Fundamentals of Materials Processing (Part–1)
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Lecture Number 02
Solidification (Casting)

Okay, so we are now into second lecture and today we will start with 'solidification'. So as I said, in this particular course we are covering solidification and powder processing. So this is the solidification part. What is 'solidification'? Or basically why is, let us start with why science of solidification so important?

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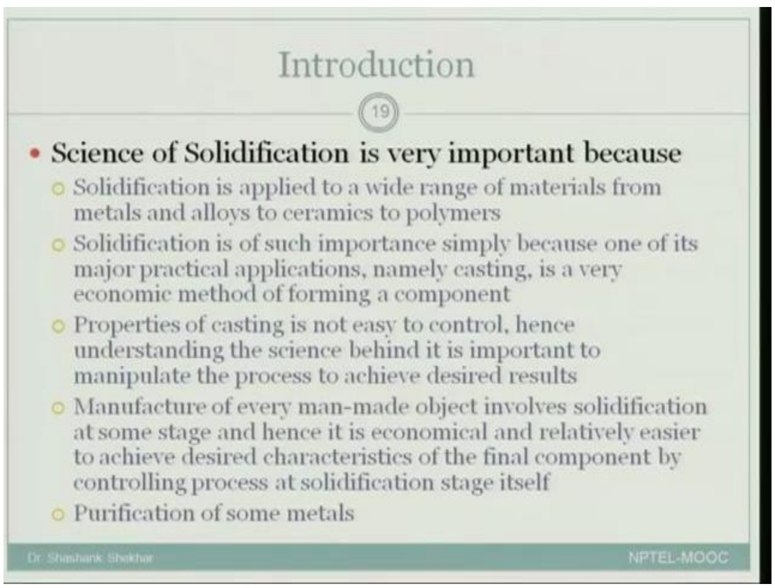

Solidification is applied to a wide variety of materials; from metals and alloys to ceramics and to polymers. Although we will be here (concen) concentrating only on crystallography or crystalline materials; for example metals, alloys and ceramics, not the polymer part but the solids. The solidification can also be used for polymers as well as glasses. Solidification is of such importance, simply because one of its major practical applications, which is casting is a very economical method of forming components.

Now you would have seen the metal, so many metal components or metal parts in your home. Now at some stage, that particular metal component must have been in a molten stage, it must have been in a bullet form after that, and then given different shapes, it may be, it may become the fan-blade, or it may become automobile component and so on so forth. Now properties of casting is not so easy to control, okay, hence understanding the science behind it is important. And, so this is another very important reason why we must understand the science because you cannot easily manipulate the casting process, and only if you understand the science that you will be able to manipulate the process and hence be able to achieve desired results.

Now the fourth point I have already made – manufacture of every manmade object involves solidification at some stage, and hence it is economical and relatively easier to achieve desired characteristics of the component by controlling process at solidification stage itself. For example, let us consider 'macrosegregation'. Macrosegregation is a problem in casting which cannot be gotten rid of in later stages during any other kind of forming process, whether you are doing metal forming or whether you are doing powder processing, macrosegregation would exist. So, why not control this macrosegregation in the casting, in the solidification stage itself by controlling the parameters. And that will be possible only if you understand the science of solidification.

This science of solidification is also important because it has allowed us to ensure or to make purify some metals. You would be we would be looking at some examples where purification or whatever, also called as, the process is called as zoom refining is possible because we understand the process and the fundamentals properly. Some of the important processes, let us look at some of those processes which involve solidification. Like I said casting is one of the big classes, so you can have ingot casting, meaning just large chunk of metals being formed or die casting, where you will have a mould with a desired shape that you want to make, or it can be investment casting, where, which is also called as 'lost-wax casting'. And then there are something called as continuous casting, we will look at one slide for each of these.

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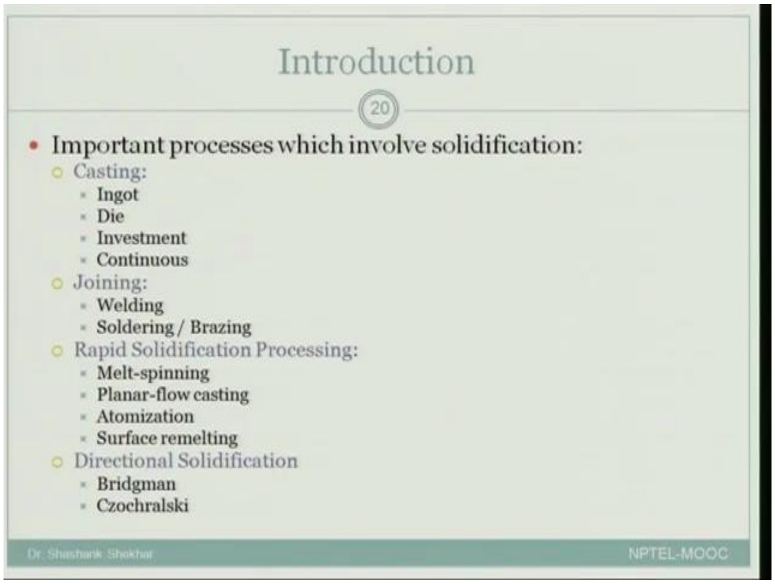

Another important place where solidification is used is joining. So, like I said, one of the example was welding. Another is welding involves melting of the base metal as well as the filler metal. Another joining process which does not involve melting of the base metal but only of the filler metal are ‘soldering’ and ‘brazing’. So these are also joining process; soldering you would know is used in electronic components; brazing you would see in small components where you have metals which have, for joining metals which do not have very high melting point.

Other than that, there are some exotic, let us say exotic processes; for example melt-spinning, planar-flow casting, atomization which is used for making powder particles for powder processing, surface remelting to get some special properties at the surface. Then, you have the directional solidification which I was talking about, which we use in turbine blades, to make single crystals, or for making single crystals for silicon (silic) single crystal, large chunks of (sili) single crystal silicon, which can then be cut into small thin wafers, which are then later used for electronic industry for making your smartphones, laptops or televisions etc.

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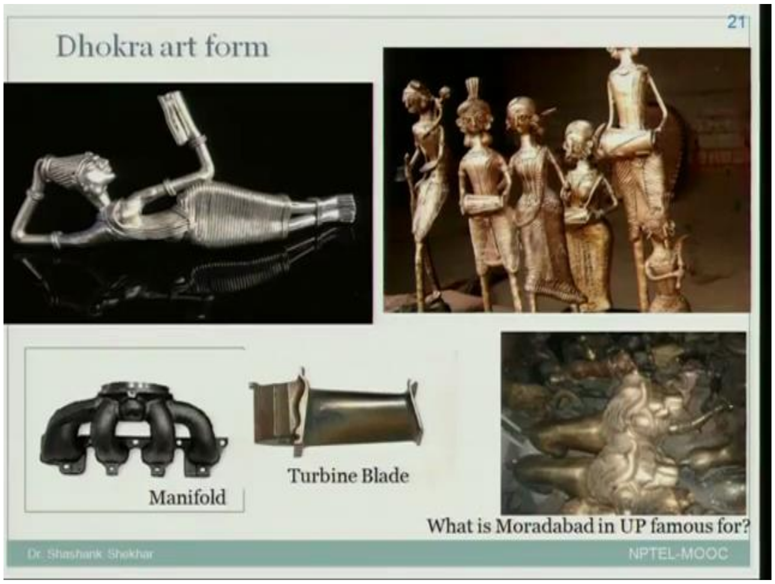

So let us again come back to the, some of the pictures that we saw earlier. So, in order to understand or appreciate solidification, let us look at two processes, casting and welding. Now I said earlier also that casting we use in decoration form, in the art form, as well as for utility form. And again I have shown you some of the pictures over here; the two top ones are the 'Dhokra' art forms, which is from the Indian culture; actually you would be glad to know that, in India we had this technology or this knowledge four thousand years back, and people were using this 'Dhokra' art form which is nothing but lost-wax form, for making sculptures like this.

And even today, I showed you the example of Moradabad where the sculptures are formed. Moradabad which is also called as the 'Peetal Nagri' or the 'Land of (Bronze) Brass, because a lot of brass sculptures were made there, and now people are, because of the rising cost of brass, people have now slowly and steadily changing to aluminum alloys, and that has again been possible only because you understand fluidity. For example, this, why were we using brass; because brass has very good fluidity. Now how to get good fluidity in aluminum alloys which is cheaper; if you know that, then you it will be desirable to switch to such materials, because it will reduce the cost. And these are again the utility things, manifolds and turbine blades.

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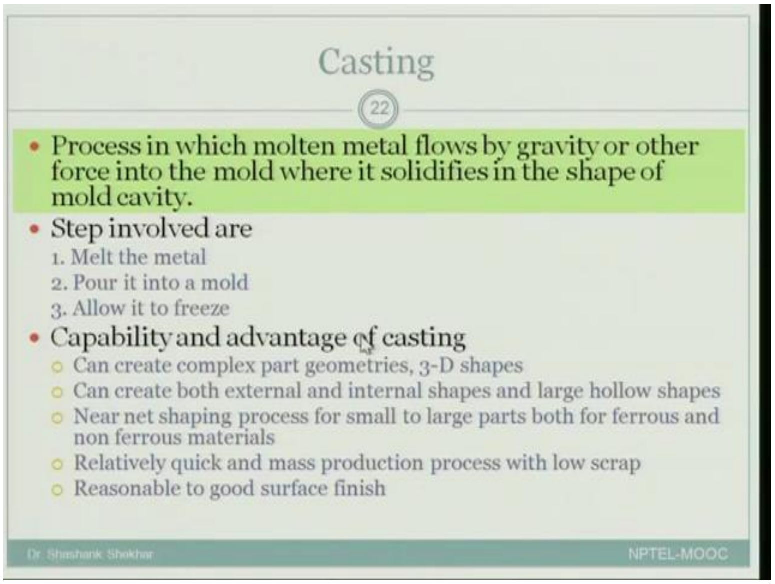

Now let us look at the definition of casting. Casting is a process in which molten metal flows by gravity or other force into the mould where it solidifies in the shape of mould cavity. You will have a mould cavity, and you pour in the liquid metal and it freezes there. So there are basically three steps involved: melt the metal, pour it into a mould, allow it to freeze, and then you get the final component or decorative form, whatever you were planning to get. Now this casting, like I said, is one of the most widely used technique which comes under solidification. So there must be some large (advan) large scale advantages of it, and it is, it can create complex part geometries. In solidification you can get very very complex shapes, 3D shapes; you can create both internal and external shapes. For example, I was talking about undercut shapes; those undercut shapes are also possible by using casting, and both solid, solid as well as large hollow shapes.

You can get near net shaping process, for small to large components, for both ferrous and non-ferrous material. So it is not that casting is only limited for ferrous metals, which is actually a very weak class of metals. You can also get non ferrous metals and we have already seen the example, the (bross) brass and the aluminum alloys. Another thing is that it is relatively quick and mass production can be done with very low scrap. So you can, because whatever scrap is there, you can put it back into the melt and then you get back or you are able to reutilize it.

And you can very quickly get, all you need is a basically, let us say wooden pattern; and if you have a wooden pattern, you would as I will show you in the next slide, you can make the mould around it, and in that mould, you can get the desired shape. So all you need to do is make a wooden pattern for whatever shape that you wanted to or that you desire to make. So it is relatively quick. And, depending on what technique you can what technique you are using, you can get very very good surface finish. Let me caution you here. When I say good surface finish, it is not always that in casting you can get good surface finish. It will depend on what particular casting process you are using.

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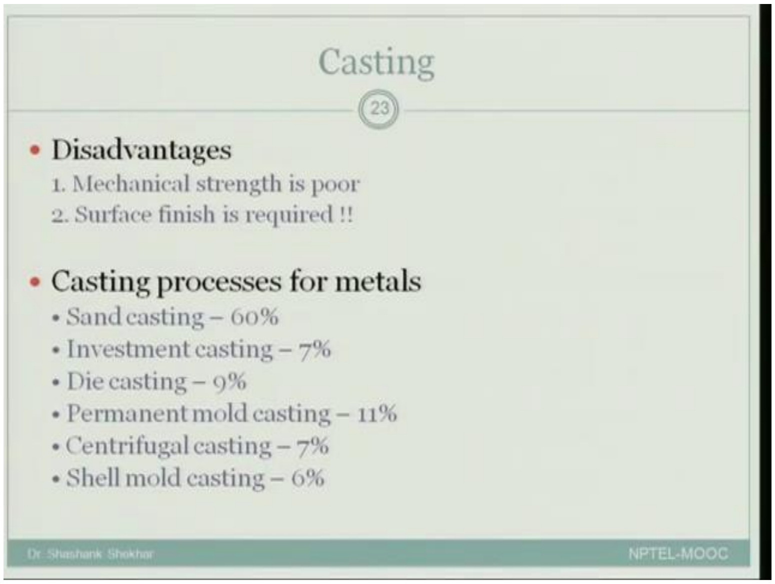

Now there are also some disadvantages of casting. One of them is mechanical strength is poor. Why is the mechanical strength poor? Because the microstructures that form, are very inhomogenous, and near the surface, like even in the first example that I showed you, near the surface you get chilled zone and inside you get some columnar zones, and therefore the microstructure is not so homogenous, and so you get not so good strength. And, like I said, surface finish is also a disadvantage because in most of the basic casting techniques, like the sand mould casting, you will require some amount of surface finish to be able to use it as a component.

So casting is again very large class of manufacturing techniques. What are the specific casting techniques? Sand casting is one of the most commonly used, in fact, if you know that the engine blocks in automobiles are made by sand casting. So sand casting composes 60 percent of all the casting that is done. Then there are some other techniques like investment casting, die casting, permanent mould casting, centrifugal casting and shell mould casting. So those were the different specific examples of casting, but we can also classify casting on a different type, or basically on what kind of mould and pattern you are using.

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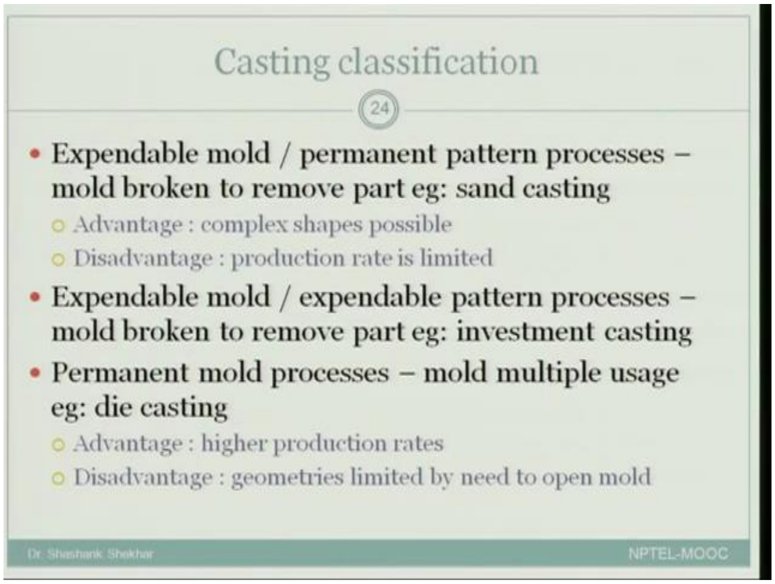

So in that way we have three different classes of casting: one is expendable mould, permanent pattern casting. In here what you have that the pattern is permanent, that is it is not being made again and again, you just use the same pattern and keep using it again and again, not you have to make it again and again. But the mould part, which is the surrounding part, that is expendable. So if for example in the the most common example is the sand casting. You take a wooden pattern, make the sand sand mould around it, and then pour the liquid metal inside it, then break it, you have a component. Then again use the same wooden pattern, put the sane mould around it, and you have another component and so on. Advantage is that you can get very complex steps using this technique, and the disadvantage is that production rate is limited because you have to make the mould again and again.

Another example, another class of casting is expendable mould, expendable pattern. So here, the pattern is also expendable, not only the mould, mould (also), in the previous example you saw, the mould was being broken, but here, even the pattern is being broken and one of the most common example is investment casting. So you take take a pattern; for example you make it from a wax, then you coat it with a slurry or a ceramic which is very hot, and then you melt the wax out of it so that the wax comes out so the pattern is gone, and then you pour the metal inside it. Now the metal has to take in the shape, the cavity shape, but then you break that (cavi) the slurry that, or the ceramic mould that was around it; so the mould is also gone and the pattern is also gone. So this is a expendable mould, expendable pattern process.

And the third one is permanent mould process. So in this process you would not even need a pattern perse; you have a permanent mould; whatever shape that you wanted to get, you will have to use that and you can pour the liquid metal directly; again take out the component, again pour the liquid metal into it and so you can get several of these components very, at a very fast rate. So yes that is the advantage, higher production rate. But, again the disadvantage is what? Since you have the permanent shape, you will now you will be limited by geometries, you cannot get any kind of geometry. So that geometry is limited and it needs to be an open mould, so that you can open it easily when the casting is completed.

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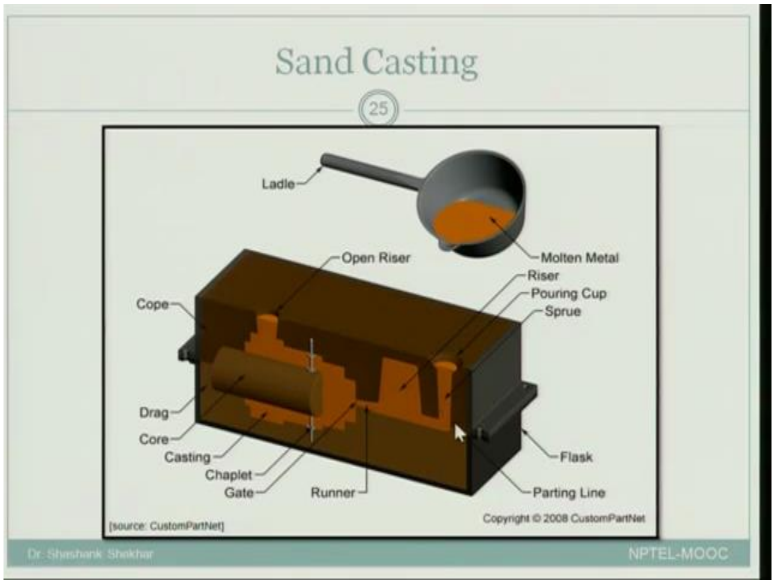

So here is a detailed drawing of sand casting. Over here, what you see is there are two [parts of the flask. On the outside what you see as this grey region, this is a flask; on the top, the top flask is called a cope, and the bottom flask is called the drag. Now in the, this orange region that you see is the hollow part where the liquid metal will get into, and this is, upto this part is your component that you want to make; and you also see there is some sand component is put in there, it is called core; meaning, for example, the component that you want, you want it to be hollow over here, so you put a core in here.

The core is also made out of nothing but sand. But this is a different kind of sand which is a little harder. We will look at some of the properties over there in next, in one of the slides, and to ensure that it remains in place, because the liquid metal may be flowing at very large speed over there and it has very large buoyancy, you put in some chaplets, which ensures that this core remains in its place.

And then there is a pouring cup, from which you pour the liquid, and then there are open riser from which the liquid will come out, otherwise the gases, the gases or the air has to come out; so that is the open riser. Apart from that, you also have what is called as a blind riser, to ensure that whatever you say light, impurities that may be there in the liquid metal, they will get trapped into this. So this, this is called a blind riser, and this is an important part of the design if you need to have good purity of the material.

So this is a simple way to end this (stand) sand casting. And , so what you look at in the browns, brown parts are the actually the sand part; and you put that sand part around the pattern and hammer it to ensure that the (ham) the pattern takes the shape or the sand takes the shape along the pattern, and runs the pattern has been formed into the sand, you take away the two flasks; the bottom part and the top flask, and then take out the pattern slowly from inside, and once the pattern has been taken out, there will be a hollow region; and then you put the bottom flask and the top flask on top of it, and into that into, when you put that together, you would be able to pour the liquid metal into it. So here, through using this pouring cup, and this liquid will go into the sprue.

Now, if you understand the science of casting, you would be able to understand that why there is a taper in this sprue. It it cannot be a parallel kind of shape for this taper, it cannot be a parallel cylinder; this, there is a taper here, and there is a reason for it. We will look at that later on. So again let us look at some examples of the sand casting. So here is an example.

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So here is the components or the shape, not the components, sorry, the shapes that have been, or the pattern which needs to be formed. So you see, there is a hollow region here, and there is a sand, like I said, this is a core, and these cores are kept here in horizontal, these two cores, and there is a vertical core over there, and this is the drag part, this is the cope part, you put it over there, and the pattern has already been taken out from it, so you put it back, and then you pour the liquid in it, and the liquid will go inside and it will fill all those hollow regions and you will get something like this. So this is the component, or this is the four components put together along with the sprue and the pouring basin, you can see over here, and when you cut it off, when you separate it off, you will get these four components, casting which is obtained from the above mould.

Now sand casting, like I said is a very commonly used method; so there must be some advantages to it. So let us quickly take a look at some of the advantages that we have in sand casting; it is relatively cheap, it has (suffi) it is sufficiently refractory even for steel foundry use. So sand, sand has such a high melting point; you can use it as a refractory even for melting of steel. So this is another very big advantage for sand casting; so even very high melting material like steel can be easily melted and given shapes using sand casting. But, it is not that sand casting has only advantages, it also had some (dis) has some disadvantages. It has various, various heat treatments may have to be applied to relieve stresses from the initial cooling and to add hardness.

Once you do sand casting, because of the stresses that are generated onto the surface, you may have to apply some additional heat treatments, after the casting process is done, so that the stresses are relieved. If the, if you do not release the stresses, then the component may have very poor properties, specially the mechanical properties may become very poor. So, additional heat treatments may be required whenever you are doing sand casting. When we are doing casting, another disadvantage is when we are doing casting with metals like iron or lead, which are very very heavy metals, then on top of the cope, you need to put in some heavy material, or heavy weight. Why is that? Because the buoyancy of these metals may cause the cope or the top part of the mould to start floating, and therefore this kind of problem is called as floating mould, and to get rid of this, you must put some heavy weight onto this sand casting.

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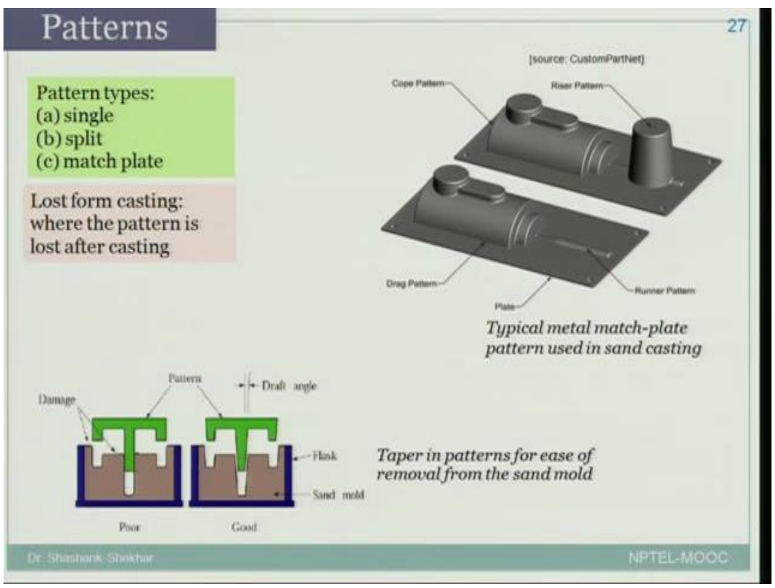

So let us, since we are looking at casting as one of the important applications of solidification, and sand casting is very commonly used casting techniques; so let us look at casting, in a little bit, particularly the sand casting in a little bit more detail, so that we can understand and appreciate what is going on when we understand or when we try to understand the science behind it.

So there is a pattern over here; now you can make these patterns; for example by simple two wooden blocks. It can be in a single piece, or it can be split, or you can have a matching plate, like the matching plate is seen over here; you put the two parts together and then put the sand around it; it will allow you to take the shape and then, take away the pattern out of it to create the hollow region where you will pour the liquid. So this is the pattern and the purpose of the pattern.

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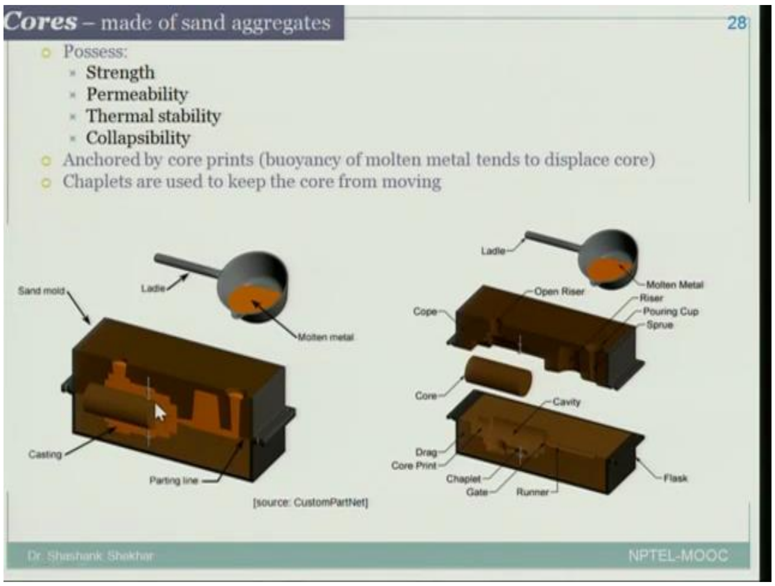

Then there are also cores in sand mould, and again let me bring back the picture that we showed you earlier. So there is a core over here, because you wanted a hollow region. So the purpose of the core is to allow formation of hollow regions inside your surface. Now again, like I said, this is also formed of sand; but it has certain different properties from the sand that you are using for the mould purpose. What is different? It must possess strength. You see this is held over here, but it is still not breaking. So this must be very high strength, and it is obtained, how do you obtain this strength? You put it in the furnace, you make this desired shape, desired hollow core shape, and then put it in the furnace to make it hard.

Then it must have permeability. Now when the liquid metal flows into it, a lot of gases would evolve. Now those gases may also get into this core region. Now core region must have permeability to allow those gases to escape through it. If not, then again the core may break. Another is thermal stability, because we are talking about liquid metal temperature, which is of the order of 1200 or 1500, so the core must be able to retain strength even at those temperatures. So thermal (stabi) stability must be there. And finally collapsibility. So it may look like collapsibility is inverse of strength, but it is not really. Collapsibility, you need, because at the end, when you have done all the, when you have made the component using casting, you want to reuse the sand. You want to break it, and then reuse it. So, it should also have collapsibility along with the strength.

These cores, like I said, can be anchored by core prints, or chaplets to ensure that buoyancy of the liquid does not displace it from its place. Now the sand mould casting, when we are talking about; we should also understand that the sand is not just any sand. There is, the sand that is used has to have certain characteristics; for example, what is most commonly used is green sand, because we are adding some moisture to a mixture of sand grains clay and water. Now each of these have some purpose. For example, sand grain that will form the basic building block, while clay and water or the moisture will form the glue. So it holds the particles together.

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Other kind of sands use different kind of binders. For example in the green sand that I talked about, clay is the binder; water and clay are together forming the binder. So this is the most general one. Other binders that you may have in different kinds of sand include organic resin, or inorganic binder, for example sodium silicate and phosphate. So based on it, we can have different kinds of sand mould. Green sand mould, the one which is, which has moisture; so since it has moisture, it is called green sand mould. Then there is dry sand mould, where you, since you do not have moisture, you add something else; for example organic binders, rather than clay and water. Then there are skin dried mould, where the mould cavity surface of green sand mould is heated to form a strong layer, upto a thickness of 10 to 25 millimeter.

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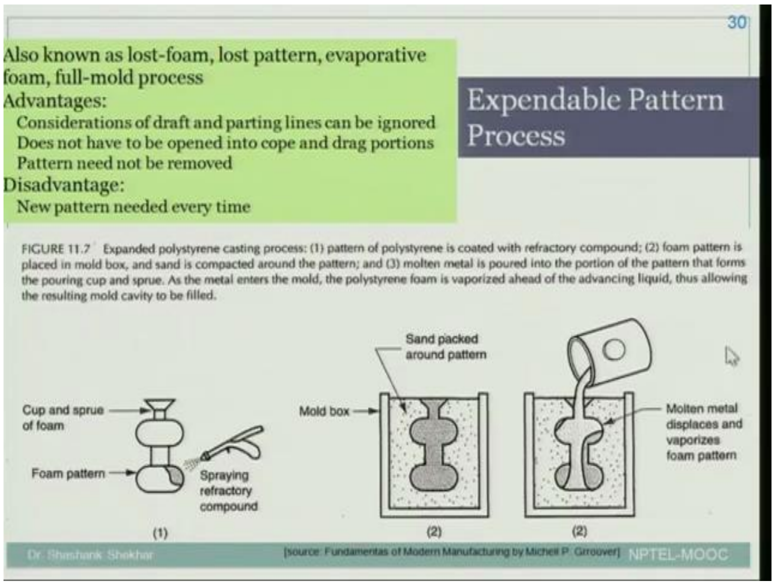

So that is the expendable mould process. We can also have a expendable pattern process, like I said earlier. And in this, for example this is the picture, which explains what is expendable pattern process, whereas of course some advantages for it as well as disadvantages for it. Here we have a mould wall. Inside it, you will make a polystyrene or a foam pattern, and you will spray it with some refractory material, so that the surface finish comes out good, and then put the sand around it so that the sand takes again the shape around it.

Now instead of taking this polystyrene foam out of the mould, as we did in the case of sand mould using wooden pattern. Here we can directly pour the liquid metal into it. Why? Because this polystyrene foam is can very easily melt and escape. So when we pour the liquid metal, this polysterene foam will melt and it will escape from here and create the vacuum space or the hollow space, when it is needed to fill the liquid metal. And therefore this process will be called expendable pattern process.

Advantages is that you do not have to design your pattern and there will be no parting lines, most of the time you will have, when you have pattern, it will be of two different components, two different parts, so there will be a parting line, and you will have to design the patterns accordingly to ensure that the parting line is minimum and it is not obstructing with taking it out.

So those kind of things you do not have to consider over here. Pattern need not be removed. So there will not be any breakage while removing the pattern. But the disadvantage is that every time you will need a new pattern.

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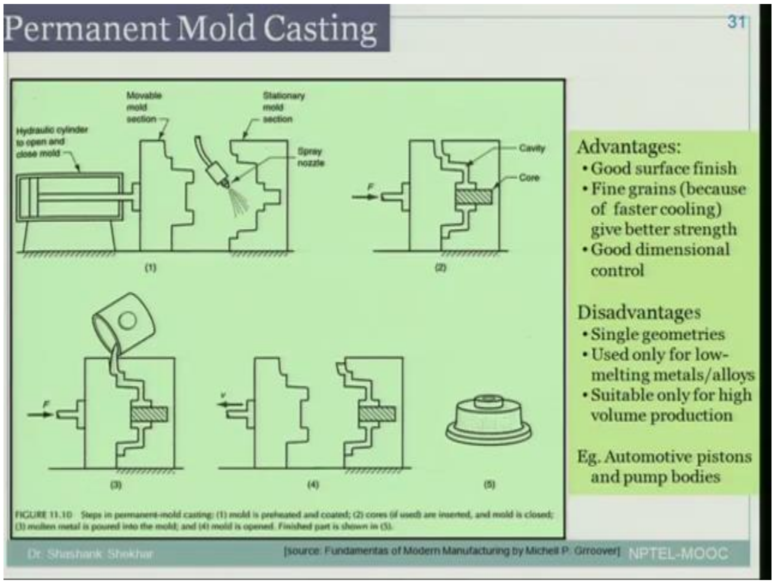

Another example of casting which we described earlier was permanent mould casting. So we had expendable mould casting with permanent pattern, expendable mould, expendable pattern, and then permanent mould casting. So this is the third class of casting that we talked about earlier. In here, we have something like this. This is the mould. So these are the two pieces of mould as you can see, and when you put them together, there will be a hollow region, with this is the hollow region; and if you want to put a core, you can also have a rod in over here along with, or even have a sand core, for that matter, and then pour the liquid metal. Now when you separate the two pieces of the die, you will have the required shape. So this is the required shape that you can get.

Now as you can see, the mould has not been damaged, and it remains as it is. The pattern was formed using the mould, so you do not need a pattern; and therefore this is a permanent mould casting without any requirement for pattern. Advantage. Since the this (pat) permanent moulds are made out of metals, so one of the biggest advantage here is you get good surface finish. You do not need to do any final finish to give a good to ensure fine surface finish.

You get fine grains because the heat conductivity is very high, so you can get very fast cooling rate, giving very good strength. And you can also get very good dimensional control.

Disadvantage is that you will have to have, you can only have single geometry. Now you, this particular die cannot be used for any other purpose. You can only have this particular shape, you cannot make any other shape.

So this is used only for low melting metal alloys; if you, for (ex) this the, like I said, these dies are made of some metals, and those metals are usually steel. So, if the melting point of the metal comes very close to steel, you would not be able to put or pour it into it. So the material or metals that can be used are only those which have very low melting points with respect to the die material.

And this is only suitable for high volume production. As you can see, you have made a permanent die, so you must have invested a lot. So you will be able to use it only for very very large volume production purposes. So examples are, there are lot of examples in the automotive industries. for example automotive pistons and pump bodies which are regularly manufactured using these permanent mould casting technique.

So we will end over here, and next time we will look at some more casting techniques along with the welding that we talked about with some of, and also give you a layout that we are going to cover for solidification. Thank you.