Manufacturing Processes - I

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Module - 2
Lecture - 9
Metal Casting

Good morning. Today, we will be learning about the gating system and solidification.

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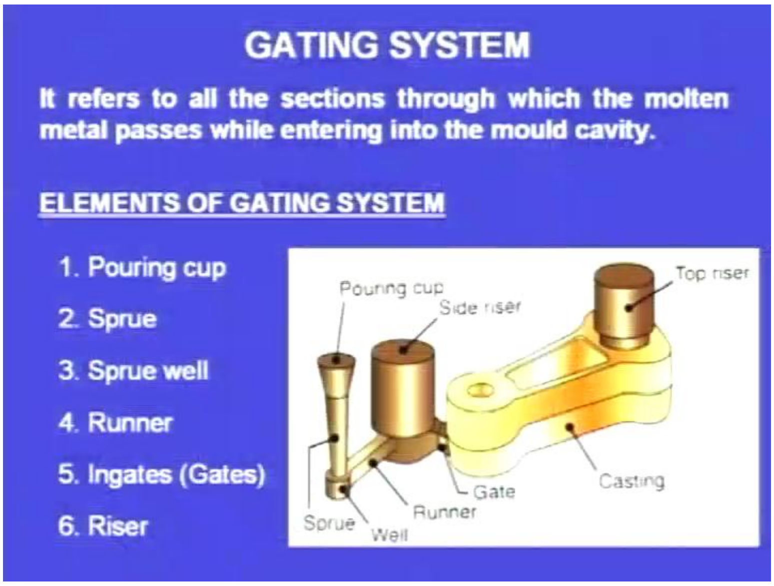

GATING SYSTEM

It refers to all the sections through which the molten metal passes while entering into the mould cavity.

ELEMENTS OF GATING SYSTEM

1. Pouring cup
2. Sprue
3. Sprue well
4. Runner
5. Ingates (Gates)
6. Riser

First, let us see the gating system. What is meant by gating system? Gating system refers to all the sections, through which the molten metal passes, while entering into the mould cavity. So, these are the elements of the gating system; these are shown in this diagram. The first element is the pouring cup. We pour the molten metal into the cavity, and there will be pouring cup, which is enlarged at the top and it will receive the molten metal. So, this is the pouring cup.

Next one is the sprue. Sprue is the narrow passage - vertical passage - through which we pour the molten metal, through the pouring cup. We pour the molten metal, through the pouring cup here, and the molten metal passes through this sprue, and it further passes into the cavity. So, it passes - vertical passes - through which the molten metal enters into the mould cavity - that is the sprue.

Next one - sprue well. So, here we can see this is the sprue. At the bottom of this sprue, we can see the sprue well. So, this acts as a small reservoir of the molten metal. So, it receives the molten metal through this sprue, from this pouring cup. Then from this sprue well, the molten metal will be passing into the further sections of the gating system. So, it is a small reservoir - this sprue well.

Next element of the gating system is the runner. From this sprue well, the metal flows through the runner. This is the runner, and into the further sections of the gating system.

Next one - ingates; these are also sometimes termed as gates. So, here we can see small section. So, metal we have poured through the pouring cup, and through this sprue, it has reached this sprue well; then it has passed through the runner; then it will reach this place; this is known as the ingates. In this casting, only one ingate is shown, but in large castings, there will be multiple ingates. In fact, the multiple ingates will be connected to the runner, and from the runner the molten metal is distributed such that the molten metal will be passing through different ingates into the mould cavity. So, these ingates are the entrance of the molten metal to the cavity, and this is the mould cavity. So, this is the casting, which we are going to obtain after solidification.

Next element of the gating system is the riser; this is one riser here; we can see one riser. So, we have kept this riser on the top of the mould cavity. So, this is the top riser. In the earlier section, we have learned that the primary function of the riser is to compensate the shrinkage of the liquid metal while it is freezing. So, here we have kept one riser. So, this is the top riser, and because of this top riser when the liquid metal in the cavity is undergoing freezing, then it under goes shrinkage; that time the liquid metal in the stop riser compensates the shrinkage - that is the primary function of the riser. Sometimes riser is also kept on a side. So this is the side riser, because there is hole here, and it is very difficult to place a riser above this portion. So, we have kept a side riser. This also compensates the shrinkage which the casting under goes during solidification.

So, these are the elements of the gating system: pouring cup, sprue, sprue well, runner, ingates, and riser. Now, let us see how these elements are designed; we will see one by one. First, let us see how this pouring cup is designed.

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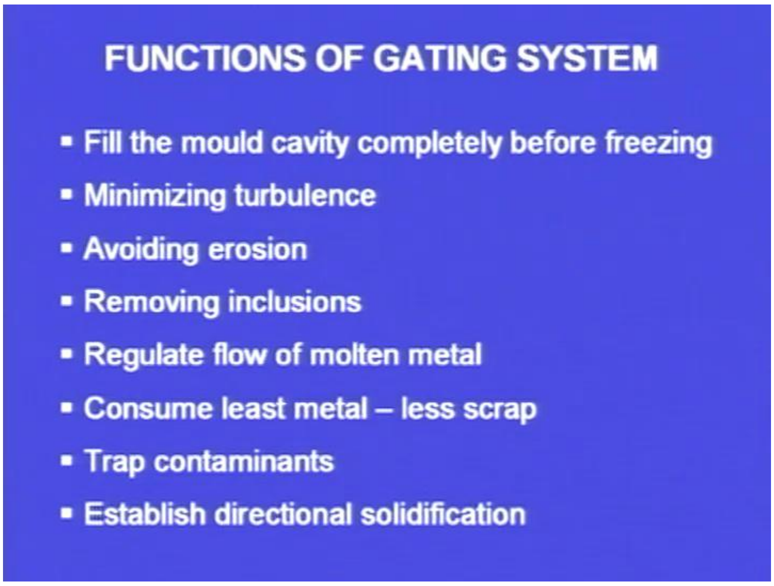

FUNCTIONS OF GATING SYSTEM

- Fill the mould cavity completely before freezing
- Minimizing turbulence
- Avoiding erosion
- Removing inclusions
- Regulate flow of molten metal
- Consume least metal – less scrap
- Trap contaminants
- Establish directional solidification

First, before that we should see the functions of the gating system. It should fill the mould cavity completely before freezing. Before the mould cavity is filled with the molten metal, freezing should not start.

Next one - while the molten metal is entering into the gating system, it should not be under go any turbulence; there should be minimum turbulence. And there is a chance that when the liquid metal is entering into the cavity, it may erode the sand and this erosion of the sand should be minimized. And there is a chance that some inclusions may enter into the cavity, and these inclusions should be removed, and the molten metal flow should be regulated while it is entering into the cavity. And the gating system should consume least metal, so that there will be less scrap, and the contaminants may enter into the cavity; the contaminants should be trapped by the gating system.

And next one is the establishment of the directional solidification. Directional solidification means - the path which is away from the riser, it should solidify first; next, the path of the casting, which is nearer to the riser that should solidify; finally, riser should solidify - that is the meaning of the directional solidification. So, a good gating system should ensure all these functions.

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Design of Pouring Cup

Now, let us see the design of the pouring cup.

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Pouring cups

So, this is a molding box and this is a mould, and inside there is a cavity, and here we can see the pouring cup - this is cut manually. This is a convention - in most of the cases pouring cup is cut manually in a conical way, but there are some limitations - drawbacks - of this pouring cup, which is cut manually. One is the surface of this conical cup is rough and there will be sand particles. When we pour the molten metal on this cup, small particles of the sand they are eroded and they go inside the cavity. And another drawback is the molten metal swirls, it rotates, and finally, it will create turbulence inside the cavity. So, these are the drawbacks of the manually cut pouring cup.

So, to overcome these drawbacks, nowadays many companies are manufacturing readymade pouring cups - ceramic cups. So these are the ceramics cups available in the market.

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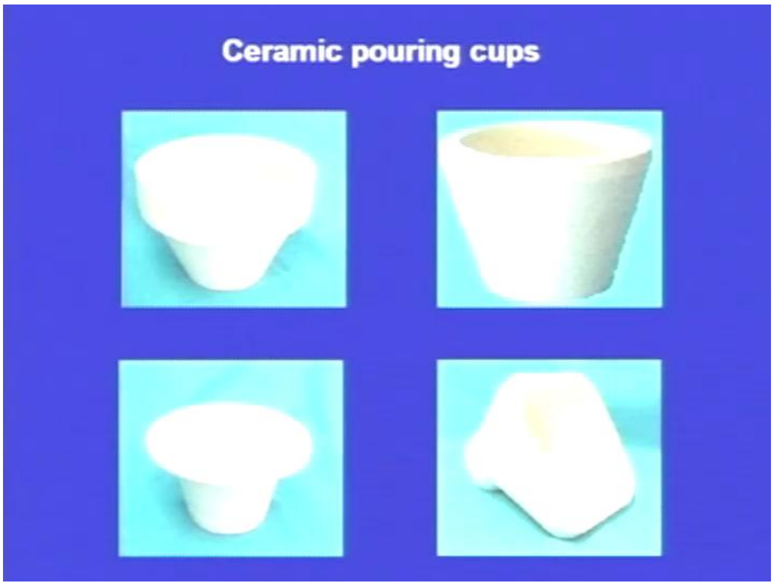

Ceramic pouring cups

So these cups are available at different dimensions, depending upon the casting we are going to make, depending upon our requirement, we can purchase any pouring cup which suits our requirement.

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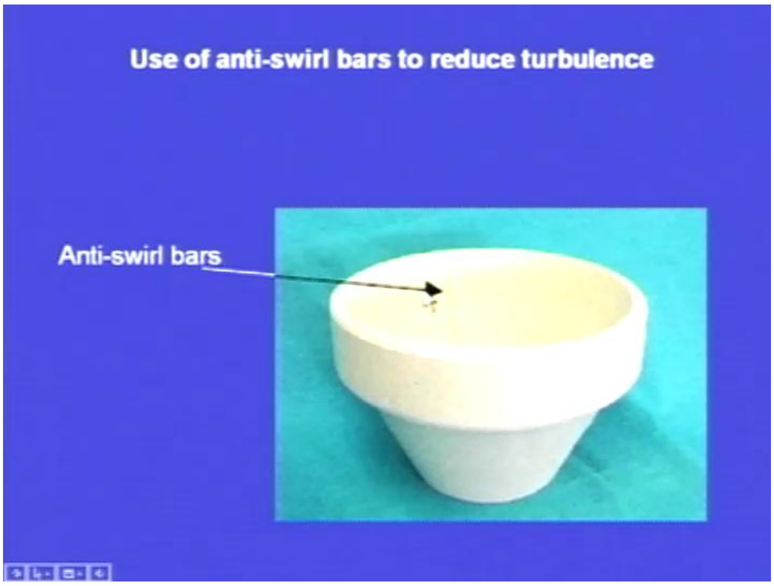

Use of anti-swirl bars to reduce turbulence

Anti-swirl bars

And here we can see one drawback is when we pour the molten metal into the cavity through this pouring cup, the molten metal starts swirling, it rotates, and when it goes inside there will be turbulence, and that should be prevented in the very beginning itself.

So, here we can see - this is the pouring cup, here we can see the anti-swirl bars. So, it prevents the swirling or the rotation of the molten metal, so that the molten metal passes inside straight and there will be minimum turbulence. So that is another advantage of using these ceramic pouring cups.

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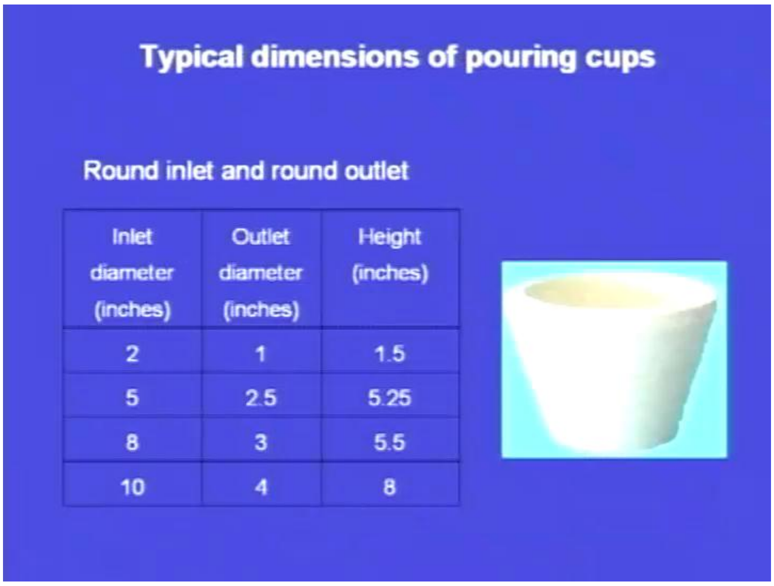

Typical dimensions of pouring cups

Round inlet and round outlet

Inlet diameter (inches)	Outlet diameter (inches)	Height (inches)
2	1	1.5
5	2.5	5.25
8	3	5.5
10	4	8

So these are the typical dimensions of the pouring cups. Pouring cups are available round shapes, round inlet, and also square inlet. For the round inlet and round outlet cups, these are the dimensions: the inlet diameter will be 2 inches; outlet diameter will be 1 inch; and height will be 1.5. Here 5 inches; 2.5 inches; and 5.25 inches. And here 8 inches; 3 inches; 5.5 inches; 10 inches; 4 inches; and the height is 8 inches.

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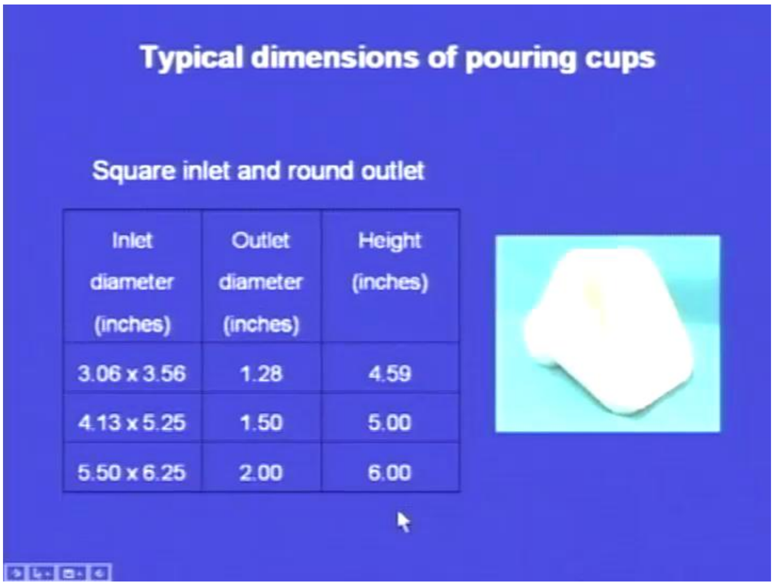

Typical dimensions of pouring cups

Square inlet and round outlet

Inlet diameter (inches)	Outlet diameter (inches)	Height (inches)
3.06 x 3.56	1.28	4.59
4.13 x 5.25	1.50	5.00
5.50 x 6.25	2.00	6.00

And if it is a square inlet and round outlet, these are the dimensions. The inlet diameter will be 3.06 into 3.56 and the outlet diameter will be 1.28 inches and the height will be 4.59 inches. Here 4.13 into 5.25; here it is 1.5 and the height is 5 inches. Here 5.5 into 6.25 and the outlet diameter is 2 inches and the height is 6 inches. So, these are only the typical dimensions. In fact, many more dimensions are available and depending upon our requirement the appropriate pouring cup can be chosen.

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Design of Sprue

Now, let us see the design of the sprue.

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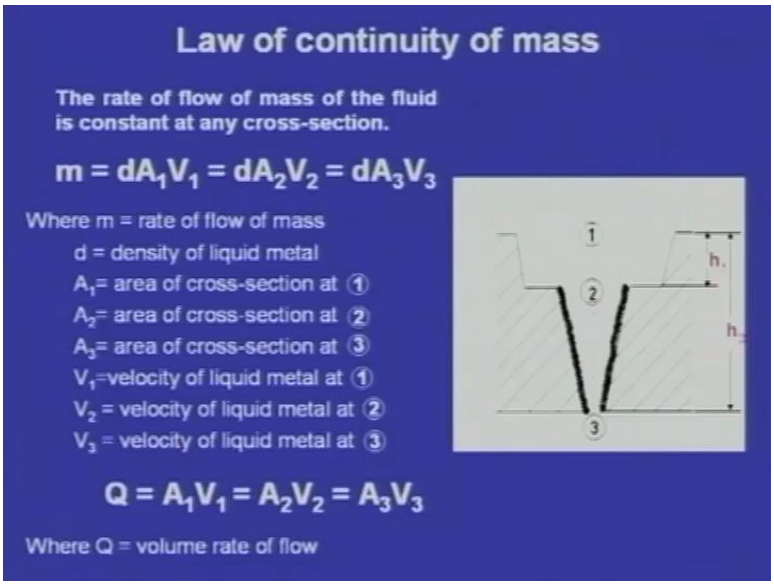

Law of continuity of mass

The rate of flow of mass of the fluid is constant at any cross-section.

$$m = dA_1V_1 = dA_2V_2 = dA_3V_3$$

Where m = rate of flow of mass
d = density of liquid metal
A_1= area of cross-section at ①
A_2= area of cross-section at ②
A_3= area of cross-section at ③
V_1=velocity of liquid metal at ①
V_2 = velocity of liquid metal at ②
V_3 = velocity of liquid metal at ③

$$Q = A_1V_1 = A_2V_2 = A_3V_3$$

Where Q = volume rate of flow

The design of the sprue is based on the law of continuity of mass. The law of continuity mass states that the rate of flow of mass of the fluid is constant at any crosses section. This is the pouring cup - the upper portion, and this portion from 2 to 3 is the sprue. We pour the molten metal this way through the pouring cup, and the molten metal passes through the 2 and 3. Finally, it goes inside the cavity - cavity is gating system and the cavities are below this point 3. Now, the mass of the liquid metal flowing through 1 and 2 and 3 will be same as per the law of continuity of mass.

So, we can say that m - the mass - flow rate is equal to d A 1 V 1 that is equal to d A 2 V 2 that is equal to d A 3 V 3, where d is the density of the liquid metal; A 1 is the area of cross section at point 1; A 2 is the area of cross section at point 2; A 3 is the area of cross section at point 3. Next one - V 1 is the velocity of liquid metal at point 1; V 2 is the velocity of liquid metal at point 2; V 3 is the velocity of liquid metal at point 3.

So, if we divide this above equation - this equation - by d, whole thing if we divide by d, here this d gets cancelled, mass is the product of density and volume; so that density gets canceled and here we get Q, that is the volume is equal to A 1 V 1 that is equal to A 2 V 2 that is equal to A 3 V 3. So, Q is the volume rate of flow.

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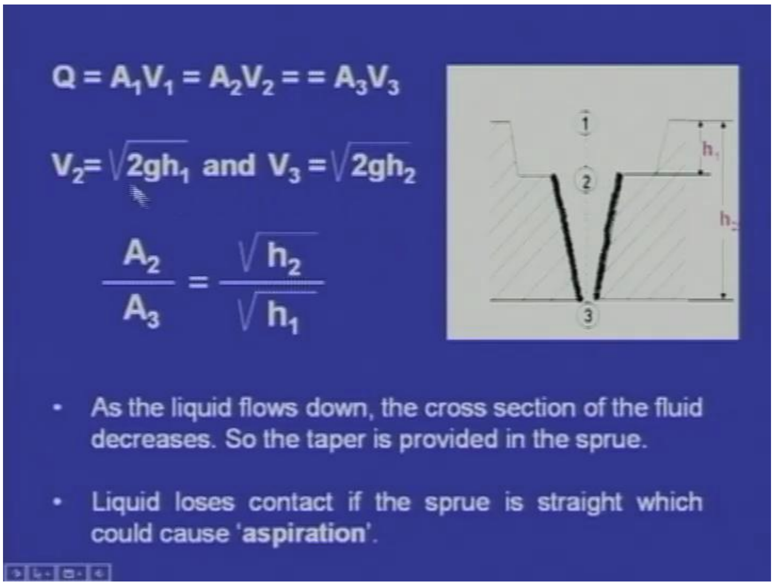

$Q = A_1V_1 = A_2V_2 = = A_3V_3$

$V_2 = \sqrt{2gh_1}$ and $V_3 = \sqrt{2gh_2}$

$$\frac{A_2}{A_3} = \frac{\sqrt{h_2}}{\sqrt{h_1}}$$

- As the liquid flows down, the cross section of the fluid decreases. So the taper is provided in the sprue.
- Liquid loses contact if the sprue is straight which could cause '**aspiration**'.

So, this is the equation, which we have got earlier. Now, V 2 - that is the velocity of the liquid metal at 0.2 - is given by root of 2 g h 1 where h 1 is this height and V 3 - that is the velocity of the liquid metal at point 3 - is given by root of 2 g h 2 where h 2 is this much. Now, A 2 by A 3 is equal to root h 2 by root h 1. Now, this h 2 is greater than h 1. So, this ratio is greater than 1; that indicates that the A 2 should be greater than 1; means that A 2 should be greater than A 3; means the area of cross section of this sprue at the inlet - that is at point 2 - should greater than the area of cross section at 3. That is why the sprue should be given a taper. If this taper is not given, then that results in aspiration; they enter into the mould cavity. So, based on this law - law of continuity of mass - this sprue is designed. The sprue is given a taper, the area of cross section at the inlet is more; the area of cross section at the exit - that is at point 3 - will be less.

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Design of Choke

Next one - let us see the design of the choke.

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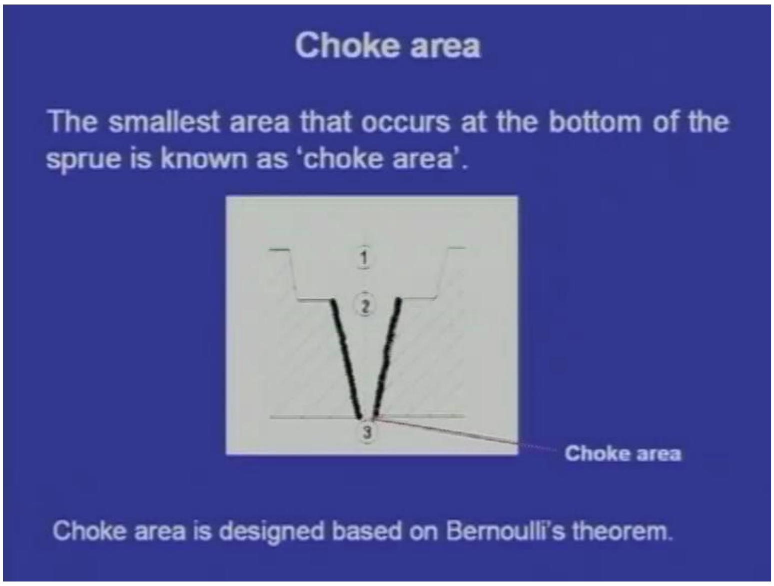

Choke area

The smallest area that occurs at the bottom of the sprue is known as 'choke area'.

Choke area is designed based on Bernoulli's theorem.

First of all, what is meant by choke? Again, let us see - this is the pouring cup and this is the sprue. And we have already seen that the cross sectional area at the inlet of this sprue will be more than cross sectional area of this sprue at the exit. And the minimum cross section or the smallest area that occurs at the bottom of the sprue is known as the choke area; means the cross sectional area that is occurring at this point 3 or that is at the exit is the choke area.

So, this choke area is designed; once the choke area is designed, even this A 2 can be designed - that we have already seen. Choke area is designed based on Bernoulli's theorem.

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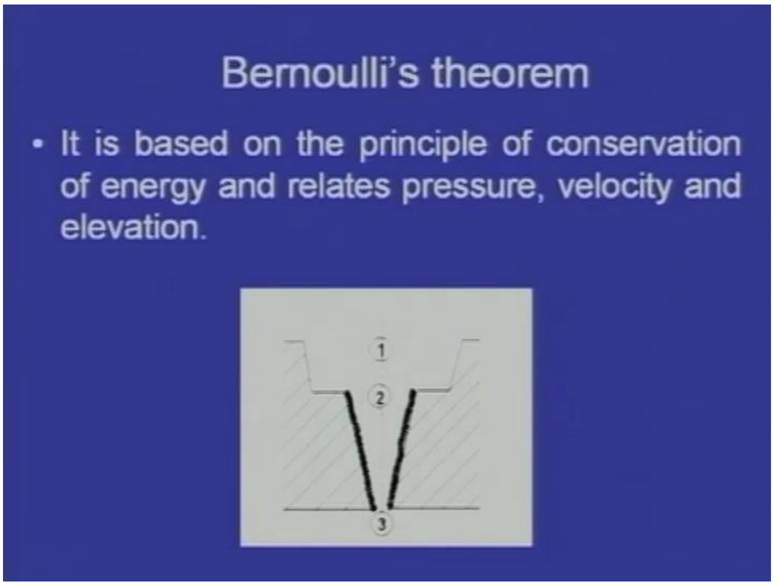

Bernoulli's theorem

- It is based on the principle of conservation of energy and relates pressure, velocity and elevation.

Now, let us see this Bernoulli's theorem. Bernoulli's theorem is based on the principle of conservation of energy and relates pressure, velocity, and elevation.

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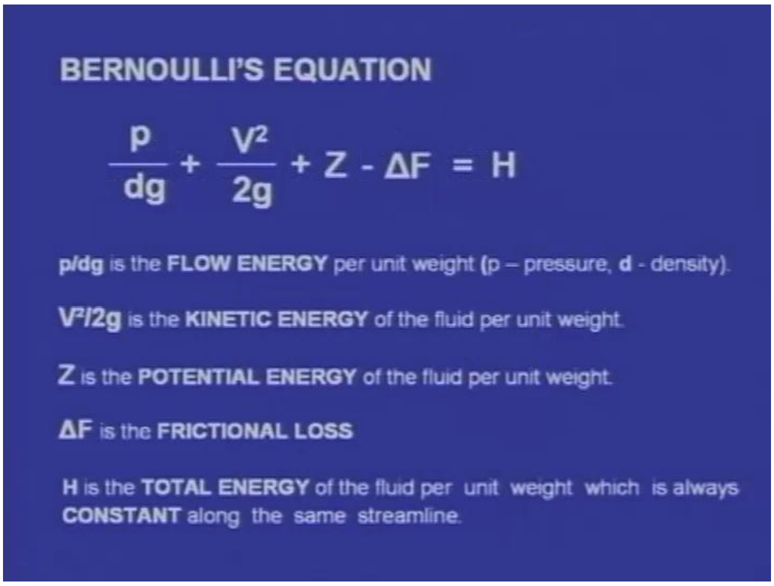

BERNOULLI'S EQUATION

$$\frac{p}{dg} + \frac{V^2}{2g} + Z - \Delta F = H$$

p/dg is the **FLOW ENERGY** per unit weight (**p** – pressure, **d** - density).

$V^2/2g$ is the **KINETIC ENERGY** of the fluid per unit weight.

Z is the **POTENTIAL ENERGY** of the fluid per unit weight.

ΔF is the **FRICTIONAL LOSS**

H is the **TOTAL ENERGY** of the fluid per unit weight which is always **CONSTANT** along the same streamline.

Let us see the Bernoulli's equation. The Bernoulli's equation is well known and it states that p by dg plus V square by 2 g plus Z minus delta F is equal to H; where p by dg is the flow energy per unit weight; p is the pressure; d is the density of the liquid metal. V square by 2 g is the kinetic energy of the fluid per unit weight. Z is the potential energy of the fluid per unit weight. Delta F is the frictional loss; yes, when the molten metal is passing through the gating system, yes, there will be friction; there will be frictional loss. And H is the total energy of the fluid per unit weight, which is always constant along the same streamline. So, this is the Bernoulli's equation.

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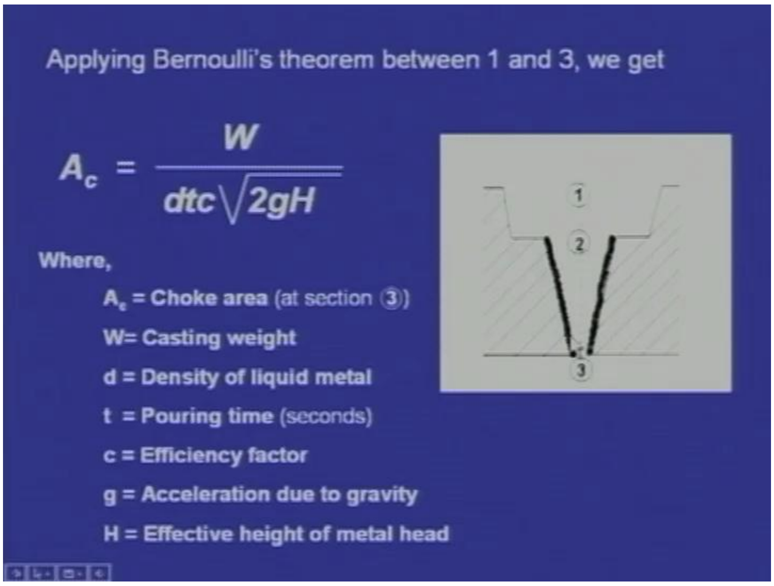

Applying Bernoulli's theorem between 1 and 3, we get

$$A_c = \frac{W}{dtc\sqrt{2gH}}$$

Where,

A_c = Choke area (at section ③)

W= Casting weight

d = Density of liquid metal

t = Pouring time (seconds)

c = Efficiency factor

g = Acceleration due to gravity

H = Effective height of metal head

Applying Bernoulli's theorem between point 1 and 3, we get Ac is equal to W by dtc root of 2 gh; where Ac is the choke area - choke area at this point 3 that is the minimum lowest cross sectional area that occurs on the sprue - along the sprue. W is the casting weight. D is the density of the liquid metal. T is the pouring time in seconds. C is the efficiency factor. G is the acceleration due to gravity and h is the effective height of the metal head. And we may pour the molten metal from here, then the effective height is between 1 to 3.

Generally, there will be another pouring basin will be there on the side of the pouring cup; in most of the times, the liquid metal is poured in the pouring basin. From the pouring basin, the liquid metal enters into the pouring cup; if that be the case, the effective height of the metal head will be between 1 and 3.

Sometimes the liquid metal is poured directly from the ladle from a far away height - may not be very far, little above point 1- and directly from the ladle it will be falling into the sprue cup. That be the case, wherever the molten metal is dropped, from there up to point 3 is the effective height.

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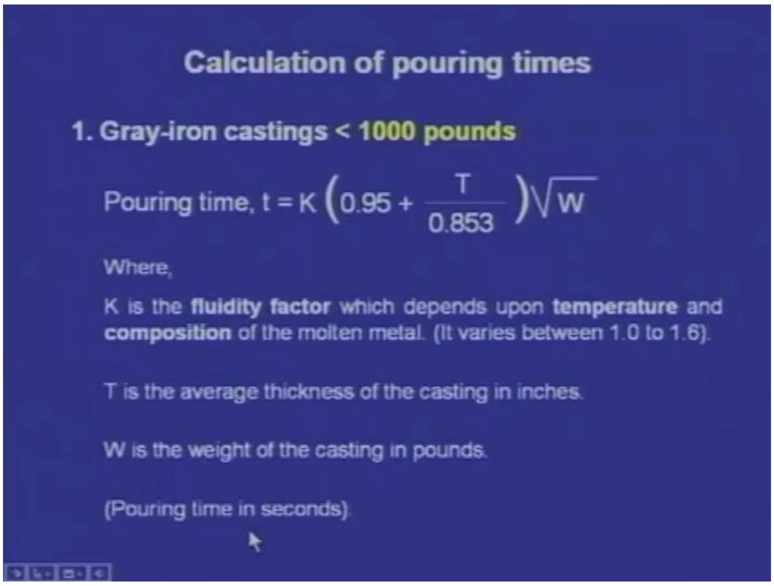

Calculation of pouring times

1. Gray-iron castings < 1000 pounds

Pouring time, $t = K\left(0.95 + \frac{T}{0.853}\right)\sqrt{W}$

Where,

K is the **fluidity factor** which depends upon **temperature** and **composition** of the molten metal. (It varies between 1.0 to 1.6).

T is the average thickness of the casting in inches.

W is the weight of the casting in pounds.

(Pouring time in seconds).

Now, calculation of the pouring time. In the previous slide, we have seen there is pouring time. So, how to calculate this pouring time? For gray iron castings, and that too when the casting weight is less than 1000 pounds, pouring time is given by this formula:

pouring time t is equal to K into 0.95 plus T by 0.853 multiplied by root of W; where K is the fluidity factor, which depends upon the temperature and composition of the molten metal and this K varies between 1 to 1.6. T is the average thickness of the casting in inches. W is the weight of the casting in pounds. Pouring time in seconds.

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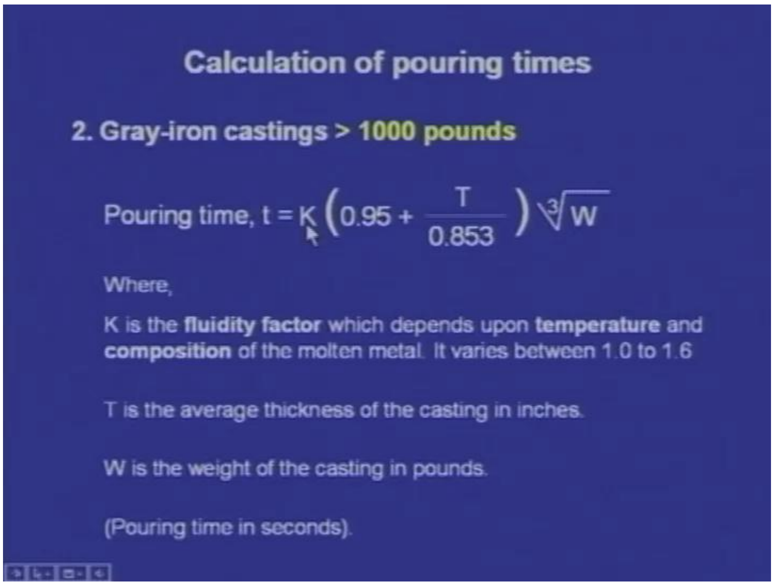

Calculation of pouring times

2. Gray-iron castings > 1000 pounds

$$\text{Pouring time, } t = K\left(0.95 + \frac{T}{0.853}\right)\sqrt[3]{W}$$

Where,

K is the **fluidity factor** which depends upon **temperature** and **composition** of the molten metal. It varies between 1.0 to 1.6

T is the average thickness of the casting in inches.

W is the weight of the casting in pounds.

(Pouring time in seconds).

And let us see the pouring time for gray iron castings, when the weight of the casting is more than 1000 pounds. The pouring time t is given by K into 0.95 plus T by 0.853 multiplied by Qth root of W. Where K is the fluidity factor, which depends upon the temperature and composition of the molten metal and it varies between 1 to 1.6. T is the average thickness of the casting in inches; W is the weight of the casting in pounds; pouring time in seconds.

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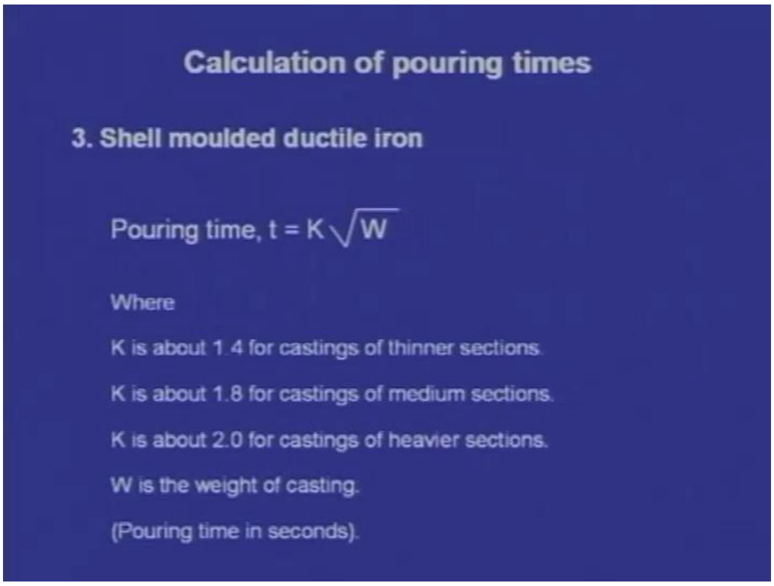

Calculation of pouring times

3. Shell moulded ductile iron

Pouring time, $t = K\sqrt{W}$

Where

K is about 1.4 for castings of thinner sections.

K is about 1.8 for castings of medium sections.

K is about 2.0 for castings of heavier sections.

W is the weight of casting.

(Pouring time in seconds).

Now, let us see the pouring time for shell molded ductile iron. Pouring time is given by t is equal to K into root of W. K is about 1.4 for castings of thinner sections, and this K is about 1.8 for castings of medium sections, and it is about 2 for castings of heavier sections. W is the weight of the casting; and pouring time in seconds.

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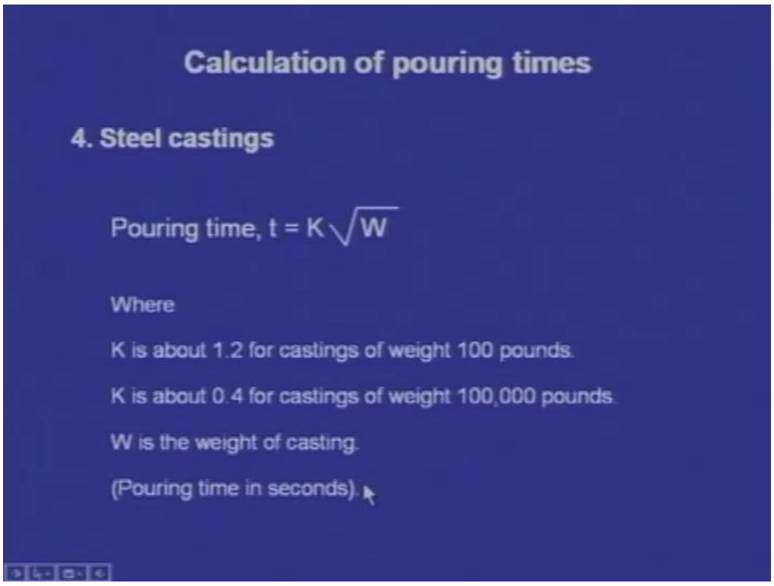

Calculation of pouring times

4. Steel castings

Pouring time, $t = K\sqrt{W}$

Where

K is about 1.2 for castings of weight 100 pounds.

K is about 0.4 for castings of weight 100,000 pounds.

W is the weight of casting.

(Pouring time in seconds).

Let us see the pouring time for steel castings. Pouring time t is given by K into root of W; where K is about 1.2 for castings of weight 100 pounds.

It is about 0.4 for castings of weight 100000 pounds and W is the weight of the casting; and pouring time in seconds.

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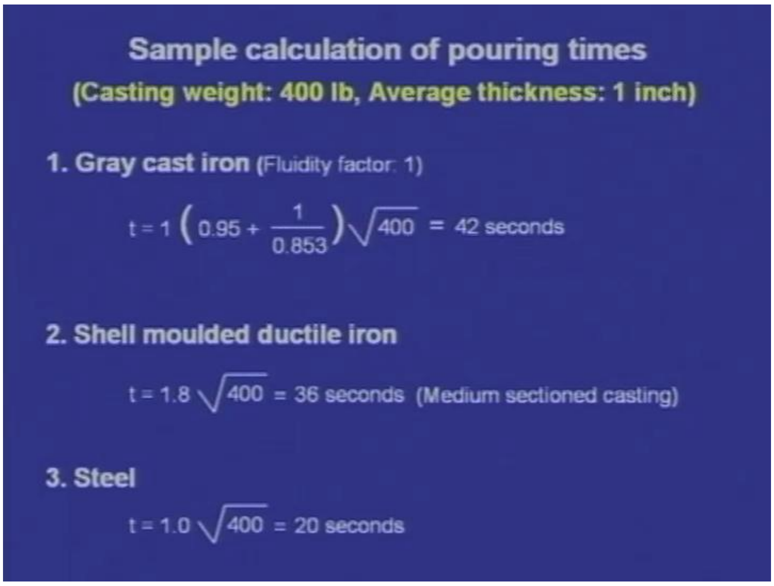

Sample calculation of pouring times

(Casting weight: 400 lb, Average thickness: 1 inch)

1. Gray cast iron (Fluidity factor: 1)

$$t = 1\left(0.95 + \frac{1}{0.853}\right)\sqrt{400} = 42 \text{ seconds}$$

2. Shell moulded ductile iron

$$t = 1.8\sqrt{400} = 36 \text{ seconds (Medium sectioned casting)}$$

3. Steel

$$t = 1.0\sqrt{400} = 20 \text{ seconds}$$

Let us make a sample calculation. Let us consider a casting of weight 400 pounds and the average thickness of the casting is 1 inch. And if it is - the casting - is made up of gray cast iron and the fluidity factor given is 1 - how to calculate the pouring time?

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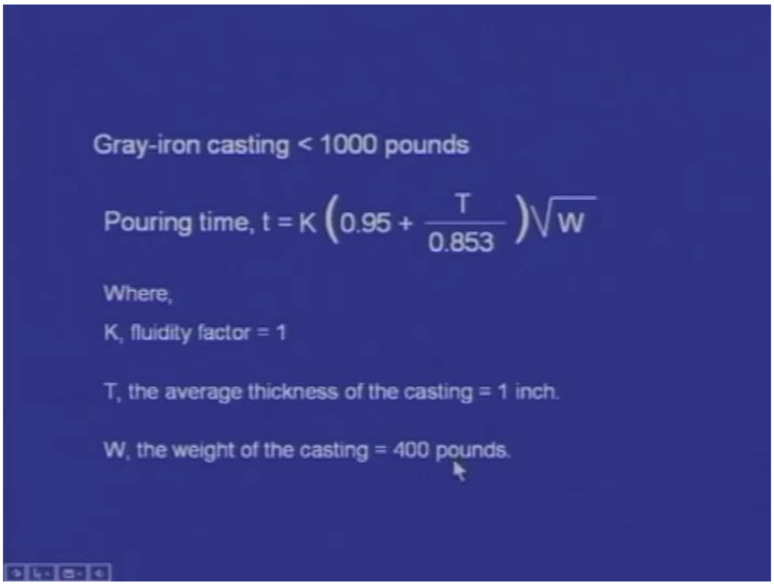

Gray-iron casting < 1000 pounds

$$\text{Pouring time, } t = K\left(0.95 + \frac{T}{0.853}\right)\sqrt{W}$$

Where,

K, fluidity factor = 1

T, the average thickness of the casting = 1 inch.

W, the weight of the casting = 400 pounds.

For gray cast iron the pouring time is given by t is equal to K into 0.95 plus T by 0.853 multiplied by root of W and fluidity factor is given 1; t is the average thickness of the casting, that is 1 inch; and W is the weight of the casting that is the 400 pounds.

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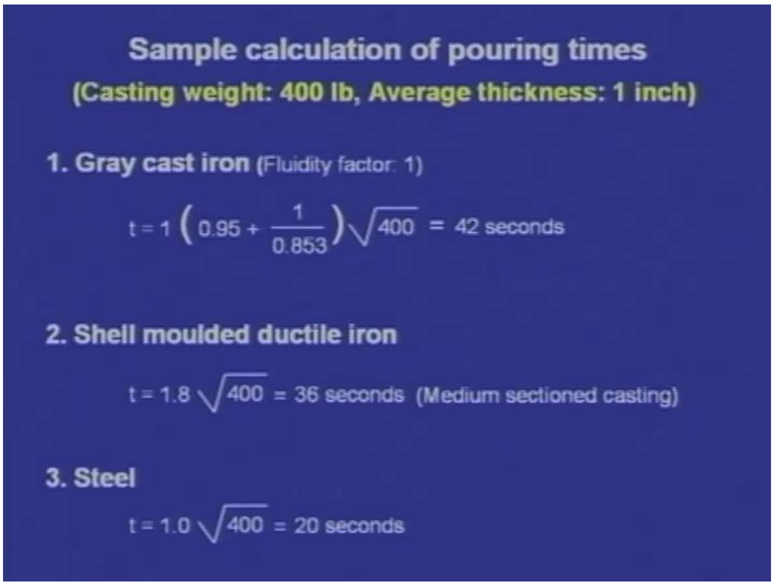

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3. Steel

$$t = 1.0\sqrt{400} = 20 \text{ seconds}$$

So, these values we will substitute in this equation. Then we will get that is equal to 42 seconds.

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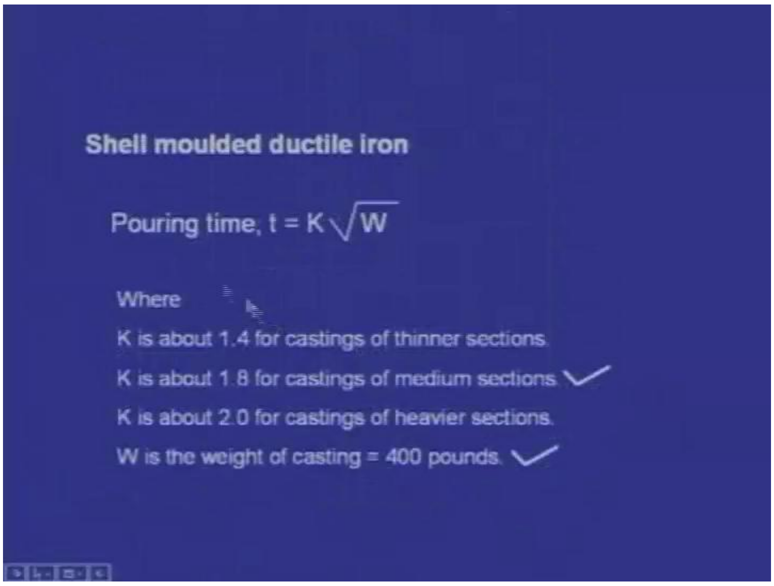

Shell moulded ductile iron

Pouring time, $t = K\sqrt{W}$

Where

K is about 1.4 for castings of thinner sections.

K is about 1.8 for castings of medium sections.

K is about 2.0 for castings of heavier sections.

W is the weight of casting = 400 pounds.

And if the material is of shell molded ductile iron the pouring time is given by T is equal to K into root of W. And here the K is about 1.8 for castings of medium section - we consider this casting as medium sectioned casting - and weight of the casting is 400 pounds.

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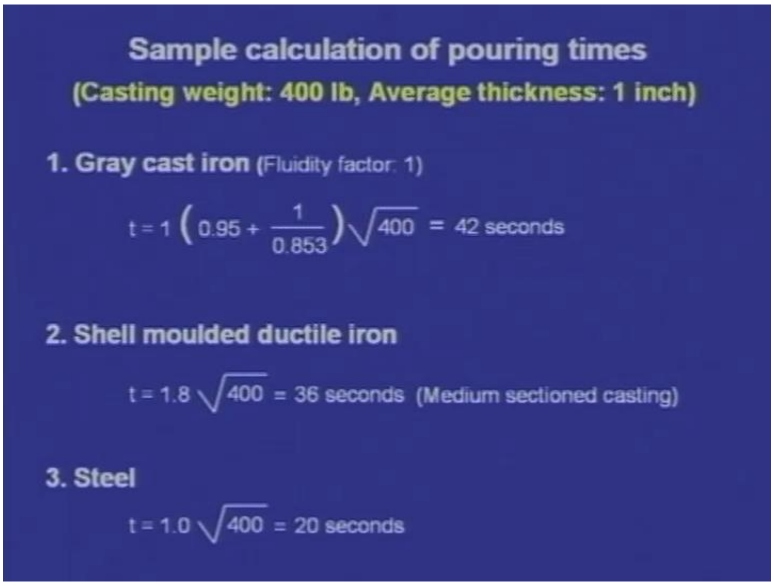

Sample calculation of pouring times

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$$t = 1\left(0.95 + \frac{1}{0.853}\right)\sqrt{400} = 42 \text{ seconds}$$

2. Shell moulded ductile iron

$$t = 1.8\sqrt{400} = 36 \text{ seconds} \quad \text{(Medium sectioned casting)}$$

3. Steel

$$t = 1.0\sqrt{400} = 20 \text{ seconds}$$

So, this K that is 1.8 and W we will substitute in this equation, then we will get the pouring time as 36 seconds.

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Steel castings

Pouring time, $t = K\sqrt{W}$

Where

K is about 1.2 for castings of weight 100 pounds.

K is about 0.4 for castings of weight 100,000 pounds.

For a casting of weight 400 pounds, K is taken as 1.0 ✓

And if the casting is made up of steel, the pouring time is given by this formula: t is equal to K into root W, where K is that factor which is about 1.2 for castings of weight 100 pounds and we considered this K as 1.

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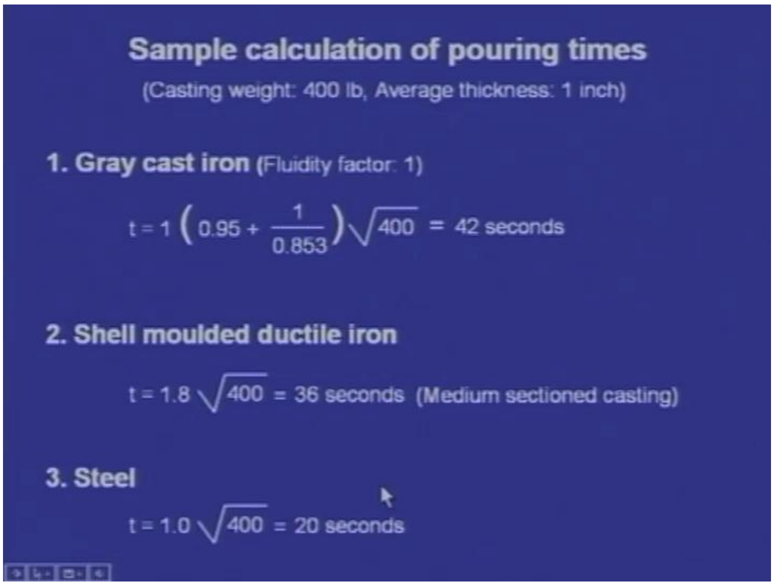

Sample calculation of pouring times

(Casting weight: 400 lb, Average thickness: 1 inch)

1. Gray cast iron (Fluidity factor: 1)

$$t = 1\left(0.95 + \frac{1}{0.853}\right)\sqrt{400} = 42 \text{ seconds}$$

2. Shell moulded ductile iron

$$t = 1.8\sqrt{400} = 36 \text{ seconds (Medium sectioned casting)}$$

3. Steel

$$t = 1.0\sqrt{400} = 20 \text{ seconds}$$

So, we will get this pouring time as 20 seconds.

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Design of Runner and Ingates

Now, let us see the design of runner and ingates.

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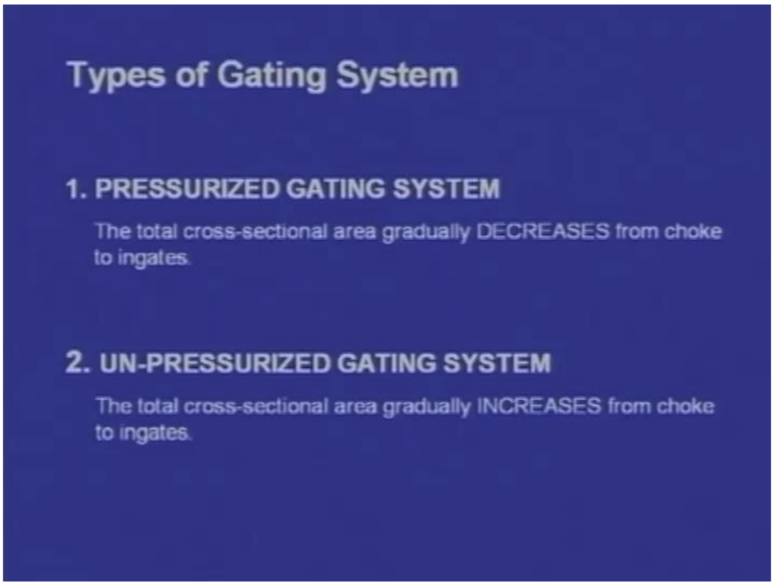

Types of Gating System

1. PRESSURIZED GATING SYSTEM

The total cross-sectional area gradually DECREASES from choke to ingates.

2. UN-PRESSURIZED GATING SYSTEM

The total cross-sectional area gradually INCREASES from choke to ingates.

This design of the runner and ingates depends upon the type of gating system that we use. There are two types of gating systems. One is pressurized gating system in which the total cross sectional area gradually decreases from choke to ingates.

In the un-pressurized gating system, the total cross sectional area gradually increases from choke to ingates, generally.

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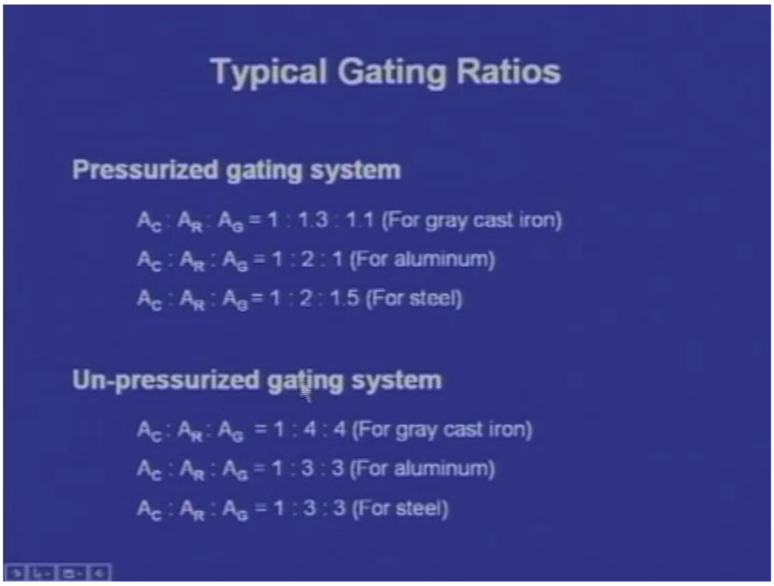

Typical Gating Ratios

Pressurized gating system

$A_C : A_R : A_G = 1 : 1.3 : 1.1$ (For gray cast iron)

$A_C : A_R : A_G = 1 : 2 : 1$ (For aluminum)

$A_C : A_R : A_G = 1 : 2 : 1.5$ (For steel)

Un-pressurized gating system

$A_C : A_R : A_G = 1 : 4 : 4$ (For gray cast iron)

$A_C : A_R : A_G = 1 : 3 : 3$ (For aluminum)

$A_C : A_R : A_G = 1 : 3 : 3$ (For steel)

So, these are the typical gating ratios. In the case of the pressurized gating system, Ac - that is the choke area, and Ar that is the cross sectional area of the runner; Ag that is the total cross sectional area of the ingates. So this ratio is given by 1 is to 1.3 is to 1.1 - this is for gray cast iron. And this gating ratio a is to Ar and is to Ag is given as 1 is to 2 is to 1 for aluminum castings; and this ratio will be 1 is to 2 is to 1.5 for steel castings. So these ratios are for pressurized gating system.

And in the un-pressurized gating system, the area of cross section of the runner will be more than the area of cross section of the choke. So, here Ac, that is the choke area; Ar that is the area of cross section of the runner; Ag that is the area of the cross section of the ingates - that is the total cross sectional area, sometimes we may use multiple ingates, that is why this is the total cross sectional area of the ingates, that is taken as 1 is to 4 is to 4 - for gray cast iron. And for aluminum casting it is taken 1 is to 3 is to 3; and for steel castings it is taken as 1 is to 3 is to 3. So, these are the typical gating ratios.

So, once we design the choke, then we can design the runner. The runner cross sectional area is proportional to this choke area. Based on this ratio we can take, suppose if the choke area is 1 unit, then the cross sectional area of the runner will be 1.3. Then the total cross sectional area of the ingates will be 1.1. Likewise, we have to change the total cross sectional areas of the ingates and the cross sectional area of the runner.

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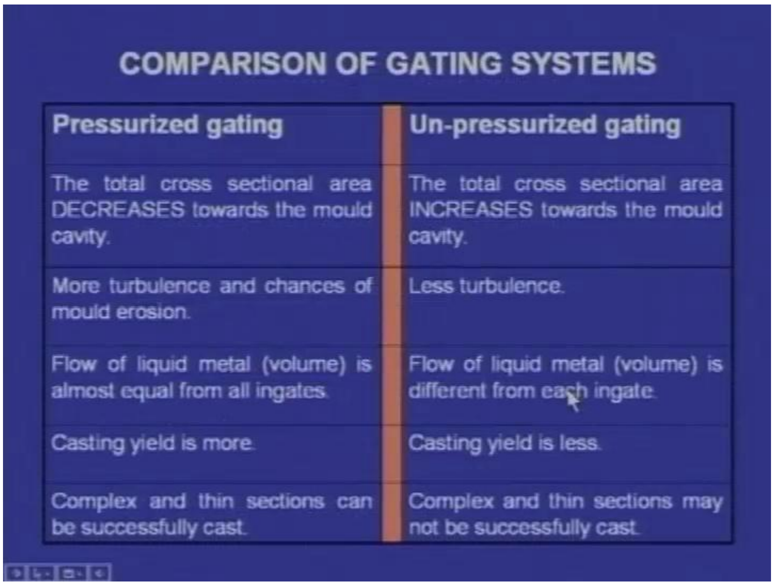

COMPARISON OF GATING SYSTEMS

Pressurized gating	Un-pressurized gating
The total cross sectional area DECREASES towards the mould cavity.	The total cross sectional area INCREASES towards the mould cavity.
More turbulence and chances of mould erosion.	Less turbulence.
Flow of liquid metal (volume) is almost equal from all ingates.	Flow of liquid metal (volume) is different from each ingate.
Casting yield is more.	Casting yield is less.
Complex and thin sections can be successfully cast.	Complex and thin sections may not be successfully cast.

This is the comparison of the two gating systems - pressurized gating system and un-pressurized gating system. So, in the case of the pressurized gating system the total cross sectional area decreases towards the mould cavity. Whereas, in the un-pressurized gating system, the total cross sectional area increases towards the mould cavity.

In the case of the pressurized gating system, there is more turbulence and chances of mould erosion; here less turbulence.

In the case of the pressurized gating system, flow of liquid metal in volume is almost equal from all ingates. Here in the un-pressurized gating system flow of liquid metal is different from each ingate.

In the case of the pressurized gating system, it has the cross sectional area is becoming narrow towards the mould cavity, less metal is required, so that results in more casting yield; here we get less casting yield.

And complex and thin sections can be successfully cast in pressurized gating system; whereas, complex and thin sections may not be successfully cast with un-pressurized gating system.

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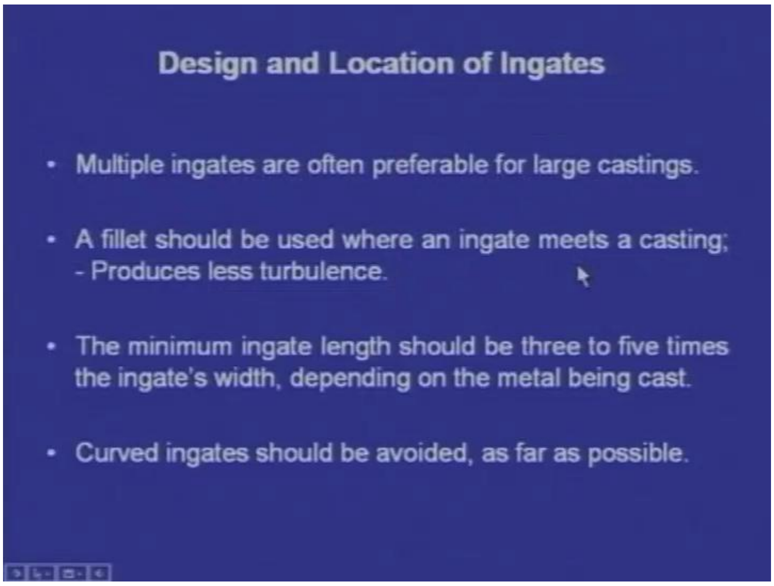

Design and Location of Ingates

- Multiple ingates are often preferable for large castings.
- A fillet should be used where an ingate meets a casting; - Produces less turbulence.
- The minimum ingate length should be three to five times the ingate's width, depending on the metal being cast.
- Curved ingates should be avoided, as far as possible.

Design and location of ingates. So, what are the guidelines for design and location of the ingates? Multiple ingates are preferred for large castings and whenever an ingate needs the casting, there should be a fillet; this reduces the turbulence; and the length of the ingate should be 3 to 5 times the ingate's width depending up on the metal being cast. Curved ingates should be avoided as far as possible.

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Design of Riser

Next, let us see the design of riser.

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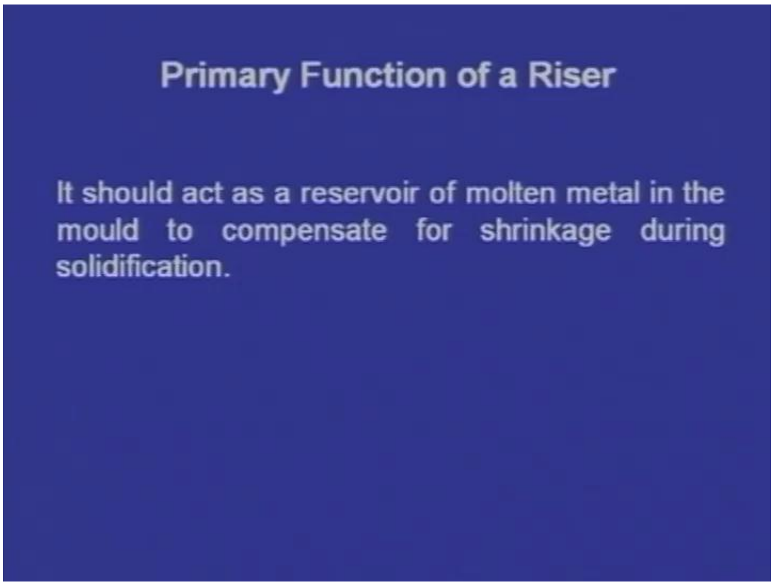

Primary Function of a Riser

It should act as a reservoir of molten metal in the mould to compensate for shrinkage during solidification.

What is the primary function of a riser? It should acts as a reservoir of the molten metal in the mould to compensate the shrinkage during solidification.

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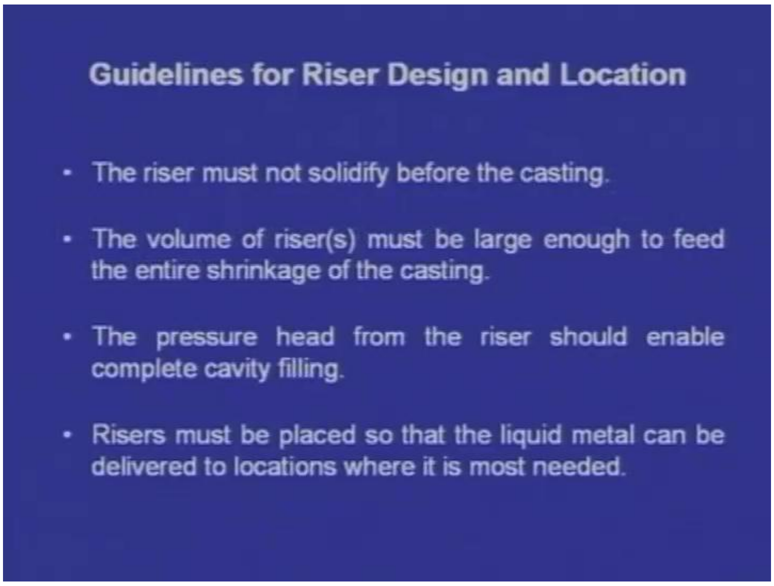

Guidelines for Riser Design and Location

- The riser must not solidify before the casting.
- The volume of riser(s) must be large enough to feed the entire shrinkage of the casting.
- The pressure head from the riser should enable complete cavity filling.
- Risers must be placed so that the liquid metal can be delivered to locations where it is most needed.

Guidelines for riser design and location. The riser must not solidify before the casting. Second one, the volume of the riser or risers must be large enough to feed the entire shrinkage of the casting. Next one - the pressure head from the riser should enable complete cavity filling. Next one - risers must be placed, so that the liquid metal can be delivered to locations where it is most needed.

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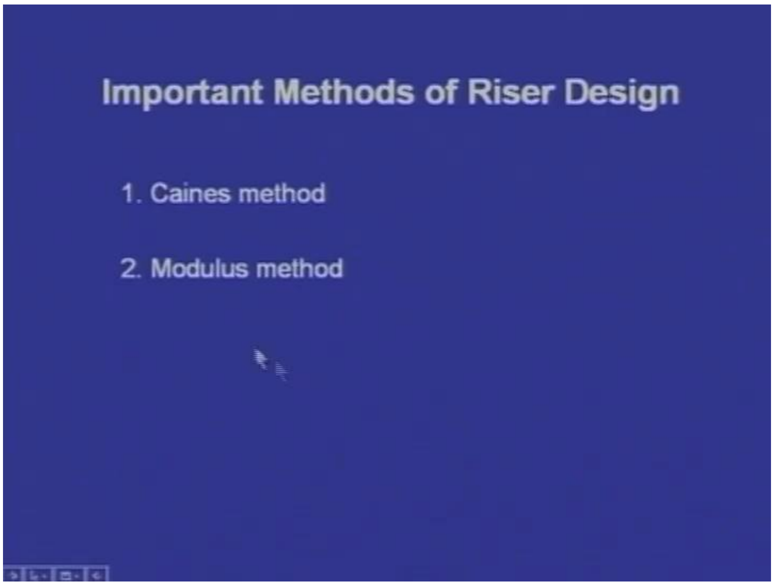

Important Methods of Riser Design

1. Caines method
2. Modulus method

Important methods of riser design. One is Caine’s method and the other one is Modulus method. First, let us see this Caine’s method.

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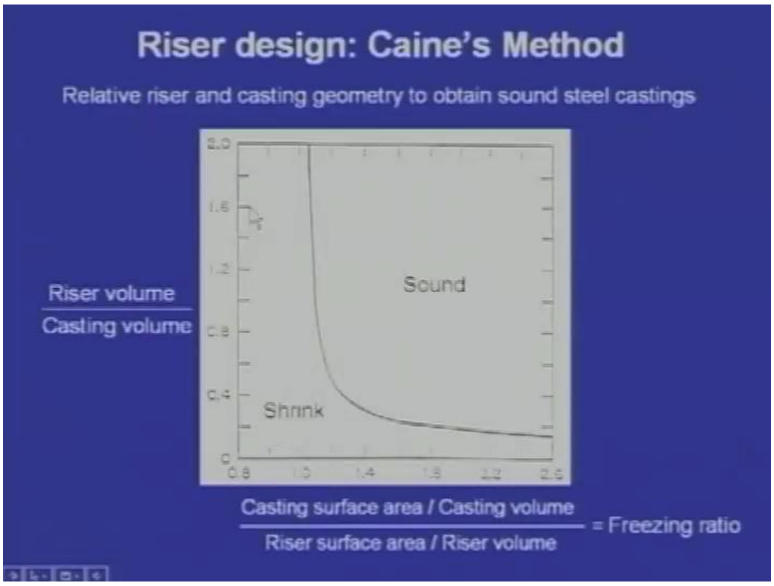

Riser design: Caine’s Method

Relative riser and casting geometry to obtain sound steel castings

So, here this is the method suggested by the Caine. He has suggested that we have to find out two ratios before we judge whether a riser will give us a sound casting or a defective casting. One ratio is riser volume by casting volume we have to find out. And we have to find out another ratio, which is known as freezing ratio. This freezing ratio is given by this expression: casting surface area by casting volume whole divided by riser surface area by riser volume.

So, when we design a riser for a casting, these two ratios we have to find out. And if these two ratios are meeting somewhere here, means that is a sound casting, means here he has plotted a curve, which will judge the nature of the casting, which we are going to obtain after solidification; here is the curve we can see.

So, if these two ratios, if these two points are meeting on the right side of the curve, then we will get a sound casting. On the other hand, if these two ratios are meeting on the left side of this curve, then there will be a shrinkage. That is how we can judge whether the riser is effective or not, whether the riser, which we have designed will lead to a sound casting or it will result in a shrinkage casting.

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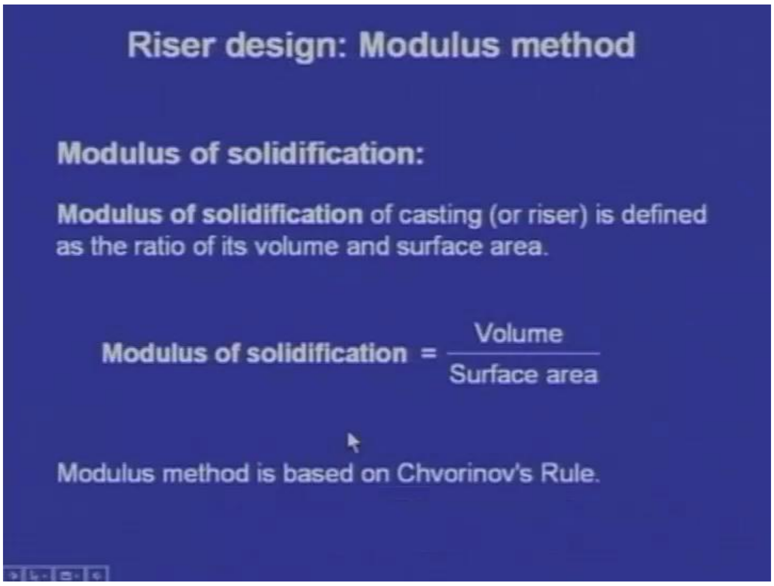

Riser design: Modulus method

Modulus of solidification:

Modulus of solidification of casting (or riser) is defined as the ratio of its volume and surface area.

$$\textbf{Modulus of solidification} = \frac{\text{Volume}}{\text{Surface area}}$$

Modulus method is based on Chvorinov's Rule.

Next one - the riser design using modulus method. Here we can see modulus of solidification. Modulus of solidification of a casting or riser is defined as the ratio of its volume to surface area. So, this is the expression - modulus of solidification is the volume divided by surface area. This method is based on Chvorinov’s rule.

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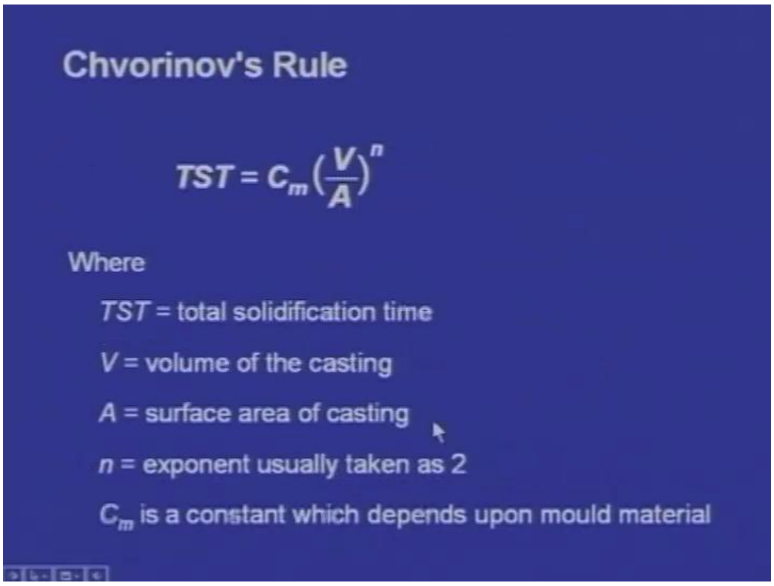

Chvorinov's Rule

$$TST = C_m \left(\frac{V}{A}\right)^n$$

Where

TST = total solidification time

V = volume of the casting

A = surface area of casting

n = exponent usually taken as 2

C_m is a constant which depends upon mould material

Let us see this Chvorinov’s rule; this is the Chvorinov’s rule. Chvorinov has suggested that TST is equal to Cm into V divided by A to the power of n - where TST is the total solidification time; V is the volume of the casting; A is the surface area of the casting;

and n is the exponent and it is usually taken as 2; cm is a constant, which depends upon the mould material. So, here we can see V by A that is the modulus. What Chvorinov's rule tells us?

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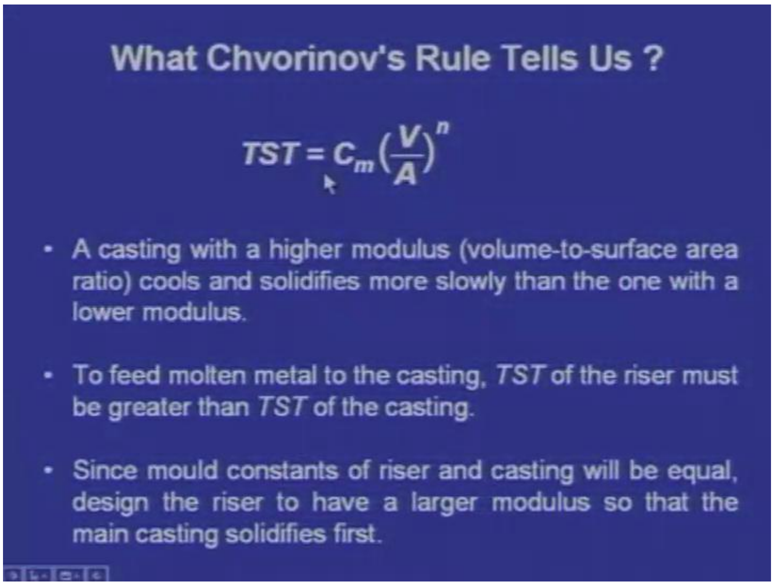

What Chvorinov's Rule Tells Us ?

$$TST = C_m \left(\frac{V}{A}\right)^n$$

- A casting with a higher modulus (volume-to-surface area ratio) cools and solidifies more slowly than the one with a lower modulus.
- To feed molten metal to the casting, *TST* of the riser must be greater than *TST* of the casting.
- Since mould constants of riser and casting will be equal, design the riser to have a larger modulus so that the main casting solidifies first.

So, this is the Chvorinov's expression. A casting with a higher modulus solidifies more slowly than a casting with a lower modulus. Even this expression tells us the same thing. And to fit the molten metal to the casting, the total solidification time of the riser must be greater than the total solidification of the time of the casting. Since the mould constants of riser and casting will be the same design the riser, so that the riser will have larger modulus, so that it remains a liquid state for a longer time. It takes more time for solidification, so that it will be feeding the casting.

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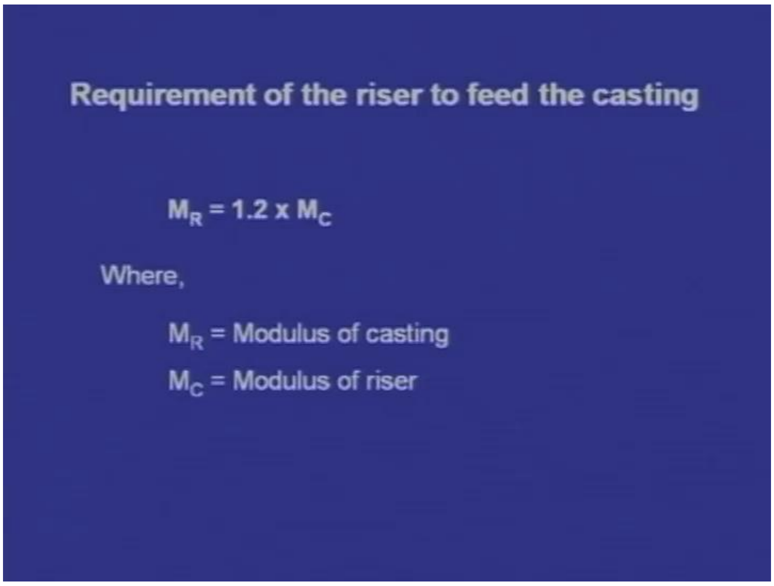

Requirement of the riser to feed the casting

$M_R = 1.2 \times M_C$

Where,

M_R = Modulus of casting

M_C = Modulus of riser

So we have seen that the modulus of the riser must be greater than the modulus of the casting, then only the riser can feed the casting. The modulus of the riser must be greater than the modulus of the casting. If that be the case, it should be greater by how much? From the experiments, it was found that the modulus of the riser must be at least 1.2 times the modulus of the casting. If the modulus of the riser is 1.2 times the modulus of the casting, then the riser can successfully feed the casting.

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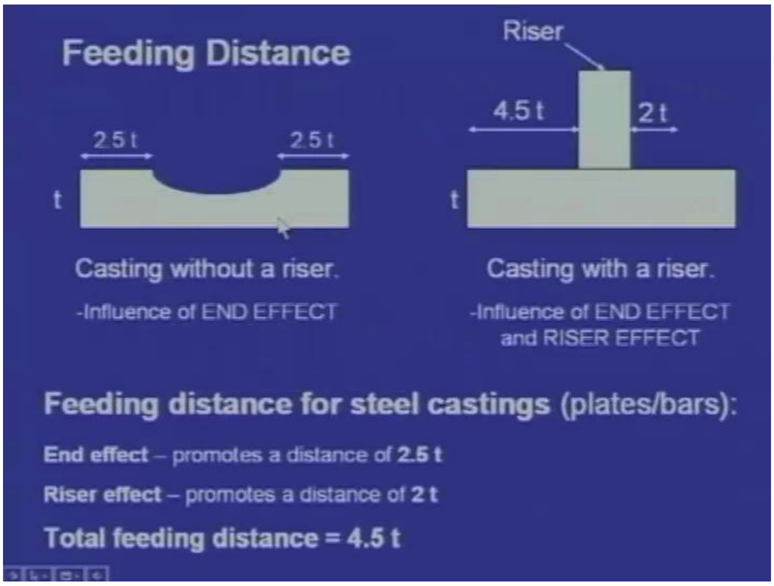

Feeding Distance

Casting without a riser.

-Influence of END EFFECT

Casting with a riser.

-Influence of END EFFECT and RISER EFFECT

Feeding distance for steel castings (plates/bars):

End effect – promotes a distance of **2.5 t**

Riser effect – promotes a distance of **2 t**

Total feeding distance = 4.5 t

Now, let us see the feeding distance. To what extend a riser can feed a casting? A casting may be so long and we may use one riser; does it mean that the one riser will feed the entire long casting? No, it will feed to certain extent, and if so, by how much distance it will be feeding, that is the feeding distance.

Let us see two cases. Here we can see one casting where there is no riser, but we can see after solidification here there is a shrinkage; but here one portion, it is solidified successfully without any shrinkage. Riser was not required for this portion, and here also we can see this portion has solidified successfully; riser was not required, because it was exposed to the walls of the mould. So, this portion was solidified; even though there was no riser, it was solidified successfully; riser is not required for this portion.

So, the portion of the casting, which was solidified without any shrinkage due to the walls of the mould that is known as the end effect. End effect means, walls of the mould, they are able to solidify the casting without any shrinkage, so that is equal to 2.5 t where t is the thickness of the casting. So, here we can see one portion is solidified without any shrinkage that is 2.5 t and this side another portion 2.5 t.

Let us see another case in which there is a riser; this is the riser, because we have kept a riser this time, there is no shrinkage, means this portion; previously there was a shrinkage that is compensated by this riser; because we have kept a riser, this portion, we did not get any shrinkage, means this portion is taken care by the riser.

So, this is the riser effect; riser effect means it is the shrinkage compensation taken care by the riser and that comes to be 2 t where t is the thickness of the casting. So, that total feeding distance when we keep a riser will be 4.5 t. So, here we can see the influence of end effect, and here we can see the influence of end effect and riser effect.

Feeding distance for steel castings where the castings are of the shapes, plates and bars end effect will be up to 2.5 t, even though there is no riser, the casting will be solidified up to a distance of 2.5 t; that is the end effect.

When we place the riser, because of the riser, certain area will be there without any shrinkage; that is the riser effect and that will be 2 t; and the total feeding distance will be sum of end effect and riser effect, that will be 4.5 t.

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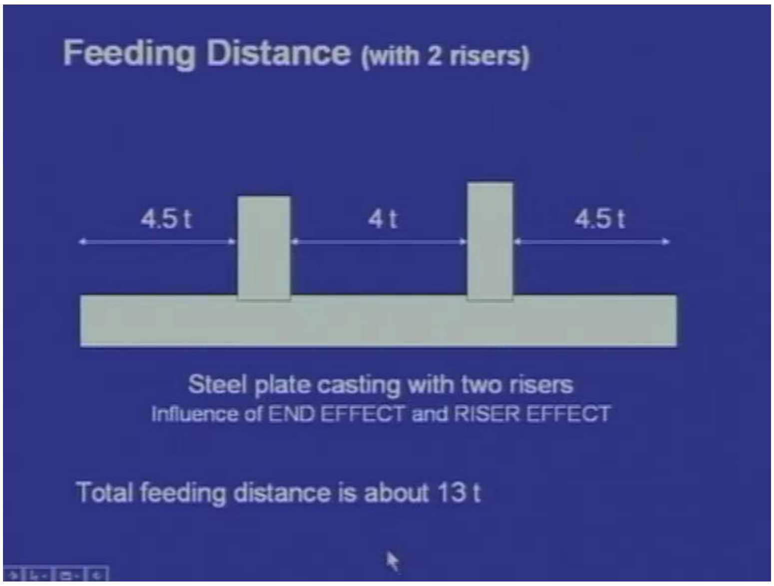

Feeding Distance (with 2 risers)

Steel plate casting with two risers
Influence of END EFFECT and RISER EFFECT

Total feeding distance is about 13 t

Feeding distance with two risers. This is a longer casting, so we have kept two risers. So, this side there is end effect and riser effect; end effect is 2.5 t and riser effect is 2 t. So, this side it is 4.5 t; and this side riser affect 2 t; this side riser effect 2 t. So, this total distance is 4 t. And this side again from here to here it will be riser effect; from here to here it will be end effect. So, the total feeding distance here it will be 4.5 t. So, the total feeding distance will be about 13 t with a casting, where there are two risers.

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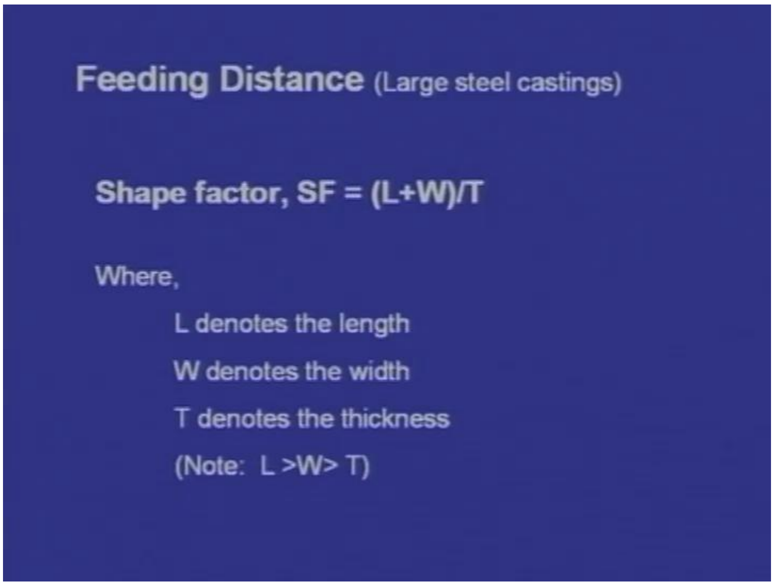

Feeding Distance (Large steel castings)

Shape factor, SF = (L+W)/T

Where,
- L denotes the length
- W denotes the width
- T denotes the thickness
- (Note: L >W> T)

Feeding distance of large castings. Previously we have seen the feeding distance in the case of the steel castings of bars and plates. Here we will see the feeding distance for large steel castings, where the volume is more and the surface area is more. And here, one shape factor will come into picture, which is defined as L plus W divided by T; where L denotes the length, W denotes the width, and T denotes the thickness. And L should be greater than W, and W should be greater than T.

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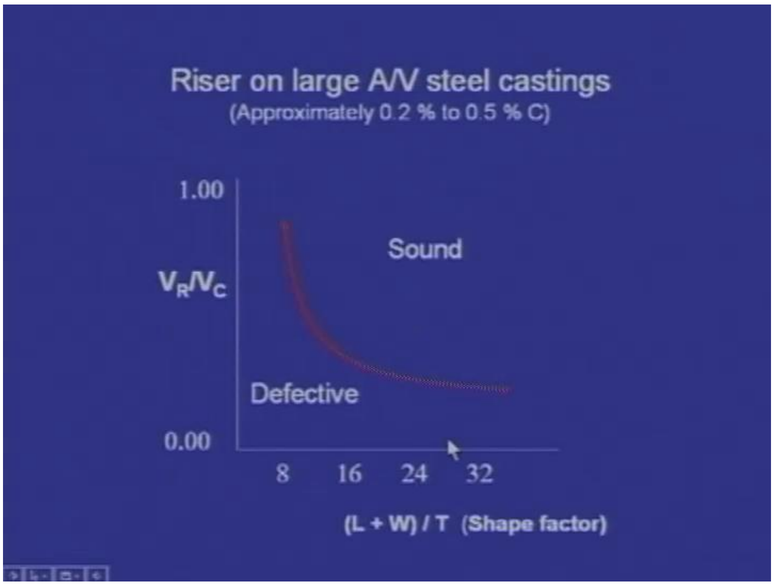

Riser on large A/V steel castings

(Approximately 0.2 % to 0.5 % C)

That be the case, now here we have to make… again two factors are there. One is L plus W by T; that is the shape factor is plotted on the x-axis; and the ratio of Vr by Vc that is the volume of the riser and the volume of the casting is plotted along y-axis. And if these two ratios are meeting on the right side of this curve, then a casting will be a sound casting without any shrinkage. And if these ratios are meeting on the left side of this curve, then the casting will have a shrinkage. That is how we can judge whether the riser - that we have designed - is sufficient to feed the casting or not.

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Fluidity of Molten Metal

Next one - let us see the fluidity of the molten metal.

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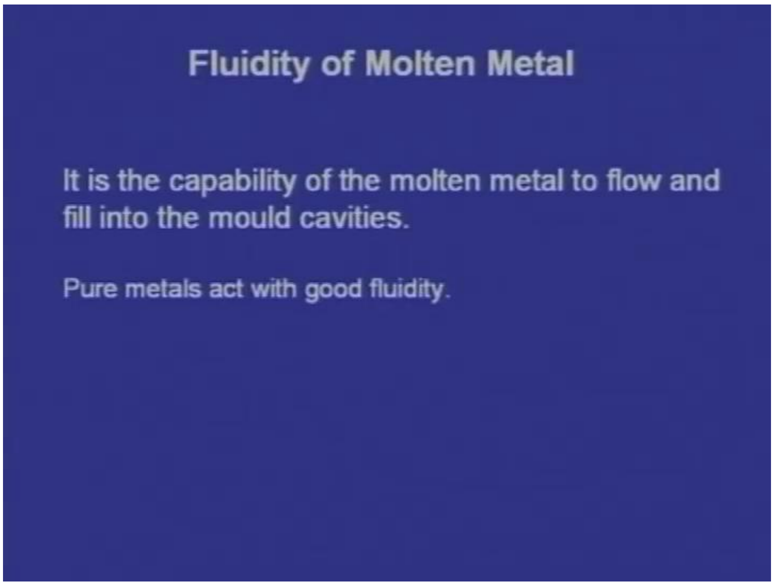

Fluidity of Molten Metal

It is the capability of the molten metal to flow and fill into the mould cavities.

Pure metals act with good fluidity.

It is the capability of the molten metal to flow and fill into the mould cavities, and it was found that pure metals act with good fluidity.

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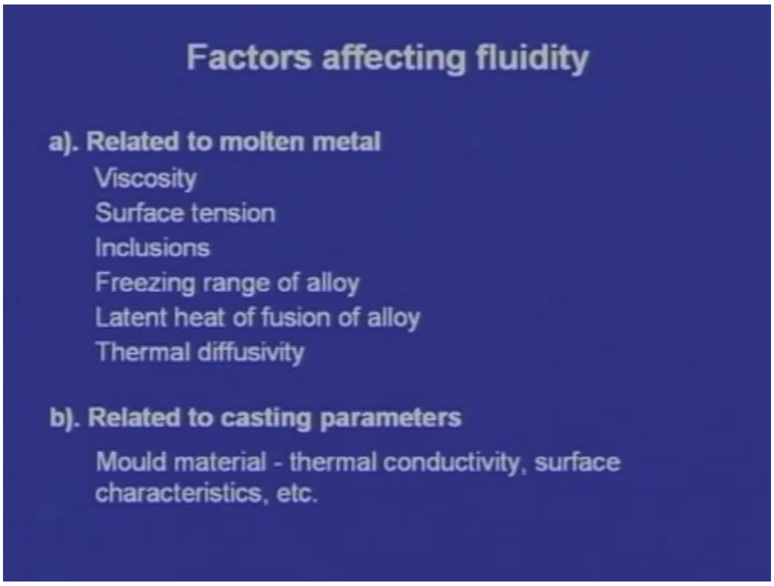

Factors affecting fluidity

a). Related to molten metal

- Viscosity
- Surface tension
- Inclusions
- Freezing range of alloy
- Latent heat of fusion of alloy
- Thermal diffusivity

b). Related to casting parameters

- Mould material - thermal conductivity, surface characteristics, etc.

Factors affecting fluidity, And these are related to molten metal: one is viscosity that influences fluidity; and surface tension influences fluidity; inclusions in the molten metal, they influence fluidity; freezing range of the alloy that influences the fluidity. When an alloy is freezing, it freezes over a range and this freezing range influences the fluidity. Latent heat of fusion of the alloy influences the fluidity; thermal diffusivity will influence fluidity; and the factors related to casting parameters such as mould material, thermal conductivity, surface characteristic, and so on, they influence the fluidity.

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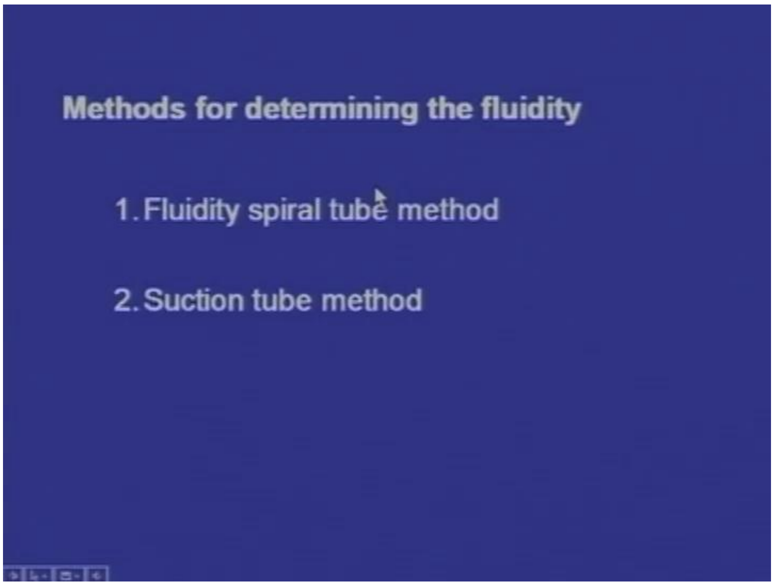

Methods for determining the fluidity

1. Fluidity spiral tube method
2. Suction tube method

Methods for determining the fluidity. One is fluidity spiral tube method; another one is suction tube method. Let us see this fluidity spiral tube method.

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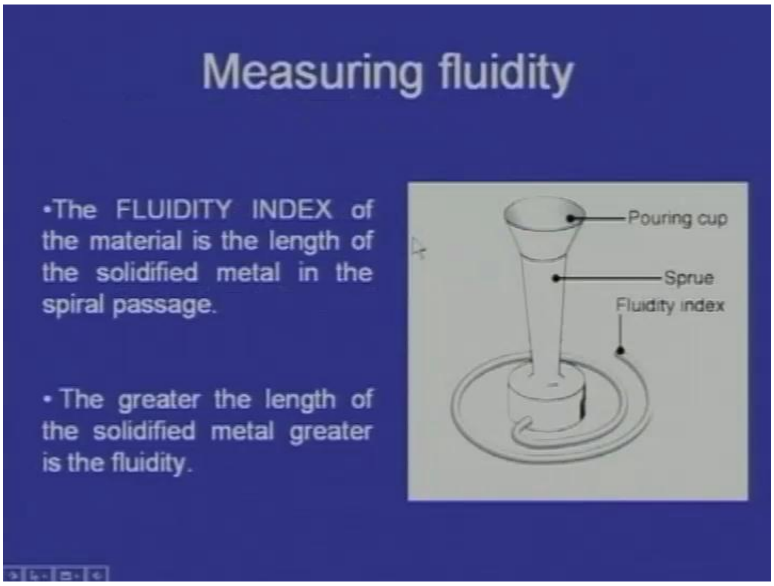

Measuring fluidity

- The FLUIDITY INDEX of the material is the length of the solidified metal in the spiral passage.
- The greater the length of the solidified metal greater is the fluidity.

In this fluidity spiral tube method, here we can see a pattern. That pattern will be like this: there will be pouring cup, and there will be sprue; and there will be a spiral, this will be molded inside the molding boxes, and when we withdraw this pattern the mould will have a small tube - a spiral tube. Then, we pour the molten metal through the pouring cup and through the sprue. The molten metal passes through this way and it passes through the spiral cavity - like this, and the length of the molten metal that is passing through this spiral cavity will be dependent on fluidity of the metal.

If the molten metal has got higher fluidity, it travels in this spiral for a longer distance; and if it has got a lower fluidity, it travels for a shorter distance. So the length - that is length of the molten metal - that is solidified in this spiral cavity is the measure of the fluidity.

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Solidification of Castings

Next one - solidification of the casting.

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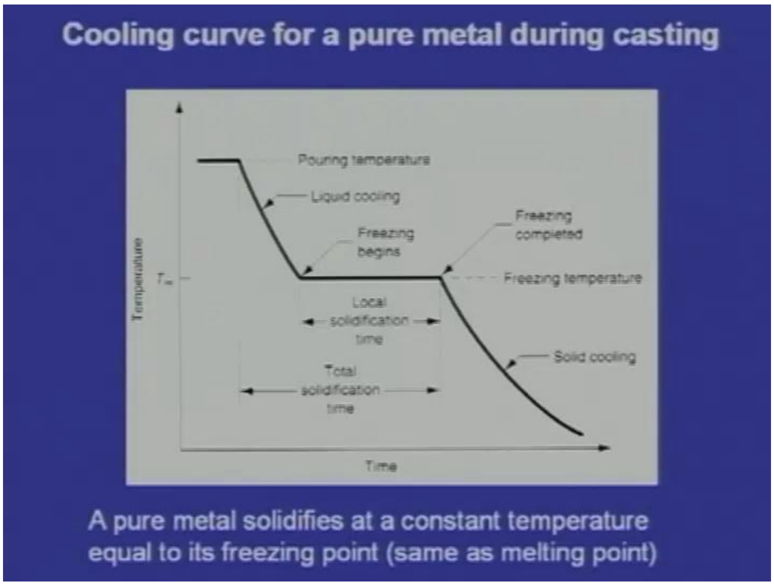

Cooling curve for a pure metal during casting

A pure metal solidifies at a constant temperature equal to its freezing point (same as melting point)

And this is the cooling curve for a pure metal, and this is the pouring temperature, and from this point to this point, the liquid metal is losing its temperature and its temperature comes down. And when it reaches this temperature, freezing begins, and during freezing the temperature is same. And by this time when reaches this temperature, freezing is over. After freezing is over, then again temperature falls down; that is the solid shrinkage

- solid cooling. So, this is the cooling curve for a pure metal. So one thing you important is it freezes at a constant temperature, at the same temperature it freezes.

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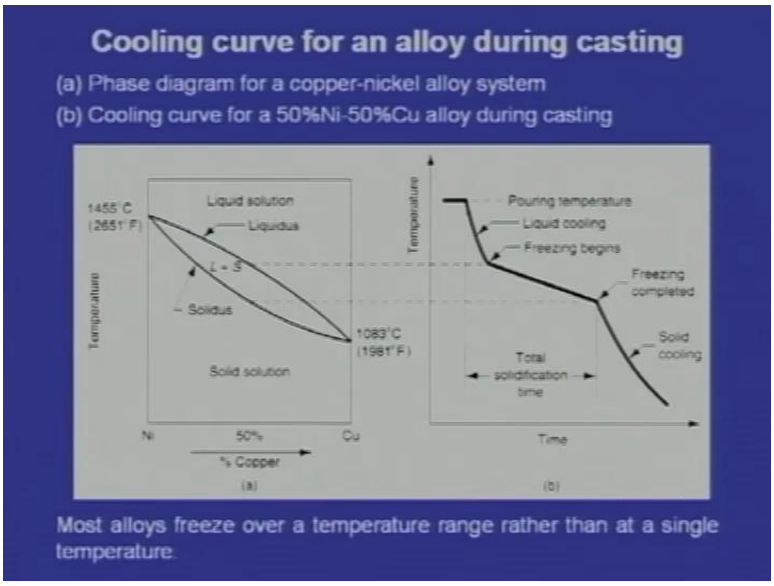

Cooling curve for an alloy during casting

(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, let us see the cooling curve for an alloy during casting. And here we can see, the phase diagram for a copper and nickel alloy. And this side, we can see the nickel, which starts freezing at a temperature of 1455 degree centigrade, and this side we can see the copper, which starts freezing at a temperature of 1083 degree centigrade. And this is the curve - some zone, two-phase zone is there, where liquid and solid is present; and this is the curve known as liquidous. This curve is the boundary, which is separating liquid and the two-phase zone - that is the liquid and solid phase.

And here we can see another curve that is known as the solidus. This is the boundary, which is separating the solid, and the liquid and solid phase. And here we can see the cooling curve for a alloy in which there is 50 percent copper and 50 percent nickel. And this is the pouring temperature, and from this point to this point, the liquid metal lost its temperature, and from this point onwards it is starts freezing. From this point to this point freezing goes on; and this point freezing is completed; and from this point to this point, the solid under goes cooling - that is the solid shrinkage.

So, from this cooling curve, we can see that an alloy undergoes freezing over a range. In the case of a pure metal, it was freezing at a constant temperature, whereas an alloy freezes over a range.

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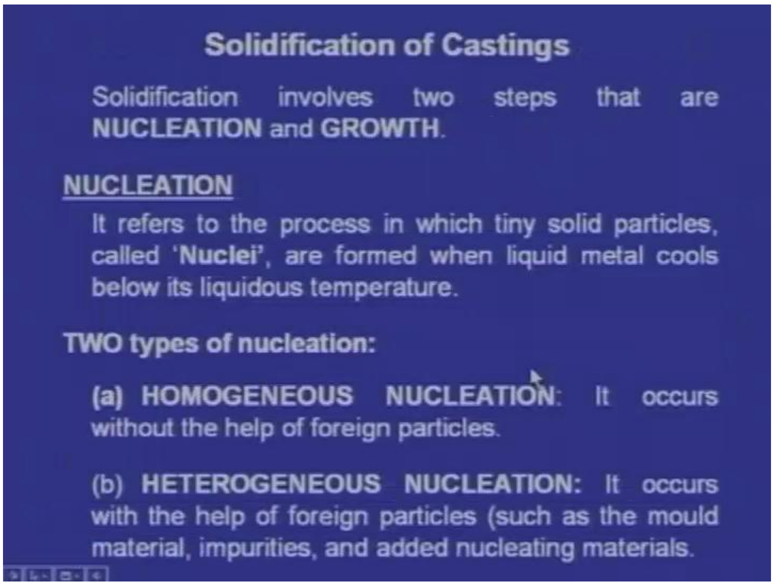

Solidification of Castings

Solidification involves two steps that are **NUCLEATION** and **GROWTH**.

NUCLEATION

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

TWO types of nucleation:

(a) **HOMOGENEOUS NUCLEATION**: It occurs 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.

Solidification of castings. In solidification there are two terms: one is nucleation and growth. Nucleation refers to the process in which tiny solid particles called nuclei are formed when the liquid metal cools below its liquidous temperature. These nuclei will grow and form solid particles and it results in solidification. So, initially small tiny particles known as nuclei are generated; later they grow into solid.

And there are two types of nucleation: one is homogeneous nucleation and the other one is heterogeneous nucleation. In the case of the homogeneous nucleation, it occurs without the help of any foreign particles. In the case of the heterogeneous nucleation, it occurs with the help of foreign particles, such as mould material, impurities, and sometimes we also add some materials, which are known as nucleating materials or nucleating agents.

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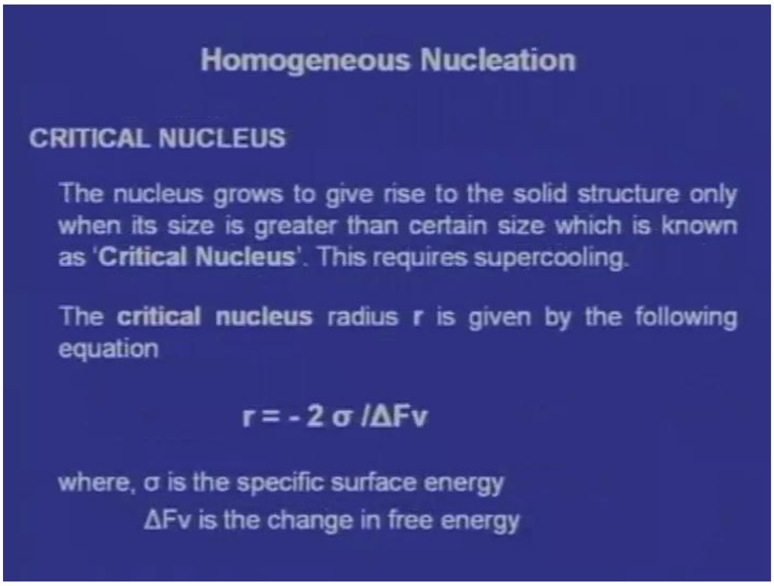

Homogeneous Nucleation

CRITICAL NUCLEUS

The nucleus grows to give rise to the solid structure only when its size is greater than certain size which is known as '**Critical Nucleus**'. This requires supercooling.

The **critical nucleus** radius **r** is given by the following equation

$$r = -2\sigma/\Delta Fv$$

where, σ is the specific surface energy
ΔFv is the change in free energy

Now, let us see something more about homogeneous nucleation. In the nucleation, we have seen that first the solidifications starts like - this tiny solid particles are generated, and these tiny solid particles will be growing and it will result in solidification; but if these tiny solid particles have to turn into solid casting, the size of these tiny particles must be a certain size, that is known as the critical nucleus. Critical nucleus means, it is the nucleus of the minimum size, which will develop into solid casting. This requires super cooling.

The critical nucleus radius r is given by the following equation: R is equal to minus 2 sigma divided by delta Fv, where sigma is the specific surface energy and delta F v is the change in free energy.

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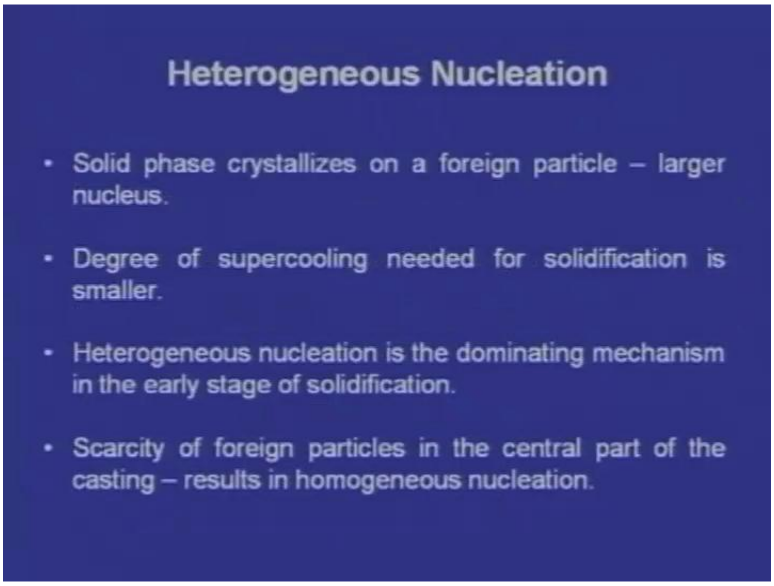

Heterogeneous Nucleation

- 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.

Next, let us see the heterogeneous nucleation. In this heterogeneous nucleation, the solid phase crystallizes on a foreign particle. Hence, larger nucleus is generated, and the degree of super cooling needed for solidification is smaller. And in castings, the heterogeneous nucleation is the dominating mechanism and scarcity of foreign materials in the central part of the casting will be less. So, that results in homogeneous nucleation.

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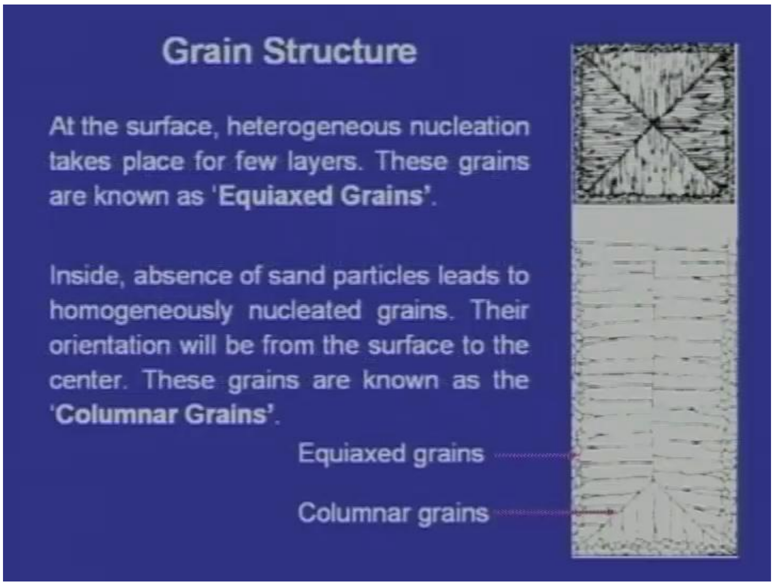

Grain Structure

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

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**'.

Let us see this grain structure, and at this surface, heterogeneous nucleation takes place for few layers, because foreign particles are present at the mould surface - at the end of the cavity, which is closer to the mould surface there are sand particles may be there. So the molten metal is mixed with this tiny sand particles or other impurities; then heterogeneous nucleation will be taking place.

So because of this heterogeneous nucleation equiaxed grains are generated here, and as the solidification advances inside, inside the casting there is a scarcity of the foreign materials. The impurities and the sand particles are more present at the surface of the cavity; whereas, at the center of the cavity, their presence is less that results in homogeneous solidification or homogeneous nucleation.

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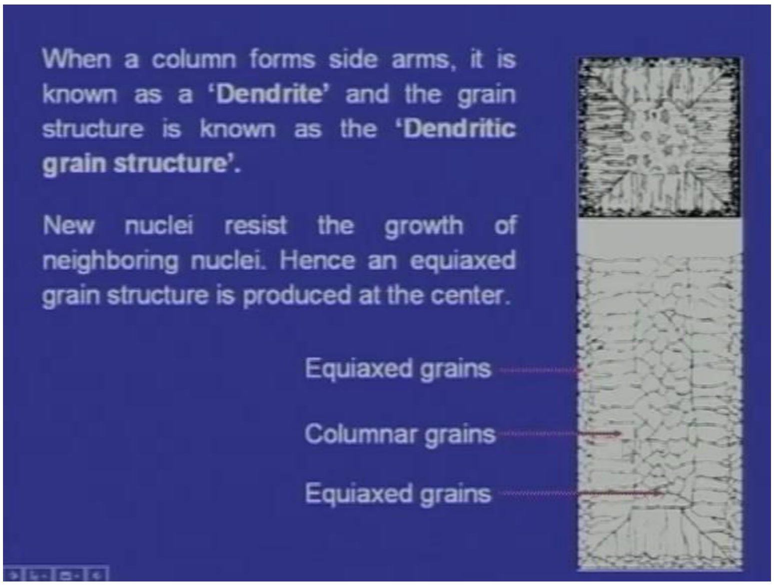

When a column forms side arms, it is known as a **'Dendrite'** and the grain structure is known as the **'Dendritic grain structure'.**

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

When this homogeneous nucleation is there, these kind of columnar grains are generated. Now, when you column forms side arms, it is known as dendrite and the grain structure is known as dendritic grain structure. And as the columnar grains are advancing, new grains are generated. This new nuclei resist the growth of the neighboring nuclei, because of that, again equiaxed grain structure is generated inside.

So outside because of the foreign particles, because of the impurities, equiaxed grains are generated; and inside because of the purity of the metal, because of the absence of the foreign materials, columnar grains are generated; and inside this columnar grains are resisting the growth of the nuclei, again equiaxed grains are generated.

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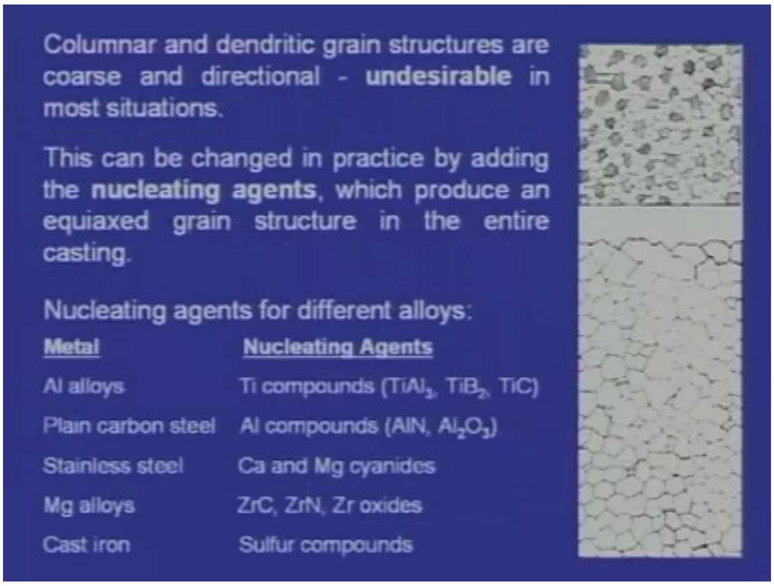

Columnar and dendritic grain structures are coarse and directional - **undesirable** in most situations.

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

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

And this columnar and dendritic grains structures are coarse and directional, and they are undesirable in most of the situations. So, this can be changed in practice by adding nucleating agents, which produce equiaxed grain structure in the entire casting. We add nucleating agents. And the nucleating agents for different alloys are as under: for aluminum alloys, titanium compounds; and for plain carbon steels, aluminum compounds; and for stainless steel, calcium and magnesium cyanides are used as the nucleating agents. And for magnesium alloys - zirconium carbide, zirconium nitride and zirconium oxides - they are used as the nucleating agents; and for cast iron, sulfur compounds are used as the nucleating agents. So using these nucleating agents, we can get a better structure.

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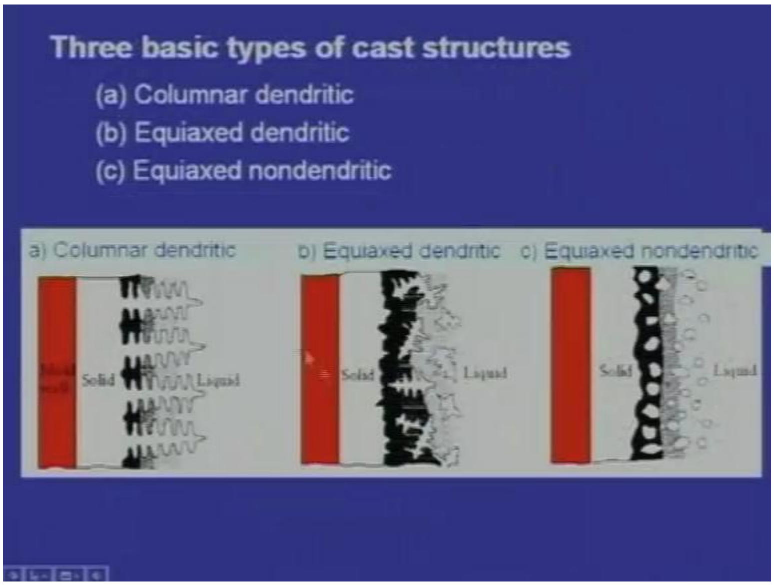

Three basic types of cast structures

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

So, these are the three basic types of cast structures. One is columnar dendritic. So, this is the columnar dendritic. And another one is equiaxed dendritic - here we can see equiaxed dendritic. And another one is equiaxed non dendritic - this is the equiaxed non dendritic structure. So, these are the three basic types of cast structures.

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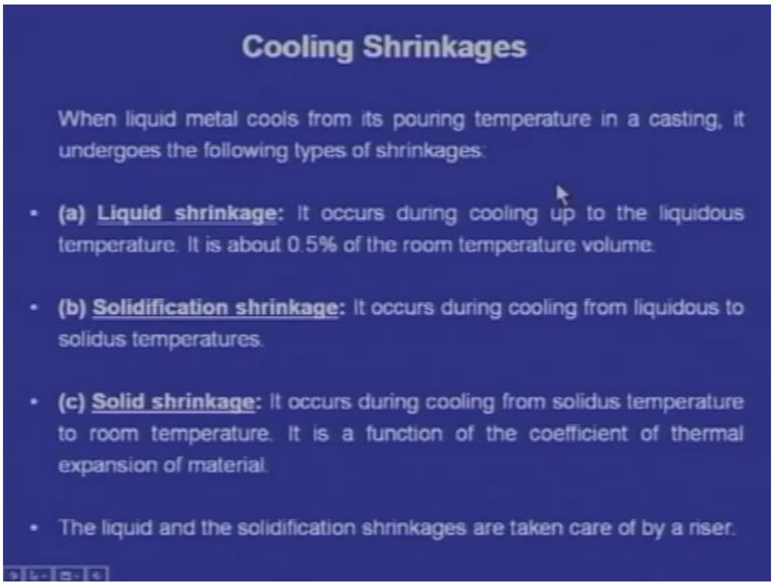

Cooling Shrinkages

When liquid metal cools from its pouring temperature in a casting, it undergoes the following types of shrinkages:

- **(a) Liquid shrinkage:** It occurs during cooling up to the liquidous temperature. It is about 0.5% of the room temperature volume.
- **(b) Solidification shrinkage:** It occurs during cooling from liquidous to solidus temperatures.
- **(c) Solid shrinkage:** It occurs during cooling from solidus temperature to room temperature. It is a function of the coefficient of thermal expansion of material.
- The liquid and the solidification shrinkages are taken care of by a riser.

Now, let us see the cooling shrinkages. When a liquid metal cools from its pouring temperature in a casting, it undergoes three types of shrinkages. One is liquid shrinkage -

it occurs during cooling up to the liquidous temperature, and it is about 0.5 percent of the room temperature volume; it is very small.

Next one is the solidification shrinkage - as we have already seen, that an alloy freezes over a range. So, it occurs during the cooling from liquidous to solidus temperature, and this is taken care of by the riser, this shrinkage. In fact, liquid shrinkage and solidification shrinkage, they are taken care of by riser. The liquid metal present in the riser compensates the shrinkage caused due to liquid shrinkage and solidification shrinkage.

Next one is the solid shrinkage - there is a difference; this is a solidification shrinkage, means shrinkage which is caused when the liquid metal is transformed into solid metal during solidification. Whereas, this is the solid shrinkage, means shrinkage after the metal is completely solidified, when the solidified metal is cooling down to room temperature, it under goes shrinkage. And it is a function of the co-efficient of thermal expansion of the material. And this can be taken care of by providing shrinkage allowance to the pattern.

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Solidification shrinkages for important cast metals/alloys

S.No	Metal or alloy	Solidification shrinkage (% volume)
1.	Aluminum	7.1
2.	Zinc	6.5
3.	Gold	5.5
4.	Copper	4.9
5.	Magnesium	4.2
6.	Lead	3.2
7.	Al-4.5 % Cu	6.3
8.	Al-12 % Si	3.8
9.	Brass (70-30)	4.5
10.	90 % Cu -10 % Al	4
11.	Carbon steels	2.5 to 4
12.	White iron	4.5 to 5

Liquid shrinkage is about 0.5 % by volume with normal superheat.

And these are the solidification shrinkages for important cast metals and alloys. For aluminum, it is 7.1 percent by volume; for zinc it is 6.5 percent by volume; for gold it is 5.5 percent by volume; for copper 4.9; for magnesium 4.2; for lead it is 3.2; and for aluminum and 4.5 percent copper it is 6.3. And for aluminum and 12 percent silicon it is 3.8; and for brass it is 4.5; and for 90 percent copper and 10 percent aluminum it is 4 percent. And for carbon steels it is 2.5 to 4 percent; and for white iron it is from 4.5 to 5 percent. Liquid shrinkage is only about 0.5 percent of the volume.

So, in this episode we have learned about the gating system, and the functions of a casting. The gating system includes the sprue, the pouring cup, the sprue well, the runner, ingates, and the riser. We have seen the functions of each and every element of the gating system. We have also seen the concept of feeding distance - the distance covered by a riser to compensate the shrinkage. We have seen the concept of end effect and the riser effect. We have also learned about the fluidity and the solidification. We have seen that pure metals solidify at a constant temperature, whereas alloys they solidify over a range. And we have also learned about the cooling shrinkages - they are the liquid shrinkage, solidification shrinkage, and solid shrinkage. This liquid shrinkage and solidification shrinkage are compensated by providing the riser. Whereas, this solid shrinkage is compensated by providing shrinkage allowance to the pattern. And in the next episode we will be learning about the casting defects.

Thank you.