Manufacturing Guidelines for Product Design
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Lecture 19
Design Guidelines for Sand Casting

Namaskar friends, welcome to session 19 of our course on manufacturing guidelines for product design. So, as you were well aware currently we are in the fourth week of our discussion on this important topic and in the fourth week our focus primarily is to understand the guidelines for manufacturing processes. So, guidelines of manufacturing processes that are useful for the product designers and in the fourth week we started our discussion with selection of processes.

So, we have taken 2 lessons or 2 sessions on this topic that is selection of processes 1, selection of processes 2 and we have try to identified important attributes based on which we can compare the manufacturing processes. We can select the manufacturing processes depending upon the attributes which are related to the product design. For example the product may have a specific weight, so based on the weight or the mass of the product we may choose a specific process similarly the shape.

Similarly the kind of surface finish required, similarly the batch size or the number of parts to be produced. So, therefore based on this criteria we can easily select the manufacturing process and a good part for the product designers is that there are number of charts, number of compiled data sheets which are available which the product designer can make use of and easily try to locate that which process is suitable for his or her product.

Similarly the most important of all these charts was the process material chart where which process is suitable or which combination of processes are suitable for specific category of materials was pointed out with the help of dots. So, different types of process and different attributes charts are available based on which we can decide. Then the first and second session was an selection of processes based on the product design attributes.

And the third session in this week was on process capability and if you remember we ended the yesterday's session or the previous session on a note that there are compiled datasheets which are available which can give us a clear cut idea of the capabilities of a manufacturing process.

We have taken an example of sand casting in the previous session and we have seen that what kind of weight or mass for the products can be manufactured by sand casting, what is the achievable surface finish by sand casting, what are the application areas for sand casting, what type of materials can be cast using the process of sand casting. So, we have got a compiled data based on which we can see that whether sand casting is applicable to the product that we have designed.

And if sand casting is not applicable which other processes can be used based on the design requirements or the attributes of the design. Based on which we can decide that which process is compatible or feasible for that particular design based on the shape, size, material, number parts to be made based on all these criteria we will see which process is suitable.

So, we have currently in this week focused on 3 different sessions, selection of processes 1, selection of processes 2 and process capability. Today we start our discussion we ump to a another domain where we will select a process and try to see that what are the manufacturing guidelines or the guidelines for product to be designed or product to be made by different processes, today the title as you can see on your screen is design guidelines for sand casting.

So, there are number of processes for different types of material you can yourself gage the enormity of the information that is available the exhaustive information that is available. If you take only one chart that we have seen in the first or the second session during this week that is week number 4 one chart shows a long list of processes. Now what were these processes, the classification was very very simple, forming processes, forming for metals, forming for polymers maybe forming for ceramics, 3 different materials number of processes.

Then the joining processes, then maybe the finishing processes, so long list of processes and even longer list of materials. So, if we start discussing each and every process in context of each and every material where it can be applied it becomes a humongous, it becomes a very very exhaustive exercise. So, therefore what we have done, we have try to find out or we have tried to list down few processes which are most commonly used.

Also we believe that this course that we are studying may not only be relevant to the industrial product designers but must also be relevant to the learners who are studying engineering or who are doing post-graduation in engineering courses. So, therefore from the academic benefit point of view we have identified the processes which are usually taught at the UG or the PG level.

So, that the learners can get benefited maybe from the academic point of view maybe from the knowledge point of view maybe from the competition point of view maybe from the examination point of view. So, therefore we have identified those processes which are mostly taught in the UG curriculum or in the classroom. So, one such process which is most commonly used for shaping of metals is the sand casting process.

So, if you remember what we have covered in the very first week our focus was primarily on manufacturing aspects. And therefore there also we have seen the versatility of the sand casting process. But we have not gone into the product design guidelines which must be kept in mind when we are designing a product which has to be made by casting process.

So, today we are going to focus on those guidelines which must be kept in mind when the product has to be designed by casting process. There are number of guidelines we will try to club them into a maybe a set of guidelines which every product designer must know. Now another thing is all product designers may not be mechanical engineers, so they may not be knowing the all the details about the casting process.

So, we have included the first slide which gives us an idea that what a casting process actually is just a brief introduction of 1 or 2 minutes. Once you know what is the casting process, the product is going to made by casting process then what are the guidelines in the product shape, product complexity, product surface that must be taken into account during the design stage that we are going to discuss in the subsequent session.

So, let us now quickly see what is the sand casting process this has already been discussed in the first week of our course but again we will come back to this diagram which is given here.

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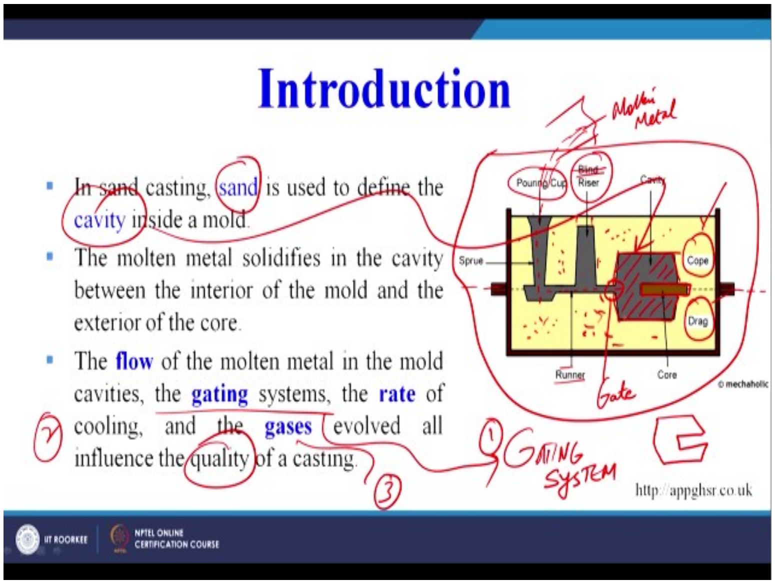

So, this is basically a sand casting setup or an apparatus, so basically this is be it starts with the pouring cup the molten metal is brought in a ladder and it is poured into the pouring cup. So, this is the molten metal which is poured into the pouring cup or the pouring basin, so it travels down the sprue, this is sprue well and it runs through the runner and enters into the mold cavity this is the shape of the product that we want to produce.

So, this is our product and this core is used to create the hollow cavity inside our product later on this core is usually made up of core sand this is broken down and the sand is taken out. So, the final product that we may get from here may something look like, this will be the shape of our final product. The upper part of the molding box is called cope and the bottom part is called the drag.

So, these terminology I am trying to explain the most simplistic manner because some of the terms may come in our discussion in today's session. So, there is a cope there is a drag, then ,there is a poring basin through which the metal is poured into the mould box or the molding box there is a sprue runner and this is the riser it is called blind because it is not open to the atmosphere or open to the environment, so therefore it is blind.

If this would have gone to the top surface of the molding sand it we could have cut this word blind then it could have been the open riser. So, this is basically a casting setup, so you melt the metal in a furnace you bring the metal to the mould box and then there are it is made up of cope and drag there is a mould cavity inside and all this thus combination of pouring cup, sprue, runner, gate there is a gate here through which the metal enters into the mould cavity gate.

So, all these system pouring cup, sprue, sprue well, runner, gate, riser this is called as the gating system. So, this is the way the casting is done, so let us now see and all these yellow portion is basically sand and therefore the name sand casting. So, we see in sand casting, sand is use to define the cavity inside the mould which is the cavity, this cavity.

So, basically in sand casting sand is use to define the cavity inside the mould, the molten metal solidifies in the cavity between the interior of the mould and the exterior of the core. Now this is the core, so the metal will solidify exterior and interior to the sand mould, so this is a sand on all sides there will be sand, metal will solidify in the inside of the sand and outside of the core.

The flow of the molten metal in the mould cavities has to be controlled by the gating systems which I have already written here. So, the gating system the rate of cooling the gases evolved all influence the casting or the quality of the casting. So, the gating system is an important parameter, second is the rate of cooling or the solidification that takes place, the third one are the gases that are evolved.

So, all these will define the quality of the casting that we are producing or the quality of the cast products. Now this is what the basic casting usually looks like but this is not so easier as said and done. There are books very good books available only on metal casting and which takes into detail each and every aspect that we have discussed even the sand maybe discussed in 2 or 3 chapters the kind of molding sand, the type of the additives to be added, the type of properties that are desirable in the molding sand.

Similarly the design of the gating system is also very very important there are different types of pouring cup or pouring basins the size and shape of the sprue the cross-section of a runner the types of gates, the types of risers. So, all these things have to be discussed in much more detail but as a product designer I may know that casting is the process in which the metal is melted and then it is poured into the mould cavity and takes the shape of the mould cavity.

Now what type of product I must design, so that it is easier to make using the casting process that is the target of our discussion. Now let us quickly see that what are the design guidelines for sand casting, the process of sand casting briefly has been discussed in the last maybe 10 minutes. And I think all learners have the mechanical engineering background or who do not have will today may have got basic understanding of the sand casting process.

So, the mould here is made by sand, so therefore we say that the mould is made inside the sand, so therefore we called it a sand casting. In many cases the mould maybe made in metallic mould, so there we will say it is a permanent mould casting process. Because here after 1 casting is made we will break the mould and again we will reuse the sand with certain additives to again make the casting process. So, here we use expandable mould for making the casting specially in case of the sand casting procedure whereas in the metallic mould the molds are reusable and can be used again and again.

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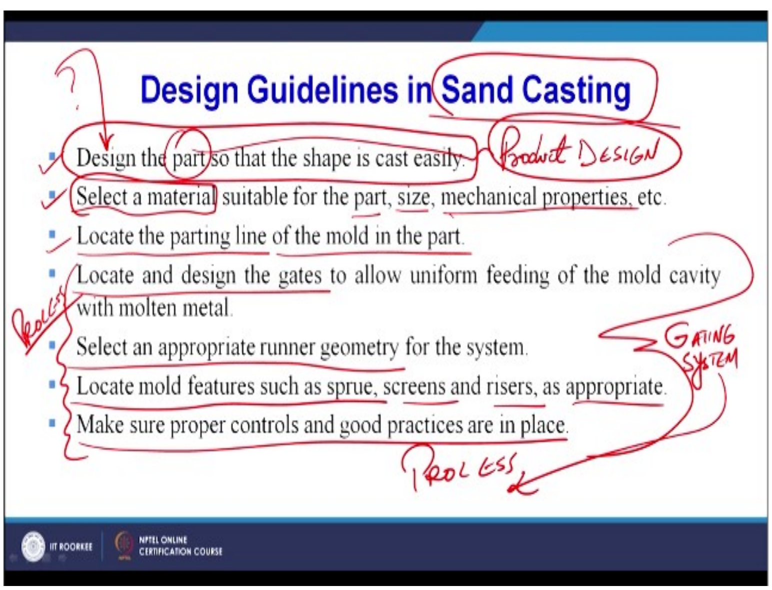

But here our focus is on sand casting, so today we will focus only on sand casting, so we can see the very first point is important for our course. That is design the part the part can be our product, so design the product, so that the shape is cast easily. Then select a material suitable for the part the size of the part and the mechanical properties, now we can do metal casting there can be different types of metals that we can use for the casting process, so we have to select the material accordingly.

So, already we have discussed regarding the selection of materials in our week 2 during our discussion engineering materials. Now the third guideline is locate the parting line of the mould in the part, so we have to decide that where the parting line has to be in the design of our casting. Now what is the parting line I will go back to the previous slide and here we say this is basically the parting line.

Now here it is symmetric half of the part of the design is in the co part another half is in the drag part. So, when we are designing a product we have to design it in such a way that the parting line is properly selected. We will see in today's session parting line must be it must be tried that when we are designing a part that parting line must be straight it must not be at varying cross-sections across the mould cavity.

So, that we will see in the next slides with a help of certain examples locate and design the gates to allow uniform feeding of the mould cavity with molten metal. So, this is locate and design the gates, select an appropriate runner geometry, locate the mould features such as sprue, screens and risers as appropriate, make sure good proper controls and good practices are in place.

All these 4 points are related to the design of the gating system and this is related to the processing or the process that is a sand casting process. Our target is in our course to focus only on this aspect that is the product design that how we must design our product. So, that it is easier to cast once the product is designed keeping in mind the guidelines all these 4 points location and design of gates appropriate runner geometry, sprue, riser, design of sprues and risers all that takes place at the second stage.

First stage is the product that we have designed which has to be made by the casting process, other things are related to the as I have already highlighted related to the process. So, once we have designed the part with the process things can always be optimized. So, our focus will be on the design that what must be kept in mind when designing the part to be made by casting.

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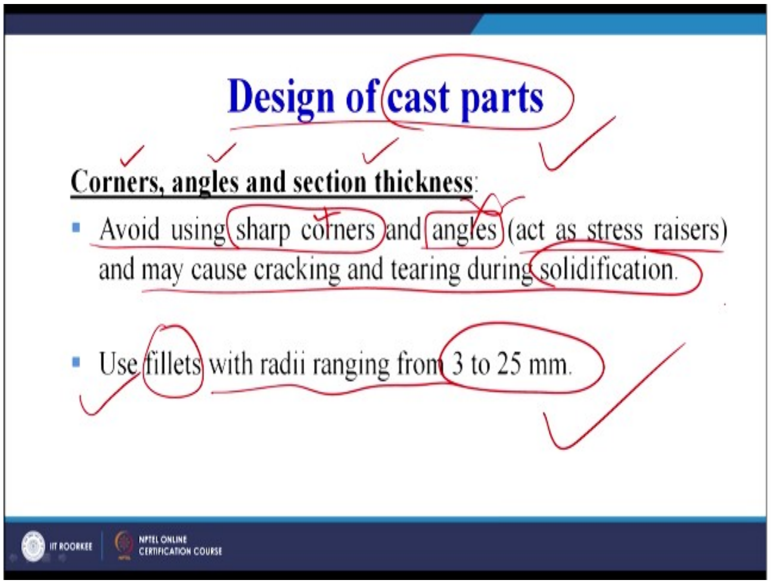

Now let us see design of the cast parts that is our target we are not going to discuss casting process and if you refer to our database of NPTEL there are number of very good session which detail out all the significant information related to the casting process. So, there may be sessions maybe 10 sessions, 15 sessions only on casting, so our focus is not to repeat what is casting, how to design a sprue, how to design a riser, what is the solidification rate, what is the Chvorinov's rule, what is the solidification time.

All that is not the target of our course, our course is focused on the guidelines which a product designer who may not be a mechanical engineer knows that these guidelines must be kept in mind when the part has to be made in metal as well as the part has to be made by the casting process. So, first thing is related to corners, angles and section thickness, avoid using sharp corners very good guideline for product designers.

So, for any metallic part otherwise also we must avoid using sharp corners from the safety point of view but here we are not talking about the safety, we are talking about the process. So, when you do sand casting sharp corners may not be possible or sometimes our process may not be uh suitable for making the sharp corners. Then angles, sharp angles must also be avoided we will try to see this with the help of diagrams act because why the angles will act as stress raisers.

And may cause cracking and tearing during the solidification, now what is happening the molten metal as we have seen in the process those into the molten metal goes into the sand mould it travels through the pouring base in the sprue, the sprue well the runner through the gate it enters into the mould cavity. And then it solidifies there, so it may cause cracking and tearing during that solidification process what can cause that the sharp corners and the angles.

So, use fillets solution is also given if we want to avoid the sharp corners we do not want angles also we do not want what should we do, we must use fillets with the radii range ranging from 3 to 25 millimeter, so 1 guideline is there that we must avoid the sharp corners and angles.

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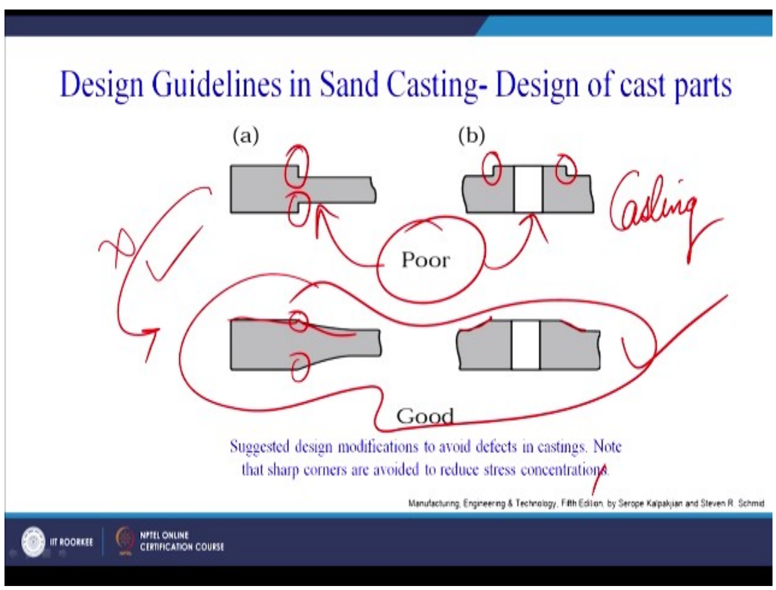

Now here we can see this is a sharp corner here again here, so what can be done the process if it is possible then you can may give a fillet here and here also instead of sharp transition we can have a gradual transition. So, both of these are poor product designs from the casting point of view and both of these are good designs from the casting point of view. So, sometimes it may not be possible for us to do these type of modifications from here to here may not be possible why?.

Because of the design constraints but maybe 70 to 80% of times the designers are not aware about the problems. So, therefore they can easily change this thing change the design from A to B but because of lack of information the product goes as it is. So, therefore this type of information is useful for product designers when wherever possible they can change the geometry to avoid the sharp corners and the angles. Suggested design modifications to avoid defects in casting, sharp corners are avoided to reduce the stress concentration, so this is already discussed.

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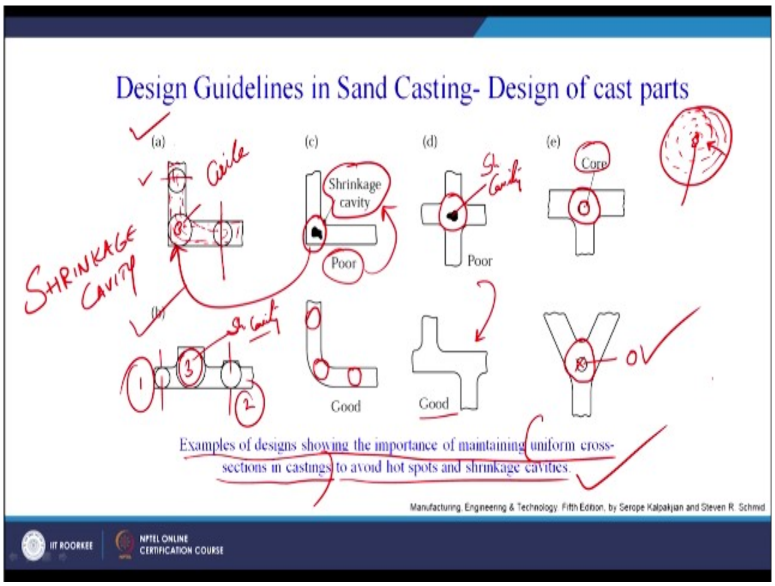

Then this is again related to the design of the parts, now this is 1 channel A, 1 product this has a tendency to form a shrinkage cavity if you can read it I will write here. It is shrinkage cavity and it can be easily located that where the shrinkage cavity will be formed why because here there is more metal because of this circle inscribed circle at the different cross-sections of the product design or the product geometry, we can see that where we can fit in the biggest circle.

So, where the biggest circle can be fit that is the place where the volume of metal will be maximum and the cooling will be slow why because the molten metal will solidify or cool down slowly in the place where there is large amount of metal. So, therefore when it will cool down the cooling usually starts from the surfaces or from the periphery. So, cooling will travel inside the metal will starts solidifying from the surface towards inside.

And then maybe at the center we may be left with the cavity where the metal there is lack of metal or the metal is not there, so cavity is formed because of this shrinkage from the surface towards inside. Again we can see if there is a shape like this the solidification will start from the surface and it will travels towards the center in this direction. So, from the surface the metal will solidify then the inner surface will solidify the further inner then further inner and finally this core.

So, we may get a cavity here, so here we can very easily see that there is a tendency to form the shrinkage cavity. So, if we have this type of product with uniform cross-section there is a chances or there are chances of finding or producing a shrinkage cavity there which is not desirable. In the similarly in B also using the same principle we have these 3 circles, circle 1, circle 2 and then this is circle 3, circle 3 has the biggest diameter.

So, there are chances that a shrinkage cavity form here, how it can be avoided now, it can be avoided by changing the design. Now this is a poor design because of the shrinkage cavity but if you change this we have a circle here we can make a similar circle here we can make a similar circle here. So, we have tried to avoid this larger circle or larger volume of metal at 1 place which on solidification will generate a shrinkage cavity, so this can easily be avoided.

Similarly this is also a poor design if you make a circle here the biggest circle, so this is a shrinkage cavity, how it can be avoided by modification in the design. So, if possible modify the design in such a way that the shrinkage cavity is avoided similarly this is another thing we can have a core here central core here also why this core is required because if you make a circle this will be the biggest circle and again the same problem may come there.

So, you modify your design you make a central core or a central hollow junction here so that shrinkage cavity is avoided. And similar is the case here this can easily be avoided by putting a circle here which is desirable. So, you can change the product design in order to avoid the formation of a shrinkage cavity because of a higher volume of metal or the higher volume of molten metal at 1 particular section of the product design or 1 particular section of the product geometry.

So, these are the examples of designs showing the importance of maintaining uniform cross-sections in casting. So, this can be 1 guideline that we must try to maintain uniform cross-sections in the casting to avoid hotspots and shrinkage cavity. So, here we can see the concept of shrinkage cavities how they can be avoided that can be done with the help of design modifications in the product geometry.

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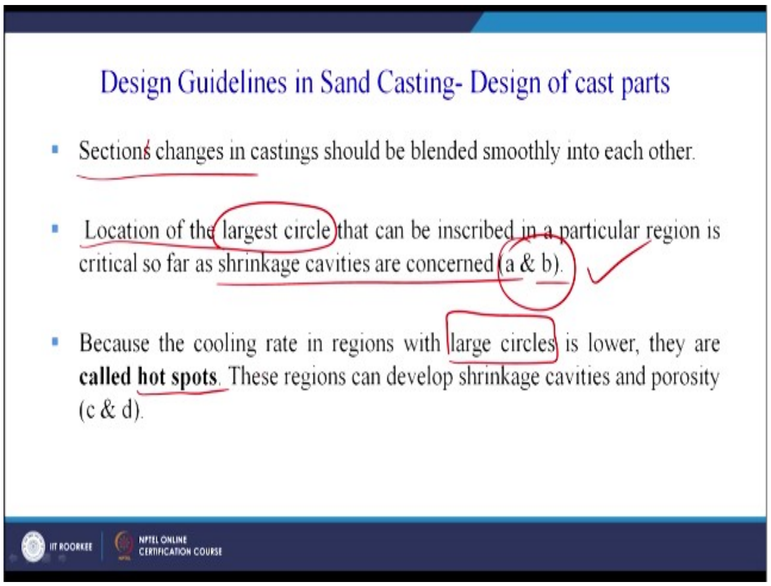

Now let us see whatever we have covered let us try to summarize it, now section changes in casting should be blended smoothly into each other. So, section changes we have seen that wherever the section is changing at that point we must have a uniform profile instead of a sharp profile, location of the largest circle as we have seen in the previous slide, largest circle that can be inscribed in a particular region is critical, so far as the shrinkage cavities are concerned figure A and B.

In the previous slide explains this wherever the circle is of the largest diameter that is the place where shrinkage cavity can form. Because the cooling rate in regions with large circles already I have told because there is large volume of metal, so the cooling rate maybe slower. Because the cooling rate in region will larger circles is lower they are called hotspots. These regions can develop shrinkage cavity and porosity.

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Now cavities at hotspots can be eliminated by using small cores that we have seen in the diagram towards the right hand side where a y channel was shown at the center we can have channel sorry channel like this was shown. So, here there are chances, so we can put a core here, so that we can these are change the design modification to avoid the shrinkage cavities, it is important to maintain as much as possible again this guideline is coming.

Uniform cross-section and wall thicknesses throughout the casting to avoid or minimize the shrinkage cavities, metal chills in the mold can eliminate or minimize the hotspot. Now what are these metal chills we will see with the help of the diagram.

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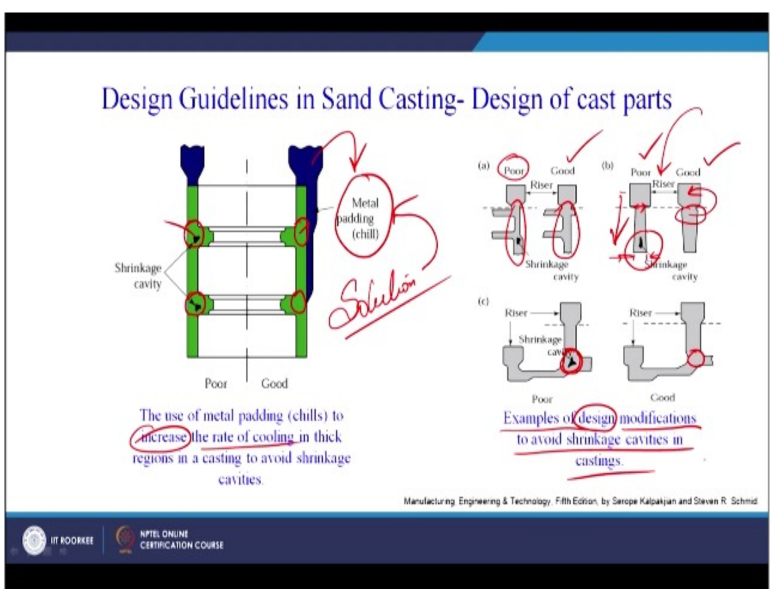

Now here we can see this is a metal chill here design guidelines in sand casting for the cast parts, now here we can see here you if you make a circle there are chances or formation of shrinkage cavity similar is the case here also. So, location can be easily identified, now how it can be avoided we can accelerate the rate of cooling why the shrinkage cavities forming or the hotspots because of the slower rate of cooling.

So, we can accelerate that rate of cooling with the help of this metal padding or the chill, so the use of metal padding chills to increase the rate of cooling in thick regions in a casting to avoid the shrinkage cavity. So, this is one maybe solution to avoid the shrinkage cavity, so accelerate the rate of cooling. So, 2 solutions we have seen solution number 1 is ensure uniform cross section, avoid sharp corners, avoid sharp angles, avoid the areas with larger inscribed circles in the geometry of the product.

Second is if that is not possible then what you need to do you need to provide a secondary source of cooling which can be a metal padding or chills which will accelerate the rate of cooling or will increase the rate of cooling and will avoid the formation of the shrinkage cavity. So, here we can see here this is a poor design, there is a problem of shrinkage cavity here, so there is a modification if you see this section there is a modification in the design here.

So, this is a good design, it is showing the uniform cross-section, so here also this is the riser the term we have used in case of the sand casting in the very first slide today. Now riser is used to store the additional molten metal which can be used when the shrinkage of the metal takes place on solidification. So, we can see here is small, the section here is larger.

The larger section is away from the riser, so we can modify the design here the larger section is near to the riser. So, the riser will have the molten metal it will come down and fill this shrinkage cavity and will avoid the defect. So, this is a good design this is a poor design where the larger section is away from the riser. So, here the larger section is near to the riser a good design.

So, here we can again see there are chances that a shrinkage cavity may form here because of the non-uniform section also. So, here it can easily be avoided here you can see their larger circle is this but here you can see the larger circle has been made smaller.

So, we can change the design of our products to avoid the defects that maybe caused because of the formation of shrinkage cavity. So, some examples we have taken that if he change the design the defects can be eliminated. So, these are the examples of design modifications to avoid the shrinkage cavities in the casting.

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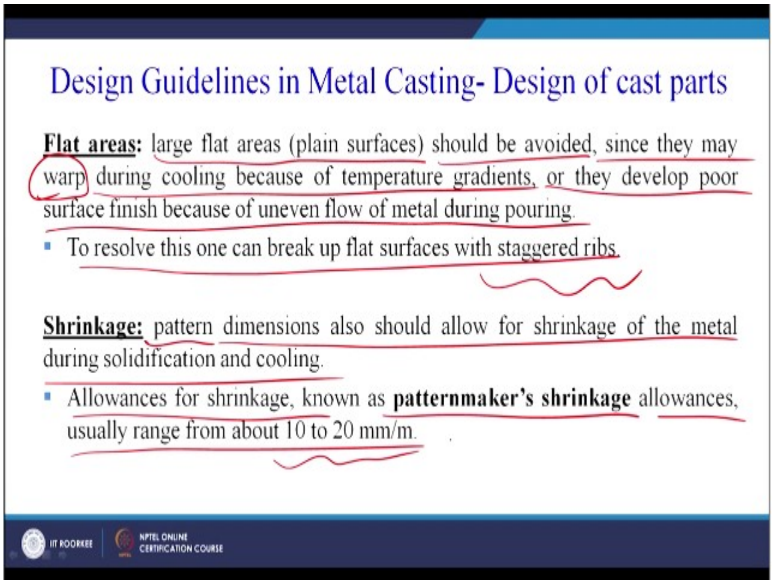

Now there are other guidelines also the design guidelines in metal casting that are related to the flat areas. Large flat areas or the plain surfaces should be avoided since they may warp one defect warpage, change in shape during the cooling because of the temperature gradients or they develop poor surface finish because of the uneven flow of the metal during pouring.

So, when you have to make a large cross-section, large flat plate sheet or flat plate has to be made flat plate though it must not be made by the casting process, why because of the problems given here. There are tendency of warping there can be a problem related to the surface finish of the large sheet there are the plate that we are making by casting, so that must be avoided.

To resolve this solution is given, one can break up the flat surface into the staggered ribs, so the staggered ribs can help us to avoid the problem of warpage as well as the poor surface quality of the flat plate which has to be made by the casting process. Shrinkage also is very very important sometimes the shrinkage maybe such that a size of the product that we have made by casting is smaller than the actual designed size or the actual design of the product.

So, how the shrinkage can be avoided pattern dimensions also should allow for shrinkage of the metal during solidification and cooling. Allowances for shrinkage known as the patternmaker's, shrinkage allowances usually range from about 10 to 20 millimeter/meter. So, basically what is the shrinkage allowance, so when we all of know when the metal will solidify it will shrink, so therefore the cavity that we have made in the sand must be slightly larger as the range given 10 to 20 millimeter/meter slightly larger than the actual size of the product.

Now how much larger that we have to calculate that we have to see, so for that the pattern that is use. So, we are not discussed the pattern we have directly assumed that there is a mold cavity which is exactly the replica of the final product that we want to make. So, that cavity inside the sand will be produced by a pattern and there are different types of patterns such as single piece pattern, loose piece pattern, skeleton pattern, sweep pattern, number of types of patterns are there.

They may be made by wood, they may be made by wax, they may be made by metal, they may be made by plaster of Paris. So, there are different materials which can be used for making pattern there can be different types of patterns depending upon the requirement but we will use a pattern to create a cavity inside the sand. Now that cavity will be filled by the molten metal which will pass through the gating system and will enter into the mold cavity and solidify there.

So, therefore when the metal will solidify is the dimensions maybe slightly less than the exact product. Therefore we will make a larger size pattern slightly larger, so that it accounts for the shrinkage. So, that is what is the shrinkage or the pattern makers allowance, there are other types of allowances also as we have seen that sand casting produces a poor surface finish on the metal surface.

And therefore we have to do machining in order to get a good surface finish, so therefore we will also need to have a machining allowance also. So, therefore we will make our patterns slightly larger the product that we will get will be slightly larger than the exact size of our product and then finally we have to machine it to get the desired shape of our product not the shape, shape we will get after the casting but desired size and dimensions of our product.

So, this is related to shrinkage allowance that we need to give on the pattern then there are other guidelines also depending upon specific parts.

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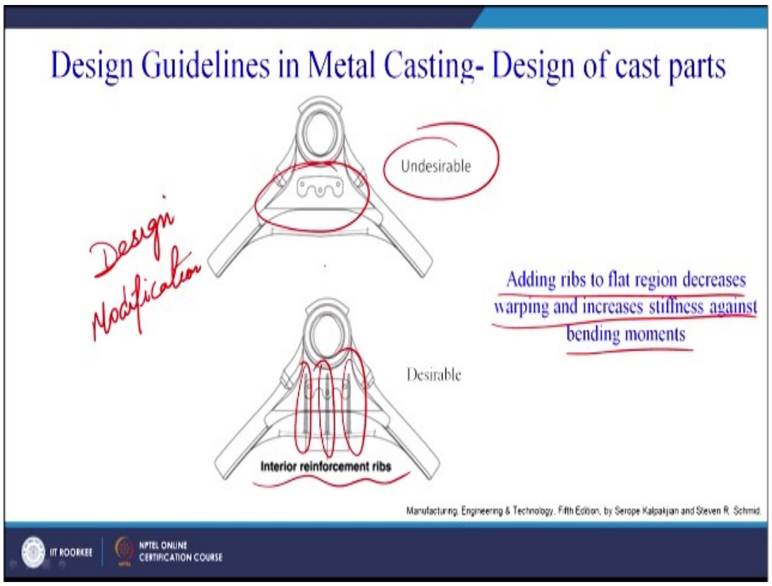

So, this is undesirable why because there are chances of warpage in this region, how it can be avoided, it can be avoided by giving this internal ribs. So, internal reinforcement ribs can be given to avoid the warpage which is written here adding ribs to the flat region decreases warping and increases the stiffness against the bending movement. So, this is also a designed modification which is specific to this product which has to be made by the casting process and it will give strength to this region as well as avoid the problem of warpage.

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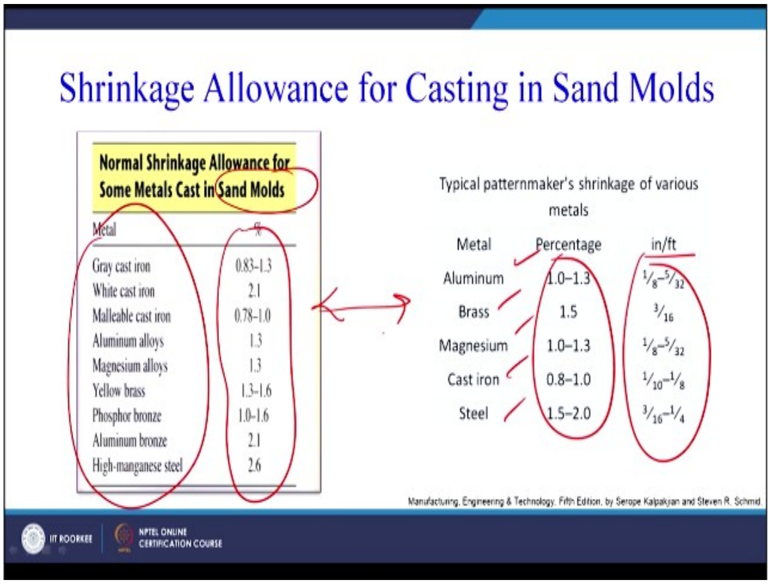

Now what we have already discussed the shrinkage allowance for casting in sand mold this is given here, this has been taken from manufacturing and technology by Kalpakjian and Schmid. So, normal shrinkage allowance for some metals casting the sand molds, so we are studying sand molding, so what is a shrinkage metal sorry the shrinkage allowance to be given for different metals this is long list of metals given here and this is a percentage of shrinkage allowance that must be given.

This is typical pattern makers sorry shrinkage of various metals again metal is aluminum, Brass, Magnesium, Cast iron, steel what is the percentage and this is given inch/feet what must be the shrinkage allowance. So, this information gives us an idea that when we are designing our casting we must take care of this shrinkage allowance, so that the pattern can be designed accordingly and this shrinkage can be easily taken care of. Now the other guidelines we are now towards the last part of our session today lettering and marking which is very simple.

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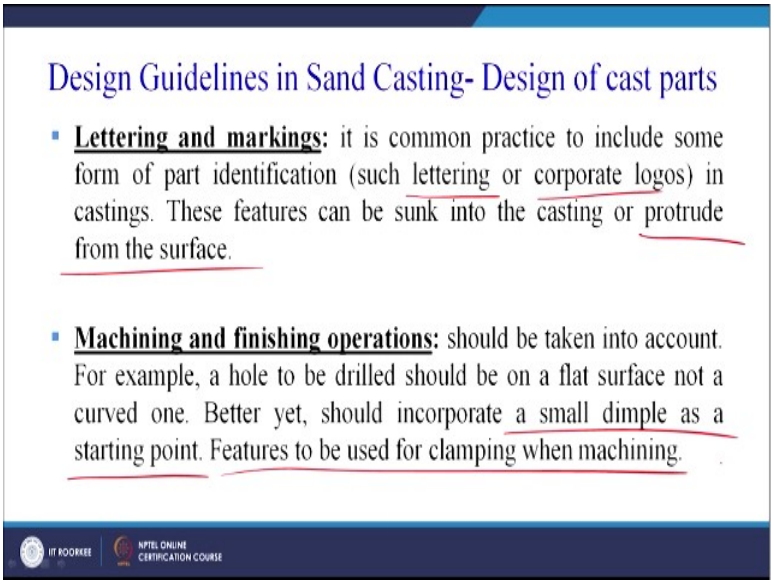

It is a common practice to include some form of part identification such as some letters or the corporate logos in the casting these features can be sunk into the casting or protrude from the surface. So, when we are designing a product which is to made by casting we can make some letters which can be either sunk or maybe into the depressions they can be made as a writing on the sand or they can be protruding out or embossed on the surface.

So, they can be protruding from the surface of the casting, so either they can be made into depression or sunk into the casting or maybe protruding out of the casting just to indicate the product belongs to X, Y or Z company. Then as I have already told machining and finishing operations should be taken into account for example a hole to be drilled should be on a flat surface not on a curved one.

This we will also cover when we will talk about the manufacturing design guidelines for machining processes, better yet should incorporate a small dimple as a starting point why a small dimple is required that is a long story related to drilling. Because the drilling chiesel edge is not straight and there are chances of drill wavering when it touches the surface.

So, there can be a small starting point, so that the cut the chiesel or the casting has to be machined after casting, so therefore we need to have a proper holding features through which it can be held on the machine for improving the surface finish.

So, therefore the machining aspects have to be taken into account during the design stage of the product which has to be made by the casting process.

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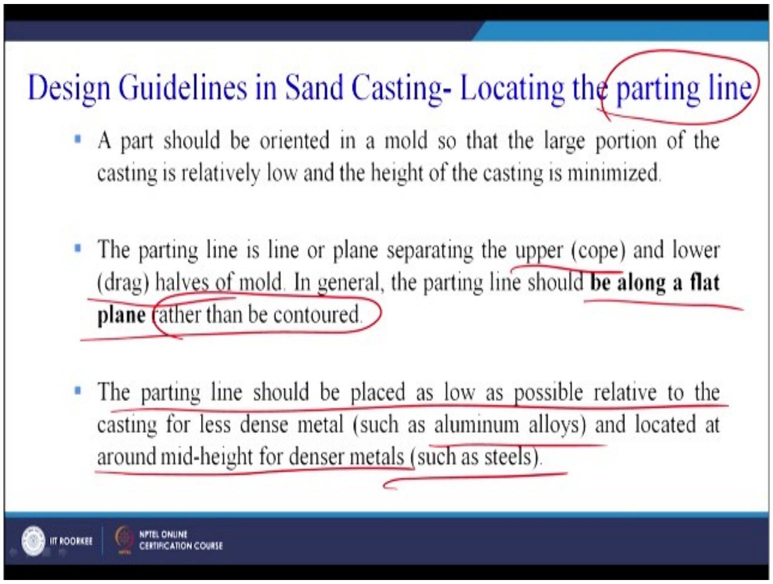

So, this is the last part we have already seen what is the parting line, so this is guideline related to the parting line. A part should be oriented in the mold so that the large portion of the casting is relatively low and the height of the casting is minimized. So, we have to decide that how much of the casting has to be in the cope part and how much has to be in the drag part.

The parting line is a line or a plane separating the upper that is the cope and the lower that is the drag halves of the mold. In general the parting line should be along a flat plane rather than be contoured. So, cross-section may not be too varying or the parting line must not be contoured it must be straight as far as possible. The parting line should be placed as low as possible relative to the casting for less dense metals such as aluminum.

And located at around mid-height for denser metals such as steels, so this is a guideline related to the placement of the parting line that for aluminum alloys it must be possible as low as possible related to the casting and located at around the mid height for denser metals such as steel.

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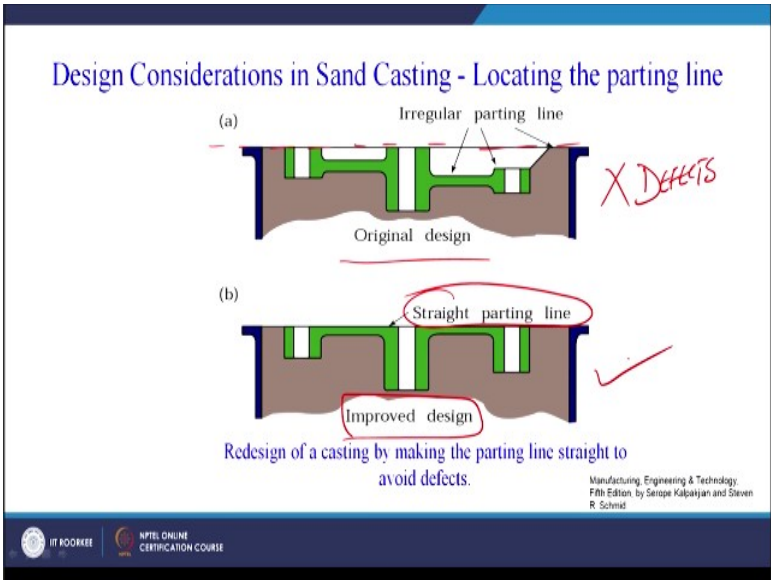

So, we have seen the parting line, now this is basically what is the parting line, so it must be straight it must not be contoured. This is the original design, so this is a straight parting line which is good this is a improved design it must be straight but here it is not straight in this case. This is a original design it can be improved by making the parting line like this redesign of a casting by making the parting line straight to avoid the defects.

So, here there are chances of different types of defects in the casting but this can be the improved design. So, with this we conclude the today's session that what are the product design guidelines that we must take into account when the product has to be made by the sand casting process. In our next session we will focus our attention on the other form here it is expandable mold, sand mold is made product is made ready.

And the mold is broken down the sand is reused, so expandable mold we will now focus on a permanent mold. In permanent mold the mold will be made up of metal and then the molten metal will be poured insert and it will take the shape of the cavity which has been created between the 2 halves of the mold. So, we will discuss that what are the design guidelines that must be kept in mind when the product has to be made by the die casting process or the permanent mold die casting process.

Thank you.