Manufacturing Processes – Casting and Joining
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Lecture – 05

Hello and welcome back to the course on Manufacturing Processes - Casting and Joining. Let me remind you that in our last discussion session we started discussing the Gating System and the Gating Design. We said that to get a proper casting, proper flow of the material, proper behaviour of the sand and overall a good quality of the casting, we have to have an appropriate gating design.

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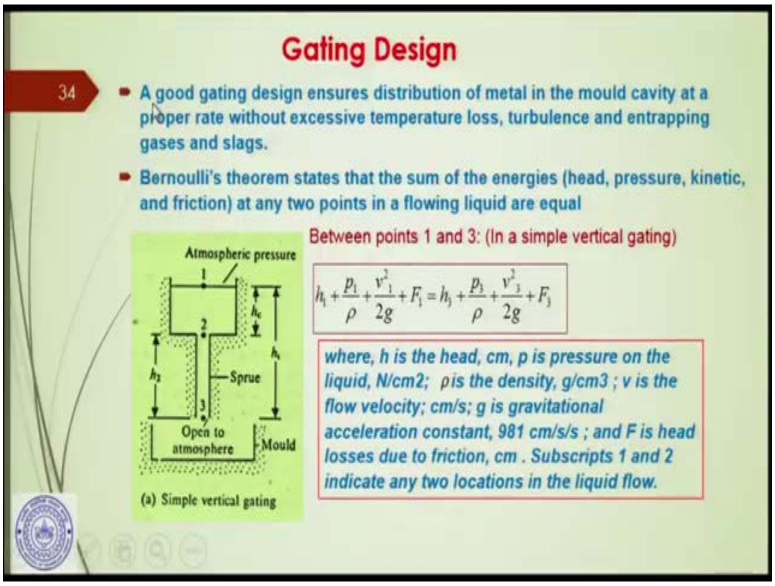

Now, if you look at the slide that I will repeat for the recap that a good gating design ensures distribution of metal in the mould cavity at a proper rate without the excessive temperature loss, turbulence and the entrapping of the gases and the slags.

This says that the distribution of the molten metal or entrapping of the gas, these are the important factors and the turbulence because if we have it while pouring the molten metal, we have to ensure that the rate of flow is appropriate.

If it is more in that case, there will be a turbulence and the mould cavity may actually get destroyed. So, here for the gating design let us use the Bernoulli’s theorem, which states that the sum of energies, that is the head, pressure, kinetic and the friction energy at any two points in the flowing liquid are equal. So, we have taken a simple vertical gating system as an example and the molten metal is filled up here. This is the entrance to the mould cavity.

Here we take three points, let us say 1, 2 and 3. So, with respect to 1 and 3 we said that the Bernoulli's equation can be written in this way $h_1 + \frac{p_1}{\rho} + \frac{{v_1}^2}{2g} + F_1 = h_3 + \frac{p_3}{\rho} + \frac{{v_3}^2}{2g} + F_3$

ρ is the density, p_1 and p_3 are the pressure on the liquid, v_1 and v_3 are the flow velocity, g is the acceleration due to gravity and F is the head losses due to friction.

Here, , h_1 is equivalent to h_t. Then p_1 is equal to p_3 because, both of these points will be open to the atmosphere and then the v_1 is equal to 0 because this is the level, which is maintained constant, that is what we said.

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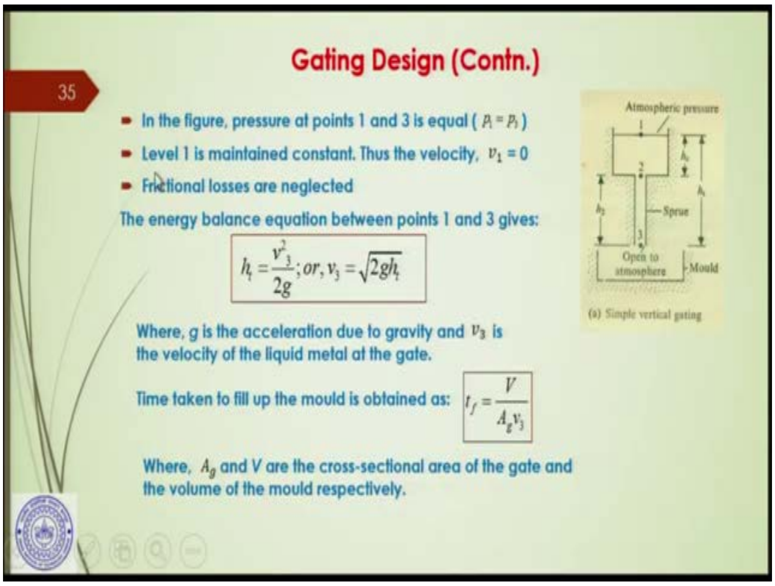

So, what will be if we put these conditions and these conditions we have said in here that p 1 is equal to p 3, v 1 is equal to 0. Friction losses are neglected, in that case we have seen that v 3 that is the flow velocity at this point will be equal to $v_3 = \sqrt{2gh_t}$ h_t is the height from the level of the pouring cup up to the entrance of the mould cavity.

So, v_3 is determined. In that case we can find out the t_f which is the time taken to fill up the mould, $t_f = \frac{V}{A_g v_3}$. This will depend on the volume of the mould cavity, V, the cross-sectional area of the gate, A_g and the flow velocity, v_3.

So, as you can see that the time taken to fill up the mould is directly proportional to the volume of the mould cavity and inversely proportional to the cross-sectional area and the flow velocity.

Here as you understand that the flow velocity at this point, at the entry level of the mould cavity - this is very important, because then we can find out the time taken to fill up the mould cavity which is inversely proportional to the v_3 that is the flow velocity at point 3.

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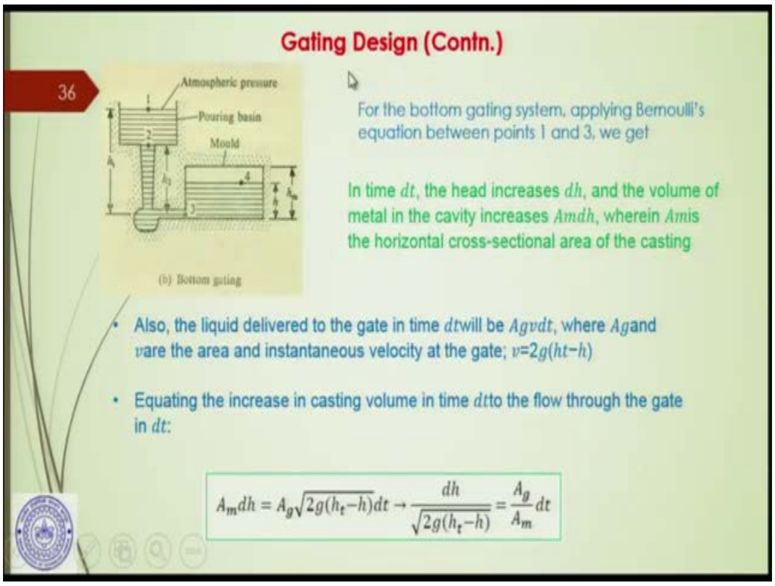

Now, let us say here we have taken an example of the bottom gating system. So, this is the mould cavity and the molten metal enters from here. This is the bottom cavity and here we have the pouring cup, sprue, well, runner and the whole gating system. So, through this the molten metal enters and flows to the mould. The mould cavity is enclosed here. This is the sand in the mould.

So, this is the bottom gating system and for the bottom gating system we applied Bernoulli's equation between 1 and 3. We will take up level 1 here that is equivalent to what we have done for the vertical gating. Let us say level one is the pouring level when we have started pouring the molten metal in the cup and when it goes to the sprue.

Now, for a certain time d_t, the head increases let us say d_h this is small height for a small time at any instant of time the height changes to d_h let us say and the volume of metal in the cavity increases by $A_m dh$ wherein *Am* is the horizontal cross-sectional area of the casting. This is the cross-sectional area at any horizontal cross-section and the *dh* is the increment in the head at any time of *dt*.

The liquid delivered to the gate in time *dt* we can find out as $A_g vdt$. *Ag* and *v* are the area and the instantaneous velocity at the gate. *v* is equal to, $v = 2g(h_t - h)$. Earlier we have seen that.

Now, we equate the increase in casting volume in time *dt* to the flow through the gate in *dt* . So, we have is the following: $\frac{dh}{\sqrt{2g(h_t - h)}} = \frac{A_g}{A_m} dt$

So, this expression is equating the increase in casting volume in time *dt* to the flow through the gate in *dt* . So, basically as you understand that these two parameters are the same that is why we are equating them that is $A_m dh$ is the same as the $A_g \sqrt{v} dt$.

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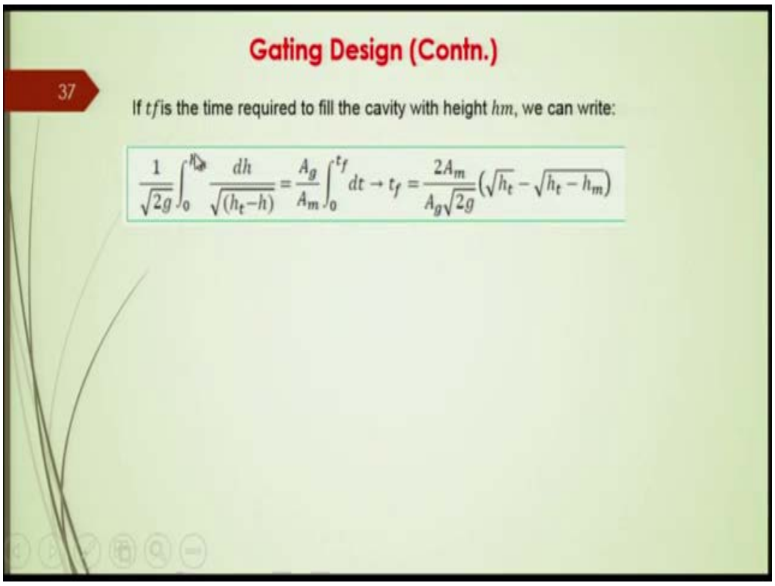

Now, let t_f be the time required to fill up the cavity with height h_m What we mean to say is that suppose we have the cavity which is of h_m height and the entire mould cavity has to be filled up; this we are talking about for the bottom gating system.

So, this we can find out by integrating both sides of the earlier equation as shown in the slide.

So, we are integrating both the sides. So, from here we can find out the value of the t_f ; this is equal to $t_f = \frac{2A_m}{A_g\sqrt{2g}}\left(\sqrt{h_t} - \sqrt{h_t - h_m}\right)$. So, t_f is an important parameter which is equal to time to fill the cavity with the height h_m.

In case of simple vertical gating system we have found out this time taken to fill the mould cavity and this was much easier because it was filling up by gravity and therefore, it actually will give you $\frac{V}{A_g v_3}$.

Whereas, in this case it is not the gravity, but it is because of the pressure given by the subsequent flow of the molten metal it is getting filled up. So, here we are using this equation, that is, we are equating the increase in casting volume here in this mould cavity in time and this will be equal to the flow through the gate in that time dt.

So, these two parameters will be same if we equate them then we integrate them from 0 to h_m with the time 0 tot_f, then we will be getting the value of the t_f. This is not very difficult to understand, but this equation or the outcome of the t_f will be more complicated than the one that we got for the vertical gating system.

So, now you can compare the time to fill up the cavity. Whether the time to fill up the cavity in case of the simple vertical gating system, the bottom gating system will be different. How much different they are that you can now compare because you have both of these expressions and you know now how these two expressions can be derived. Once again this is not very difficult to derive.

I am not repeating this because this is very simple using the Bernoulli's equation between any two points. So, here we are talking about the level 1 and 3, and then we are writing this equation with respect to 1 and 3 and we are getting the v_3. So, once we got the v_3 we know the volume, we know the cross-sectional area, we can find out the time taken to fill up the cavity.

Here in this case, in the case of the bottom gating we are using this equation that is the increase in the casting volume within a certain time this is equal to the flow through the gate at the same time. So, once we are using this if you integrate both the sides then we can get the value of the

t_f and that integration will be from 0 to h_m and the integrate time will be 0 to t_f . This is how we can find out the value of the t_f , .

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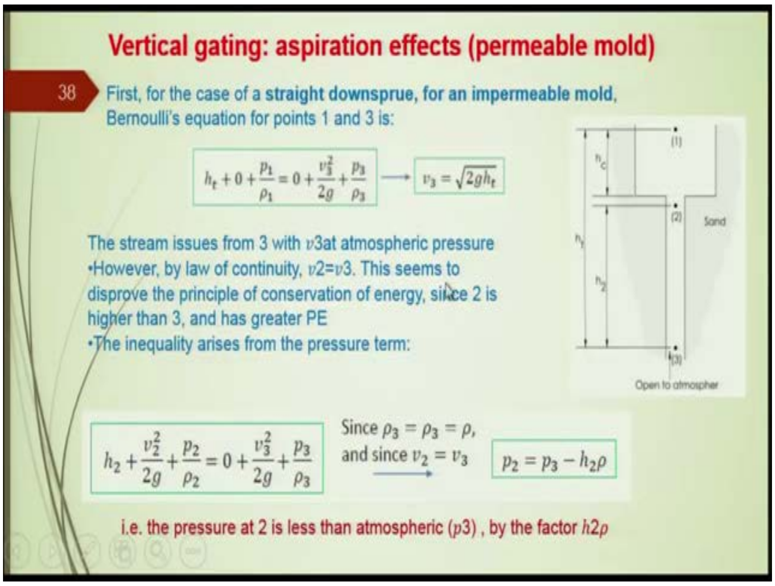

Now, let us discuss the aspiration effect in the vertical gating system. Let us talk about the permeable mold . There are molds which are not permeable meaning that through that mold the gas cannot actually escape.

So, this is the permeability. Now, we are talking about the permeable mould that is the sand mold let us say. So, in the sand mould the aspiration effect is the one where the air from the atmosphere gets mixed with the molten metal.

So, what will happen is as you understand that gas bubble will be formed. It may not be able to escape because the metal gets solidified and that gas bubble or the air bubble will be entrapped within the casting that will actually create the casting defects. We will discuss that later , i.e. what kind of casting defects those bubbles can create . So, that is called the aspiration.

How the aspiration takes place, let us see. Let us do an analysis herefor vertical gating that we have already seen. First, for the case of straight down sprue. Let us say this is a straight cylindrical for an impermeable mold. We will apply Bernoulli's equation for points 1 and 3 again. Point 1 is the entry point to the mould cavity and point 3 is the pouring point.

Now, h_t will be the height between points 1 and 3. At point 1, the height is h_t plus 0 since there is no velocity at level 1, plus $\frac{p_1}{\rho_1}$. So, the summation of these three energy heads will be the following: $h_t + 0 + \frac{p_1}{\rho_1}$

At level 3, the height is 0, v_3 is the flow velocity here divided by 2g plus $\frac{p_3}{\rho_3}$; p_3 is the pressure here at this point 3. So, the summation of these three energy heads will be the following: $0 + \frac{v_3^2}{2g} + \frac{p_3}{\rho_3}$. From here we can find out the v_3, as: $v_3 = \sqrt{2gh_t}$.

Now, the stream issues from 3 with the flow velocity v_3 at the atmospheric pressure from here. However, by law of continuity v_2 is equal to v_3. Law of continuity says that velocity at any two points in the flow is equal. This seems to disprove the principle of conservation of energy since point 2 is located at a higher level than point 3 and has the greater potential energy.

Now, the inequality arises from the pressure term. If we apply Bernoulli's equation between points 2 and 3, we will get $h_2 + \frac{v_2^2}{2g} + \frac{p_2}{\rho_2} = 0 + \frac{v_3^2}{2g} + \frac{p_3}{\rho_3}$.

Now, ρ_2 is equal to ρ_3 . Since v_2 is equal to v_3, therefore, putting this values into the above equation, we can get the value of p_2 as: $p_2 = p_3 - h_2\rho$. This is a very important derivation that you have to understand.

Once again, I will repeat that we are considering the point 2 and point 3 in the vertical gating system and we can write the Bernoulli's equations with respect to these two levels in this way. Now, the ρ_2 and the ρ_3 are the density of the flow material, that is the molten metal. v_2 is equal to v_3 as per the principle of conservation of energy.

Now, point 2 is higher than point 3, but by law of continuity we said v_2 equal to v_3 but the principle of conservation of energy says that it will be not so because 2 is at higher level at than 3. Then we found out that therefore, that there is a difference in the pressure between 2 and 3 and this is equal to $p_3 - h_2\rho$. So, that means, the pressure here is less than pressure 3 by $h_2\rho$.

This is the issue that at these two points the pressure is different; that means, the pressure at 2 will be different than 3 by $h_2\rho$. The pressure at 2 is less than atmospheric pressure p_3 by the factor $h_2\rho$. Point 3 is open to atmosphere. So, this is an atmospheric pressure, and point 2 is inside the molten material. So, as we said that p_2 is less than p_3 by this . So, it will be less than the $h_2\rho$; h_2 will be this height from 2 to 3.

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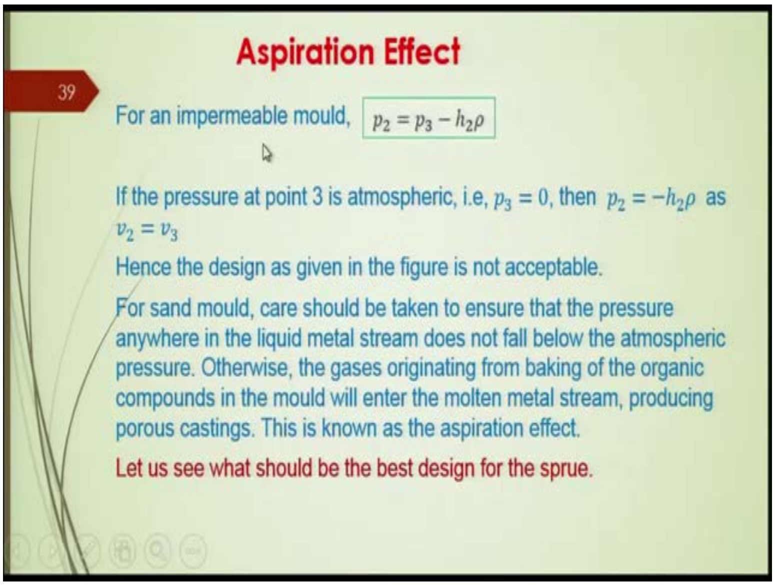

Now, for an impermeable mould this is the case if the pressure at point 3 is atmospheric pressure then p_3 is equal to 0. Then p_2 is equal to $p_2 = -h_2\rho$ because the v_3 is equal to v_2 as per the law of continuity.

Therefore, since p_3 is equal to 0 because the pressure at p_3 is atmospheric, then from this equation we will have the $p_2 = -h_2\rho$ because the v_2 is equal to v_3. Hence the design as given in the figure is not acceptable. What is not acceptable? This one because here we are saying, that these two are of at different level 2 and 3.

Here what will happen is that the aspiration will take place. For sand mould care should be taken to ensure that the pressure anywhere in the liquid metal stream does not fall below the atmospheric pressure. Let us see, why this aspiration? Because this point is at atmospheric pressure and at this point the pressure becomes less than the atmospheric pressure by $h_2\rho$.

Therefore, the air will go through and it will come to that point 2 because there the pressure is less and that is what we are calling as the aspiration; that the air from the atmosphere goes in to the molten metal . Once again, for sand mould care should be taken to ensure that the pressure anywhere in the liquid metal stream does not fall below the atmospheric pressure.

Otherwise, the gases originating from baking of the organic compounds in the mould will enter the molten metal stream producing porous casting. This is known as the aspiration effect. Now, once again I am telling you where the gases are originated from. We have made the mould and we have those additives to allow the expansion of the sand mould. So, those additives including the wood dust, organic compounds they will actually burn, and produce gas.

That gas has to be escaped. For that we actually make different kind of small holes for taking out that gas, but if that gas remains within the molten metal, in that case there will be gas bubbles inside the molten metal and there will be casting defects in the final casting.

So, what is not desirable is that p_2 should not be less than atmospheric pressure p_3 by this amount $h_2\rho$. So, let us see what should be the best design for the sprue. Right now, what we are saying is that the design of the sprue is this; we have assumed that this cylindrical.

And, if it is that, in that case, we have seen that the pressure at this point within the molten metal is becoming less than the atmospheric pressure. And, this is not acceptable because in that case the air can penetrate, and it can spoil the casting. So, let us see what should be the best design for the sprue.

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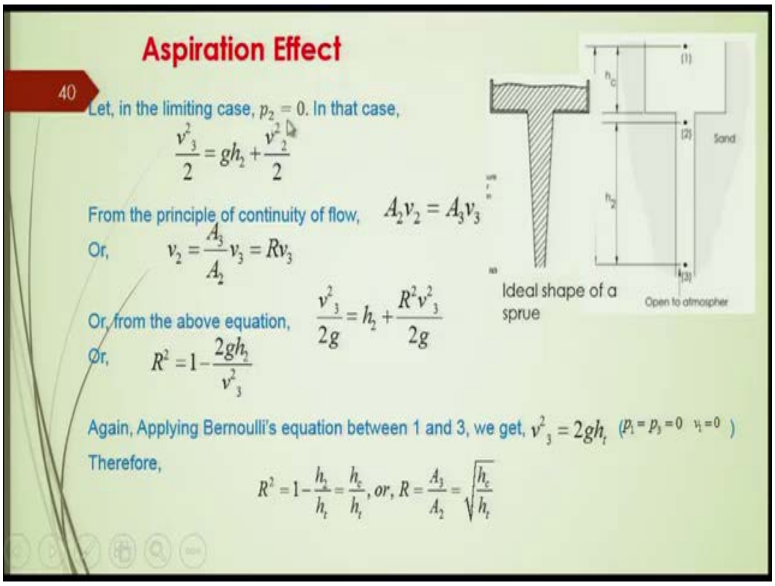

Now, in the limiting case *p2* is equal to 0 in that case $\frac{v_3^{\ 2}}{2} = gh_2 + \frac{v_2^{\ 2}}{2}$ if we compare levels 2 and 3 applying Bernoulli's equation, and putting the value $p_2 = 0$.

This I am not repeating because here are the points 2 and 3, and these equations are obtained by applying Bernoulli's law. Here if you put the value $p_2 = 0$ for limiting case then we will have this equation. From the principle of continuity of the flow $A_2v_2 = A_3v_3$, this is known. This is the principle of continuity of the flow.

Now, v_2 from here is equal to $v_2 = \frac{A_3}{A_2}v_3$ and let us assume that $\frac{A_3}{A_2} = R$. Therefore, $v_2 = \frac{A_3}{A_2}v_3 = Rv_3$. So, from the above equation what we will get is that $\frac{v_3^{\ 2}}{2g} = h_2 + \frac{R^2v_3^{\ 2}}{2g}$ So, we will get that from here by putting the value of the R.

Therefore, from here we can get the value of R^2 as: $R^2 = 1 - \frac{2gh}{v_3^{\ 2}}$. Again, applying Bernoulli's equation between 1 and 3, we are getting $v_3^{\ 2} = 2gh_t$. This derivation we have discussed earlier.

So, we are putting this value considering the Bernoulli's equation at 1 and 3 that $v_3^2 = 2gh_t$. This is by considering $p_1 = p_3 = 0; v_1 = 0$. So, $v_1 = 0$;I am once again repeating that this is the level of the molten material, which is kept constant.

So, from here this R^2 can be equal to this or from here R is equal to $\frac{A_3}{A_2}$ which is equal to $\sqrt{\frac{h_c}{h_t}}$; h_c is the distance from the level 1 till the entry of the sprue and h_t is the complete distance or the distance between the level 1 and 3. So, what we are getting is that R which is the $\frac{A_3}{A_2}$ is equal to $\sqrt{\frac{h_c}{h_t}}$. Material related to this we will discuss in our next session of discussion.

Thank you.