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

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Lecture 05

Welcome to Lesson 5 in this course on manufacturing for turbines. In today's lecture, we will discuss manufacturing processes and manufacturability. So continuing from the previous lesson, we will complete the discussion on engineering materials, in which we will cover the details of ceramics and composites. After that, we will move on to the manufacturing process and the manufacturability of materials, where we will look at materials information, manufacturability, and the basic properties of materials that influence manufacturability. So we have already understood this classification of engineering materials in terms of metals, plastics, ceramics, and composites. In today's lecture, we will discuss details about ceramics.

So in ceramics, we know these are compounds of metal and non-metallic elements. Ceramic is basically a term derived from "keramos," which means potter's clay. The use of ceramics is very ancient. It can be traced back to as early as 4000 BC, when ceramics were used to make pottery and bricks.

Ceramics are widely categorized into two types. The first category is traditional ceramics. So traditional ceramics include whitewares, tiles, bricks, and pottery. Industrial ceramics include cutting tools, semiconductors, gas turbine components, and automotive components, which, for example, include spark plugs. Examples of engineering ceramics include simple oxides such as silicon oxide, aluminum oxide, and iron oxide.

Mixed metal oxides also fall into the category of ceramics. And then we have nitrides, which are used in several hard coatings. Examples of nitrides that are used in hard coatings include silicon nitride, aluminum nitride, and others. Now, the distinguishing features of ceramics are being discussed. So, ceramics essentially consist of a compound or a mixture of metallic and nonmetallic elements.

So, this means that in ceramics, one of the atoms will be a metallic element, and the other will be a non-metallic element. So, ceramics are also characterized by a lower density than most metals because the combining nonmetal is generally either an oxide or a nitride. Or maybe it's carbide. So, because of that, the density is much lower than that of traditional metals. Ceramics are also generally stronger than metals, especially under compressive loading conditions.

They have low resistance to fracture. This means they have very low toughness. They cannot absorb much energy, and it is often known that ceramics fracture under impact loads. Their low ductility and low malleability mean that they have low plasticity. They have a high melting point.

They are poor conductors of electricity and heat. They are single crystals when they are transparent, and except for glass, most ceramics exhibit a regular arrangement of atoms. They are resistant to heat, and they are chemically stable. Applications of ceramics include several electrical insulators, abrasives, cutting tools, and thermal insulation coatings. This is particularly useful when we look at the gas turbine manufacturing.

The thermal barrier coating in the gas turbine blades utilizes ceramics. Then, windows, screens, etc., in the form of concrete are also used in highways and roads. Biocompatible coatings are used in scaffolds, among other things. Magnetic tapes, body armor, hip implants, and radiation shielding.

So, these are some representative applications of ceramics. So, in the subcategory of ceramics, we also have glass. So, glasses are amorphous solids with the structure of a liquid. So these glasses are produced by supercooling at a very high rate so that the crystals are allowed to form. So glasses generally don't have a distinct melting or freezing point, and their behavior is very similar to that of ceramics.

So glasses are widely used in window glass, container glass, and they are also used to make fiberglass, which is used as reinforcement in several composites. These are some examples of glasses, which include soda-lime glass, lead-alkali glass, borosilicate glass, and fused silica glass. Next, we will look at details about composites. Now, composites are basically a combination of two or more chemically distinct and insoluble phases. So these are hybrid classes of materials where the properties of the composites are superior to those of their constituents.

Another distinguishing feature of composites is that the constituents of the composites are distinguishable. And they do not combine on a microscopic level; rather, the constituents combine on a macroscopic level. So, this means that we can distinguish both the constituents there. And generally, in the case of composites, we have the reinforcement of different types, which can include fiber, filament, or particulate, etc. that are characterized by high strength, high stiffness, and low density.

So, because of these properties, the filament and/or the particulate come under the category of the reinforcing phase, which is surrounded by the matrix. Now, this matrix can be either a polymer matrix, a metal matrix, or a ceramic matrix. So the matrix generally covers the reinforcement from all sides, and it exhibits good shear properties and low density. Combining the reinforcement and matrix gives a result of a composite that generally has high strength, high stiffness, good shear properties, and low density. And here the essence of combining both the things, that is the matrix and reinforcement is because we have a physically distinct interface between, say, the fiber or the reinforcement and the matrix.

So, we can distinguish between both of them, and there is no reaction or combination on the microscopic level. Now, if we talk about composites, they utilize fibers, especially the structural composites that are used in aerostructures or in wind turbine blades. So, they utilize fibers, especially synthetic fibers like glass fiber and carbon fiber, or in some applications. Kevlar or boron fiber may also be used, and in many applications, natural fibers derived from plants and animals may also be used as reinforcement. In terms of matrix, the matrix material can vary between polymer, metal, or ceramic.

In the case of polymers, thermosets can be used, and thermoplastics can also be used as the reinforcement. So, we know from our previous lesson that thermosets are basically polymers in which permanent crosslinking bonds are developed. And then what happens once the permanent crosslink bonds are developed? Here, the remoulding upon the application of heat is not possible. In the case of thermoplastics, we know there are no permanent cross-links, so we can remould them upon the application of heat again and again. And in metals, many times it is observed that non-ferrous metals are used as reinforcement to develop metal matrix composites, which include aluminum, magnesium, and titanium.

Then we can also have ceramic-based composites where silicon carbide, silicon nitride, or aluminum oxide-based matrix materials are used. So, as I have already mentioned, ceramics are very popular in applications that require high strength and low weight. So, aerospace applications are one of the largest users of composite materials here. Now, with that, we enter the next module of this discussion topic of the course, which is the manufacturing processes. We will be spending some time discussing the overview of the manufacturing processes; nevertheless, we are not going to go into specific details.

So manufacturing processes, as we know, are basically processes to convert raw materials. So we convert these raw materials into finished goods. And then what happens in this is that we are converting the raw material into finished goods, so there can be either primary shaping processes. There can be secondary shaping processes, joining processes, or surface treatment processes. So, some of the processes in the case of primary shaping include casting-based processes, such as sand casting, die casting, and investment casting.

Then, in the case of molding methods, which are especially popular with polymers, we have injection molding, compression molding, or blow molding. Deformation-based methods include rolling, forging, and drawing. Powder metallurgy-based, powder-based methods like sintering, hot isostatic pressing, and slip casting are available. Composite forming methods are available, such as hand layup. Filament winding and resin transfer molding.

Then we can have special methods such as rapid prototyping, layup, electroforming, etc. In the case of secondary processing, we have machining or heat treatment. In machining, we can have a wide variety of processes like cutting, drilling, etc. Heat treatment can involve processes such as quenching, tempering, age hardening, etc. There are joining processes that include fastening using rivets, welding, which is fusion-based, or possibly solid-state welding.

We can have heat bonding, snap fits, adhesives, etc. So, surface treatment methods can also be included, which involve engineering the surface of the developed product. This includes polishing, texturing, plating, metallizing, anodizing, painting, etc. And by completing all these processes, we basically convert this raw material into the finished product. So for any product, it is not just one manufacturing process that is used; rather, a sequence of manufacturing processes is used.

And this is dependent on the material that is used in making that particular product. So we will now see an overview of all the manufacturing processes as shown here, starting with this casting process. So the casting process is one of the primary shaping processes where we have a mold that is created using a pattern. So, the mold is basically a cavity that takes the shape of the pattern, and upon pouring molten metal into this mold cavity. Upon solidification, the molten material takes the shape of that mold cavity.

Now this depends on different types of molds; different types of patterns can involve different types of casting processes. So, we popularly have the sand casting process where the mold is made of sand. Then we have the die casting process, where we have a permanent mold made up of metallic molds, and this is popular with non-ferrous materials. And upon solidification, what is done is that the mold is not broken; rather, with the help of these ejector pins, we can remove the solidified cast product. Then we have the investment casting process, where the casting is done using wax patterns.

So this is very popular, especially for making the gas turbine blades. We will see in great detail as we go forward in this course. And then there is low-pressure casting, where we have zirconia sand mixed with a binder, and with the help of the low pressure maintained here, We can pump liquid or molten metal, and sometimes we also utilize cores to create cavities or hollow castings as per the requirements of the end product. So then next are the forming waste processes. So forming waste processes are just the processes that change the shape of the product by applying stresses beyond the yield stress but less than the fracture stress.

So it is that the forming processes function in the plastic zone of the loading deformation of the particular material. So, in this case, we have a forging process where we have two dies in which the workpiece is placed, and upon applying these compressive forces, the workpiece takes the shape of these dies. Then we have a rolling process where, in the case of rolling, we have these two rolls through which the workpiece is passed. And it takes the shape of this cross-section between the rolls, or we can have extrusion where a billet is pushed through the die while it is being pushed. The product takes the shape of the die opening, or we can have this type of spinning process where sheet metal can be shaped into appropriate shapes.

Next are the machining processes discussed earlier. So machining is basically a secondary processing of products. where, of course, we want to have different shapes imparted, or we can have different forms imparted to the product. especially if we want to have a smooth surface or create some holes, etc. So in machining processes, what happens is a relative motion generally known as relative motion between the cutting tool.

So, in conventional machining, there is a relative motion between the cutting tool and the workpiece. And this relative motion between the cutting tool and workpiece is achieved using a machine tool on which the workpiece and the cutting tool are mounted. So, now this relative motion creates this, applies these forces, and stresses are induced; essentially, the shear stresses are induced, which cause the formation of a chip in conventional machining. And in conventional machining, as shown here by the example of turning and milling, the performance of conventional machining is highly dependent on the hardness of the cutting tool. So, this green color is, for example, the milling cutter or the single point cutting tool used in turning.

So, generally, in conventional machining, the hardness of the cutting tool is much higher than that of the workpiece. Machining is not only done using conventional methods, but there are several non-conventional methods as well. where energy in some other form may be heat, chemical, plasma, discharge, etc. Or maybe the kinetic energy of abrasives can also be used to remove material; for example, here it is shown how the plasma cutting process works, where this plasma beam is generated. And then this plasma beam, as we know, has a very high temperature.

So this is a thermally based machining process. So this plasma beam interacts with the base material, and because of this, wherever it interacts, melting of the workpiece takes place, and consequently, material removal occurs. Then we have electro discharge machining, where several electric discharges between the tool and workpiece remove material. And we can also have water jet cutting, where we have abrasives entrained in a high-pressure water stream. And when this high-pressure water stream strikes the surface of the workpiece, because of the inherent hardness of the abrasives, we can remove material and machining can take place. So, we can say that machining, in all senses, be it conventional or non-conventional, is a subtractive manufacturing process.

So it means material is being removed in the machining process. Next we have joining processes. So, joining processes are also secondary processes where we join two different parts that are produced using previous processes, as discussed. So they can be cast, formed, or machined.

So joining is very essential. So we can have different methods of joining depending on the different types of materials. So very popular adhesives are used in many joining processes, which basically is a form of glue. which are applied to the faying surfaces of the products that need to be joined, and then subsequently, some pressure may be applied to help the adhesive join the two parts. Sometimes these adhesives may also need some heat, as they also need curing. So sometimes heat may be applied, or leaving that adhesive in atmospheric conditions may also result in the joint.

So now we can also have the joining using various fasteners; this joining can be done using several fasteners. Like rivets, screws, or maybe snap fits, what happens here is that we need to drill holes, and subsequently, these can be applied. This can be a temporary fastening where we can open up. The joint is used as needed, especially when we want to do some repair or maintenance, but in the previous case, adhesive joining is a permanent joining. So below we have the example of fusion welding, where an example of manual metal arc welding is shown.

Where we have an electrode and workpiece, an arc is created between them, and because of this arc, melting takes place, resulting in the complete fusion of the base material, and the filler may also fuse. We also have examples of welding from the hot bar polymer welding process, where heat from this hot bar is used to melt the polymer sheets and join them. If you look at the manufacturability of the materials, you will find that it is dependent on the basic properties of the material. These are also dependent on the performance, processing, and structure of the materials. This interconnection between all four parameters influences the performance and manufacturability of any material for a given product.

So, the basic properties that influence manufacturability for any material include strength, which is the amount of load a particular material can withstand. It is also dependent on hardness, which is the resistance to scratching. It depends on the toughness, how much energy can be absorbed, and what the melting point of the material is. That is the temperature at which the material changes phase from solid to liquid. What is the viscosity that tends to flow in the molten state? What is the tendency to form oxides that is captured by the process of oxidation? So, using these different properties, we have developed specific maps where the various properties of the materials are mapped.

So, here, for example, the density of the material is shown on the x-axis, and the strength of the material is shown on the y-axis. Then all the materials that we have discussed up to now, which include plastics, polymers, metals, ceramics, composites, other natural materials, and foams, are considered. So, for example, if we look at this chart comparing strength and density, we can see the material's density. So, here we can see that the foams have a much lower density, and their strength is also much lower. Here, it is important to note that the scale of these graphs is not a linear scale; rather, it is a logarithmic scale.

So, the properties they increase tenfold at the next major point. So what happens here is that the foam, for example, in the case of foams, has a much lower density, but if you compare it to metals, the density is much higher. So now what happens is that by using these maps, we can choose the appropriate material and use it for a specific application. So, in this slide, we look at the representative maximum service temperatures for various materials. So we have seen that our strength, melting point, or maybe hardness, etc. influences it, so it is very important to understand this concept of service temperature.

Also, service temperature is important. Basically, the temperature at which the product will satisfactorily perform its intended function is based on the classification of materials that we understand: metals, polymers, and ceramics. And in hybrids, we can see that certain materials have service temperatures. Very few, maybe up to 500 degrees Celsius; most of these carbon steels, copper-based alloys, aluminum-based alloys, and magnesium alloys function below 500 degrees Celsius.

And whenever there is a requirement for high-temperature materials, we have refractory materials such as tungsten-based alloys. Or we can have nickel-based superalloys, which are widely used in gas turbine blades, as we will see in the next few lectures. Then, in the case of polymers, we know that they cannot sustain very high temperatures. So, their service temperature is generally on the order of 100 to 120 degrees centigrade, and for some polymers, it may be even lower, near room temperature, and so on. For ceramics, we know that they are very stable at high temperatures.

So, what you will observe here is that most of the ceramics have very high service temperatures of more than 1,500 degrees centigrade. So, the service temperature is also important to understand from the perspective of the melting point. So, generally, the service temperature of any material may be around 0.4 to 0.6 times the melting point of that particular material. So, all of these ceramics have very high service temperatures. So all the high-temperature needs are fulfilled by using this ceramic material. And in the case of hybrids, which include composites, we have ceramic foams that can withstand particularly high temperatures. But all other engineering structural polymer composites, like CFRP and JFRP, have service temperatures on the order of 100 to 120 degrees Celsius. Then we can also look at the representative comparisons between strength and toughness.

So, strength is the maximum load-carrying capability, and toughness is the total energy absorption of the material before failure. So, it is observed that metals generally have high toughness and strength. And at the same time, ceramics or glass, whatever we have discussed, has low toughness. So, they are only relatively on the right-hand side of this curve and the left-hand side of the curve. Then, relative hardness and approximate strength are taken into consideration.

So, for most engineering materials, hardness and strength are directly proportional. And hardness, we know, is the ability to resist scratches. And hardness can be measured using various hardness scales like Rockwell, Vickers, and Mohs. Wherever materials are known to have high strength, they are also known to have a high hardness impact. Then, what is the very important price of the materials per unit volume? Of course, this is very important once we make products because the cost of the product also includes the cost of the raw materials that go into making them.

So, some of the metals, like cast iron, aluminum-based metals, and carbon steels, are relatively lower in cost compared to other metals. Alloys such as nickel-based superalloys and titanium-based materials are present. Polymers, most of which have a lower cost than metals, include some, such as PEEK and PTFE. They will have significantly higher costs compared to their counterparts in the polymer industry. Ceramics, such as traditional ceramics like stone, brick, and glass, are low-cost, but engineering ceramics are not.

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Polymers generally have a lower cost, even less than metals, but some polymers, like PEEK or PTFE, have a significantly higher cost compared to other polymer counterparts. Ceramics, such as traditional ceramics like stone, brick, etc., are of low cost, but engineering ceramics are different. Aluminum nitride, tungsten carbide, and boron carbide all have a very high cost, and of course, in the case of composites. Hybrids, such as glass fiber and carbon fiber, have a very high cost due to the high cost of the reinforcement.

All other hybrid materials are placed according to their relative cost. So, it is very important to appropriately pick the material according to the cost because the cost of the product is largely dependent on the cost of the raw material. So, with this, we summarize today's lecture. So, what we have understood is the details about the engineering materials. In engineering materials, we have looked at ceramics and composites.

Then we have looked at the basic classification of manufacturing processes. We have looked at manufacturability. So what properties influence the manufacturability of any material? Then we looked at certain property maps. We have looked at, for example, the comparison between strength and density and the comparison between toughness and strength. Then we looked at the concept of service temperature. We have also looked at the concept of relative cost and how it influences the selection of the appropriate material.

So, with this, we complete this lesson, and in the next lesson or lecture, we will look at the mapping between materials and the manufacturing processes. In terms of mass components, tolerance, section thickness, surface roughness, economic path size, and shape of the component. And then we will summarize the manufacturing processes and how we have to select the appropriate manufacturing process.

Thank you.