Manufacturing Processes – Casting and Joining
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Lecture – 12
Various Casting Processes and Cost Analysis

Hello and welcome to the course on Manufacturing Processes Casting and Joining. Right now we are discussing casting processes and I remind you that in my earlier lecture session, I was discussing the die casting. And you were told that, die casting the name came because the molds are called the dies; this is same as the permanent mold casting, I mean to say the molds. And it is made of metal, two halves are there; one is movable, another is the permanent.

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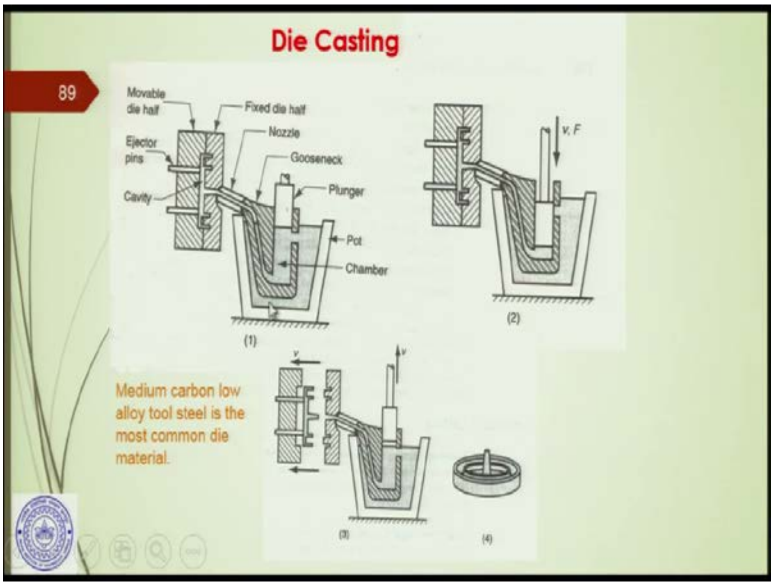

If you see the slide here, these are the two parts; one is fixed, one is movable. And there are ejector pins to facilitate the ejection of the part, which is here, which will be formed here. After the molten metal is solidified, this is the cavity. Now, when the two halves are joined together, the cavity is formed and the molten metal can be forced into this cavity; normally it is pumped from at a high pressure from chamber .

Inside the pot, there is the molten metal; metal is melted and with the help of a plunger, it is forced into this mold cavity. And as we said, this can be up to a pressure of 350 mega Pascal, so this is a very high pressure. Now, here you can see that this is the second stage, where the plunger has gone to this position; that means certain amount of liquid metal has been forced into this mold cavity. After that it is kept at that pressure for sometimes till this cavity, till this molten metal in the cavity is solidified.

Then these two halves are separated. The movable die goes to this side and with the help of the ejector pins, the casting is taken out from the mold cavity. Here you can see the movable die, half of the die and it is actually going to the left side and while doing so the ejector pin will actually eject the casting. And the casting, of course, will come along with the gating system.

So, they have to be segregated, they have to be cut off. Now, in this case, what is shown here is the casting without the gating system because it is the fixed die and the metal die. Here you can see that there is no gating system as it is attached to this casting, and the final product you can see from here, this is the final product.

In this case, when the movable part is taken away then the plunger goes up and ready for the next stroke, that is for pressurizing the molten metal. This is the entire cycle shown in these three steps.

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And here it is written what I have said already. In case of the hot chamber die casting, metal is melted in a container and a piston injects liquid metal under the high pressure into the die. The high production rate up to 500 parts per hour, this is not uncommon.

Applications are limited to low melting point metals that do not chemically attack plunger and other mechanical components. As you understand that, otherwise melting metal will be difficult. It is normally used for low melting point metal. And the metal should not react with the plunger chemically; otherwise, plunger will be worn out and very often plunger has to be changed and therefore, the setup is expensive.

In case the plunger has to be replaced frequently, in that case the cost of the casting will be very high; it will be increased. Casting metals are normally the low melting point metals as we said - zinc, tin, lead and magnesium. Here of course, the cast iron is not used; because of the very high melting temperature.

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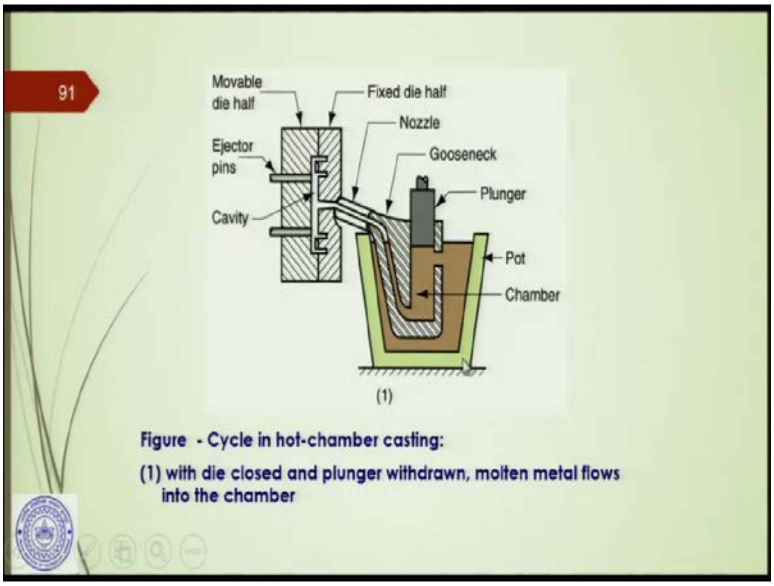

Here is a better picture; this is showing how the mould is made ready for the molten metal to move in. Cycle in hot chamber casting; with die closed and plunger withdrawn, molten metal flows into the chamber.

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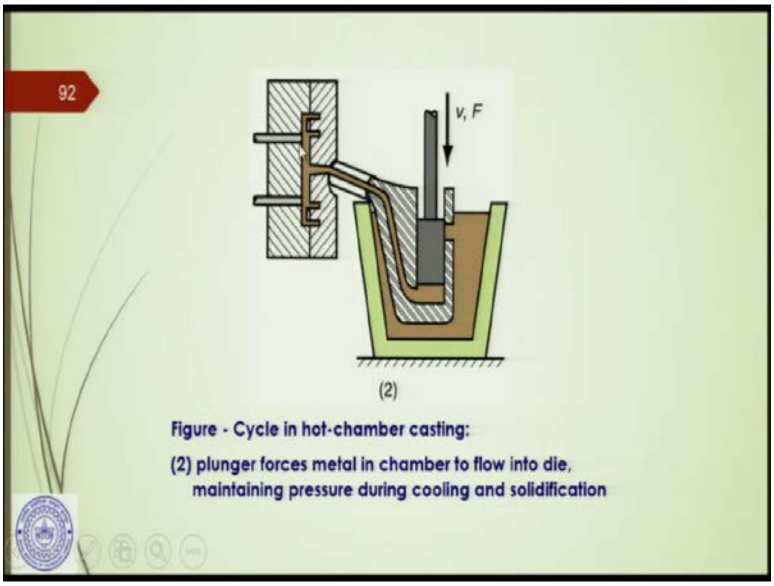

Cycle in hot chamber casting - continuing plunger forces metal in chamber to flow into the die, maintaining pressure during the cooling and the solidification. What is said here is that the die is closed, and plunger withdrawn, molten metal flows into the chamber.

As it is going up, the molten metal is filling up the chamber. In the next cycle, the plunger comes down and it is forcing that metal, which is in the chamber molten metal to go to this cavity, to fill up the cavity.

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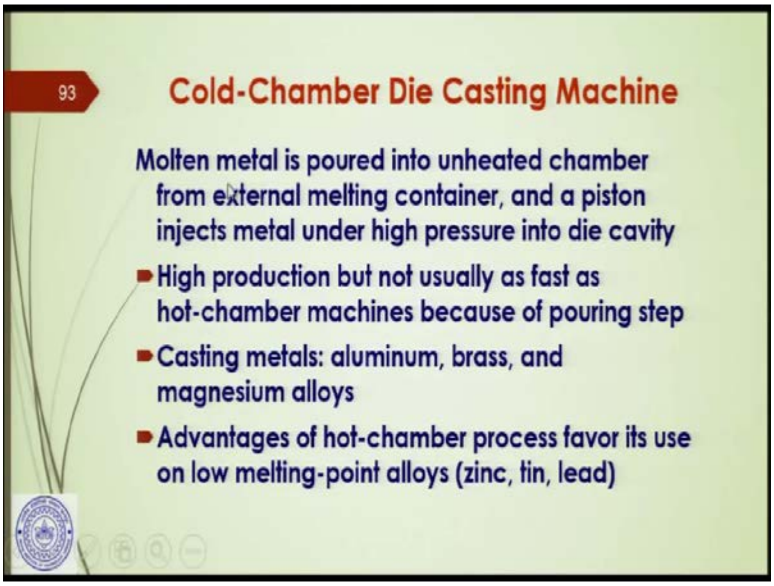

Now, molten metal is poured into the unheated chamber, this is the cold chamber; we have talked about the hot chamber, when it is heated up. And when it is cold chamber, molten metal is poured into the unheated chamber from the external melting container. And a piston injects metal under high pressure into the die cavity.

High production but not usually as fast as hot-chamber machines because of pouring step. Here the mold is cold, that is not heated up. So, the process becomes little slower, because of the steps. Casting metals are aluminium, brass, and magnesium alloys. And the advantages of hot-chamber process favor its use on the low melting point alloys, zinc, tin, lead.

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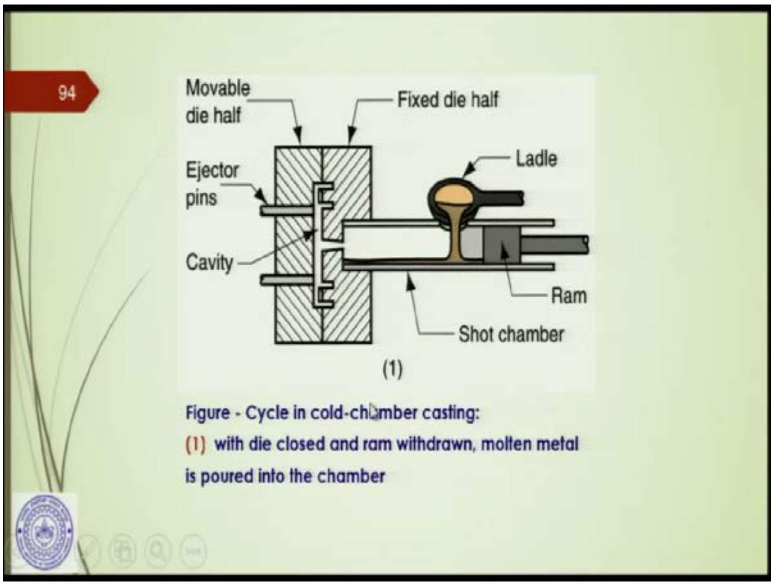

Here are the cycles in the cold chamber casting; this is the fixed die, and themoveable die half, like in the case of the hot chamber. But here this is absolutely different as you can see.

This is not heated up and this is the shot chamber, where with the help of a ladle the molten metal is poured. Then there is a ram which moves in and forces the molten metal to enter into the cavity. With die closed and ram withdrawn, molten metal is poured into the chamber. In earlier case it was drawn to the chamber, but here it is poured.

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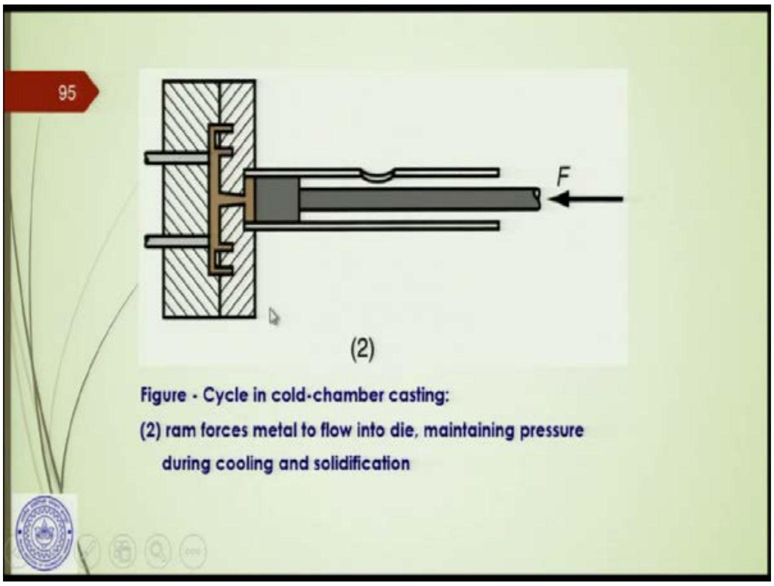

Cycle in cold chamber - second cycle is the ram forces metal to flow into the die; maintaining pressure during the cooling and the solidification. So, it will stay like this for sometimes till the molten metal gets solidified. Here also you can see that ejector pins and as it moves towards the left, ejector pin will help in removing the casting from the cavity.

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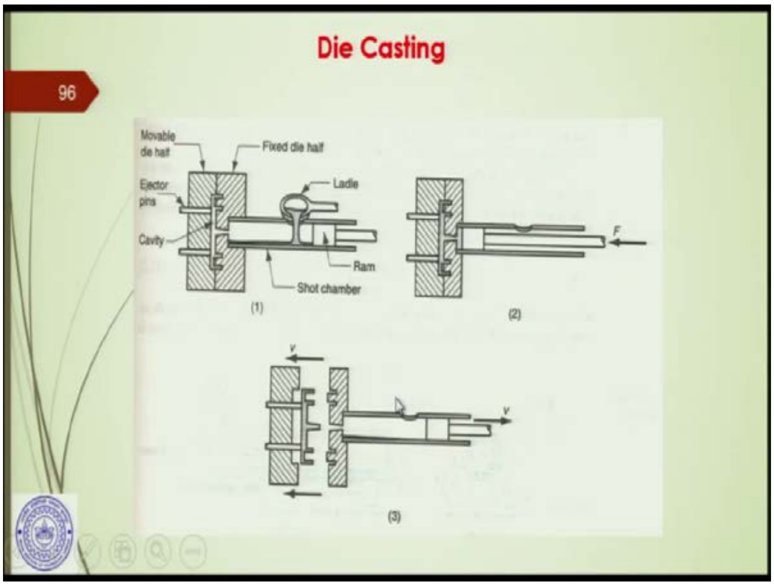

Here all of those three are together, the same as we have seen earlier.

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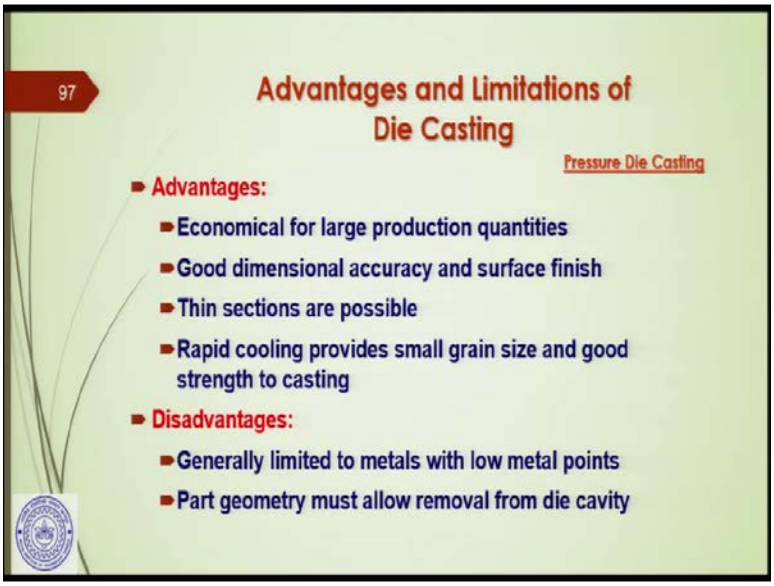

Now, the advantages and the limitations of die casting are the following. Advantages are the economical for large production quantities, good dimensional accuracy, and surface finish; because it is the permanent mold casting. Its characteristic feature I told you earlier of the permanent mold casting.

Thin sections are possible; rapid cooling provides small grain size and good strength to casting. This remains the same as in case of the permanent mold casting; here also we have the metal mold. So, the cooling will be rapid, and the grain structure will be smaller. The strength will be high.

But the die casting disadvantages are that they are generally limited to metals with low melting points. Part geometry must allow removal from the die cavity. Therefore, you cannot have very intricate shape of the part.

Otherwise, once again I am repeating that, it will not be able to be taken out from the cavity after the casting is made or two halves cannot be separated out . There is a small video clip again for the pressure die casting and I would like to show you, so that you could have an idea about how this pressure die casting works in practice.

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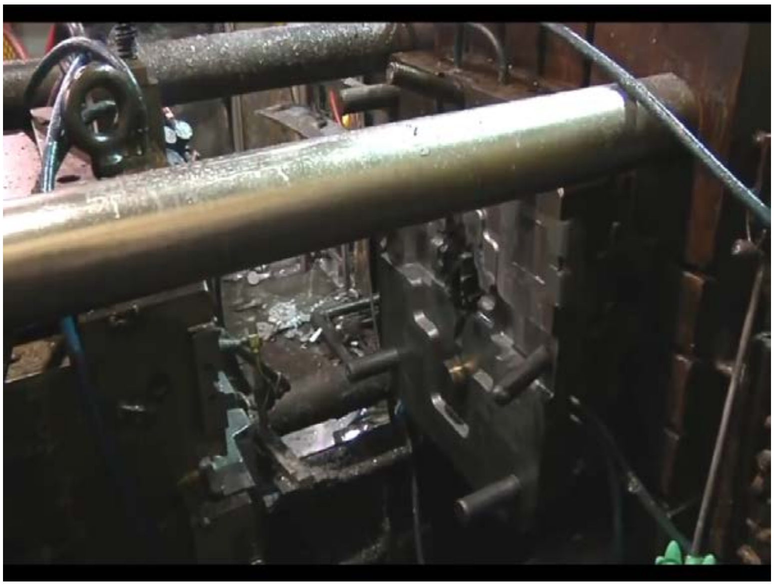

In the die casting process, the reusable steel dies or molds are preheated and coated with a die release agent to lubricate and protect the surfaces of the dies before each use.

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Next pre-measured amounts of molten metal are injected into the dies at extremely high pressures.

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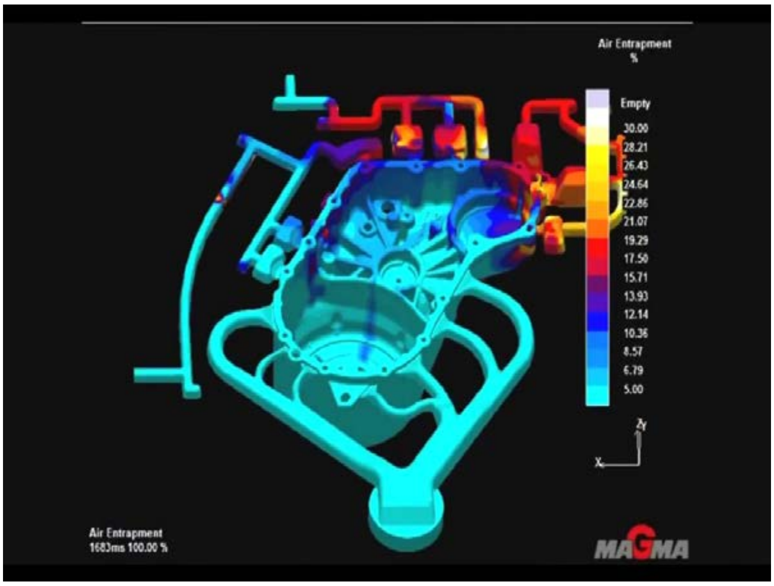

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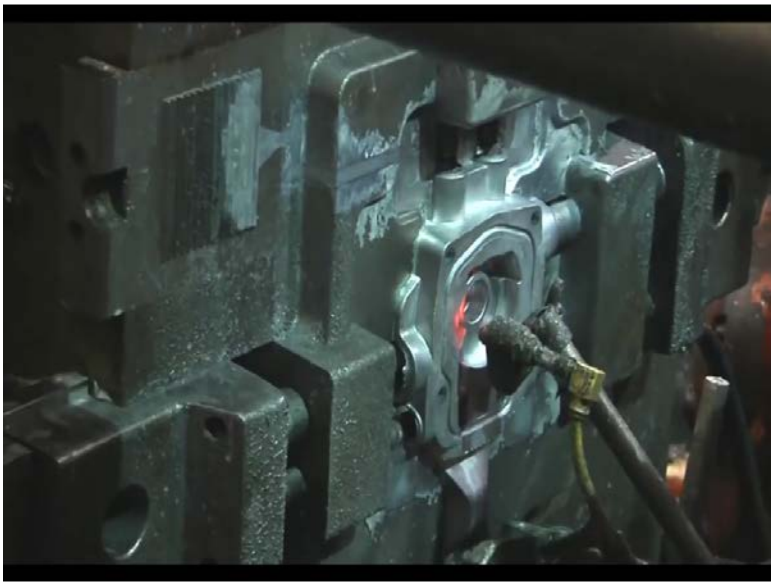

The newly formed part is then removed from the dies and the cycle is repeated after the die cools.

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The dies must be stronger than those used in the permanent mold process, to withstand the high pressure injections.

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These dies can be engineered to produce complex shapes with a high degree of accuracy and repeatability.

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Dies can be used many thousands of times, so the die casting process is used when very large quantities are needed.

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Die cast parts can be sharply defined with smooth or textured surfaces and are suitable for a wide variety of finishes.

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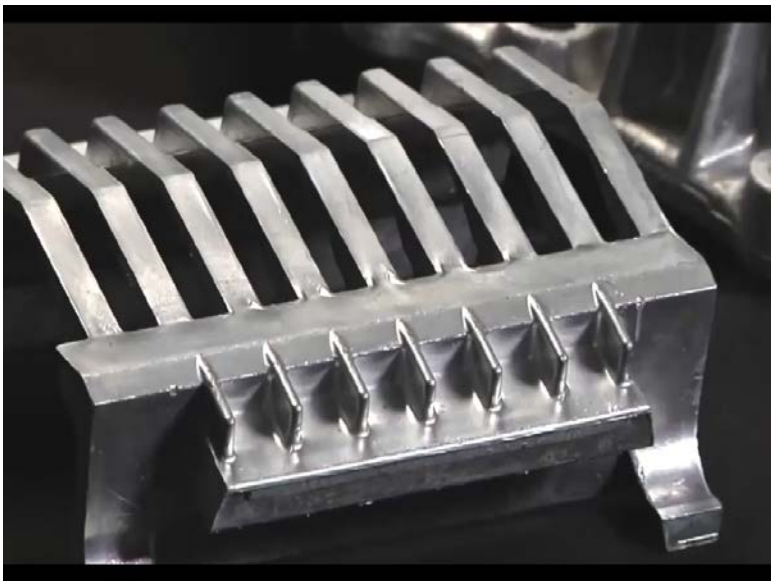

This high pressure process produces a dense, fine grained surface structure with a wide range of physical and mechanical properties, such as fatigue strength.

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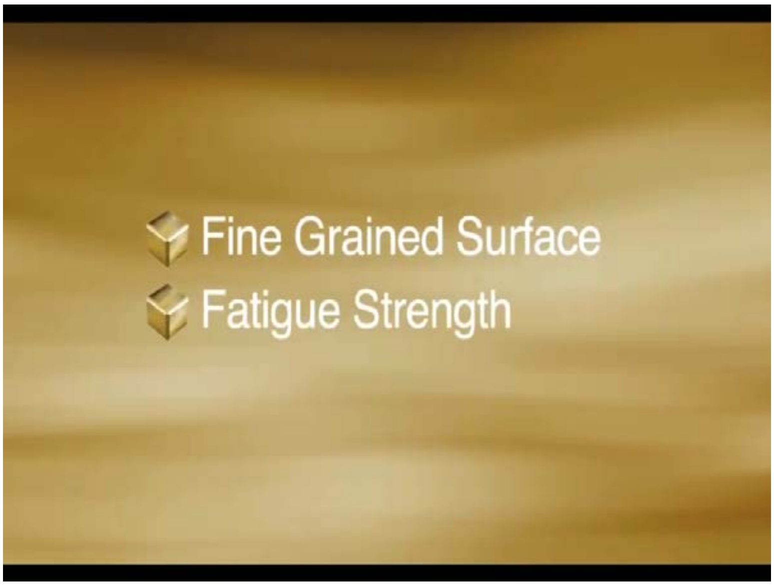

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As with the other casting processes, choosing the alloys is to be used for this process depends on their physical and mechanical properties.

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The ones that are often used for die casting are zinc, aluminium, magnesium and brass alloys. So, this is a small clip through which you could see how intricate shapes and how good accuracy parts can be produced, castings can be produced in the die casting. Either it is a hot chamber, or it is a cold chamber process.

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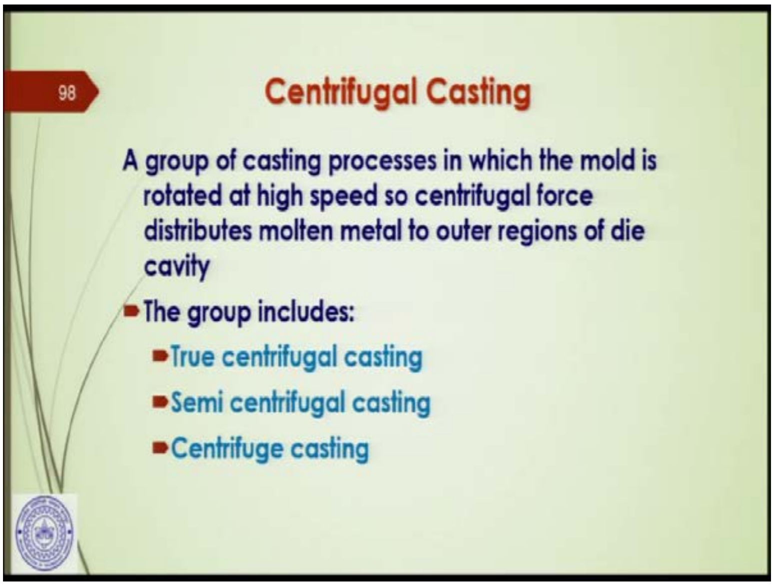

Now, there is another method of the casting which is also very important, and which is also very widely used, this is called a centrifugal casting. The name itself says that there is a certain centrifugal force that is used for forcing the metal into the cavity. A group of casting processes in which the mold is rotated at high speed, so centrifugal force distributes molten metal to outer region of the die cavity.

The group includes true centrifugal casting, semi centrifugal casting, centrifuge casting. These are the three different kind of casting processes; in all of them the centrifugal force is used. As you understand that when the centrifugal force is used, cavity or the mold rotates.

And as the metal is forced, by centrifugal force it will be distributed around the periphery of this inside rotating cavity or the mold . Normally the cylindrical type of castings are produced.

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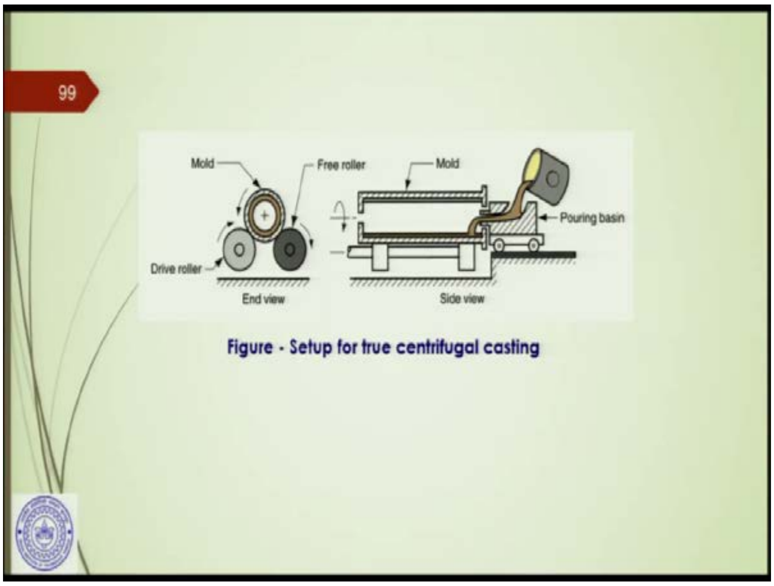

Here is the setup. For giving you an idea, this is the side view. What we have here in the centrifugal casting is the mold; as you can see that this is a cylindrical mold with a cavity inside. And this is rotated by the drive roller and this is the mold shown in sectional view.

If you take the section, like this along with the rollers, it is shown here; this is the free roller and this roller rotates, it drives, and this is a supporting roller or the free roller.

From here, there is a pouring basin and through the pouring basin and the ladle, the molten metal is poured inside, while it is rotating; therefore, as soon as it gets into the mold cavity, it gets distributed along the periphery, and the molten metal is allowed to solidify, while rotating and then the final casting is taken out after it is solidified.

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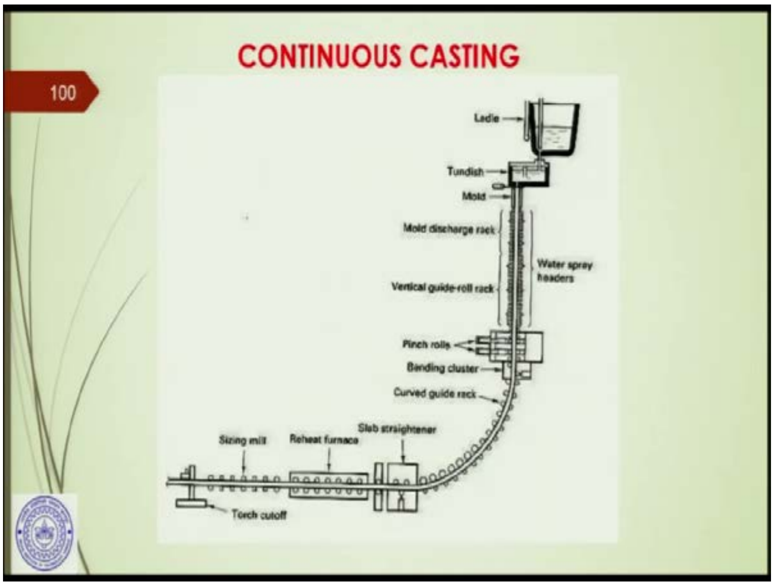

This is another type of casting, which is popularly used when we need very long rods for example or railway lines for example, this is a continuous casting. Here we have the ladle, where the metal is melted, and the molten metal is kept here.

Molten metal is fed to the tundish, and it goes through the mold; this is the mold at the exit of the tundish. This is a kind of pot where the molten metal can be fed. This goes through the mold and then it goes through the discharge rack. While it goes through the discharge rack, there are water spray headers here.

So, water is spread to cool down and here at the vertical guide roll racks, so that it can assist the metal to go through. The pinch rolls are there and the bending cluster, so that it can be bent. There is a slab straightener, this will straighten up the entire rod or whichever form you are getting the casting; then it will go through, it may go through some kind of heat treatment.

This is the reheating furnace. This is the sizing mill and the torch cut off into sizes. This is a continuously coming out from this setup. And it will make very long rods or rails as I said, and it can be cut off into pieces as per the requirement. This is also a very high production process, and this is widely used in practice.

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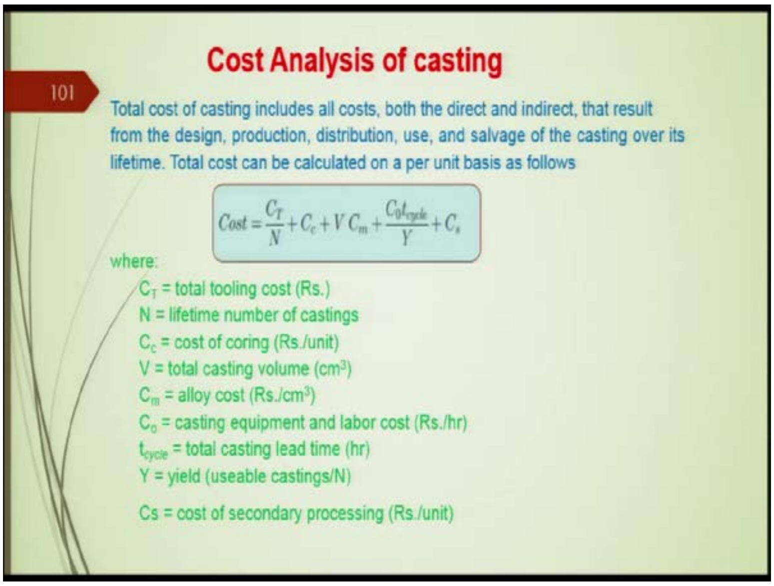

Now, let us see in brief how the cost can be analysed. Total cost of casting includes all costs, both the direct and indirect that result from the design, production, distribution, use and the salvage of the casting over its lifetime. The total cost can be calculated on a per unit basis; per unit basis means per casting.

This cost is equal to $\frac{C_T}{N}$. Now, the C_T is the total tooling cost in rupees and N is the lifetime number of castings ; how many castings you are making plus C_c, C_c is the cost of coring; in case there is a core required for the internal cavities in the casting that is rupees per unit; plus VC_m; V is the total casting volume in cm^3 into the alloy cost, that alloy cost will be rupees per cm^3.

Plus $\left(\frac{C_0 t_{cycle}}{Y}\right)$; C_0 is the casting equipment and the labor cost , t_{cycle} is the total cycle lead time, this is in hour divided by the yield, that is the usable castings which you are gettingin number. Now, what does it mean? That there are castings which will be actually rejected, because of different kinds of defects that we will be discussing now. Now, we are not considering that; we are considering only the usable castings, i.e. yield.

This Y is that usable cast, number of usable castings. Plus C_s, C_s is the cost of secondary processing; secondary processing means, I told you already that, after you get the casting, you need to segregate the system that is attached to that, that means the gating system.

And you have to clean it up by the sandblasting or the metal ball blasting and then you have to machine to get the allowances removed and get the final dimensions and the accuracy. All those things will lead to the cost of the secondary processing that will be rupees per unit.

Once again, the cost per casting will include these five components. C_T is the total tooling cost, C_c is the cost of coring, C_m is the alloy cost, C_0 is the casting equipment and the labor cost, and C_s is the cost of secondary processing. These are the five basic costs which are involved in the total cost per casting, . And of course, they will be suitably multiplied or divided by the numbers as shown here.

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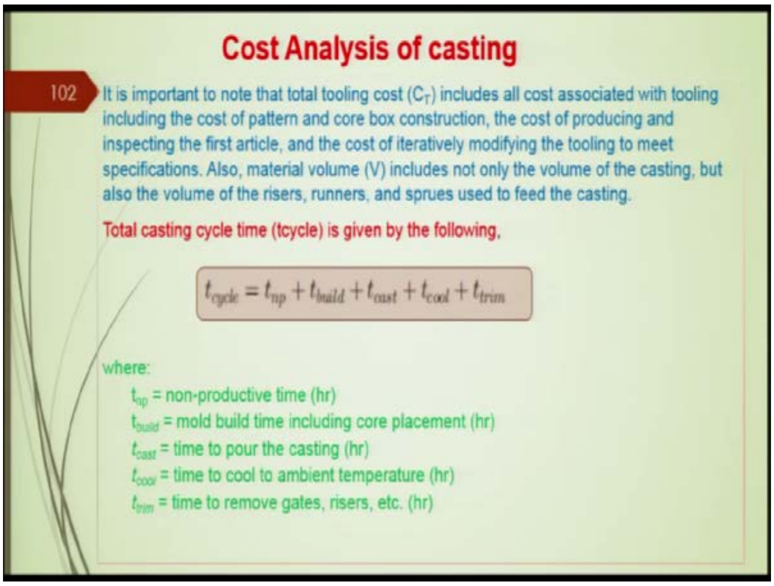

Now, the cost. It is important to note that the total tooling cost C_T includes all costs associated with the tooling that includes the cost of pattern and the core box.

So, you understand that this is the tooling also; this falls under the tooling, core box is required it is like flask. You need to have the core box to make the core. That is also included in this C_T, total tooling cost. The cost of producing and inspecting the first article and the cost of iteratively modifying the tooling to meet specifications.

Also, material volume includes not only the volume of the casting; but also the volume of the risers, runners and the sprues used to feed the casting. This has to be also kept in mind that, when we are making, for example, this volume this is not only the volume of the casting, but volume of the gating system and all others that are included here, i.e. risers, runners and sprues.

Similarly, that C_T we have said, this C_T includes the cost associated with the tooling, ; that is including the cost of pattern, core box construction, producing and inspecting the first article, cost of iteratively modifying the tooling to meet the specification and so on. All those costs cannot be neglected, and they have to be included in the tooling cost, that is very important; otherwise, the cost of one casting cannot be properly or accurately calculated.

Now, the total casting cycle time is given by the following; it also has the five different cycles, five different times, which are included in that total cycle time. And these are one which is t_{np}; t_{np} is the non-productive time in hour. By non-productive time, I will remind you in the machining, it is equivalent to idle time, when the machining process is not going on or in this case, when the casting process is not; you are making the arrangement for making the casting.

So, this is the non-productive time, when the casting process is not made. Second is t_{build}; t_{build} is the mold build time including core placement, that is also in hour. Then the third one is the t_{cast}; t_{cast} is the time to pour the casting that is in hour, this is the third one. The fourth one is the t_{cool}; this is the time to cool to ambient temperature, the solidification time, that how it is coming out to coming to the ambient temperature, room temperature.

And the trimming time; time to remove the gates, risers, etc. So, all these times have to be considered while calculating the time it takes for making one cycle.

Why it is important that, cycle time is very important to find out the production rate; $\left(\frac{1}{t_{cycle}}\right)$ will always give you the production rate, more the cycle time less will be the production rate. It is inversely proportional. If the cycle time is fast, then more metal castings can be made in unit time.

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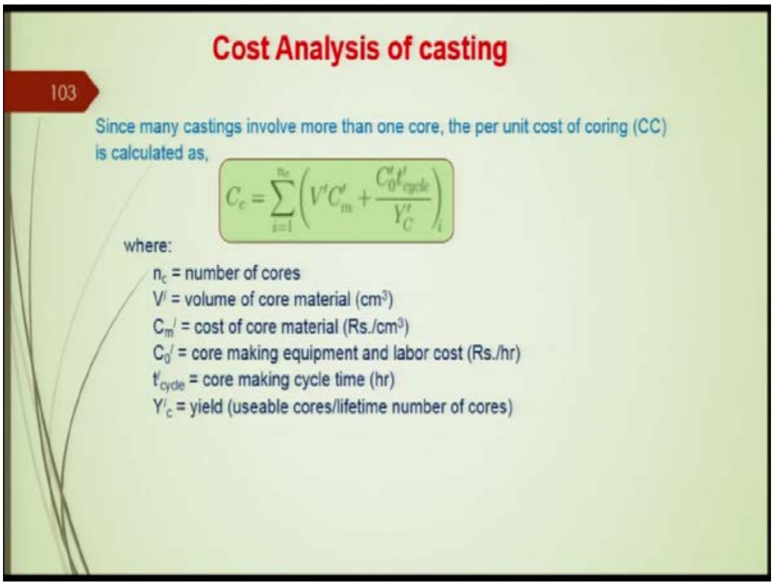

Next in the cost analysis is the following. Since many castings involve more than one core, the per unit cost of coring is calculated as this. Here one thing that you have to consider is the cost you are incurring in the core as well. How to find out that separately? This is $\sum_{i=1}^{n_e} \left(V'C'_m + \frac{C'_0 t'_{cycle}}{Y'_c} \right)_i$.

V' is the volume of core material, this is in cm^3 and C'_m is the cost of core material, this is in $\frac{Rs}{cm^3}$. This is similar to what we have seen earlier, when you are calculating the cost per casting. C'_0 is the core making equipment and the labor cost, this is also $\left(\frac{Rs}{hour} \right)$.

t'_{cycle} is core making cycle time, Y'_c is the yield; that means how many cores you are making, which are usable per lifetime number of cores. Out of all cores that you have made, how many cores are usable - that is the number, that is the yield.

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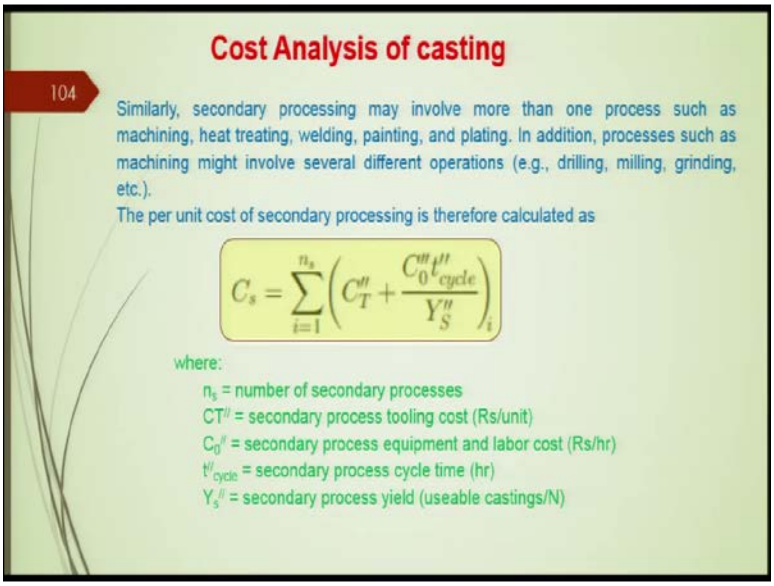

Similarly, secondary processing may involve more than one process such as machining, heat treating, welding, painting and plating etcetera. In addition, processes such as machining might involve several different operations drilling, milling, grinding, etcetera.

All those complicated phenomena have to be considered; because every time you are going through this process one or more of those processes, you are incurring cost. And if you are not considering all the costs, then the total cost cannot be accurately found out.

Now, the per unit cost of secondary processing is therefore, calculated as the C_s which is the secondary cost of the secondary processing; this is equal to $\sum_{i=1}^{n_s} \left(C_T'' + \frac{C_0'' t_{cycle}''}{Y_s''} \right)_i$, n_s is the number of secondary processes. Now, we said that secondary processes can be several machining, heat treatment, welding painting, plating.

This is 1 to n_s number of secondary processes; C_T'' is a secondary process tooling cost, this is in rupees per unit c. C_0'' is secondary process equipment and the labor cost, this is $C_0'' t_{cycle}''$, that is the secondary process cycle time.

Y_s'' is secondary process yield. This is similar to one that we have just now discussed; this is the unit work, per unit of the coring. This is the cost per unit of the casting. This one is simpler than the one that we are showing for the per casting.

Because in casting, the cores and all other things are involved there and here we are only making the core. Therefore, this per unit cost of the coring will be easier to find out or simpler to find out. And this is also similar to the one that we have seen for the core as I said. Once again, this is the per unit cost of the secondary processing which may be as we said, machining or heat treatment or welding or painting or similar such operation.

n_s is how many numbers we are considering. And we are summing up the secondary process tooling cost plus the equipment and the labor cost into the cycle time divided by the secondary process yield.

That means, these are the usable costing per *n*, per number; that means how many castings can be used and we are not considering those which are rejected. The rest of the material in this casting section we will discuss in our next session.

Thank you for your attention.