Metal Casting
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Module - 03
Melting, Fluidity And Solidification
Lecture - 04
Solidification

Good morning friends. In the previous classes, we have been learning about the melting practices treatment of the molten metal, and how to remove the gases from the molten metal. Now once we pour the molten metal into the mould the metal solidifies.

Now, in this lecture we will be seeing the solidification phenomenon how does it occur and how to control the solidification.

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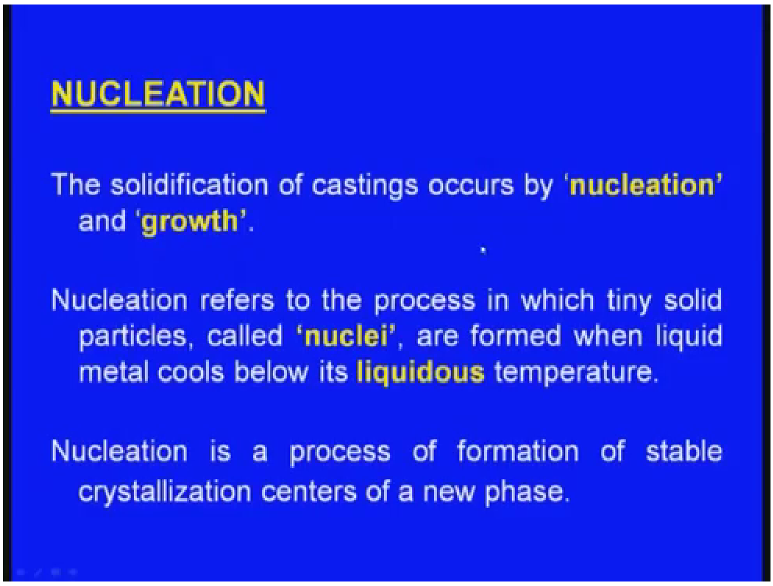

NUCLEATION

The solidification of castings occurs by 'nucleation' and 'growth'.

Nucleation refers to the process in which tiny solid particles, called 'nuclei', are formed when liquid metal cools below its liquidous temperature.

Nucleation is a process of formation of stable crystallization centers of a new phase.

Before we learn about the solidification phenomenon in a casting it is necessary for us to learn about certain terminology.

First let us see there is a term called nucleation what is this nucleation the solidification of the casting occurs by nucleation and growth. Nucleation refers to the process in which tiny solid particles called a nuclei are formed, when liquid metal cools below its liquidus temperature.

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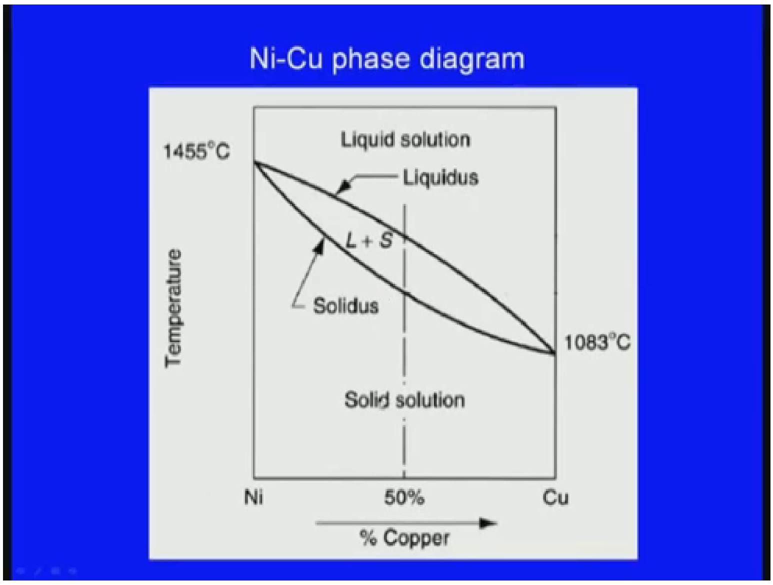
Ni-Cu phase diagram

Now, you must be knowing the liquidus temperature anyway I will show you the liquidus temperature, here we can see this is the phase diagram of nickel and copper, now here we can see there are 2 lines are there, and this is the liquidus line means everything about this liquidus line is liquid. Now this is the solidus means everything below this line is solid in between is the liquid plus solid that is the mushy zone.

Now, here this is the nickel and copper alloy system, now nucleation is a process of formation of stable crystallization centers of new phase right, means between liquidus line and solidus line this nucleation takes place.

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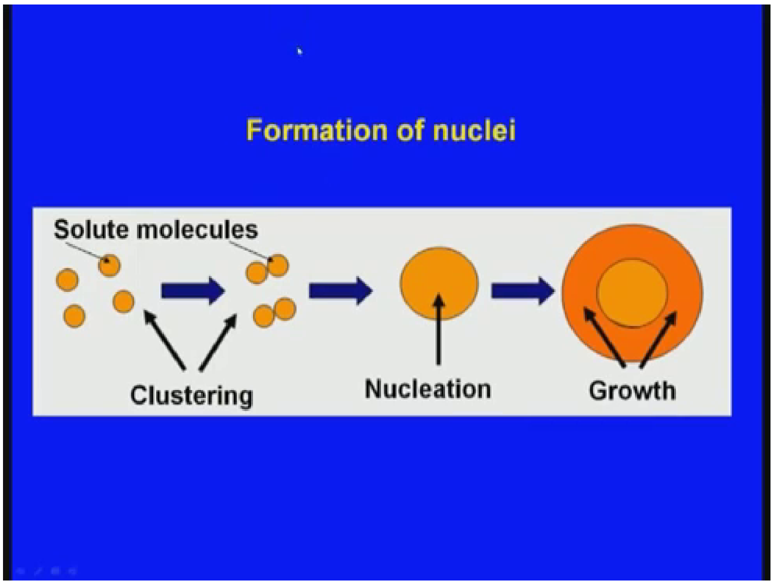

Formation of nuclei

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Now, how does it takes place what is the how does it this nuclei form, and here we can see these are the solute molecules, small solute mark what say molecules are there.

Now all these are clustered together and a nucleus is formed you see this is the form a nucleation, this nucleus will be developing and it grows and finally, it will become a crystal.

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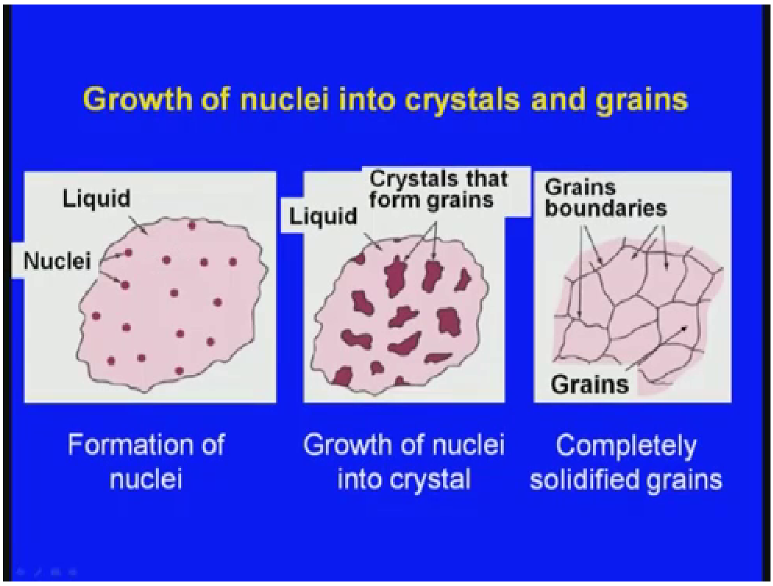

Growth of nuclei into crystals and grains

Formation of nuclei

Growth of nuclei into crystal

Completely solidified grains

.

And here we can see clearly, this is the here we can see 3 figures one is the formation of nuclei, growth of nuclei, into crystal and completely solidified grains, and here we can see there is everywhere there is liquid, but this here we can see something immediately below the liquidus line. And here we can see these are the nuclei, this is one nucleus, this is one nucleus, and this is one nucleus and so on.

Now, these nuclei will be growing and there they will be joining together, and see here they have become crystals still a little liquid is there some more liquid is there. Now these crystals will be growing finally, they will become grains. So, this is one grain, this is one grain, this is one grain.

Now this is the grain boundary. So, this is another grain boundary, so this is another grain boundary, likewise the solidification takes place first formation of the nuclei next this nuclei will be growing and growing into crystals, then these crystals will be growing into grains the once grains are form the casting is solidification is over.

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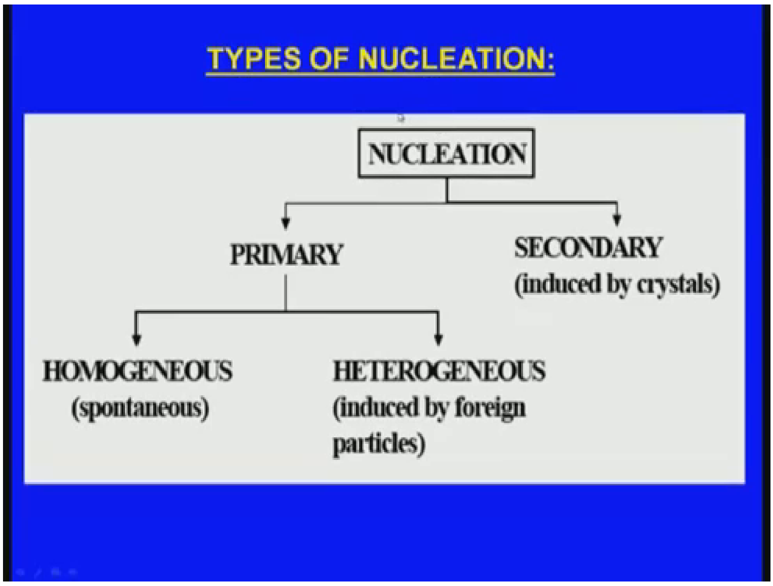

TYPES OF NUCLEATION:

NUCLEATION

PRIMARY

SECONDARY
(induced by crystals)

HOMOGENEOUS
(spontaneous)

HETEROGENEOUS
(induced by foreign particles)

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Now, this nucleation is primarily there are 2 types one is the primary nucleation, and another one is the secondary nucleation, under the primary nucleation again there are 2 types one is the homogeneous, and another one is the heterogeneous.

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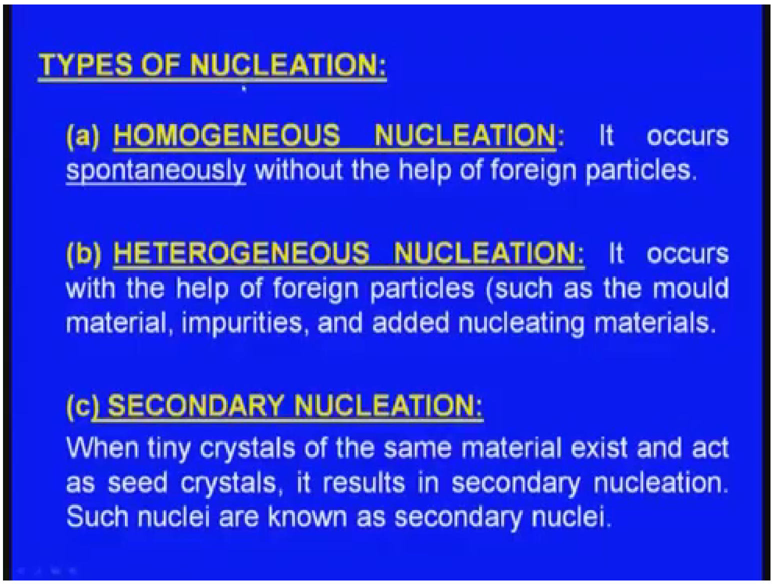

TYPES OF NUCLEATION:

(a) **HOMOGENEOUS NUCLEATION:** It occurs spontaneously without the help of foreign particles.

(b) **HETEROGENEOUS NUCLEATION:** It occurs with the help of foreign particles (such as the mould material, impurities, and added nucleating materials.

(c) **SECONDARY NUCLEATION:**
When tiny crystals of the same material exist and act as seed crystals, it results in secondary nucleation. Such nuclei are known as secondary nuclei.

Now, we will see all these, now let us see this homogeneous nucleation it occurs spontaneously without the help of foreign particles, no foreign particles, or no impurities are required for this homogeneous nucleation.

Next one is the heterogeneous nucleation it occurs with the help of foreign particles or impurities, and generally this occurs in a casting at the beginning of solidification especially nearer to the mould wall there will be impurities will be there. So, these impurities will be acting as the foreign particles and because of that they will be acting as the nucleating agents.

So this is the heterogeneous nucleation, and third one is the secondary nucleation when tiny crystals of the same material exist, and act as seed crystals it results in the secondary nucleation, such nuclei are known as the secondary nuclei. So, there are totally we can see there are 3 types of nucleation one is the homogeneous, second one is the heterogeneous, and third one is the secondary nucleation, but in casting in the castings generally this heterogeneous nucleation will be dominating.

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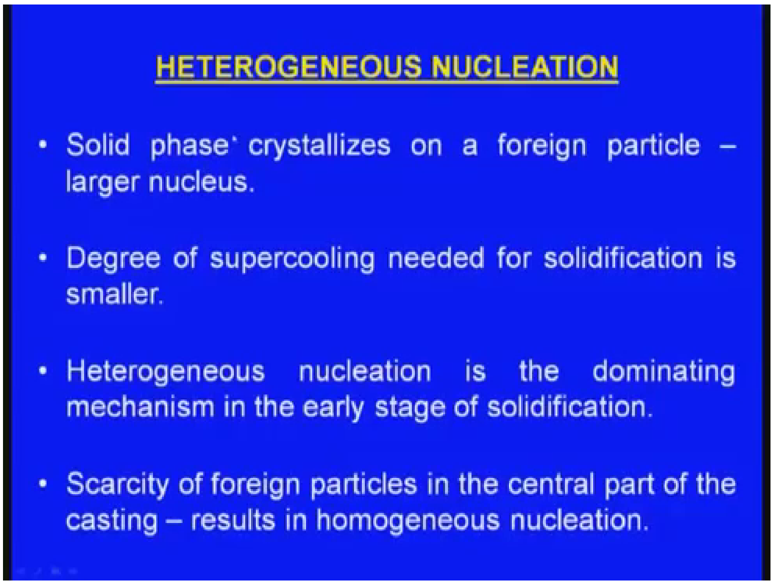

HETEROGENEOUS NUCLEATION

- Solid phase crystallizes on a foreign particle – larger nucleus.
- Degree of supercooling needed for solidification is smaller.
- Heterogeneous nucleation is the dominating mechanism in the early stage of solidification.
- Scarcity of foreign particles in the central part of the casting – results in homogeneous nucleation.

Now, in this heterogeneous nucleation solid phase crystallizes on a foreign particle right that results in largest nucleus initially there will be some say impurities will be there nearer to the mould wall around these impurities right the metal solidifies and it becomes in a larger nucleus.

Next one degree of super cooling is needed for solidification is right, next one homogeneous nucleation is the dominant mechanism in the early stage of solidification, because in the early stage of the solidification what happens the solidification commences from the mould walls and slowly it progress inside.

Now, nearer to the moulding walls there will be impurities, and because of these impurities there will be heterogeneous nucleation at the what; say early stage of the solidifications, as these solidification is progressing inside there will be scarcity of impurities then there will be homogeneous nucleation.

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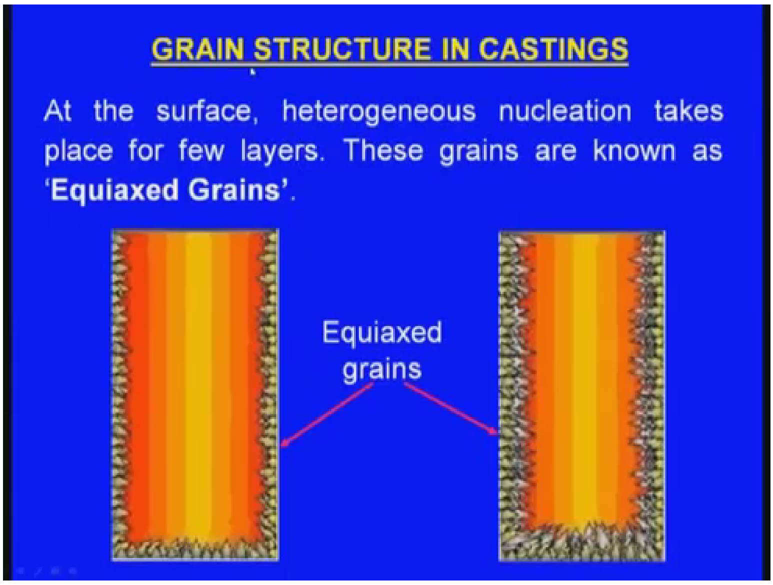

GRAIN STRUCTURE IN CASTINGS

At the surface, heterogeneous nucleation takes place for few layers. These grains are known as **'Equiaxed Grains'**.

Next one is the grain structure in castings, now how will be the grain structure in castings at the surface heterogeneous nucleation takes place for few layers this, I have already told because at the what; says remember the solidification starts from the mould wall and it progresses inside. Now nearer to the mould wall there will be impurities and because of these impurities there will be heterogeneous nucleation.

Now, because of this heterogeneous nucleation right Equiaxed grains are formed, you see these are the Equiaxed grains means of course the first figure is at the very first stage of the solidification. Now this is a little advanced what say solid stage of the solidification, now here we can see these are the Equiaxed grains means what does it mean their orientation is random, they are neither horizontal or they may be horizontal they may be vertical or they may be inclined their orientation is random. So, in such a case we call them as the Equiaxed grains.

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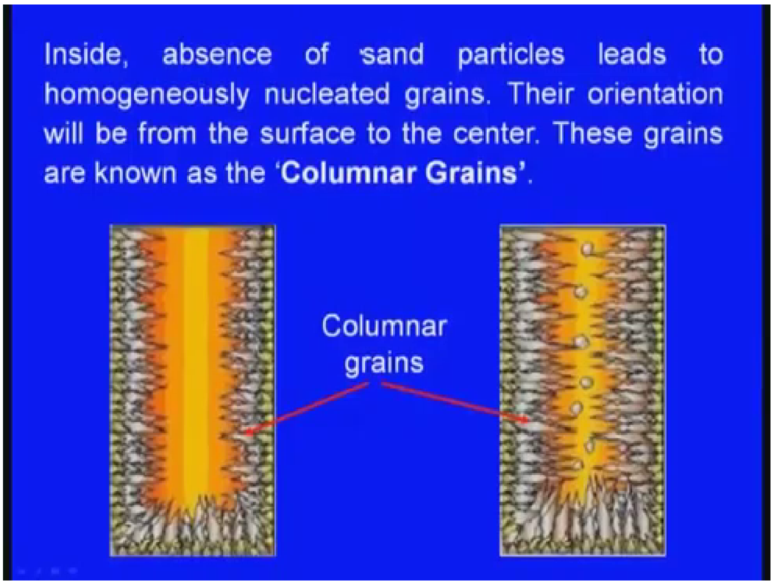

Inside, absence of sand particles leads to homogeneously nucleated grains. Their orientation will be from the surface to the center. These grains are known as the '**Columnar Grains**'.

Now, inside options of sand particles as this solidification is progressing inside, there would not be any what say impurities or the sand particle that leads to homogeneously nucleated grains, and their orientation from the surface to the center these, grains are known as the columnar grains.

Because of the homogeneous nucleation right because of the what; say options of the impurities there will be homogeneous nucleation, and in such a case columnar grains will be forming you see earlier we have seen Equiaxed grains, now these are the columnar grains means they are looking like columns.

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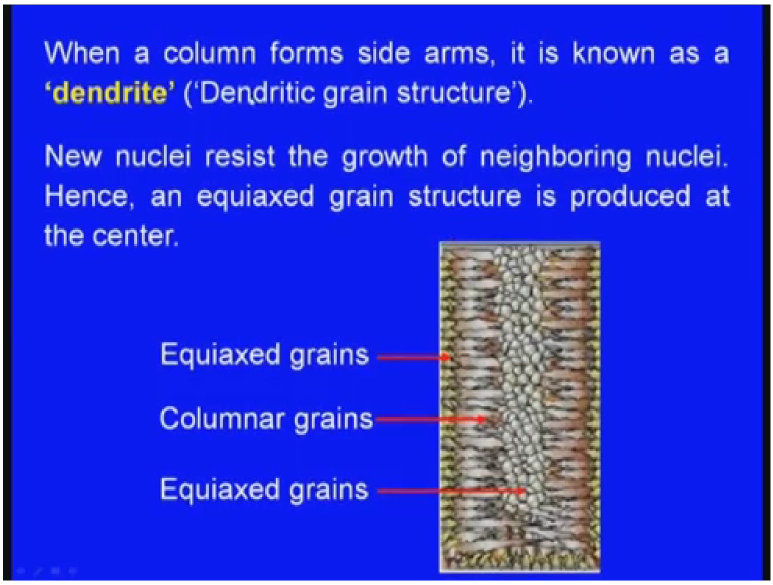

When a column forms side arms, it is known as a **'dendrite'** ('Dendritic grain structure').

New nuclei resist the growth of neighboring nuclei. Hence, an equiaxed grain structure is produced at the center.

Now, when a column forms side arms it is known as a dendrite. As the column is advancing towards the center of the casting it also develops side arms, so these are known as the dendrites right. Now the new nuclei resist the growth of the neighboring nuclei, now here the what; say columnar grains are advancing from one side, from the other side also columnar grains are advancing.

So, these will be interfering and they will be resisting each other finally, at the center we can see there are again equiaxied grains are there. So that is how in a casting we can see in the beginning there will be equiaxied grains are there. Now as the solidification is progressing there will be columnar grains and at the center of the casting they again there will be equiaxied grains.

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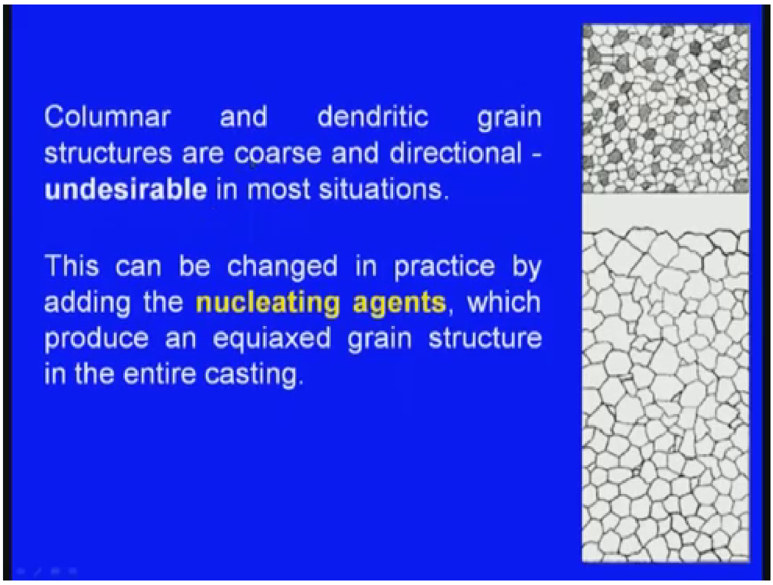

Columnar and dendritic grain structures are coarse and directional - **undesirable** in most situations.

This can be changed in practice by adding the **nucleating agents**, which produce an equiaxed grain structure in the entire casting.

Columnar and dendritic structures are coarse and a directional and they are undesirable in most of the situations, columnar grains and dendritic grains are not suitable, they are not desirable what is desirable is the Equiaxed grains are desirable. Now we need to change this, this is what say phenomenon we have to control the solidification, now what we are doing this can be changed in practice by adding nucleating agents which produce Equiaxed grain structure in the entire casting.

Just now we have seen during this solidification at the beginning of the solidification there are impurities nearer to the mould wall, because of these impurities there was heterogeneous solidification and as the what; say solidification is progressing inside, there will be columnar gains will be there and again at the center there will be Equiaxed grains.

So there is no uniformity in the grain structure, this is what we do not want we want uniformity in the grain structures that is why we intentionally add nucleating agents in the molten metal. So, that these nucleating agents will be spread all over not only at the mould wall they will be spread all over the melt all over the molten metal. So, everywhere there will be heterogeneous solidification, thus there will be what says uniform grain structure, and here we can see this is a uniform grain structure.

Now, we need to for this we need to add nucleating agents, external nucleating agents this we need to add intentionally after melting is over right.

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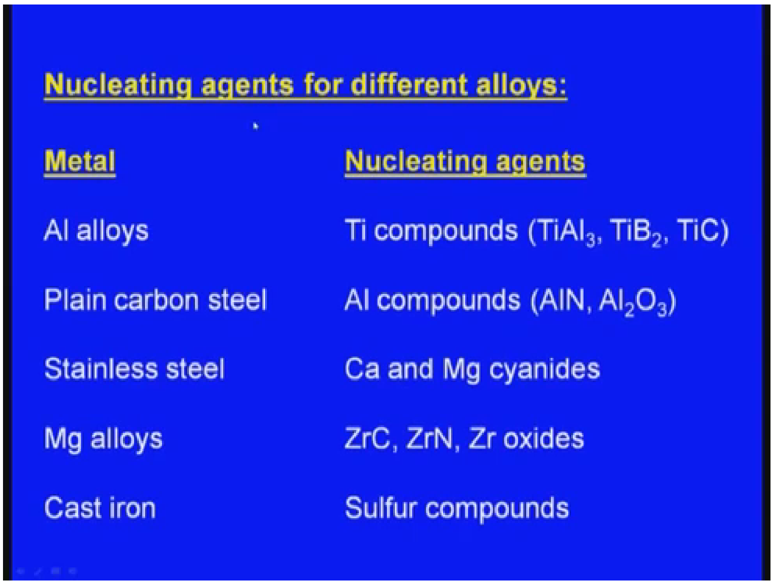

Nucleating agents for different alloys:

Metal	**Nucleating agents**
Al alloys	Ti compounds ($TiAl_3$, TiB_2, TiC)
Plain carbon steel	Al compounds (AlN, Al_2O_3)
Stainless steel	Ca and Mg cyanides
Mg alloys	ZrC, ZrN, Zr oxides
Cast iron	Sulfur compounds

So, these are the nucleating agents for different alloys for aluminum alloys nucleating agents are titanium compounds like titanium right Al 3 right. Next one titanium boron titanium carbide, next one for plain carbon steel the nucleating agents are aluminum compounds and for stainless steel the nucleating agents are calcium, and magnesium cyanides, and for magnesium alloys the nucleating agents are zirconium carbide, zirconium nitrate, and zirconium oxide, and for cast iron the nucleating agents are sulphur components.

So, these are the external nucleating agents, which we add to the molten metal intentionally deliberately, but at a very extremely small proportion. So, that they would not change the chemical composition, but they will be changing the grain structure and they will be maintaining a uniform grain structure that is the purpose of the what; say adding nucleating agents.

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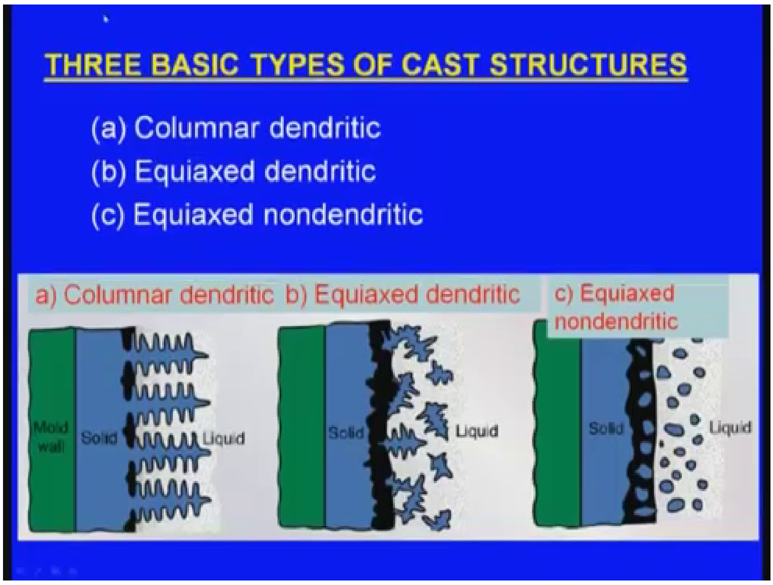

THREE BASIC TYPES OF CAST STRUCTURES

(a) Columnar dendritic
(b) Equiaxed dendritic
(c) Equiaxed nondendritic

Now, there will be 3 basic types of cast structures in the what; say castings, one is the columnar dendritic, Equiaxed dendritic, third one is the Equiaxed non dendritic. Now let us see the first one this is the columnar dendritic means, the basic structure is like a column, but to that column there will be side dendrites are there.

Second type is the Equiaxed dendritic means these what say crystals have what say random orientation, they do not have uniform orientation like the first one, but again though they have the random orientation still they have the dendrites.

So, this is the Equiaxed dendritic structure and the third one is the Equiaxed non dendritic structure means here, there are what say grains are there crystals are there they have what say random orientation and they do not have dendrites, and this is a this is an ideal what say cast structure.

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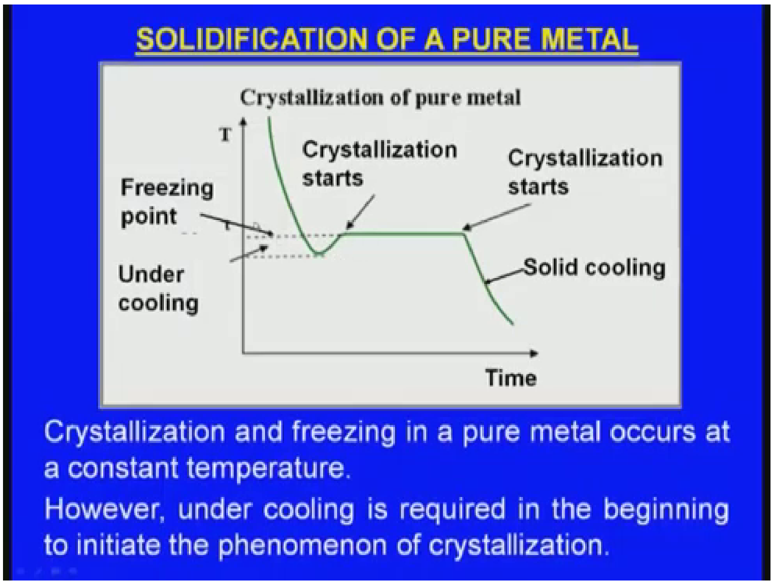
SOLIDIFICATION OF A PURE METAL

Crystallization and freezing in a pure metal occurs at a constant temperature.

However, under cooling is required in the beginning to initiate the phenomenon of crystallization.

Now, solidification let us say the solidification of a pure metal, so this is the solidification what say a structure of a pure metal crystallization of a pure metal, now here we can see the x axis is the time and y axis is the temperature right. So, as their time progresses initially we may pour here this is the pouring temperature slowly it cools down, and this is the what; say crystallization what say temperature here, this is the place where crystallization starts.

In fact, this is the freezing point at the freezing point actually the crystallization is supposed to start what happens is an under cooling is required right, crystallization and freezing in a pure metal occurs at constant temperature. So, this is the freezing point at this freezing point or at this freezing temperature crystallization takes place; however, under cooling is required in the beginning to initiate the phenomenon of crystallization here, we can see this is under cooling because of the under cooling the crystallization will be initiated.

Now, at a constant temperature right the crystallization takes place and once the crystallization is over, once this crystallization is completed grains will be formed then the what; say casting is fully solidified, now here it is the solid cooling. So, this is the solidification of a pure metal.

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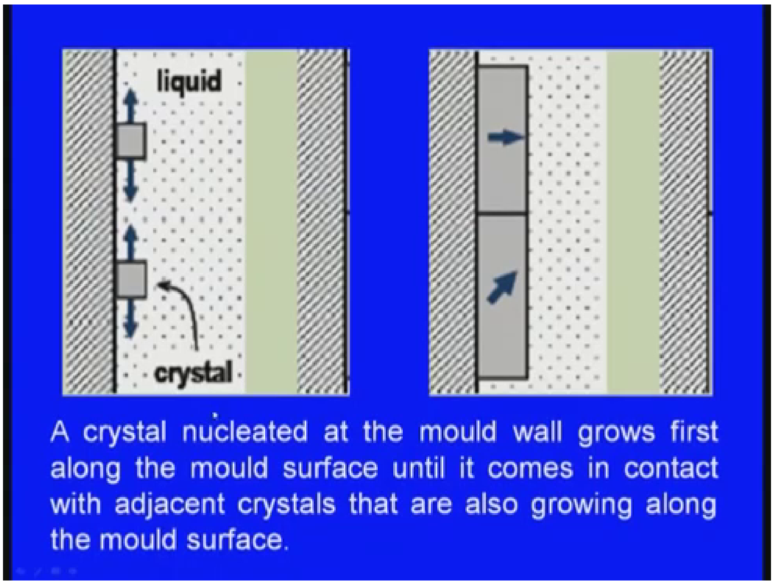

A crystal nucleated at the mould wall grows first along the mould surface until it comes in contact with adjacent crystals that are also growing along the mould surface.

Now, a crystal nucleated at the mould wall grows first along the mould surface until it comes in contact with adjacent crystals that are also growing along the mould surface, now here we can see this is the mould wall, this is the mould wall, this is one crystal, now how does growth takes place. In which direction it will be growing towards another crystal means along the mould wall, you see until it meets the next crystal, until it comes and comes in contact with the next crystal it will be growing. So, that is the direction of growth of the crystals.

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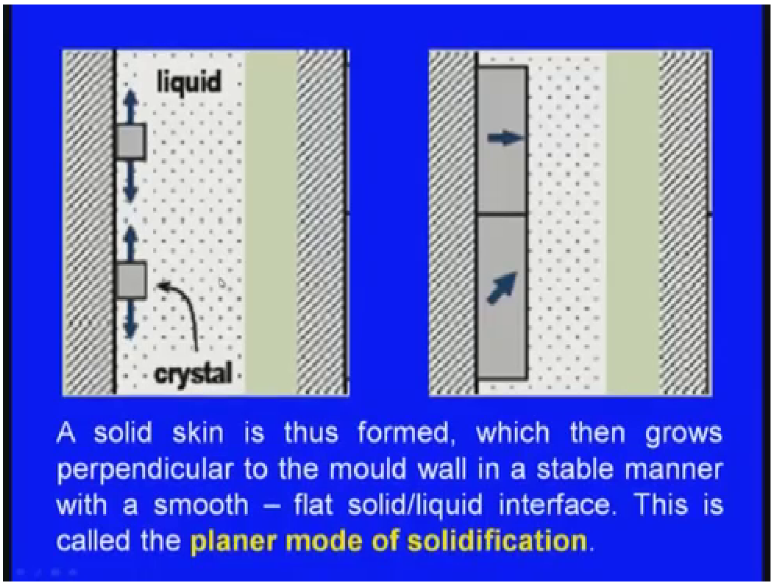

A solid skin is thus formed, which then grows perpendicular to the mould wall in a stable manner with a smooth – flat solid/liquid interface. This is called the **planer mode of solidification**.

Then what happens a solid skin is thus formed which then grows perpendicular to the mould wall, in a stable manner with a smooth flat solid liquid interface this is called the planer mode of solidification. Now what happened here there was one crystal, and here there was one crystal, likewise there will be more crystals every crystal will be grow what say moving and growing along the mould wall, and they all will be joining a skin will be formed once the skin is formed, then this skin will be growing perpendicular to the direction of the mould wall. Until then they are growing in this direction parallel to the mould wall.

Now, a skin is formed you see once the skin is formed it will be growing perpendicular to the mould wall.

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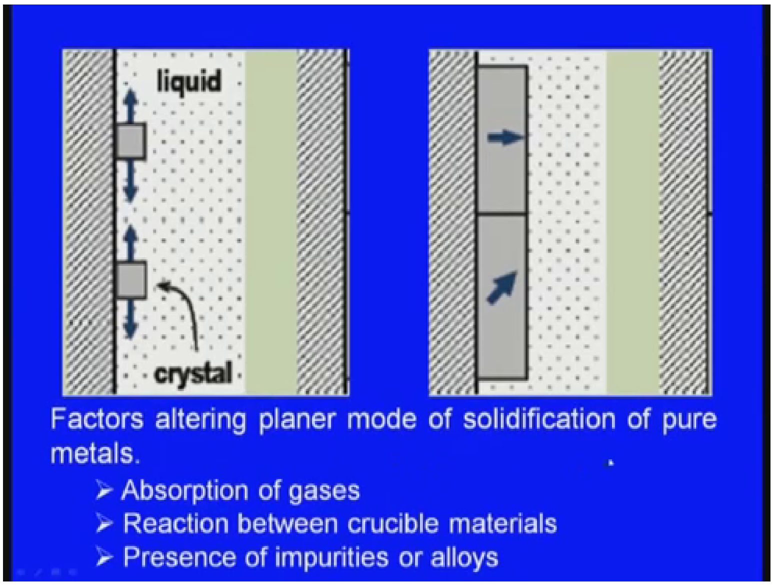

Factors altering planer mode of solidification of pure metals.

- Absorption of gases
- Reaction between crucible materials
- Presence of impurities or alloys

So, this is known as the planer mode of solidification. Factors altering planer mode of solidification of pure metal there are 3 factors, one is the absorption of gases second one is reaction between crucible materials, and the third one is the presence of impurities or alloys, when crystal grows the actual temperature of the liquid may rise due to evolution of the latent heat.

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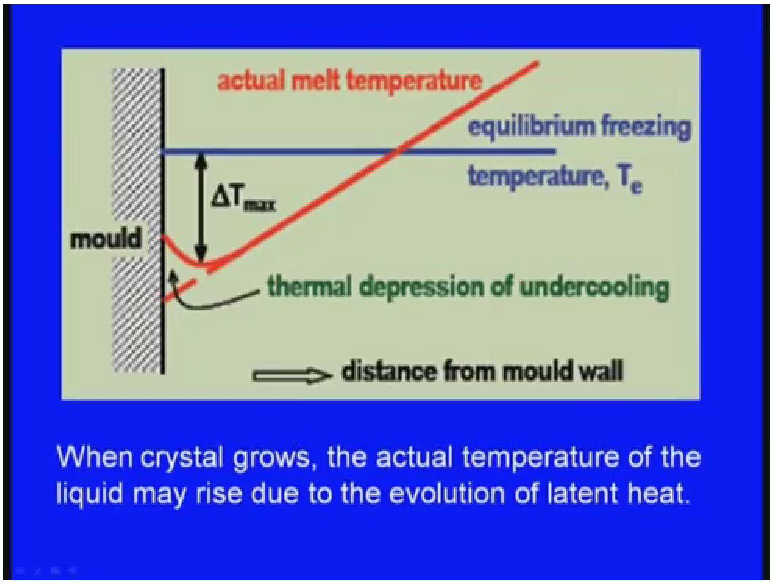

When crystal grows, the actual temperature of the liquid may rise due to the evolution of latent heat.

So, that is what we can see right in this picture. Growth of crystal along the mould wall is stopped at some stage and secondary arms of primary crystals grow inside the liquid.

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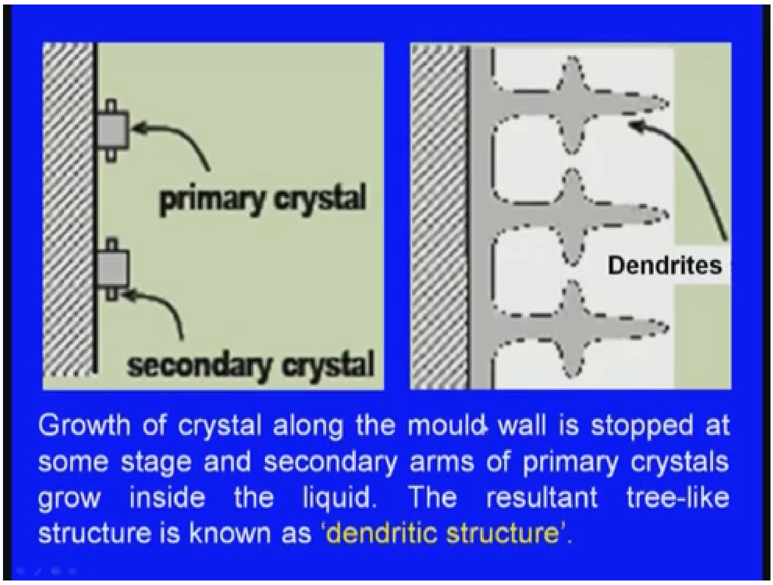

Growth of crystal along the mould wall is stopped at some stage and secondary arms of primary crystals grow inside the liquid. The resultant tree-like structure is known as 'dendritic structure'.

And here we can see, I this is the initial this is at the early stage of solidification this is the primary crystals all are what say growing parallel to the mould wall, then a skin is formed once the skin is formed it is growing perpendicular to the mould wall, but how they are growing like a column this is known as the dendrite.

So, this is one known as one dendrite. So, this is another dendrite, and this is another dendrite, not only that each dendrite will be developing side arms, like this say this is one side arm, this is one side arm, likewise every dendrite will be developing side arms, again every side arm will be developing more side arms.

Now, the resultant tree like structure is known as dendritic structure. Now let us see the dendritic growth we have seen the what; say crystals grow like dendrites, and there will be a dendritic structure.

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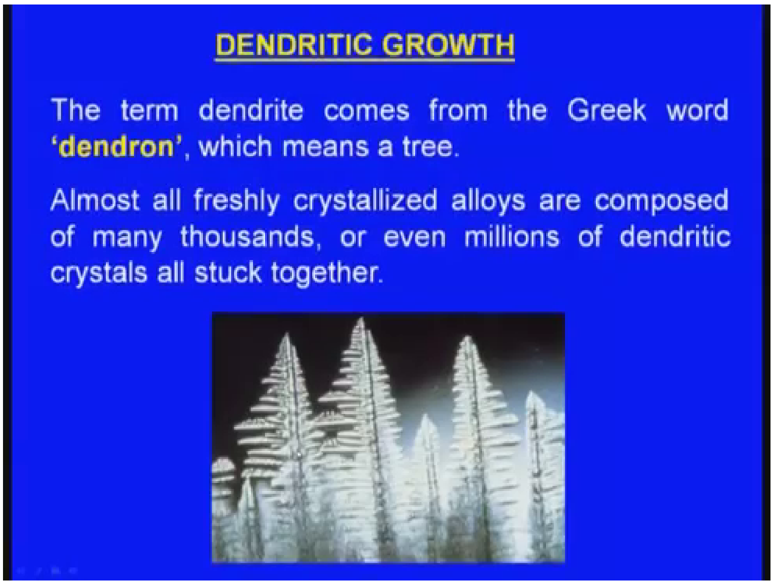

DENDRITIC GROWTH

The term dendrite comes from the Greek word **'dendron'**, which means a tree.

Almost all freshly crystallized alloys are composed of many thousands, or even millions of dendritic crystals all stuck together.

Now, let us see the dendritic growth the term dendrite comes from the greek word dendron which means a tree, almost all freshly crystallized alloys are composed of many thousands even millions of dendritic crystal, all stuck together and here we can see this is the dendritic structure, you see there are several what say columns are there columnar structures are there and each column has got the side arms again each side arm has got more side arms. So, that is the dendritic tree or the dendritic structure.

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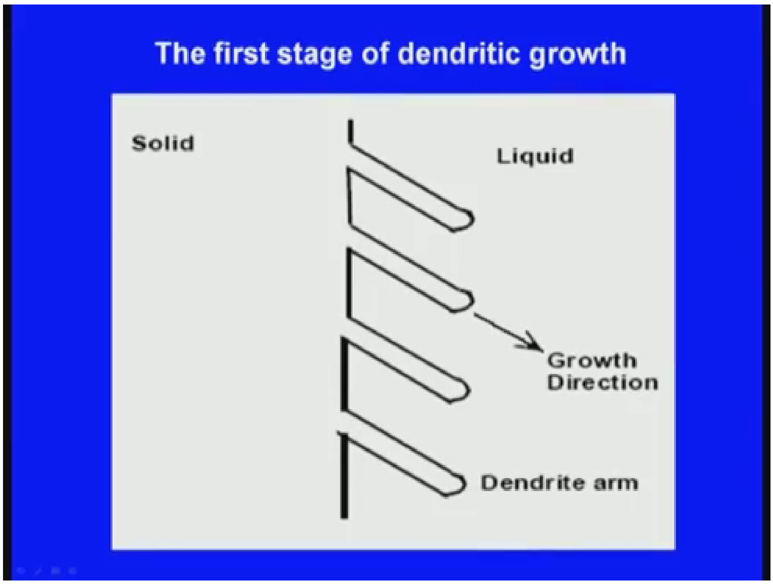

The first stage of dendritic growth

And yes this is the first stage of the dendritic growth right, this is a solid and this is the liquid, and they will be growing means here is this side is the mould wall means the towards the left side is the mould wall it is already solidified, and this is towards the center of the casting means the right side, and this is the direction of the growth of the what; say arms the columnar grains, now these are the dendritic arms.

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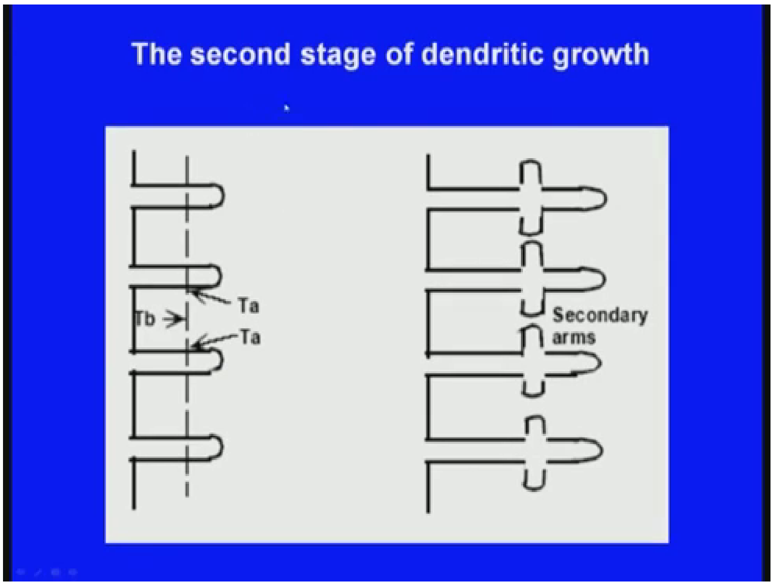

The second stage of dendritic growth

Now, this is the second stage of dendritic growth right, every what say dendritic arm will be developing side arms.

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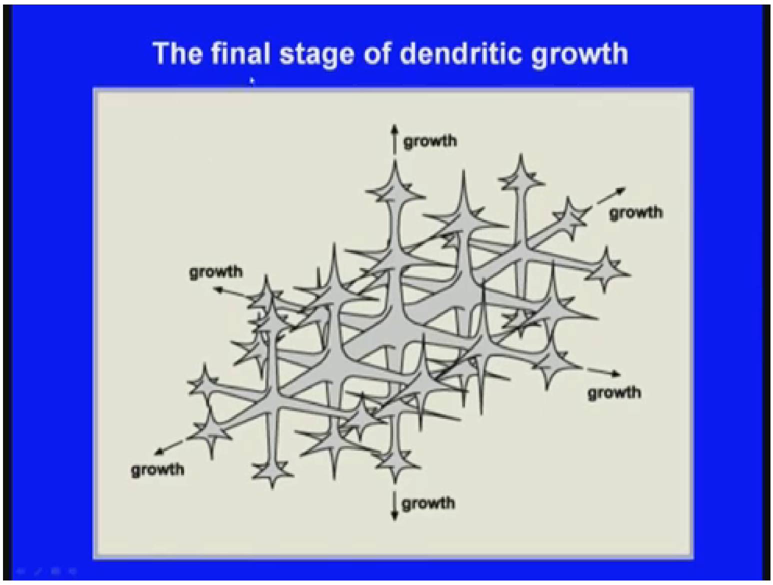
The final stage of dendritic growth

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Finally this is the final stage of the dendritic growth, you see everywhere there are what say dendritic structures are there, and there are side arms are there each side arm has developed more and more side arms, likewise they all will be what say covering the entire mould finally, they will be joining together.

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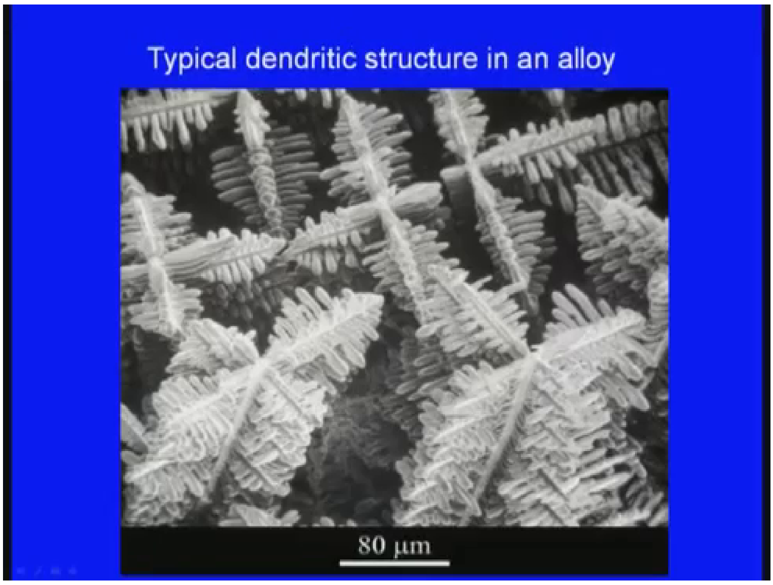
Typical dendritic structure in an alloy

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And this is the typical dendritic structure in an alloy you can see, so many dendrites are there, so many side arms are there. So, this is the dendritic structure in an alloy.

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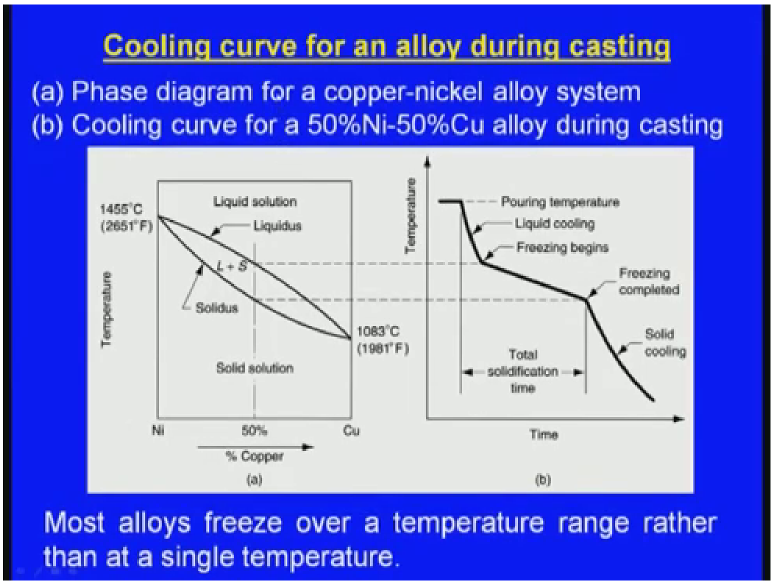

Cooling curve for an alloy during casting

(a) Phase diagram for a copper-nickel alloy system
(b) Cooling curve for a 50%Ni-50%Cu alloy during casting

Most alloys freeze over a temperature range rather than at a single temperature.

Next one solidification of alloy let us see here now cool this is the cooling curve for an alloy during casting, now here we can see 2 figures first one is the phase diagram of copper nickel alloy system. So, this is here we can see this is the what; say nickel, and as we go towards right the copper content is increasing, and here it is hundred percent copper and here it is hundred percent nickel.

Now, we are considering 50 percent nickel and 50 percent copper, that be the case yes we can go like this, but this is the what; say phase diagram for the copper nickel alloy system, at 50 percent nickel, and 50 percent copper, this is the cooling curve, and here we can see again this is the liquidus line, means above this liquidus line everything is liquid, and this is the solidus line below this solidus line everything is solid, and between liquidus line and so, what say solidus line there will be a mushy zone means liquid plus solid.

Now, this is the cooling curve for 50 percent in nickel and 50 percent, copper now most alloys freeze over a temperature range rather than at a single temperature. In case of a pure metal the crystallizations takes place at a constant temperature whereas, in the case of an alloy the crystallization and also are the freezing takes place over a temperature range right here we can see this is the pouring temperature, now at from pouring temperature there will be liquid cooling will be there, how long this liquid cooling will be there till the freezing point.

Yes this is the freezing point here the freezing begins, now from this point to this point freezing will be continuing you see the temperature is not constant, the temperature is coming down and the what; say freezing continuous. And here the freezing is totally what say completed and it became a solid casting.

Still from solid casting to the what; say it will be cooling down to the ambient temperature, so this is the solid cooling. So, from this point to this point is the solidification time, so what we can learn from this graph the what; say freezing in an alloy occurs over a range not at a constant temperature as in the case of a pure metal.

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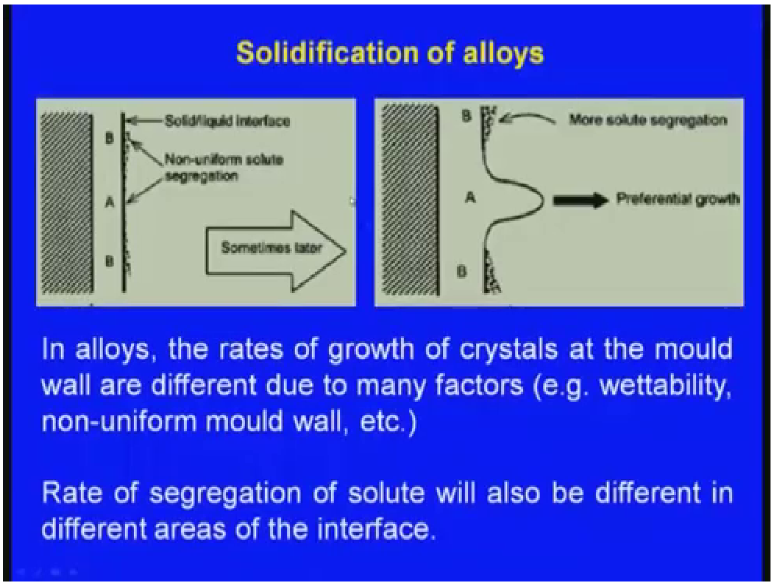

Solidification of alloys

In alloys, the rates of growth of crystals at the mould wall are different due to many factors (e.g. wettability, non-uniform mould wall, etc.)

Rate of segregation of solute will also be different in different areas of the interface.

Now, solidification of alloys right what happens in alloys the rates of growth of crystal at the mould wall are different due to many factors, due to wettability or non uniform right mould wall, and so on right. So the growth of crystals is not uniform whereas, in the case of the pure metals it was uniform, it will be uniform and here we can see there will be segregation will be there right, and here we can see solid liquid interface is there.

Next one non uniform solute segregation is here we can see, likewise there will be preferential growth will be there right. The rate of segregation of solute will also be different in a different areas of the interface and because of that you can see the solidification will not be uniform, and here we can see more solute segregation is there and there will be preferential growth will be there.

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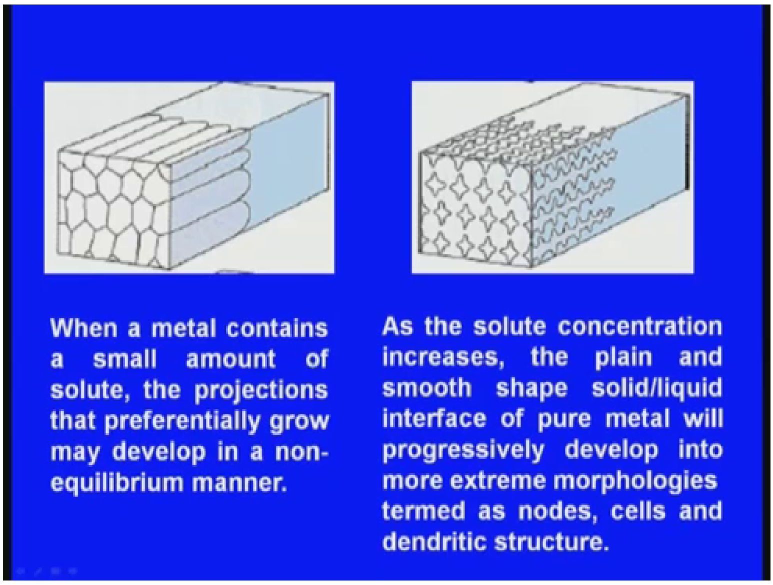

When a metal contains a small amount of solute, the projections that preferentially grow may develop in a non-equilibrium manner.

As the solute concentration increases, the plain and smooth shape solid/liquid interface of pure metal will progressively develop into more extreme morphologies termed as nodes, cells and dendritic structure.

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Now, when a metal contains a small amount of solute the projections that preferentially grow may develop in a non equilibrium manner. Next a as the solute concentration increases, the plane and smooth shape solid liquid interface of pure metal will progressively develop into more extreme morphologies termed as nodes, cells and dendritic structures.

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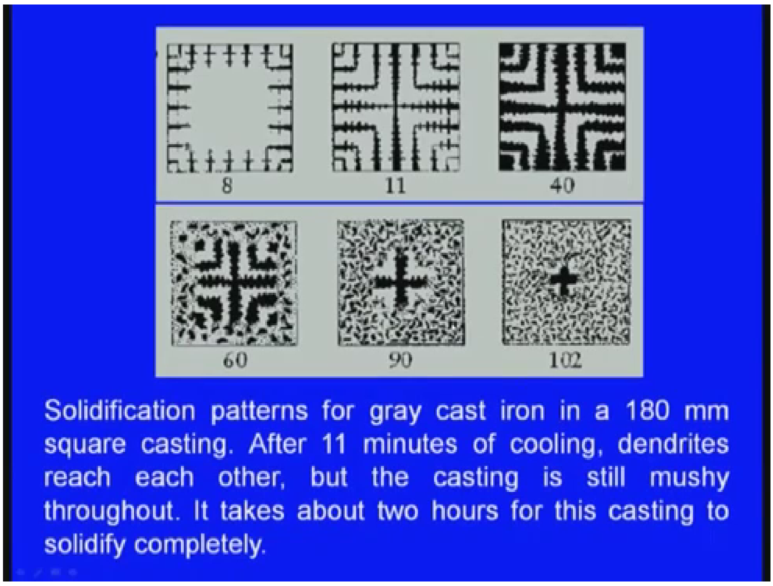

Solidification patterns for gray cast iron in a 180 mm square casting. After 11 minutes of cooling, dendrites reach each other, but the casting is still mushy throughout. It takes about two hours for this casting to solidify completely.

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Now, here we see a what say one case study right, the solidification patterns for gray cast iron in a 180 m m square casting right, after eleven minutes of cooling dendrites reach

each other, you see here the right, but the casting is still in mushy zone throughout it takes about 2 hours for the complete solidification.

Now, here what happens these are the what; say dendrites in the initial stage maybe after 8 minutes, after these dendrites will be growing, towards the center at the same time from the other side also dendrites will be growing, they all will be growing in the opposite direction yes after eleven minutes they have met one another right here.

Now, what happens there will be more side arms will be there, side arms and more and more side arms we can see here finally, nearly after 102 minutes this mushy zone has completed has come to an end and there is complete solidification.

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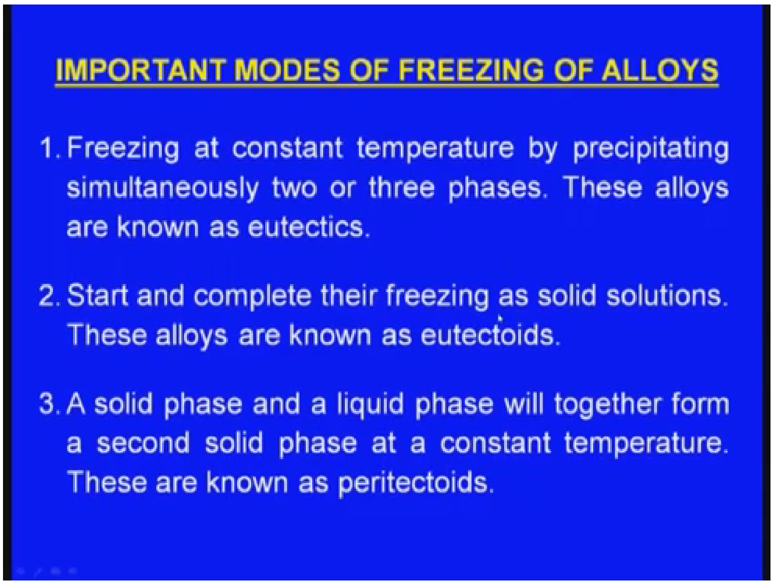

IMPORTANT MODES OF FREEZING OF ALLOYS

1. Freezing at constant temperature by precipitating simultaneously two or three phases. These alloys are known as eutectics.
2. Start and complete their freezing as solid solutions. These alloys are known as eutectoids.
3. A solid phase and a liquid phase will together form a second solid phase at a constant temperature. These are known as peritectoids.

Next one modes of freezing of alloys there are 3 important modes of freezing of alloys. One is the freezing at constant temperature by precipitating simultaneously 2 or 3 phases, these alloys are known as eutectics and the second mode is start and complete their freezing as solid solutions, these alloys are known as eutectoids there is a difference, and the third mode is a solid phase and a liquid phase will together form a second solid phase at a constant temperature these are known as peritectoids.

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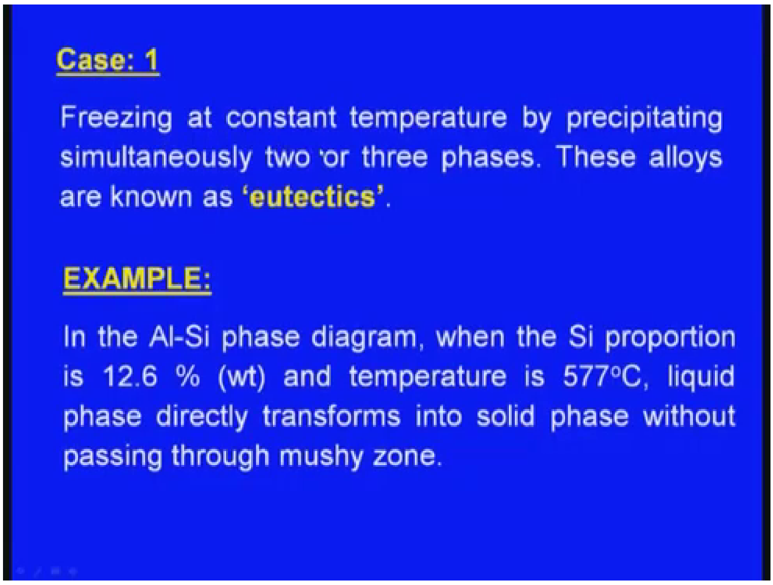

Case: 1

Freezing at constant temperature by precipitating simultaneously two or three phases. These alloys are known as **'eutectics'**.

EXAMPLE:

In the Al-Si phase diagram, when the Si proportion is 12.6 % (wt) and temperature is 577°C, liquid phase directly transforms into solid phase without passing through mushy zone.

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Now, let us see this one by one let us see the first mode of freezing; freezing, at constant temperature by precipitating simultaneously 2 or 3 phases, and these are known as eutectics. Now the best example is in the aluminum silicon phase diagram, when the silicon proportion is 12.6 percent and when the temperature is 577 degrees, liquid phase directly transforms into solid phase without passing through any mushy zone.

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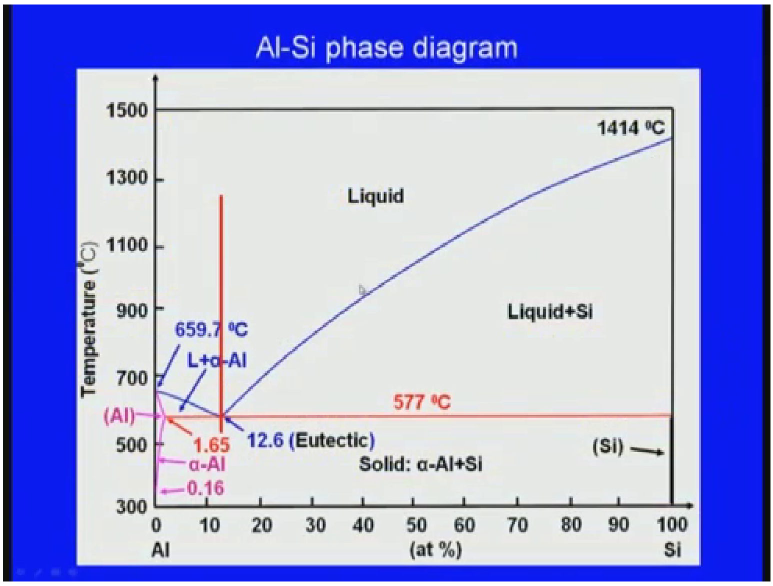

Al-Si phase diagram

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I will show the phase diagram, yes this is the aluminum silicon phase diagram, and here you can see this is the liquidus, and again this is the liquidus, above the liquidus everything is liquid and this is the solidus below the solidus everything is solid.

Now, here we can see this is the mushy zone, and here also we can see mushy zone. So, generally when a an alloy solidifying right first there will be liquid cooling, then it reaches the liquid line, then after that it will be passing through the mushy zone means there will be liquid and solid then finally it will be crossing the solidus line finally, there will be complete solid.

Now, in this case let us see when the silicon proportion is 12.6 percent and when the temperature is 577 degree centigrade, you see this point what happens, here it is liquid above this point everything is liquid. Now if you cool below 577 degree centigrade, it solid phase there is no mushy zone, right.

So, that is how it is freezing at constant temperature by precipitating simultaneously 2 or 3 phases, so these are known as the eutectics.

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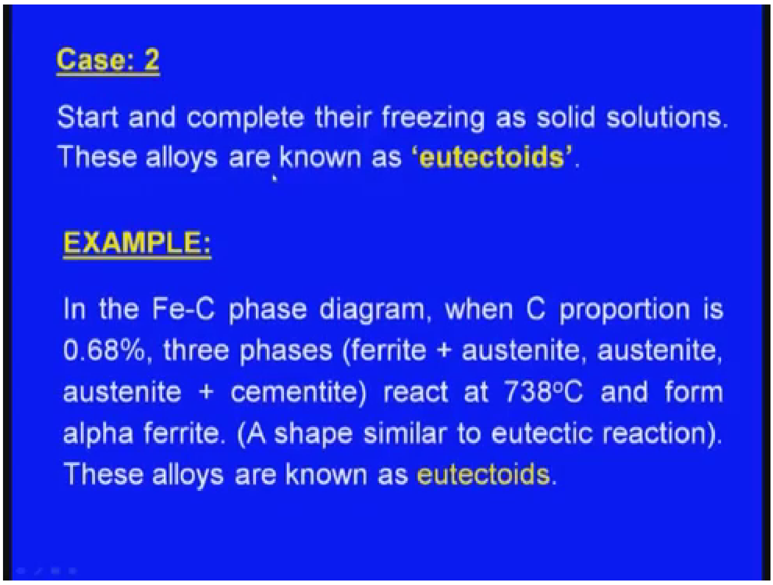

Case: 2

Start and complete their freezing as solid solutions. These alloys are known as **'eutectoids'**.

EXAMPLE:

In the Fe-C phase diagram, when C proportion is 0.68%, three phases (ferrite + austenite, austenite, austenite + cementite) react at 738°C and form alpha ferrite. (A shape similar to eutectic reaction). These alloys are known as eutectoids.

Now, let us see the second case start and complete their freezing gas solid solutions these are known as eutectoids, and the best example is in the aluminum what say sorry in the iron carbide phase diagram, when carbon proportion is 0.68 percent 3 phases they are ferrite, austenite right, plus cementite, react at 738 degree centigrade, and form alpha ferrite a shape similar to eutectic reaction these are known as the eutectoids.

They are the phase diagram will be similar to the eutectic phase diagram, but in the case of the eutectic phase diagram just above the eutectic point everything is liquid, below the liquid eutectic point everything is solid. Like a v shape here also, we can see like a v shape, but the phenomenon is not similar there is a difference.

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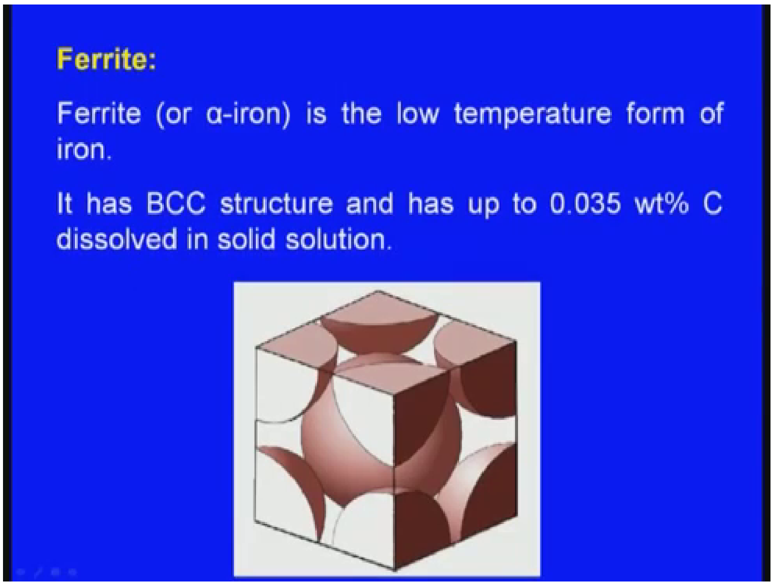

Ferrite:

Ferrite (or α-iron) is the low temperature form of iron.

It has BCC structure and has up to 0.035 wt% C dissolved in solid solution.

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What is that let us see before that let us learn about the what; say the terms which we have come across. In this case study one is the ferrite; ferrite, or the alpha iron is the low temperature form of iron, it has a body centered cubic structure and has up to 0.035 percentage weight of carbon, dissolved in solid solution it has a BCC structure you see means very little amount of carbon is dissolved.

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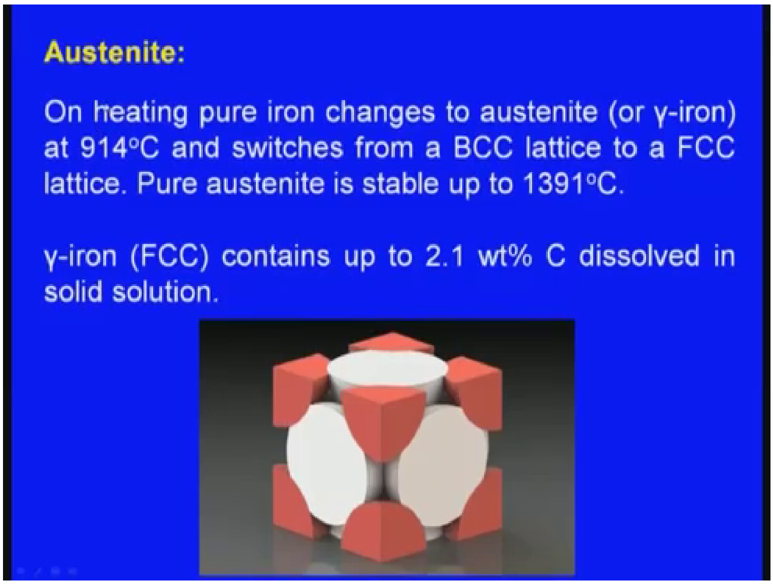

Austenite:

On heating pure iron changes to austenite (or γ-iron) at 914°C and switches from a BCC lattice to a FCC lattice. Pure austenite is stable up to 1391°C.

γ-iron (FCC) contains up to 2.1 wt% C dissolved in solid solution.

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Second one is the austenite, on heating pure iron right on heating pure iron changes into austenite or gamma iron, at 914 degrees centigrade, and switches from BCC structure to FCC structure, pure austenite is stable at up to 1391 degrees centigrade right, gamma iron that is the FCC having FCC structures contains up to 2.1 percentage weight of carbon dissolved in solid solution. So, it has an FCC structure.

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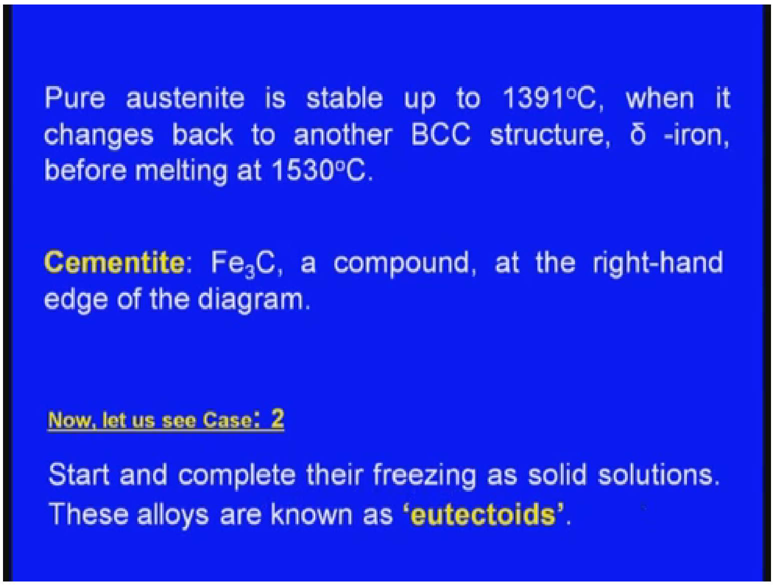

Pure austenite is stable up to 1391°C, when it changes back to another BCC structure, δ -iron, before melting at 1530°C.

Cementite: Fe_3C, a compound, at the right-hand edge of the diagram.

Now, let us see Case: 2

Start and complete their freezing as solid solutions. These alloys are known as **'eutectoids'**.

Next one pure austenite is stable up to 1391 degree centigrade, when it changes back to another BCC structure delta iron, right before melting it 1530 degrees centigrade; next 1 cementite, is iron carbide a compound at the right hand edge of the diagram. Now let us see the in case 2 start, and complete their freezing as solid solutions right this is the iron carbide phase diagram.

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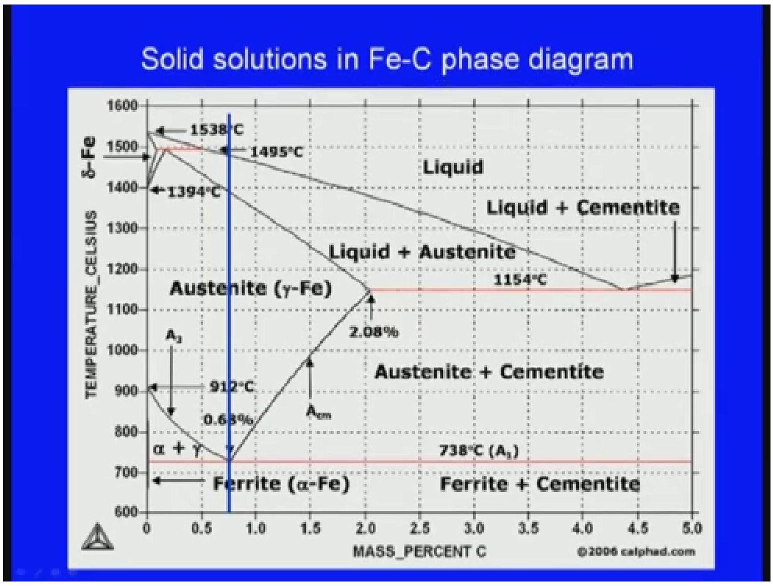

Solid solutions in Fe-C phase diagram

Now, let us consider this case where the carbon content is 0.68 percent, now you see what happens here start and complete their freezing as solid solution, now here what is this is the austenite means it is a solid. Now as the temperature is coming down what happens this is the once the temperature falls below this temperature that is the 738 degree centigrade again the structure will be changing ferrite will be forming, means what is happening start and complete their freezing as solid solutions. We can see only solid solutions before the final solidification. So, this is the second case.

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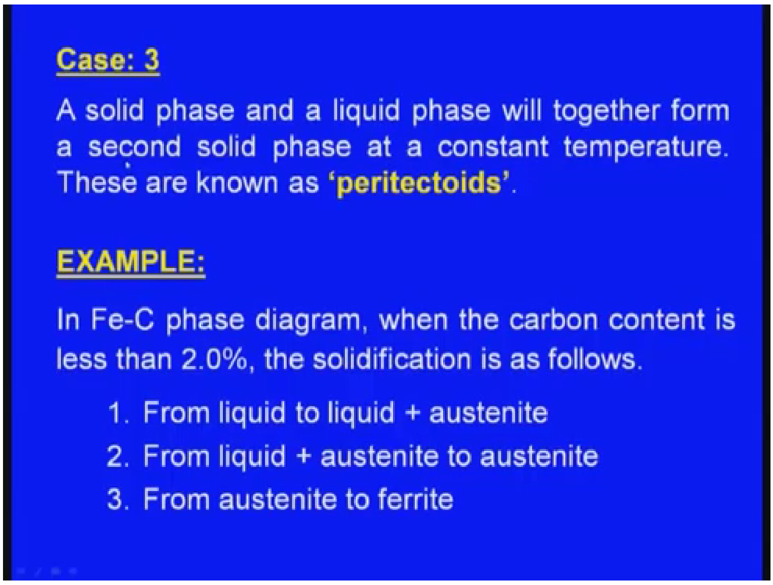

Case: 3

A solid phase and a liquid phase will together form a second solid phase at a constant temperature. These are known as **'peritectoids'**.

EXAMPLE:

In Fe-C phase diagram, when the carbon content is less than 2.0%, the solidification is as follows.

1. From liquid to liquid + austenite
2. From liquid + austenite to austenite
3. From austenite to ferrite

.

Next one let us see the case 3 a solid phase, and a liquid phase will together form a second solid phase at a constant temperature, these are known as peritectoids for this the best example again is the iron carbide phase diagram, when the carbon content is less than 2 percent the solidification is as follows right, from liquid to liquid plus austenite again from liquid plus, austenite to austenite, and from austenite to ferrite, again this is the iron carbide phase diagram.

We can see here when the carbon content is I see at about say 1.2 percent or so what is happening here we can see, different phases will be there from liquid to liquid plus austenite. So this is the liquid, and this is liquid plus austenite.

Again from liquid plus austenite to it is going to it is from becoming austenite. From austenite it is becoming austenite plus we can see austenite to ferrite. So this is the ferrite, likewise what is happening we can see there will be solid what say phase we will be there right, a solid phase and the liquid phase will together to form a second solid phase at a constant temperature, that is the exact phenomenon taking place in the case 3.

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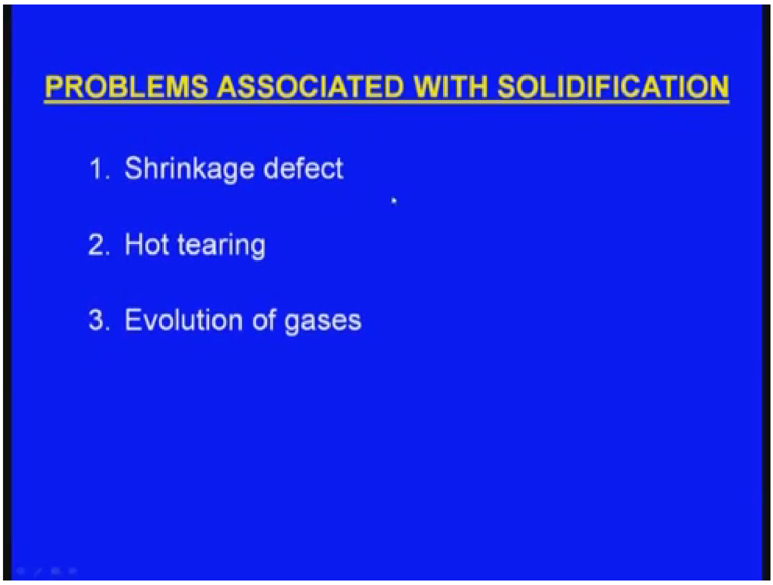

PROBLEMS ASSOCIATED WITH SOLIDIFICATION

1. Shrinkage defect
2. Hot tearing
3. Evolution of gases

Now, let us see the problems associated with the solidification, these are 3 problems shrinkage defect hot tearing and evolution of gases.

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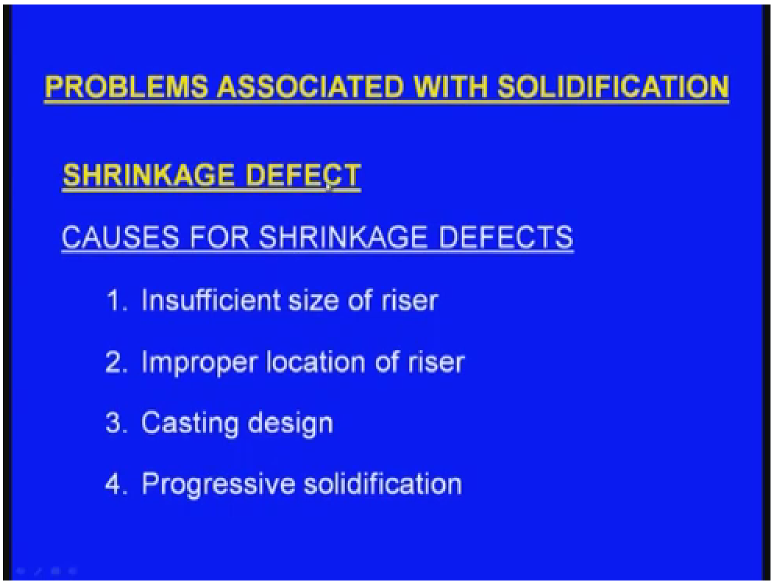

PROBLEMS ASSOCIATED WITH SOLIDIFICATION

SHRINKAGE DEFECT

CAUSES FOR SHRINKAGE DEFECTS

1. Insufficient size of riser
2. Improper location of riser
3. Casting design
4. Progressive solidification

Now, the shrinkage defect we have already covered earlier and we have what say seen how to design a riser to take care of the shrinkage defect.

Again let us review the causes for the shrinkage defect, one is the insufficient size of the riser, second one is the improper location of riser, third one casting design, and fourth one is the progressive solidification. Now these are what say causes for the shrinkage defect one has to design the riser sufficiently large, so that it can feed the what; say casting throughout the solidification process.

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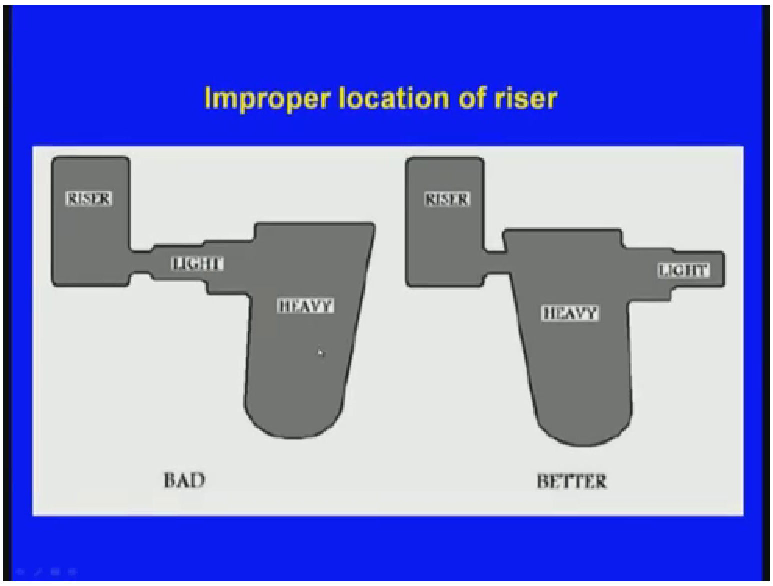

Improper location of riser

Next one, one has to place the riser in the right location for example, you see this is the casting, and this is the riser, now what happens the solidification starts from a what say far away a point right, or a small a thinner section will be solidifying first, this portion will be solidifying first, slowly the progression the solidification will be progressing towards the center of the casting.

Now, initially this is solidifying and the riser is connected towards this portion, once this solidifies the liquid metal in the riser cannot feed the casting. So, that way the riser is located in a wrong place on the other hand, let us see the this case, And now here the riser is located in the opposite direction means what is what is happening the thinner section which solidifies first is away from the riser.

Now, yes let it solidified first yes slowly the solidification will be progressing inside and the casting solidifies till the casting is completely solidified the riser will be supplying the liquid metal to the casting. So, this is the correct location of riser. So that way improper location of the riser sometimes leads to shrinkage defect.

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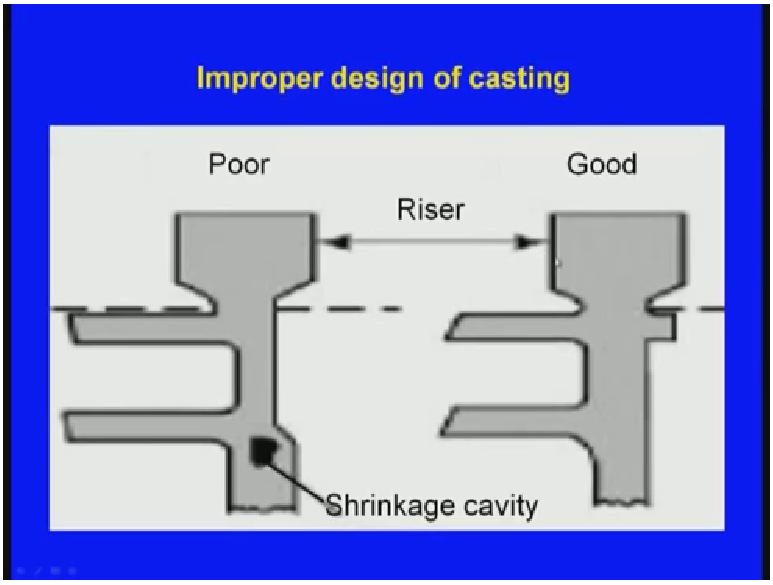
Improper design of casting

Next one casting design, also sometimes results in the shrinkage defect. Now, let us see a case study, now this is the casting and you see here and somewhere here there will be riser, now what happens here because the section thickness is very large here there will be shrinkage defect.

So, this we need to for these to overcome this defect we need to slightly modify the casting design, on the other hand you see here the design is little improved instead of what say making a thick section here, that thick section is removed here you see. Now in such a case the shrinkage defect may not occur in the second case.

So, improper design of the casting also results in the shrinkage defect, and the third one sorry the last one is the progressive solidification in the beginning itself or during the what; say earlier lectures when we were talking about discussing about the design of the riser, we were talking about the progress in solidification again I will review.

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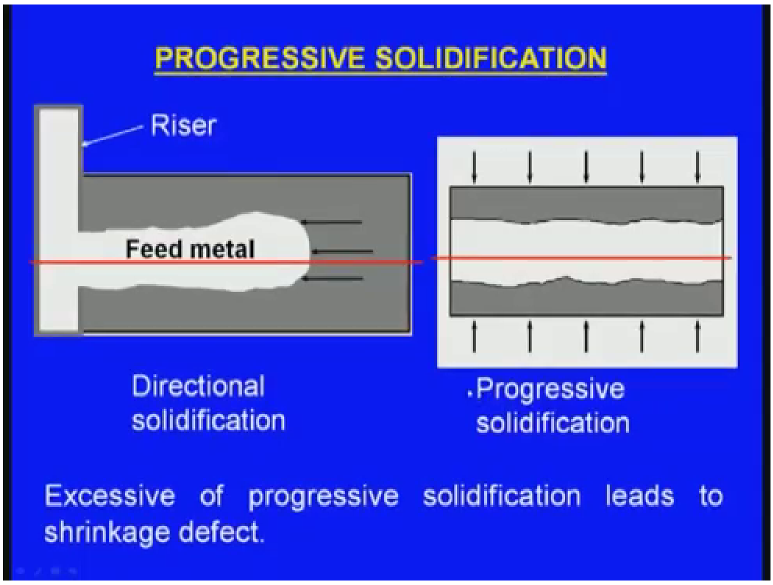

PROGRESSIVE SOLIDIFICATION

Directional solidification

.Progressive solidification

Excessive of progressive solidification leads to shrinkage defect.

Progressive solidification means what here say this is the casting right. So, this is the riser, the solidification can progress like this parallel to the axis of the casting, then it is known as the directional solidification is slowly the solidification will be progressing towards the what; say riser, in such a case riser will be feeding the casting.

On the other hand you can see here this is the progressive solidification means the solidification progresses perpendicular to the axis of the casting. This red colored one is the axis of the casting the solidification is progressing perpendicular to that, then what will happen slowly it will be closing the path maybe there are riser will be somewhere here. And this path will be closed somewhere there will be a shrinkage defect will be there, because the what; say path is closed the riser cannot feed liquid metal to that place where there is a shrinkage cavity.

Why this is happening because of the progressive solidification, yes in solidification both directional solidification and progressive solidification will be there, but progressive solidification should not dominate; only the directional solidification has to dominate right, so excessive of progressive solidification leads to shrinkage defect, now we have to analyze how to what say control this progressive solidification. Once we can control the progressive solidification or once we know the factors that are influencing the progressive solidification, we can very well control the shrinkage defect factors influencing progressive solidification.

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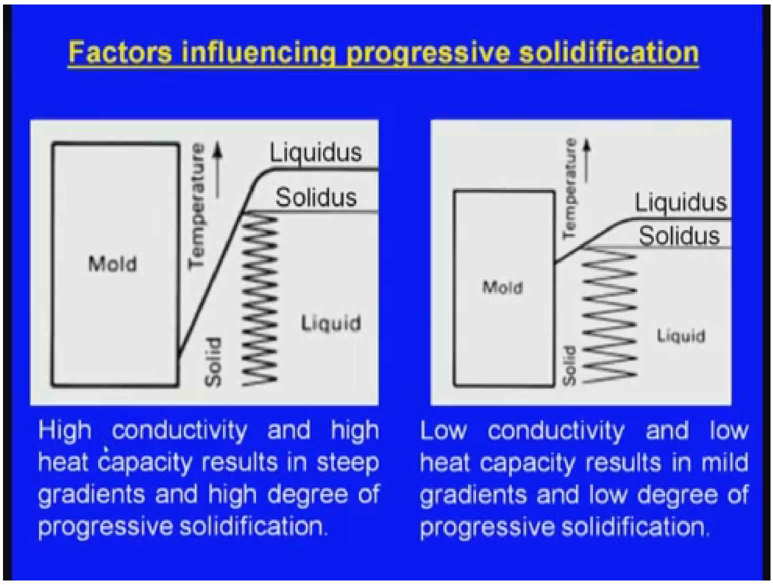

Factors influencing progressive solidification

High conductivity and high heat capacity results in steep gradients and high degree of progressive solidification.

Low conductivity and low heat capacity results in mild gradients and low degree of progressive solidification.

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One is the high conductivity, and high heat capacity, results in steep gradient and high degree of progressive solidification remember, when high heat large amount of heat is to be dissipated from the casting to the mould wall it will choose the axial radial direction of the casting right, or when a small amount of heat is to be dissipated it will be choosing the axial direction.

So, in both the directions the heat can be dissipated remember, but when large amount of heat is to be dissipated it will be choosing the axial direction means perpendicular to the radial direction, perpendicular to the axis of the what; say casting.

Now, here high conductivity and high heat capacity what happens large amount of heat is to be dissipated to the mould wall. In such a case what will happen the heat will be dissipated radially means perpendicular to the axis of the casting, in such a case progressive solidification will be more and it will be dominating or high there will be high degree of progressive solidification.

On the other hand low conductivity low heat capacity what happens large very small amount of heat is to be dissipated. In such a case it will be choosing along the what; say axial direction parallel to the axis it will be dissipating, in such a case the progressive solidification will be very smaller.

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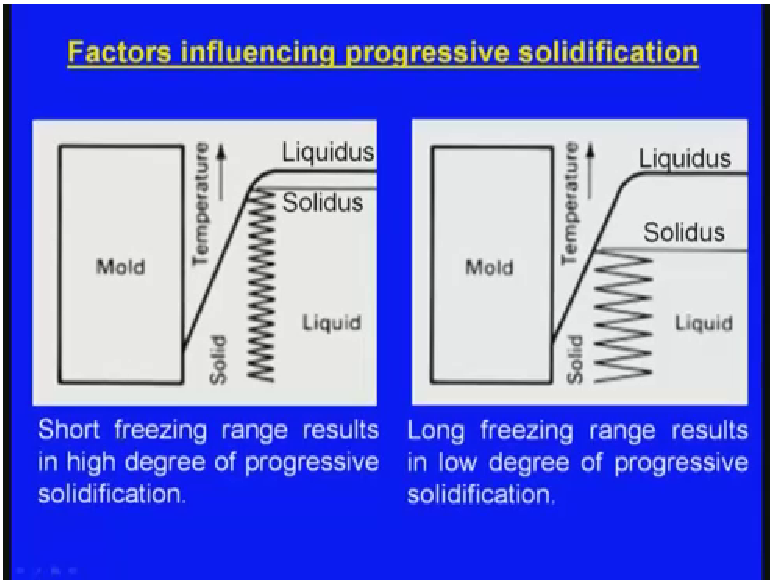

Factors influencing progressive solidification

Short freezing range results in high degree of progressive solidification.

Long freezing range results in low degree of progressive solidification.

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Now, there is another factor which influences the progressive solidification short freezing range results in high degree of what say progressive solidification, one we have learned that an alloy solidifies over a freezing range not at a constant temperature. Now when this freezing range is very small what happens whatever heat it has it has to be dissipated in a short time. In such a case it will be choosing the radial direction means perpendicular to the axis of the casting, in such a case there will be more progressive solidification.

On the other hand if it is there is a long freezing range what happens it has sufficient time for solidification, then it may choose the axial direction means parallel to the axis and the heat will be dissipated. In such a case there will be lesser progressive solidification and more directional solidifications, we want more directional solidifications, we want less progressive solidification.

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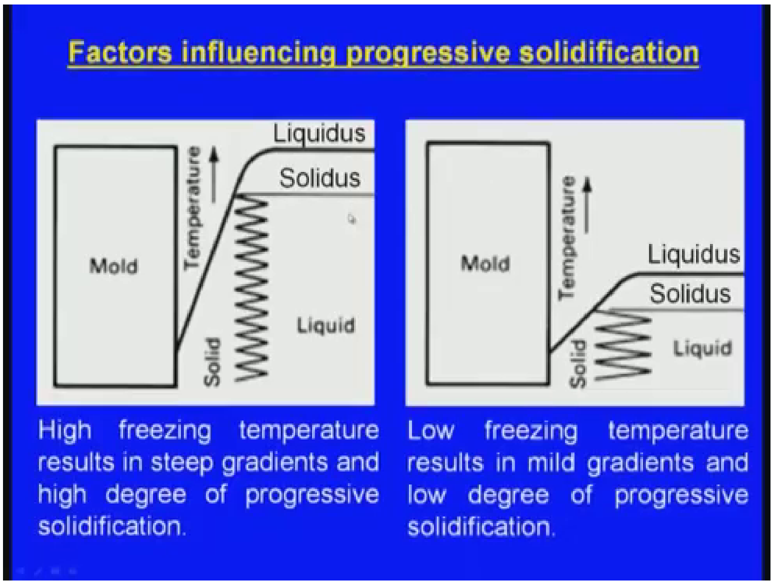

Factors influencing progressive solidification

High freezing temperature results in steep gradients and high degree of progressive solidification.

Low freezing temperature results in mild gradients and low degree of progressive solidification.

Next there is another factor which influences the progressive solidification high what say freezing temperature results in steep gradient, and high degree of progressive solidification now what say freezing temperature or the melting temperature is at a very high temperature, high freezing temperature, then what happens from such a high temperature it has to cool down, means the ambient temp what is the difference between the high pouring temperature to the ambient temperature, there is a means there is a steep gradient is there because of that more heat is to be dissipated to the mould wall. In such a case it will be choosing the what; say radial direction perpendicular to the axis of the casting.

In such a case there will be high degree of progressive solidification, on the other hand let us see this one low freezing temperature results in mild gradient and low degree of progressive solidification, here the what; say the liquidus and solidus line are not very high here, they are at a very high temperature liquidus line and solidus line you can see and here, they at a lower temperature means the gradient is not a steep gradient it is a small gradient. Because of that lesser amount will be dissipating to the mould wall, then in such a case it will be choosing the axial direction parallel to the axis of the job in such a case there will be more directional solidification and less progressive solidification. Next one is the hot tearing now these are the what; say you can see here.

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PROBLEMS ASSOCIATED WITH SOLIDIFICATION

HOT TEARING

CAUSES FOR HOT TEARING

Differential contraction, chemical composition and long freezing range are the causes for hot tearing.

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This is the casting and this is the what; say crack that has occurred during the solidification of the casting, right and there are reasons for that one is the differential contraction. Next one chemical composition and long freezing range are the causes for the hot tearing right, here inside we have kept a core because of that there was differential contraction.

Next one is the chemical composition we know that the cast iron, and a steel they contain extremely small amount of sulphur maybe 0.06 percent, right. So, that sometimes that will be useful it improves the machinability, but if this sulphur content is more it can cause cracking to the casting. Next one long freezing range also causes hot tearing next one evolution of the gases. So, this is another problem associated associated with solidification.

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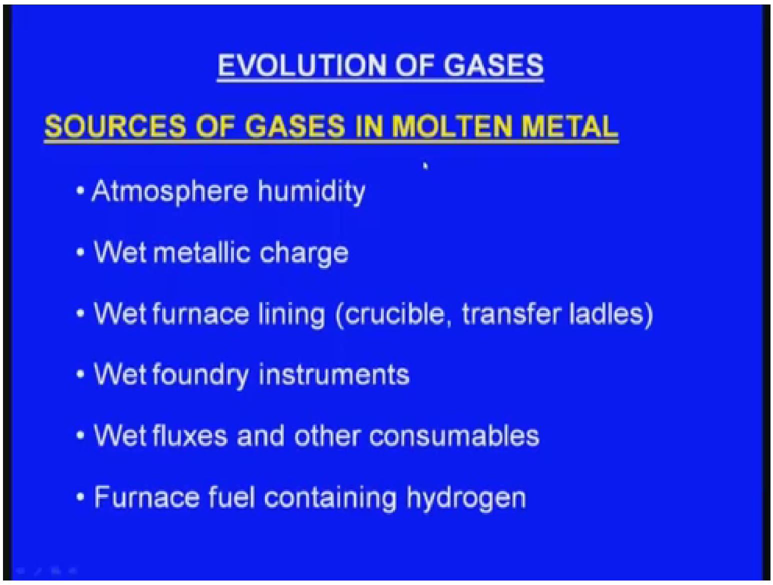

EVOLUTION OF GASES

SOURCES OF GASES IN MOLTEN METAL

- Atmosphere humidity
- Wet metallic charge
- Wet furnace lining (crucible, transfer ladles)
- Wet foundry instruments
- Wet fluxes and other consumables
- Furnace fuel containing hydrogen

Now, what are the sources of gases in molten metal one is the atmospheric humidity, second one is the wet metallic charge, third one is the wet furnace lining, fourth one wet foundry instruments, next one wet fluxes and other consumables next one furnace fuel containing hydrogen.

So, these factors will be influencing evolution of gases in the molten metal. So, in this lecture we have seen the solidification phenomenon and the crystallization grains, and the what; say complete solidification. We have seen and we have seen the solidification phenomenon of a pure metal the solidification phenomenon of an alloy, we have seen and also we have seen the factors influencing progressive solidification and also the directional solidification, and the other problems we have seen like the hot tearing shrinkage defect, and the gases. And in our next lecture we will be learning about the what; say shake out fettling and what say finishing of the solidified casting.

Thank you.