

Manufacturing of turbines (gas, steam, hydro and wind)

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Lecture 06

Welcome to this course on manufacturing for turbines. So today we will see materials versus manufacturing processes in this lesson 6 of this course. So today's lesson will cover various topics related to mapping of materials to manufacturing processes with respect to several constraints like mass, tolerance, section thickness, surface roughness, economic batch size, shape of the component, and then summary of selection of the manufacturing process, interplay between materials and manufacturing process, material process compatibility, cost considerations and then we will conclude the lecture by going through sustainability, environmental impact and what is the future trends and innovation in this topic. So, we have seen all the classification of the engineering materials earlier. So, engineering materials in particular are divided in four categories.

As we have seen so they include metals they include polymers, they include ceramics, they also include hybrids so now engineering materials are known and then we would also like to look what is the philosophy of material selection for any application. So, this philosophy of material selection is based on the some factors like materials. Of course, they need to be selected. Then it is based on the functions of the functionality of the product.

What is the functions the product is going to perform? Based on the function of the product, the shape of the product is defined and then based on the shape of the product, we define what process or manufacturing process is going to get selected among this. So, here what is happening that in case of materials we know that in materials all materials they have specific attributes which need to be known. Now, these specific attributes can be any attribute, this can be attribute related to mechanical properties or they can be related to thermal properties or optical properties or they can be related to electrical properties and so on.

So, this interplay between these important aspects like functions, let us put in the end function, then this determines the shape of the product, shape of the product determines the manufacturing process. Also, the consideration is towards the specific material attributes as we have discussed. for example we are choosing any material from the metal metal family now if for any application if we are intending for a selection of material

based on the material family so in material family also we have many classification like it is ferrous or say non-ferrous for example we go with non-ferrous in non ferrous for any application if we are choosing aluminium based metals so in aluminium based metals, so again aluminium has several alloy series like aluminium 6000 series alloy. And then in this series of alloy we will further have specific alloys say aluminium 6061 which will be having specific attributes and these specific attributes will be matching to the functionality, the shape and consequently selection of the manufacturing process. So, by going around this figure as we have drawn here, so based on this, we can understand what is the philosophy of material selection?

Next we would like to also look at the philosophy or manufacturing process selection. So, manufacturing process selection is also important because once material is selected, so on what basis do we select the manufacturing process. We have highlighted some of the basics of the manufacturing process in the previous lesson. So, we know now the all the for example, we know what are the all the manufacturing processes are known. So, all from the all the manufacturing process we first start by you know translating the design requirement.

What I mean by this point is by translating the design requirement I mean we need to identify the functionality or the functions. We need to understand the technical and quality requirements which are decided by certain objectives, objective functions and maybe there may be some free variables available. So, then after doing that essentially here what we are doing is what functions are, what is the functionality of the product, what are the materials selected, what will be the shape and so on. Next we want to screen out or screen the manufacturing processes based on constraints. So, here what we will do is we will eliminate processes that cannot do the job means if we are making any product of a specific shape. So, all the manufacturing processes not only shape, but it is also dependent on the size, mass of the product, tolerances and so on. So, the particular process cannot meet out these requirements. So, we will eliminate all those processes. Then in the remaining processes, what we will do is we will rank it, rank the processes using objectives.

So, ranking of the processes using objectives include among the screened processes, we rank how economically a process can do the job. So, here economics come into picture or the cost of running a process come into picture. And lastly, we can seek documentation regarding the say for example effect of the process parameters on certain defects. We can seek information related to optimum process parameter optimum process parameters related to the output, maybe the surface roughness or tolerance and so on. So, by following these four steps, we can reach to optimum selection of the manufacturing process.

So, this is true for making any product and be it the gas turbine, steam turbine, wind turbine anything. So, we will see in future lessons how this philosophy of selecting materials and selecting the appropriate manufacturing processes interplays while we discuss manufacturing of gas turbines, steam turbines, hydro turbines and wind turbines. So, now we would like to spend some time on understanding how the matrix of this materials and different constraints of processes it interplays, how different materials are suitable to certain processes and certain materials may not be suitable for some other process. So, we start with this first matrix discussion here where on the y-axis the manufacturing processes are mentioned and they start with the primary manufacturing processes. So, all the shaping processes are shown here which start from sand casting and up to say vacuum bagging.

Then we have certain other secondary processes. So, the joining and finishing they come in the secondary processes. Shaping as we have discussed it is a primary manufacturing process. So, now here what is happening that certain processes for example the sand casting, it is very suitable for metals and in metals it is very suitable for ferrous and non-ferrous metals. But this process is not suitable for any other class of materials be it ceramic, glasses, elastomers, thermoplastics and so on.

So, the circle shown here in the matrix basically highlights the optimum use of the particular manufacturing process with the respect to the given material. We can take any other example, for example, conventional machining. So, conventional machining we know is a subtractive manufacturing process where material removal is done by contact, physical contact between the tool and the workpiece and in all conventional machining processes the hardness of the tool is higher than hardness of the workpiece. So, conventional machining processes we know are very versatile in terms of handling workpiece materials.

So, they are suitable say here for metals which is ferrous and non-ferrous both certain extent they can also manage ceramics with very hard cutting tools, glasses, elastomers, thermoplastics, polymers, polymer foams and so on. Then there may be certain processes like in the last of the primary manufacturing processes shown here like resin transfer molding, filament winding, layup methods vacuum bagging which are only suitable to certain composites and particularly say polymer matrix composites. Similarly, in case of joining based processes where we have adhesives, used to join different parts. So, adhesives are very versatile we can see they can use be used for all class of engineering materials. But welding - Fusion welding, it is only suitable for metals.

So fusion welding is not available in any other class of materials. Similarly fasteners, they are also very versatile. Fasteners can be used to fasten any class of engineering materials starting from metals up to ceramics, polymers, etc. Then we have finishing

processes where we want to improve the surface finish. So in this we have precision machining, grinding, lapping and polishing processes.

Again, some processes are more suitable for metals and some other processes are only suitable for say polymers or ceramics etcetera. Next, we like to look at the how the mass of the component. So, mass of the component here is basically specified in kilograms. So, how the mass of the component decides the selection of the manufacturing process. So, here again manufacturing processes are listed on the y-axis and mass of the product is listed on the x-axis.

So, here we can see that some processes. For example, the sand casting process, it can manage mass from say 1 kilogram to maybe 10000 kilograms. So, very heavy parts can be managed or can be manufactured using sand casting. But at the same time if we look example of investment casting, so investment casting can make products ranging from mass 10^2 kilogram to say up to 10^4 that is up to 100 kilogram. So, it cannot manage very heavy products.

Similarly, for the colors shown here, they highlight the colors for metals like for most of the metals are shown with orange, the ceramics are shown with yellow, polymers are shown with blue and composites are highlighted with red color. So, the range of mass which a particular process can manage and accordingly the color coding highlights which process is suitable for which material and up to what mass of the product because mass of the product is very important in the functionality and similarly in joining also we can see that fasteners they can join even very small products of 10^2 kilogram also they can join very large products as we have seen in bridges and so on several rivets are used so they can also join very large products. So, this provides a versatility to the use of fasteners as an example. Next, we would like to look how the different manufacturing processes are mapped not only with material but with tolerance. So, tolerance here is a very important term with respect to manufacturing processes which is acceptable deviation in the dimensions of a product or component.

Acceptable means in any manufacturing processes it is practically impossible to produce the exact same dimension every time. So, always there will be certain variation in the dimension of the product and that acceptable range of that deviation is known as the tolerance. So, certain processes for example sand casting they can have very high tolerances of the order of 1 to 10 millimeters. So, here again tolerance is shown on x-axis in millimeters and the manufacturing processes are listed on the y-axis and they are color coded in the same fashion like orange is for metals, yellow is for ceramics, blue is for polymer and red is for composites. So, for example, the sand casting process, it can manage very heavy components, as we have seen in the previous slide and the tolerance that it produces is also very large.

And then if you look example of investment casting, we have seen it can manage components up to 100 kilogram, but it can provide tighter tolerances ranging from 0.1 to 1 millimeter. And certainly, there are other processes depending on optimization of the process parameters, we can reduce the tolerance further. For example, in conventional machining by optimizing the process parameters, selecting the appropriate tool, we can have very tighter tolerances or in nominal conditions, they can also provide a broad tolerance range. And generally, it is seen that cost of manufacturing process or cost of manufacturing, it basically is, you know, tighter are the tolerances is basically you can say is inversely proportional.

So, if tolerance are small, so cost is high, means any process which is producing precise components, the tolerances are very small, so cost is much higher. For example, if we see in case of this precision machining and grinding and lapping, so they can produce very tight tolerances but cost is much much higher. So based on what is the tolerance required in the component because Presence of tolerance is also important from the aspect of assembly of different sub components and also it is important from the aspect of interchangeability in different components which are needed for repair and maintenance aspects. Next, we would like to look at how the manufacturing processes are mapped with the section thickness. Section thickness is basically how thick components are produced using various processes.

Again, in this regard, we take example of sand casting process which can produce very heavy components. So, of course, their section thickness will also be much higher up to 10 to maybe 1000 millimeters. And then with they we have all other processes like sheet forming and so on where the thickness of the sheet is much smaller. So, their section thickness is 0.1 to up to say 10 millimeters and all other processes are shown as mentioned in this chart.

Next is the surface roughness because surface roughness again plays a very critical role in assembly and interchangeability of components. So certain manufacturing processes they produce parts with high surface roughness and certain processes they can produce components with very low surface roughness. So, surface roughness and then there is another term surface finish are both interrelated of course inversely interrelated. So, some part having high surface roughness means the surface finish is low and vice versa. So, again we know that for example sand casting is a very popular casting process here section thickness is also high, mass of the product that it can manage is high, tolerances are high and of course the surface roughness is also high.

So, whenever surface roughness is high such parts are subjected to machining to improve the surface finish or reduce the surface roughness or we can have other processes like investment casting process where surface roughness is much much less compared to sand casting and this type of processes are very popular to produce a gas turbine blades as we

will discuss in further slides. and the surface roughness, it reduces further with finishing operations as we know using grinding lapping and honing or maybe the polishing process to surface roughness is further reduced and depending on the material like these processes are more popular with metals and ceramics polymers and polymer composites do not need much extent of surface finishing operations as the primary process which make them have generated enough smooth surfaces that further need of finishing operations is not there.

Next is how the manufacturing processes are mapped to the economic batch size. Economic batch size is important that sometimes a process may only be able to produce few number of the products and in certain other cases some manufacturing processes may able to produce large number of products. So, some processes like the die casting we know is used largely in automobile industry to produce parts of automobile is also popular with non-ferrous materials to produce parts of non-ferrous materials for automobiles is able to produce large economic vessels.

Means if we are able to produce a number of units ranging from 10 raised to power 4 to So, then the process becomes economical. But in the same process if we try to produce less number of units it is not that process will not be able to make them, but it will not be economic because in manufacturing process economics is very important what is the cost that is going into making a product and sometimes making large number of products makes the process economical and in certain cases making few products only makes the process economical. So, again we will take example of say investment casting. So, where investment casting is suitable up to a small batch size up to say 10 raise power 3 and if we compare this with say sand casting it is economical to produce up to say 10 raise power 5 and if you compare it with die casting it is able to produce up to 10 raise power 7 units economically. Similarly, all the other manufacturing processes with the respective materials are mapped and shown in this slide where we can appreciate that some processes are good for small number of parts.

For example, all these polymer composite based processes like filament winding, layup methods, vacuum bagging, they produce few number of parts given all the arrangement needed to make one part. And certain metal based or maybe polymer based like injection molding and blow molding, they are able to produce large number of parts in an economic batch size. Next, we would like to look how the shape of the component because shape is a very important criteria in deciding the selection of material as well the manufacturing process. So, all these shapes shown here, prismatic, sheet shape or the three-dimensional shape whether the shape is circular or non circular. If it is a sheet, it is a flat shape or it is a dished shape.

In case it is a three dimensional shape, is it a solid shape or is it a hollow shape? So based on these considerations, so how the different manufacturing processes are mapped and in

which scenario they become economical is shown here. For example, again we take one example from the chart like conventional machining which is a very versatile process. It can manage say metals, polymers, ceramics. It is also able to manage different types of shapes with all the prismatic sheet and 3D shapes. And certain processes may not be very economical with other shapes like vacuum bagging it is only able to produce sheet shaped components with polymer matrix components and that is why it is not able to produce a circular or non-circular based prismatic shapes.

So again this is basically the summary how the manufacturing processes are selected. It is what we discussed just in the beginning slides that all the materials we know and the materials have certain attributes which influence the processing that is the shape, what is the joining method, what is the say surface treatment needed. The material also decides the functionality of the product which are determined by certain constraints or maybe objectives of selection and the shape will decide what is the shape factor and shape is course selection with respect to material properties and the shape of the product. So, we can now understand the interplay between materials and manufacturing processes wherein we can see that there is a mutual influence of material properties which influence the manufacturing process example machinability of metals influence how it can be cut or shaped manufacturing processes they also affect the properties of the materials because processes like heat treatment they may also enhance certain properties of materials say hardness or ductility We also need to understand the optimization challenges because the performance requirement may need a careful balance between material selection and manufacturing process to meet out the desired mechanical, thermal and chemical properties. We may also need to look into optimization of cost considerations where we need to choose the most cost effective combination of material and manufacturing processes.

without compromising the quality and functionality of the product. We also need to take care of design considerations which ensure the selected materials and processes can achieve the required design specification and tolerances. So, innovative solutions are available in terms of advanced materials. So, materials are continuously advancing and new materials are continuously developed in terms of for example, new types of composites which are much lighter in weight having high strength or maybe development of super alloys which can retain their hardness and strength even at elevated temperatures. Although materials are getting continuously developed at the same time. These materials they may require specialized manufacturing processes.

So, this implies the next point which is development of new manufacturing processes using innovative process example say additive manufacturing or maybe precision casting which enable the use of such advanced material in complex design. Material development may not be sufficient in parallel to material development the manufacturing processes

may also be continuously need innovation to manage the new materials in complex shape products. So, if we summarize the impact of this interplay between materials and manufacturing processes on industry. So, in industry the new product development can enhance to create high performance and reliable products. Sustainability is a very important component these days which targets improved efficiency, reduced environmental impact through optimized material selection combinations.

It can also lead to a competitive advantage leveraging advanced material and processes to stay ahead in market for any manufacturing industry. So we would also like to look at the material process compatibility, how the different properties of materials, say the mechanical properties, thermal properties or chemical properties, they influence the material and process compatibility. Influence of material process on process selection may be there in terms of machinability or formability. how the impact of process leads to change in material properties like example heat treatment effects may cause a reduced hardness or maybe improved ductility or inducing of the residual stresses, how the heat treatment may help to relieve the residual stresses. Example, aluminium alloys being used in aerospace are widely popular because they balance the lightweight requirement and strength requirement with capabilities of being formed and machined easily.

Similarly use of advanced polymers in automotive applications is from the aspect of that such polymers can be injection molded using injection molding processes into complex geometries at a very efficient cost in large economic batch sizes. So material cost as we have discussed the relative cost between different materials is very important because cost of the material is intertwined with the cost of the final product. So, cost of the raw material largely depends on the selection of the material and also it is dependent by the availability and supply chain factors because some material may not be available at a particular location, it needs to be shipped in from some other location. So, supply chain factors also play a very important role. So process cost where equipment and tooling cost also bring in the enhanced cost of manufacturing and labour and energy consumption cost also play a very important factor in the process cost.

So balancing cost and performance are important from the aspect of managing cost considerations. So trade-off between high performance material and cost effective processes may be needed. and we may imply strategies for cost optimization example hybrid materials or innovative processing techniques. So, impact of manufacturing and materials is there on the environment also. So, from the sustainability and environmental impact we need to look at materials which are renewable and recyclable.

We need to also look at materials which are biodegradable and have environmental friendly disposal options. We need to also look into innovative manufacturing processes which are energy efficient and also the processes which imply on waste reduction with sustainable recycling practices. Life cycle analysis may also be helpful in assessing

environmental impact during material extraction to product disposal and we need to have importance of sustainable practices in the modern manufacturing processes. So, the future trends and innovation on this topic include application of smart materials which are basically materials which have adaptive or responsive properties in various applications like medical devices, aerospace and consumer electronics. Advanced manufacturing techniques like utilization of digital manufacturing industry 4.0, integration of AI and internet of things in manufacturing processes. We also need to have sustainable manufacturing by following the circular economy approaches and utilizing green manufacturing technologies. So, with this we summarize the today's lesson in which we have looked at the material selection philosophy.

We have looked at manufacturing. process selection. We have looked all the mapping between materials versus manufacturing processes. in terms of various aspects like economic best size, tolerance, surface roughness, mass of the component, etcetera, etcetera. We have also looked from the different aspects related to minimization of cost considerations. And then we have summarized today's lesson by looking at future trends in materials and manufacturing processes how they influence the product development in coming times. So, in the next lesson we will look at material selection, precision and metrology in turbines.

We will look at what are the key factors in selection of materials for turbines, mechanical properties, wear manufacturing and fabrication considerations. What are the precision and metrology, how these are implied in manufacturing of turbines, key techniques, their calibration and then we will look at the future trends in the aspect of precision and metrology of turbines.

Thank you.