Manufacturing Guidelines for Product Design

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Lecture 18
Process Capabilities

Namaskar friends, welcome to session 18 of our course on manufacturing guidelines for product design. Today we are going to focus on the process capabilities, already we have a introductory session during the 1st week in which we have try to understand the meaning of the world process capabilities. But there is a lot of information related to the various processes as well as the capabilities for various processes and the source for today's session is given.

This is again the same book product design for manufacture and assembly and second edition by Geoffrey Boothroyd, Peter Dewhurst and Winston Knight. There are other references also, there are number of other references where we can try and find out that what are the various process capabilities for various processes, what is our target basically. In the previous 2 sessions for this week that is week number 4.

We have since selection for processes 1 and selection for processes 2 and we have seen that various attributes are there such as the materials to be processed, the first attribute can be the materials to be processed. The mass of the product or the part or the component, then the shape of the part or the component the tolerance that is achievable by the various processes, then the surface roughness which is achievable by the various processes.

Or on the contrary I must say the surface finish that is achievable by the various processes, so based on these attributes we have tried to understand that how the processes must be selected. So the basic target is to look at to find out to understand to discuss the various summarized compiled information which when we used as product design guidelines, specifically from the manufacturing point of view that once we are designing a product and we have to manufacture it what are the guidelines that we must keep in mind.

Now there are large variety of guidelines available, you study any good book on manufacturing you will get to know about sand casting, you will get to know that how sand casting is done, how the gating system is designed, what are the various parameters that must be taken care of when you are designing a gating system, what is the ideal shape of the riser, what is the ideal shape of the runner, how the screw must be design, what are the different types of the gates, what should be the cross-sectional shape of the runner.

We can different types of information related to the process at the end we will see that sand casting can be used for these type of applications. It can be used for making very large sized parts fairly complex parts, so that is the understanding related to sand casting but that is not our target in this course. Our target is to see to establish the ranges to learn about the ranges which are already established to compile the information under 1 umbrella where a learner can easily have a straight reference.

That yes this is the chart that I must look when I have to recommend a manufacturing process for my product which I have designed. So a product designer designs the product he has to now suggest that which product must be use. So he must have a compiled information, he may not be from the mechanical engineering background and we are not suggesting also that he must go and first study mechanical engineering for 4 years or production and industrial engineering for 4 years to gain the information related to manufacturing.

We are trying to produce a capsule, we are trying to produce a module where we want to bring together the information related to manufacturing which can be used easily which can be comprehended easily by any product designer irrespective of his educational background. So that is our target in this particular course and with this target we have seen in our week 4 session number 16 and session number 17.

We have already seen that there are few key attributes based on which we can categorize or we can compare the various manufacturing processes. At these attributes I have just now mentioned these attributes are in terms of the material of the product, in terms of the mass of the product, in terms of the shape of the product, in terms of the dimensional tolerance, in terms of the surface finish, in terms of the batch size that needs to be produce.

So, based on those parameters, those attributes different process have different ranges and based on those charts very easily a product designer can select a process as well as a flowchart was discussed that how step by step the processes can be screened out based on the design requirements of the product and finally from a large variety of processes we can boil down to a single process which can be used for manufacturing our product.

So that is what we have already covered, now there is other form of information which is easily available which gives you the length and breadth of the information or length and breadth of the data regarding any manufacturing process. Now in previous session we have seen based on the attributes we can compare the various processes. For example we say surface finish now sand casting can produce a surface finish within this range from this much micron to this much micron.

Die casting can produce a surface finish in a range from this much maybe X micron to Y micron. Similarly for shaping of plastics injection molding can produce a surface finish from this value to this value. This type of chart is available but that is in context of 1 attribute only and that attribute is the surface finish. Similarly regarding mass that X process can produce a product up to this much kilograms, this process can be produce maybe Y process can produce a Z process or P process or Q process or A process.

Any process sand casting, die casting, injection molding, compression molding, blow molding any process can produce up to from this much milligram to this much gram or this much kilogram. But the parameter or the attribute remains same but there is information which is available about the process capabilities of the individual process giving all the attributes in a structured manner in a tabular form.

So, as a product designer I can easily look at a process for example sand casting I can see from the size of my product, from the mass of my product from the surface finish that I require for my product for from the material that I have selected for my product I have zeroed down I have found out that sand casting is the process that I am going to use for my product. Now for sand casting I can check the other details also, the other information also for example the application areas, the limitations.

So, all that information is available in a compiled form in a tabular form and as a product designer I must refer to those tables before suggesting, before prescribing maybe process of sand casting for making my product. So, we will try to understand see some of the examples of these tables and then try to understand that what kind of information is available which we usually ignore when we are designing a product.

Now let us quickly see the importance of process capabilities, so let us now see that where the process capabilities fit in in reference to the product development process.

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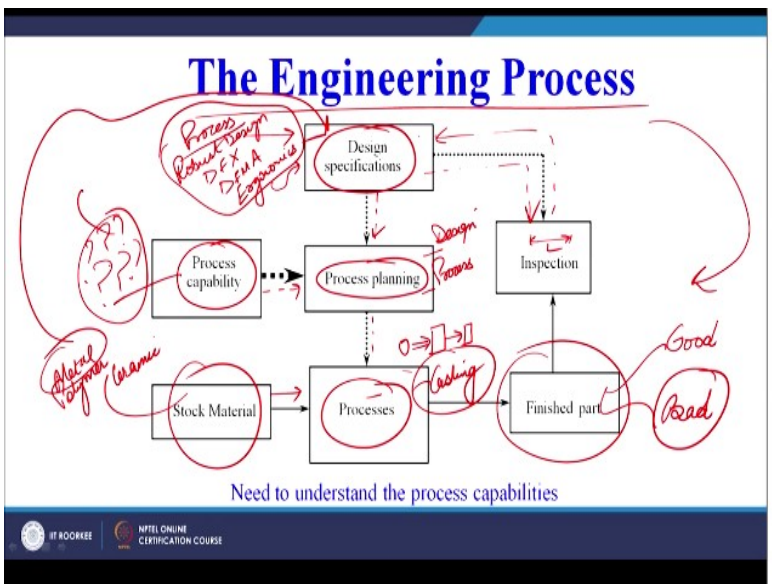

So, any engineering process is depicted in the form of this diagram and here we see that usually the design specifications are put forth by the designers. Then there is a process capability which we are trying to understand till now there is a big question mark on the process capability for various processes. Design specification is a process where the designers will undergo the various steps or they will undertake the various steps for designing the product.

So, that we have already discussed in our course on product design and development that what is the design methodology and the design procedure. So, after that the outcome will be the design specifications and here we will be making use of our discussion that we have already done we will take care of the robust design approach we will take care of DFX, we will take care of DFMA, we will take care of ergonomic aspects of product design.

So, everything will be taken care and finally we arrive at the design specifications, then the process capability is equally important and this is something that we are trying to understand today. And both of these go into the process planning which is required before going for the manufacturing and once we do the process planning we know the process capability here we know the design of the product is already available.

As well as from process capability we select the process also that which process is going to be use and then we go to the processes. We will go where the raw material will undergo any process and it will be converted into the final product. So, for undertaking the processes there will be a raw material, so the material can be it can be made in metal which is coming this information will come from the design specifications whether it has to be made from metal or it has to be made from a polymer or it has to be made from a ceramic.

So, all information is laid out in the design specification and from here the raw material will go, the processes already been decided based on the process capability and process planning has been done maybe the process identified is casting, the material identified is suppose metal. It has to be made by casting process, so we do the 2 things and we bring the material cast it and then we get the finished part.

And the finished part it can be good, it can be bad, if you make a bad part it will undergo the inspection and if inspection is done it can give a feedback to the design specification. So, the design specifications will give that what has to be checked after the final product is made we know that which parameter has to be inspected maybe the length has to be inspected. And once the length has to be inspected we will check the length, if the length is not accurate or we are not able to produce it.

We will again refer back to the design specifications that maybe what can be the tolerance that is what can be given on length or what kind of maybe design modifications that can be done. Because our casting process is not able to produce the product as per our requirement, so this is the complete engineering process and therefore we see that the design is very important.

All these parameters that we have already discussed are important, robust design DFX, DFMA guidelines ergonomics very important similarly the process capability is also very very important. So, we have very good designers who are very good from the designing point of view but maybe where we lack is the understanding of the process capability and that is what is the target of our discussion that after going through the course.

Each and every learner must have this idea of the information which is already available, how to use thus that information that is what is the target of our course. Now let us try to see from process capability point of view that how we can refer to the information which is available with us. Now process capabilities let us try to understand the word what is the process.

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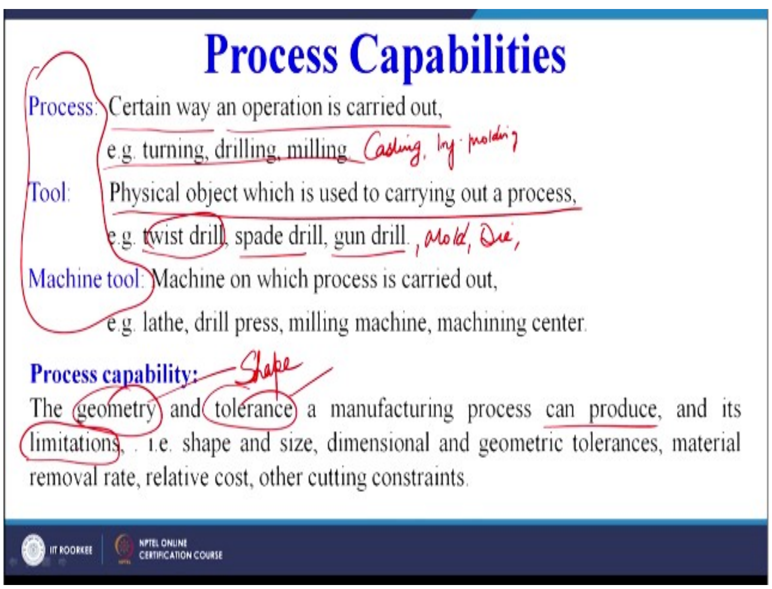

A process is a certain way an operation is carried out, for examples are given turning, drilling, milling you can have other examples for shaping the parts, you can have casting, you can have injection molding for plastics any process. So in the process it is a certain way, method, procedure in which it is being carried out, what is a tool. A tool is a physical object which is use to carrying out the process, for example a twist drill, a spade, a gun drill.

Sometimes you call it as a mold it can be a die, it can be any tool that we use to convert the raw material into the final product. Then the what is the machine tool, machine on which the process is carried out lathe, drill press, milling machine, injection molding machine, compression molding machine, extrusion machine, filament winding machine, pultrusion machine different types of machines are there which provide the relative motion between the tool as well as the die or between the material and the tool, so, that is basically what a machine tool is.

Now what is a process capability, now process capability will work around these 3 things that we have already seen the process how the material is getting converted from the raw material into the final product. The tool that we are using and the machine that we are using for making the product. Now what is the process capability, the geometry and tolerance geometry which we can say as the shape we will have little more discussion on this shape maybe in the subsequent slides.

The tolerance one of the attributes already covered in discussion in our previous session that is session number 17 already we have covered. The geometry and tolerance a manufacturing process can produce now we know that we have already understood the compatibility the inter relationship between the processes and the various attributes what were these attributes.

Attributes were in terms of the material the processes can process the shape the processes can process, the mass the processes can process all in terms of range the range of mass that the processes capable of producing, then the tolerance it can achieve, the surface finish it can achieve, the economic batch size for which it will be economical. So, there was a list of processes and the various ranges for each one of these attributes which we have already covered.

So, the geometry and tolerance are manufacturing process can produce and it is limitations, so we have already seen the ranges that for mass there is a range, for tolerance there is a range, for surface finish there is a range. For each and every manufacturing process right from the processes related to metals to the processes related to polymers, to the processes related to ceramics, limitations.

That is shape and size the process can produce, dimensional and geometrical tolerance is the processes can achieve. Material removal rate the process can achieves specially relevant in unconventional machining materials such as processes of electric discharge machining, ultrasonic machining, electro-chemical machining. So, for all these processes how much material removal rate a process can achieve is also a process capability why.

Because sometimes the material removal rate maybe so low that the process becomes unproductive for specifying it for a large economic batch size. So, when you have a very large batch size, your process is very very slow, the material removal rate is very very less you will say no I do not want to use this process because it is not giving me the desired material removal rate or in other words the desired productivity.

So, relative cost is very very important and other cutting constraint, so process capability is in terms of the shape, the size, the cost, the material removal rate, the productivity, the efficiency, the effectiveness, the tolerances, surface finish. There is a long list attributes based on which the different processes can be selected. So each process will have certain limitations in terms of all these criteria that we have listed out and we will see some of the tables and try to understand.

That sand casting for example what is the information that is available for sand casting, investment casting what is the information available or forging what is the information available based on all these criteria. So, the important point is that after undergoing this course or maybe after listening to this session that is session number 18 we may not feel that I know everything of mechanical engineering now.

But at least we will have an information that such type of compiled information is easily available which can be used while designing our products and during the designing when we have to specify that which manufacturing process must be use for producing this product. Again and again I am emphasizing because sometimes we may feel that I do not may memorize that what was discussed in the session.

So, it is not regarding memory, it is regarding the information that you have that this type of information is available and must be used.

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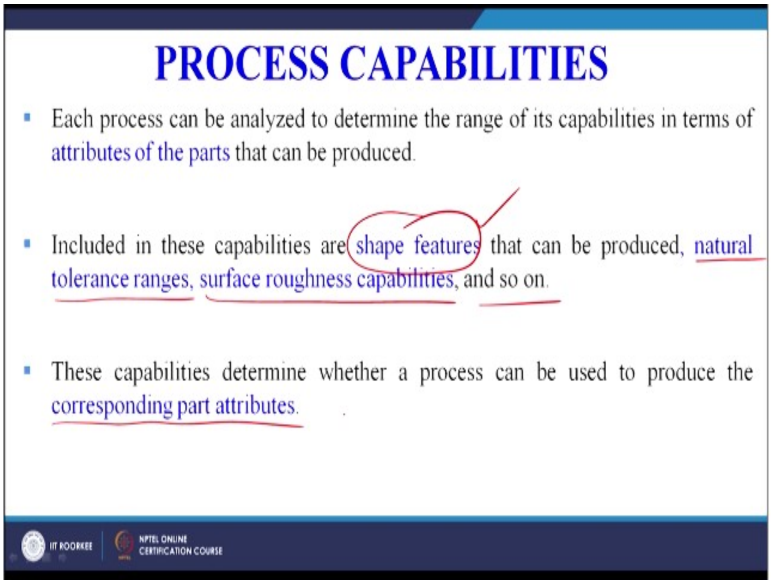

So, let us now quickly see that process capabilities that with example maybe for the specifically we will focus on the shapes and then try to see that which process can produce which type of shapes. So, each process can be analyzed to determine the range of it is capabilities in terms of the attributes of the parts that can be produced which already we have seen in session number 16 and 17 during week 4.

Included in this capabilities are shape features which we will try to highlight today that can be produced natural tolerance ranges which we have already seen surface roughness capabilities and so on so forth. So, there are other criteria or attributes also which can help us to select the manufacturing process. These capabilities determine whether a process can be use to produce the corresponding part attributes.

So, each product will have some part attributes and those attributes we need to match with the process and then find out whether the process can be used for manufacturing that part or product or not.

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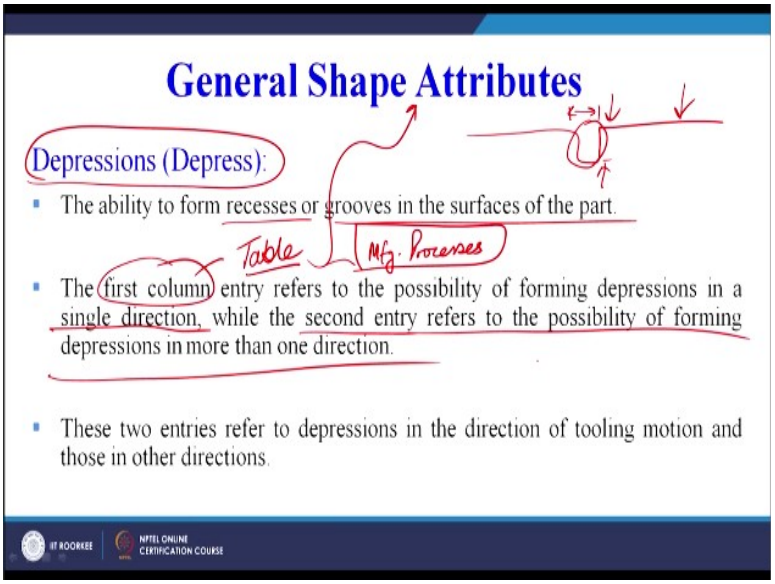

So, let us now quickly talk about the shape attributes, so the general shape attributes we will see some of the shape attribute first one are the depressions. So, depression can be maybe this is a surface there can be some depression here. So, this can be 1 depression, so the 2 important geometrical features here are the width as well as the depth of this depression. So, the ability to form recesses or grooves in the surfaces of surfaces of the part, so this is the surface.

And in this surface we want to produce this depression, now each and every process cannot produce this kind of a depression. So, therefore we have to see that this is my part attribute based upon the shape that I want to produce in my part. Then I have to look that which process is capable of giving me this type of a depression or this type of a recess or depress. So the ability to form recesses or grooves in the surface of the part.

So, the first column entry we will come to this table, first column is related to a table which is available regarding the shape attributes in context of the various manufacturing processes. That which process can produce which type of shape attributes and similarly the first column entry refers to the possibility of forming depressions in a single direction while the second column entry refers to the possibility of forming the depressions in more than 1 direction.

So, there may be a process which has the process capability of forming the depression in 1 direction only there can be processes which are more versatile in nature which can produce the depressions in 2 or more direction. So we will see that which 1 process is capable of producing depression in 1 which 1 is capable in multiple direction. Now these 2 entries refer to depressions in the direction of tooling motion and those in other direction.

So I think this will become more clear when we see the table, so there is a tabular arrangement which we will come in the subsequent slides. But let us see that what are the various shape attributes based on which we can categorize our manufacturing processes and try to relate them to the various types of shape attributes in terms of the process capability for each process that this process has this capability of producing these shape attributes.

Then another process may have a capability to produce a entirely different set of shape attributes. So those that is what we are trying to understand now, the other shape attribute is uniform wall or uniwall as given in the table.

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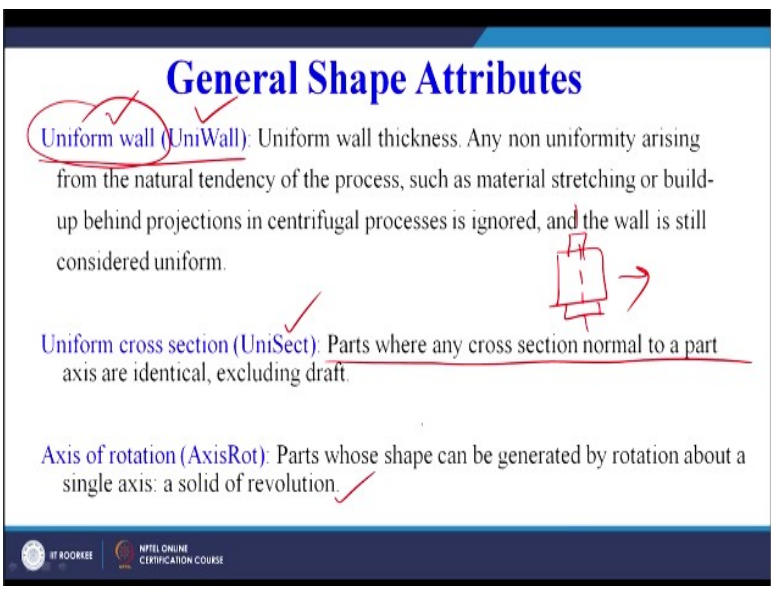

So, uniform wall thickness any non uniformity arising from the natural tendency of the process such as material stretching or building up behind projections in centrifugal processes is ignored and the wall is considered as the uniform wall. So uniform wall which process can produce we will see in the table, uniform cross-section unisect parts where any cross-section normal to a part axis or identical excluding the draft.

So, this is the basic definition of the uniform cross-section parts where any cross-section normal to the part, part axis. So maybe we have any part, we have a part axis here, so we can see parts where any cross-section normal to the part axis maybe in this direction normal to the part axis are identical excluding the draft. So this type of whose shapes which process can easily form, excess of rotation parts whose shape can be generated by rotating about a single axis or solid of revolution.

So this is easily understood the axis of rotation, regular cross-section, cross-sections normal to the parts axis contain a regular pattern.

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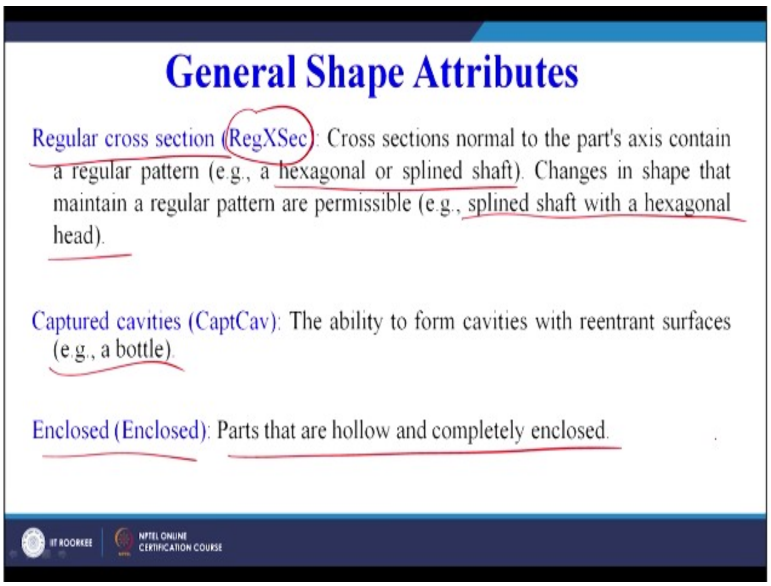

For example hexagon or a splined shaft changes in shape that maintain a regular pattern are permissible. For example a splined shaft with the hexagonal head, so which process is capable of producing the regular cross-section or the Reg XSec or Reg regular cross-section. Captured cavities the ability to form cavities with re-entrant phases for example a bottle enclosed parts that are hollow and completely enclosed.

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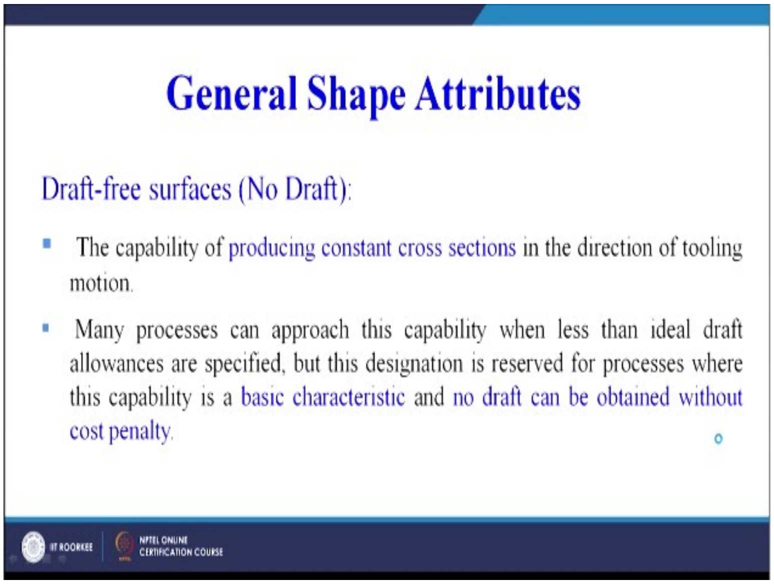

So, these are some of the general shape attributes then the draft free surfaces there is a long list of shape attributes that are that can be interrelated to the manufacturing processes. So, 1 can be draft free surface, for example there is no draft on the surface.

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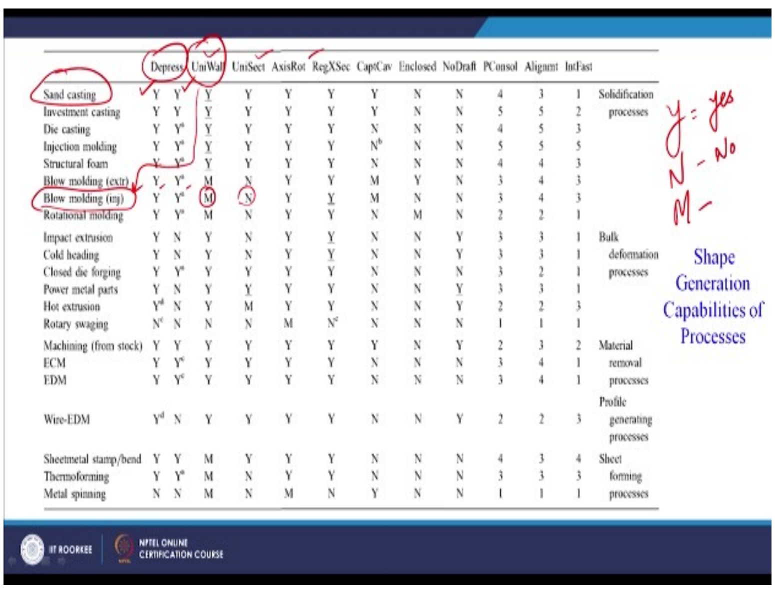

	Depress		UniWall	UniSect	AxisRot	RegXSec	CaptCav	Enclosed	NoDraft	PConsol	Alignmt	IntFast	
Sand casting	Y	Y	Y	Y	Y	Y	Y	N	N	4	3	1	Solidification processes
Investment casting	Y	Y	Y	Y	Y	Y	Y	N	N	5	5	2	
Die casting	Y	Y^a	Y	Y	Y	Y	N	N	N	4	5	3	
Injection molding	Y	Y^a	Y	Y	Y	Y	N^b	N	N	5	5	5	
Structural foam	Y	Y^a	Y	Y	Y	Y	N	N	N	4	4	3	
Blow molding (extr)	Y	Y^a	M	N	Y	Y	M	Y	N	3	4	3	
Blow molding (inj)	Y	Y^a	M	N	Y	Y	M	N	N	3	4	3	
Rotational molding	Y	Y^a	M	N	Y	Y	N	M	N	2	2	1	
Impact extrusion	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	Bulk deformation processes
Cold heading	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	
Closed die forging	Y	Y^a	Y	Y	Y	Y	N	N	N	3	2	1	
Power metal parts	Y	N	Y	Y	Y	Y	N	N	Y	3	3	1	
Hot extrusion	Y^d	N	Y	M	Y	Y	N	N	Y	2	2	3	
Rotary swaging	N^c	N	N	N	M	N^c	N	N	N	1	1	1	
Machining (from stock)	Y	Y	Y	Y	Y	Y	Y	N	Y	2	3	2	Material removal processes
ECM	Y	Y^c	Y	Y	Y	Y	N	N	N	3	4	1	
EDM	Y	Y^c	Y	Y	Y	Y	N	N	N	3	4	1	
Wire-EDM	Y^d	N	Y	Y	Y	Y	N	N	Y	2	2	3	Profile generating processes
Sheetmetal stamp/bend	Y	Y	M	Y	Y	Y	N	N	N	4	3	4	Sheet forming processes
Thermoforming	Y	Y^a	M	N	Y	Y	N	N	N	3	3	3	
Metal spinning	N	N	M	N	M	N	Y	N	N	1	1	1	

So, this is the table that I was referring to, now let us quickly see for example our sand casting process depress first column in 1 direction it can produce as well as in the multiple directions also it can produce. Uniform wall thickness is achievable by sand casting uniform section is axis of rotation is also yes, so Y means yes here and N means no. Similarly let us now take blow molding, so let us take another example that is blow molding.

Now in blow molding yes it can create depression but there is another term which is mentioned here as M. So, there are 3 terms basically we see Y which means yes it can be done as we have seen in sand casting N means no not suitable for this type of characteristics. For example we can take any N uniset it is blow molding is showing no but what do we mean by M, M means that the product must have this special characteristics if it has to be made by the blow molding process.

So, M is must have the characteristic, so this type of information that we see here can be easily used by product designer to select among the various manufacturing processes and on columns we have the various shape characteristics. So we have shape characteristics, we have processes in this direction and there is a mapping of the shape characteristics with the processes based on the depressions it can produce axis of rotation, uniform wall thickness, based on all these parameters we can select the various processes.

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Now next is the capabilities of a range of manufacturing processes again I am coming to the same point I am reiterating, remphasizing and re-highlighting the same thing again. In our previous 2 sessions our focus was to compare the various manufacturing processes based on the different attributes but the processes were compared for a individual attribute which can be shape, mass, tolerance achievable, surface roughness, batch size.

But that was on individual scale or individual nature for individual part attribute or for individual characteristic. But now for each process we want to have a compiled information that for example for sand casting what is the tolerance achievable, what is the surface roughness achievable or on the contrary surface finish achievable, what are the various application areas, what are the shape constraints, what are the number of products we must have.

Minimum number of products that will justify the use of sand casting, so there has to be tabular information based on all these attributes where the sand casting process stands or where what are the special characteristics where the sand casting process must be selected. Similarly the injection molding process where it stands in comparison to the other processes in terms of all these attributes, so all that information is also available in the compiled form.

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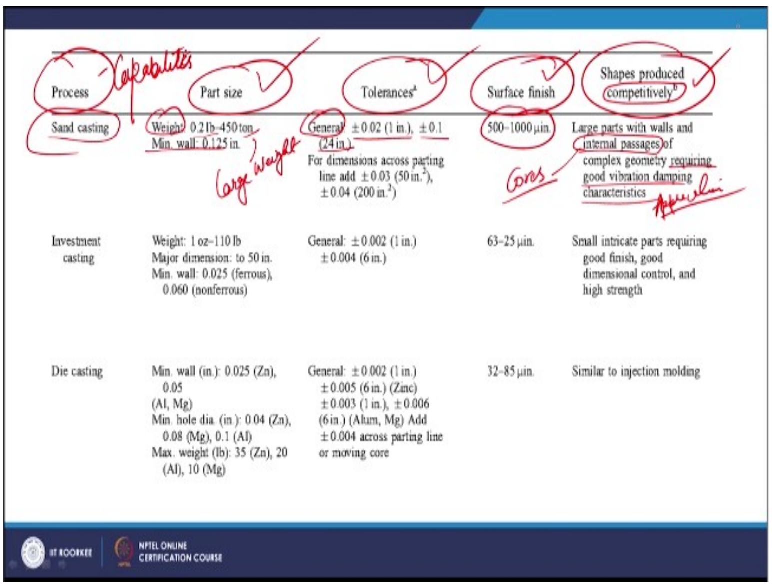

Process	Part size	Tolerances[a]	Surface finish	Shapes produced competitively[b]
Sand casting	Weight: 0.2 lb–450 ton Min. wall: 0.125 in.	General: ±0.02 (1 in.), ±0.1 (24 in.) For dimensions across parting line add ±0.03 (50 in.²), ±0.04 (200 in.²)	500–1000 μin.	Large parts with walls and internal passages of complex geometry requiring good vibration damping characteristics
Investment casting	Weight: 1 oz–110 lb Major dimension: to 50 in. Min. wall: 0.025 (ferrous), 0.060 (nonferrous)	General: ±0.002 (1 in.) ±0.004 (6 in.)	63–25 μin.	Small intricate parts requiring good finish, good dimensional control, and high strength
Die casting	Min. wall (in.): 0.025 (Zn), 0.05 (Al, Mg) Min. hole dia. (in.): 0.04 (Zn), 0.08 (Mg), 0.1 (Al) Max. weight (lb): 35 (Zn), 20 (Al), 10 (Mg)	General: ±0.002 (1 in.) ±0.005 (6 in.) (Zinc) ±0.003 (1 in.), ±0.006 (6 in.) (Alum, Mg) Add ±0.004 across parting line or moving core	32–85 μin.	Similar to injection molding

And here we have that table, so we can see here the process we are talking about the process capabilities in our session today, what are the capabilities part size, capability in terms of producing the part size, tolerances which are achievable, surface finish, shapes that can be produced competitively very very important competitively.

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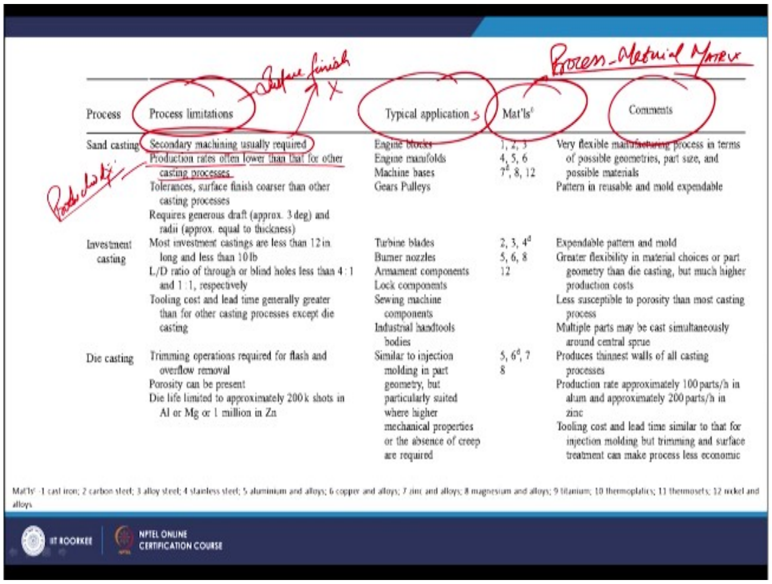

And then the other attributes process limitations, typical applications, the materials it can process and the special comments. Now we have a single process and all the attributes, so we can now compare the processes. In the previous 2 sessions for selection we have tried to discuss the individual maybe based on the materials we have seen there was a process, material matrix which we have seen in our previous sessions in session number 16.

We have seen this process material matrix, so the processes were listed the materials were listed and the dots were given. That this process is applicable for this material, so here also this is more concise, more compiled information for sand casting. So let us take the example of sand casting only by coming to the previous slide, so we can see the sand casting process can be used the weight is given 0.2 pounds to 450 tons.

So maybe for very large weight sand casting can be easily used minimum wall thickness is also specified. Similarly tolerances general tolerances can be given it is given here +/-0.02 on 1 inch similarly 0.1 on 24 inch. So, we can see the tolerances are given the size part size in terms of weight it is given surface finish is given 500 to 1000 micro inch applications or shapes that can be produce.

Large parts with walls and internal passages we can see for internal passages we can use course for those who have mechanical engineering background. So, where internal passages we can make course of complex geometry requiring good vibration damping characteristic. So, from application points also it is given, so we can see part size for sand casting what is achievable, tolerance achievable, surface finish achievable, shapes that you can produce, part weight already specified.

Then the process limitations if you see about the surface finish and if you go back to our previous session in which we have compared the process with the surface roughness and a chart was given. We have seen sand casting does not produce a very good surface finish which means a surface roughness is high. So, when the surface roughness is high in sand casting we need to do the secondary machining which is already mentioned here in this tabular information.

The limitation is secondary machining usually required why because the surface finish achieved is not very good, production rates often lower than other casting processes. Our die casting process whether it is hot chamber or cold chamber have fair degree of automation possible. But sand casting also can be automated and these days the foundries are fairly largely automated only but still the production rate for sand casting maybe because of the number of steps involved in the process is less, the productivity in terms of sand casting.

In term productivity maybe I am saying in terms of the number of parts produced per hour is less as compared to a die casting process. So, the production rates often are lower than the other forms of casting processes. So, production rate must not be confused with the word productivity, why I am so particular about productivity. Because in the course that we is going to start next semester that is on work system design we have had a lot of discussion maybe 1 or 2 weeks on productivity only.

So, we must be very very careful in the choice of our words, so therefore again I am reemphasizing the production rates are lower in context of sand casting as compared to the other casting processes. Tolerance, surface finish coarser than the other casting processes, coarser which we can simply understand as poor, the surface finish is poor as compared to the other casting processes.

Then requires the generous draft and radii which is another limitation, sometimes a draft has to be given on the product, typical applications are given engine blocks, engine manifolds, machine basis, gear pulleys. And we can see which type of materials can be used for sand casting process and I will take you to the list of materials here 1, 2, 3, 4, 5, 6, 7d, 8, 12, so it is given here I think you may not be able to read.

But ok the materials number 1 is cast iron, 2 is carbon, steel alloys, steel stainless, steel then maybe non ferrous copper and as alloys zincs and zinc, alloy magnesium and alloy. So, there is a long list of materials which can be used for the sand casting process, then the comments are very flexible manufacturing process in terms of possible geometries can produce different types of geometries.

Sand casting has that capability, part sizes can be different and possible materials because materials you can see here a long list of materials which can be produced by the sand casting process, pattern is reusable and the mold is expandable. So, we can very easily reuse the sand that we are using for making the mold in case of sand casting and the pattern maybe made of food or metal is also reusable.

So, this type of information gives a complete picture of a manufacturing process as we have taken an example of sand casting. So, if we can have this compiled information with us when we are designing our product and during that product design process wherever we have to specify the manufacturing process. We can just have a look at this summary of manufacturing processes and this summary will definitely will helpful to us when we propose the manufacturing process for making our product.

So, with this we conclude the today's session, in next session we will discuss specific product design guidelines related to the various manufacturing process that when we are designing a product, what must be kept in mind when we are going to make the product maybe by sand casting process. Then followed by maybe by die casting process, so that will be our objective of discussion in our next sessions till then.
Thank you.