know undercooling observed so your you know the planar interface that breaks. So depending upon the slope of this line basically you will have you know experience of the moderate degree of supercooling or higher degree of supercooling and based on that the structure will be changing.

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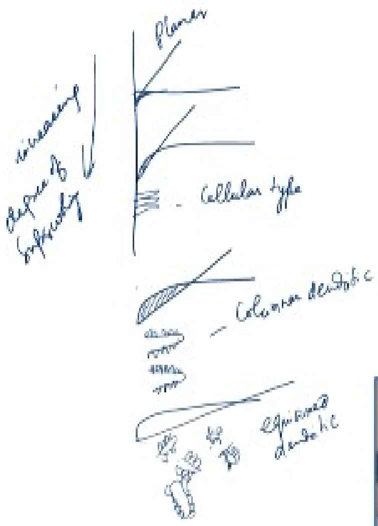

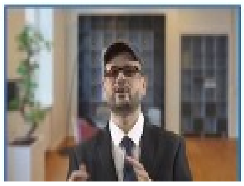

So what you can see is that when you have you know there is only you know in the case of you know normal case when you have the you know what we have seen is that when your slope of that thermal line is moving like this in that case you will have the plain front. Now if you know you go to the supercooling you know area now if your this is your change in the liquidus temperature line.

And if you line you know moves like this if you have a very small region of you know a small degree of undercooling is experienced. In those case your structure will be found will be you know that is that this is what you get in the case of the cellular type of you know solidified structure will be there and you know in this case you will have you know when you have actual case.

So in this case you go for a planar so you will have the you know increasing degree of supercooling. So if you go further and when the line goes like this you have increased degree of you know supercooling. In those cases, you will have the you know columnar dendritic type of structure. So your structure goes like this. So this occurs when you have your this line so at the interface if your cooling conditions gives you this line.

And this is further increased your constitutional undercooling is furthermore in those cases you are getting you know such kind of columnar dendritic structure. However, if your cooling rate you know gives you this kind of line where there is a very large degree of supercooling experienced in that case you are going to have the equiaxed dendritic structure. So you will have you know this way you will have you know columnar you will have the dendritic structures, but they are no longer columnar.

So you will have so this way you know you are getting so this way this is your columnar dendritic and in this case you come to the equiaxed dendritic. So you know the dendritic structures are formed you know because what you see is that in this case you will have you know in the ahead of the interface you will have some reason where they will be undercooling observed.

And in those regions because of the undercooling the you know there will be crystallization started and that leads to the formation of you know such structures so you will have a mushy zone kind of zone where you will have solid and liquid both are formed. Now these are basically you know not advantageous in the sense that when you have such structures in those cases you have the chance that in between these arms you have the probability of liquid getting trapped.

And that leads to you know so while solidification that leads to the probability of formation of shrinkage cavities because once they are you know so in such cases if suppose you have you know also that these are you know in such cases as we have discussed you have you know there is no proper you know uniform composition in the solid towards the end and also you will have the chance of entrapment of liquid zone in between you know these arms.

And if they are trapped then certainly you will have micro shrinkage possibilities in such cases. So that way you will have this is because of so that basically is because of these problems related to the solute redistribution and that is because of the change in the diffusional properties in case of solids or in case of liquids so you know so those you know. So further many a times what we do is that you further do the heat treatment because the diffusion is decreasing with temperature again diffusion rate.

So what we do in many cases we do the treatment for the chemical homogenization because then the diffusion will further start because you know as we have discussed that in such cases when there is a limited diffusion in solid state or there is no diffusion in solid state so you will have the chance of the change in the concentration of solute as the solid is formed from time to time.

So you will have you know a code structure you will have difference of concentration of the solute and for that we do it, but as far as the dendritic structures are concerned you know concerned because of the you know a concept of constitutional supercooling it is because of the material properties so how you know how the phase diagram looks like so depending upon you know the degree of you know the cooling rate which is experienced.

So based on that basically you will have the experience of the degree of supercooling and when you know that that is formed. So in those cases your planar front is broken basically and you know the plain front is broken down you know and then you will have the on start of or the start of the formation of the cellular type if your degree of undercooling is less or you know as it goes on increasing.

So it will move to columnar dendritic where you will have the arms vertically you know coming in one direction because that will be your primary direction of growth of the arm and you will have some secondary growth also secondary arms will be there connected to it, but ultimately you will have mostly the columnar structure whereas when it is furthermore then it is enough to provide the random nucleation you know and in those cases you will have the dendritic structure, but then it will be equiaxed.

And so further you know you will have the structures not looking like oriented in a particular direction, but it will have an equiaxed type of structure which occurs in this case. So basically based upon the temperature gradient line and you know this way this constitutional undercooling occurs and you know this constitutional undercooling leads to the formation of the, you know, the dendritic structures in the case of alloys. Thank you very much.