Manufacturing Processes -1
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Module - 01
Lecture - 01
Powder Metallurgy - 1

I welcome you all to the session on powder metallurgy. Today, we are going to start a very important discussion on one of the most important aspects of mechanical engineering - that is manufacturing. Now, how much importance do we give to manufacturing? As soon as we get up early in the morning, we go to our washrooms, we use the brush to brush our teeth, how much attention we give that how that brush is manufactured? Like I am sitting on a chair - how the chair has been manufactured, how much attention do I give to it.

The table, the mouse I am using the computer we are using, how much attention we give to the manufacturing aspect of all these things. All these things are directly related to our lives, but how much attention do we give to the manufacturing aspects of all these things. So, these series of lectures that we have started today, we cover powder metallurgy as well as the sheet metal forming operations. So, there will be series of 12 lectures out of which 3 lectures will be dedicated to powder metallurgy, and 9 lectures will be dedicated to sheet metal forming operations.

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So today, we will start our discussion on powder metallurgy. So, as we go through this lecture, I will just like to introduce or give to you the overview of, how we are going to go about in this 3 series of lecture on powder metallurgy. First of all, there will be a brief introduction to manufacturing, as I have already given you a brief overview that, how much important manufacturing is to our lives. As I have already give an example of tooth brush, of chair, of mouse, of television, of water bottle, of class all these things had been manufacturing using one or the other processes.

We can leave apart some of the things, which have been made by god, if we say mountains, mountains is have been created by god, we have not made them, but there are some at certain other things which we have made, like some of the examples that I have already coated in the beginning of the lecture. So, we will see that what are the different types of manufacturing processes, like casting, welding, just a brief introduction will be given. Then will come all to our major topic on introduction to powder metallurgy.

Then how powder metallurgy compares with the other manufacturing processes, like any product if we say a water bottle it can be manufactured by number of manufacturing processes. So, how powder metallurgy is important, and how powder metallurgy completes with the other manufacturing processes, that will be seen in this topic on powder metallurgy a competitive process. Then will come on to the process details, this

process details will and come pass the preparation of metal powders, mixing, compacting, sintering and secondary operations.

Just to give you an over view, powder metallurgy is a process in which we make the powder of the metals, this powder is then mixed with the some of the die lubricants or different types of additives, that commit the complete mixture is then compacted. Compacted means it is pressed and under die and punch, and then we heat rated we give it some time lecture. And then finally there are certain secondary operations, which are carried out to make the products met by powder metallurgy more applicable like, there are certain applications spectrum for which will make products by powder metallurgy.

So, these secondary operations like machining, coining and there are at number of other operations, which we will see during the course of these 3 lectures, which are done on the powder metallurgy parts to make them more and more suitable for the applications. Then coming on to another important aspect that is the economics and design considerations, now we select a selection of a manufacturing process is very, very important. Already I have told, that there are number of manufacturing processes, that can be use to make a simple product.

A simple product can be made either by casting or it can be made using machining process, it can be forced, it can be shaped or it can be made using powder metallurgy. So, as a entrepreneur, as a manufacturer, I would like to make a product with the cheapest possible manner, now cheapest possible manner means, that I make maximum profit out of that. So, economics and design consideration we will see that, how important are by convict consideration for powder metallurgy parts, how they can complete with other manufacturing processes, moreover we will see the designer aspect now, each and every part, each and every design it is not possible for us to make it using powder metallurgy.

So, there are different types of designer aspects which have to be taken care of, which will be shown using the help of some diagrams. Then, we will come on to the last aspect that is the application areas, where the powder metallurgy parts are finding applications. Then we will discuss what are the advantages of the powder metallurgy parts like, powder metallurgy can be applied to diversified application. As we use ball point pens, the balls can be made the powder metallurgy; we have different bulbs the filament of the bulb that is tungsten filament is made use of powder metallurgy.

So, there are varied applications areas, so we will see in the course of lectures what are the application areas for powder metallurgy? What are the advantages of this process? Where we can use powder metallurgy? And what are the limitation areas? So, all these things; will be recovered in course of these 3 lectures. So, these 3 lectures will be dedicated towards powder metallurgy.

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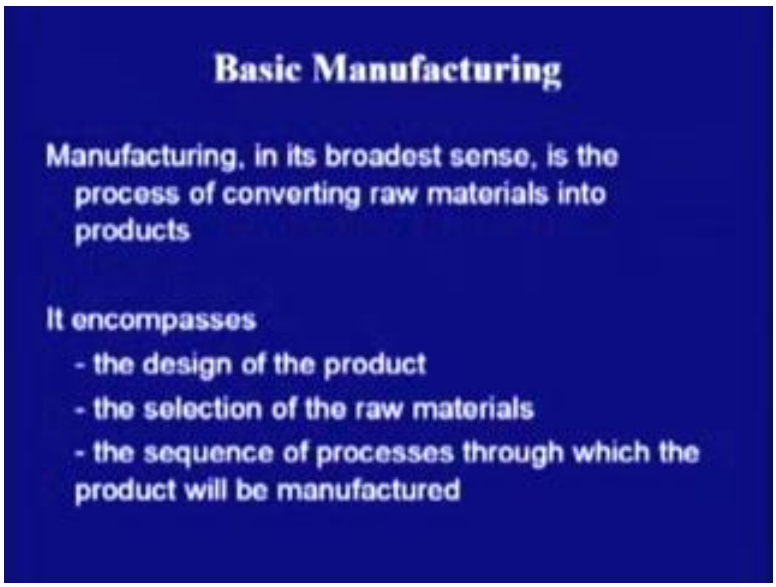

Now, as I have already told we are going to start the discussion with the very basic definition of manufacturing. So, manufacturing in it is broadest sense is the process of converting a raw material into the final product. Now, we can take example of a mouse, now this mouse is made up of plastic materials, so plastics are of different kind. So, depending upon the kind of the plastic material, we can choose the manufacturing process like, we can make use of injection molding; we can make use of compression molding. So, this mouse has been converted from a raw plastic into it is final form.

So similarly, manufacturing converts any product any raw materials into its final form, so manufacturing and comprises the design of the product, the selection of the raw material. And finally, the sequence of processes through which the product will be manufacture, now coming on to point wise point. First point says the design of the product, now the design of the mouse, the example that we have chosen the design we can see, this is the design in such that it is the ergonomic design our hand feeds on the mouse like this, I can press it very easily.

The second part is the selection of the raw material, and third part is the sequence of processes through which the product will be manufactured. Now, the raw selection of the raw material is also important, we have to decide that what type of material should be used for making the mouse. Similarly, the sequence of processes through which the product will be manufactured, there are different techniques through which this mouse can be made, but simply the most important process that is injection molding can be used, there can be other processes that can be used for making this mouse.

So, as we can see there are three important aspects of manufacturing. The first one is the design of the product, the second one is the selection of the raw materials, and the third one is the sequence of the processes through which the product will be manufactured. So, we are here to discusses regarding the sequence of processes through which the product will be manufactured, the important point is the design of the product, the selection of the raw materials, the sequence of processes. So, the design as well as the selection of raw materials will not be covered during the course of these lectures, we are going to focus our attention only on the sequence of processes that convert a raw material into a final product.

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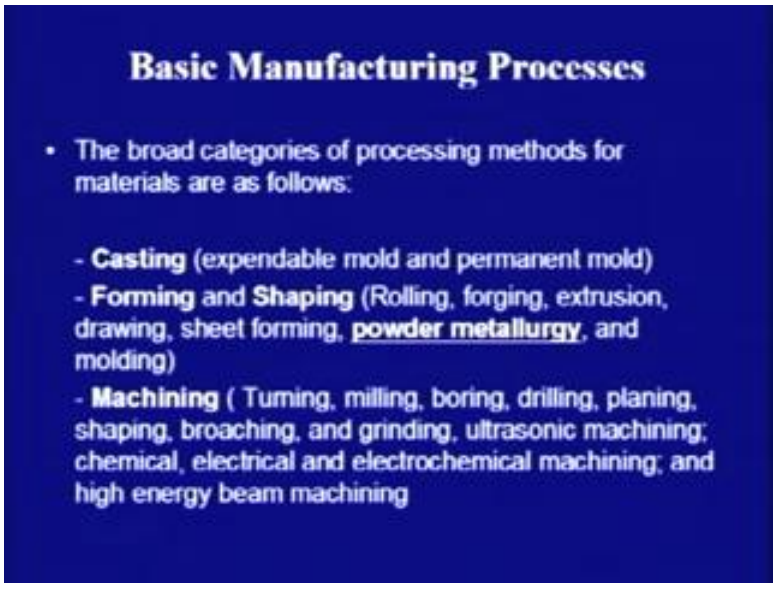

Now, coming onto the basic manufacturing processes, the broadest category of your processing methods for materials are as follows. The first one being casting, the casting can be expandable mold and the permanent mold. Expandable mold means, all of us may

be some of us, might have visited the foundries, what do be doing the foundries, basically, we may come mold out of sand, and that sand mold is used to pore the molten metal to get the final shape. So, that is the kind of expandable, casting in which the mold once after the casting has been prepared is broken down.

The second important category is the permanent mold casting, in permanent mold casting the mold is permanent in the mold is made up of different types of tools, steels or die steels, and we pore the molten metal into these die steels to get the final shape of the product. So, casting is one of the most primitive types of manufacturing process, coming on to the next categories of manufacturing processes these are forming and shaping. So, what are the different processes that fall under this broad category, these are rolling, forging, extrusion, drawing, sheet forming, powder metallurgy and molding.

So, in casting we are making use of a molten metal in forming and shaping, either we heat the metal before we use it or we can use it in the cold form also. So, we can see that, we are here to discuss the basic concepts of powder metallurgy, and powder metallurgy falls under the broad category of forming and shaping operations. Now, coming on to the third broad category of manufacturing processes these are machining processes, what are the processes that fall under machining these are turning, milling, boring, drilling, planning, shaping, broaching and grinding.

There are some un conventional machining processes also, which are ultrasonic machining, chemical, electrical and electrochemical machining, and high energy beam machining. So, what is the basic concept of machining, in machining whenever we want to give the final shape to the product, we remove some of the material in the form of chips, the chips can be either continuous chips discontinuous chips or chips with built up edges.

So here, we are losing some of the material as the waste material, because some of the material is being removed from the raw material to get the final product. So till now, we have seen that there are three important manufacturing processes those are basic manufacturing processes, which have other subsequent processes falling under their categories, these are casting, forming and shaping, as well as the machining.

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Now coming on to the next manufacturing processes those are joining. Now, joining and compasses welding, brazing, soldering, diffusion bonding, adhesive bonding and mechanical joining. Now, joining can broadly we categories into two sub categories, these are permanent joining processes and temporary joining processes. Now, mechanical joining we make use of fasteners, all of us see nuts and bolts, nuts and bolts are use to join to different parts together, whenever we want to use them or dismantle them we can remove the nuts and bolts, and we can use them again.

Similarly, welding, brazing, soldering, they make the permanent joints, once the joint has been made we have to break the joining to get the individual parts again. So, joining processes are also important manufacturing processes, then coming on to the finishing operations. Already, we have seen there are four basic manufacturing processes namely, casting, machining, forming and shaping, and joining. Now, why finishing is required, sometimes these are the days of packaging, everybody likes to have the product which looks very good, which has very good packaging, the surface finish should be very, very good, so to have a very good surface finish, we use some of the finishing operations.

So, these finishing operations are honing, lapping, polishing, burnishing, deburring, surface treating, coating and plating. We see, most of us use cars, in cars we see the finish of the sheet metal that is there the main body of the car, it is glowing like anything. So, that is but there these are coatings and plantings given to the sheet metal to give them

a very luster like finish or a metallic finish. So, finishing processes are also very important manufacturing processes, which come under the broad category of manufacturing processes.

So, we can see that to convert a raw material from it is basic form; to a useable form in the form of the final product, we use different types of manufacturing process. So, the present series of lectures will highlight powder metallurgy as a manufacturing process, focusing on process details, design aspects, economics of the process, advantages and limitations. So now, we will start our lectures series on powder metallurgy, there will be around 3 lectures or 3 sessions on powder metallurgy.

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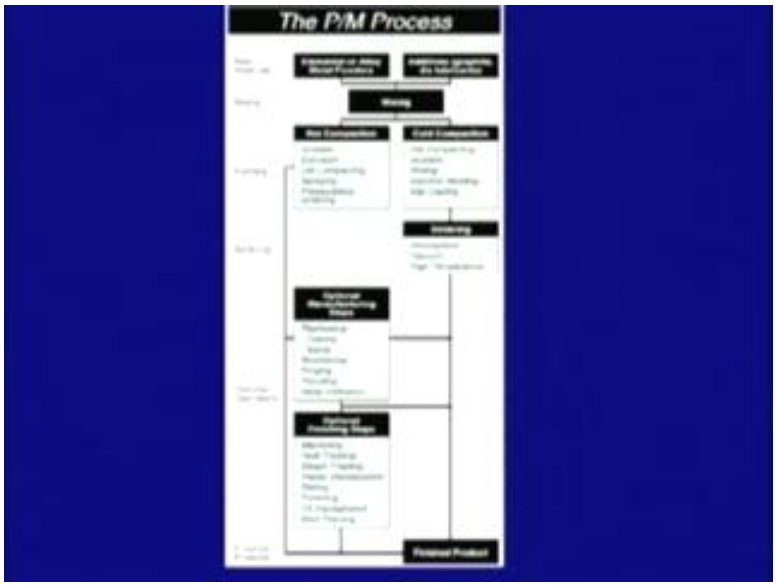

Now, this is the powder metallurgy process, already we have started the discussion with basic concept of powder metallurgy, which is that we make the powder of the metal. This metal powder is then mixed with different types of additive these can be die lubricant or some other kind of wax or polymer base lubricant, then this process is called mixing or blending. So, we have a metal powder, that metal powder is then mixed with the lubricants, then we get these two things together. Then finally, we press this mixture in to a die and a punch with the help of the die and punch. Now, these can be carried out either in a hot condition or it can be carried out in a cold condition.

Similarly, we call this process as the process of compaction, so this compaction can either be hot compaction or it can be cold compaction. Now, in hot compaction, it is they

are number of technologies or number of techniques which can be used for hot compaction processes like isostatic compaction, extrusion, die compactions, spraying or pressure less sintering. Similarly in cold compaction there are number of processes, which can be die compacting, isostatic cold compaction, rolling, injection molding, sleep casting.

So, basically in this first three shapes, we have seen that we make a powder of a metal, which is then mixed with certain additives, and then with the help of these additives and as well as the powder this mixture is pressed under the applied pressure. And there are different processes, which are used to press this mixture. Now, after that we sinter this product what is sintering? In the lay mans language, we can say that sintering is basically a heating process, heating up to a certain level of temperature, which is below the melting point of the metal powder.

Now, metal power if we are using, suppose we take example of titanium or tent alum, it has certained melting point. So, in sintering we will raise the temperature to a level, which will be lesser then the melting point of that metal, let the metal powder will not melt in case of powder metallurgy. So now we can see as we can see, after the sintering, either we can come down to the finish product or after the sintering there are certain other processes, which can be used to give the product its final properties.

Now, we can see there are optional manufacturing steps, either after sintering, we use the product in it is desired form or we pass on the products to these other optional manufacturing processes. Now, these optional manufacturing steps are repressing, coining, sizing, re sintering, forging, retrofitting, metal infiltration or this is not retrofitting this is rerolling. So again, I will go through the other optional manufacturing steps these are repressing, coining, sizing, re sintering, forging, rerolling or metal infiltration are there are other optional finishing operations.

Already, why level discuss while discussing on the basic manufacturing processes, I have told you that, why finishing processes are require to have a very good surface finish. Now, that surface finish will come, if we subject our product to this finishing operation, so what are the finishing operations? We that can be done to powder metallurgy parts, so these finishing operations basically are, machining, heat treating,

stream treating, plastic in impregnation, plating, tumbling, oil impregnation and short pinning.

So now, again basically going through the summery of the powder metallurgy process, this process basically makes the powder of the metal, then this powder basically is mixed with the die lubricants or it is mixed with different types of additives. The mixture is then pressed under the compaction processes, the compaction processes can either be cold compaction or it can be hot compaction. Then it is sintered, sintered means it is heated at a elevated temperature, after that it can be used as a finish product or it is subjected to some optional manufacturing steps.

Now, these optional manufacturing steps are employed. So that, but our mechanical properties or the physical properties or mechanical properties or the final product or the specification of the final product are required, those final product, those specifications, those mechanical properties will only come. If we subject this entered product to this optional manufacturing process, like we can take a simple example of self lubricating type of bearing. So, self lubricating types of bearings are manufactured by powder metallurgy part, powder it is a powder metallurgy part and it is manufactured using the process of powder metallurgy.

So, what is so special about these self lubricating bearings, usually we use bearing in bearings or bearing cycles and in other rotational numbers. We apply grease with handing, in normal lubrication bearings, but here in self lubricating type of bearings. There are certain pores in the powder metallurgy part which will see in the subsequent lectures; these pores are filled with some kind of a oil, so oil infiltration is done. So, it is one of the optional finishing steps or optional manufacturing steps, there we can see that the plastic impregnation can be there or oil impregnation can be there.

So, if we make a product out of a powder metallurgy, then that product if we did it in oil for some specified amount of time, this with oil will impregnate into the pores of the powder metallurgy part. And this gives the self lubricating property to the bearing, so during the operation, when the temperature will derives are under certain pressure, under the application of the capillary reaction. These oil droplets that are there in the powder metallurgy part will come out, and they will give the lubrication property to the bearing. So, that kind of things will come, if we will subject the sintered part to this other optional

finishing or the optional manufacturing steps. So, all these things we are going to covered in this series on powder metallurgy.

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Now, coming on to the introduction of powder metallurgy, the powder metallurgy existed in Egypt as early as 3000 BC. So, we cannot say that it is a process, which has been developed two decades or four decades back, the powder metallurgy dates back to 3000 BC. It was used in 19th century, to produce platinum and tungsten wires. Already, I have told you the tungsten wires are used as filaments in the incandescent bulbs. Then it was utilized in Germany for producing tungsten carbide cutting tool tips, after the First World War.

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So, a wide variety of products are presently being made by the powder metallurgy process. So, we can just look at some of the products that are made by typical powder metallurgy process. So, we can see there are certain types of gear, there are certain types of sleeves, then there are other different types of products, which can be made using powder metallurgy. Now, looking at these photographs, it seems that these are metallic products, a simple question that can be asked is cannot this products be made by any of the normal manufacturing process or the basic manufacturing process that we have already seen.

We have seen 5 different types of basic manufacturing process, what are those 5 different types of basic manufacturing process? Just to have a repeat I will say, the first one was casting, the second one was forming and shaping, the third one was machining, fourth was joining, fifth one was finishing. Now, a combination of these five process is can be used to any of the products that is been shown in this picture.

So, where does the powder metallurgy fitting, if we can make these products using any of those basic manufacturing process, why should we go for another process which we are talking. We are stressing the powder metallurgy is important manufacturing process, why powder metallurgy is required. So, we will briefly go in to the details of powder metallurgy, what are the application spectrums were powder metallurgy fitting.

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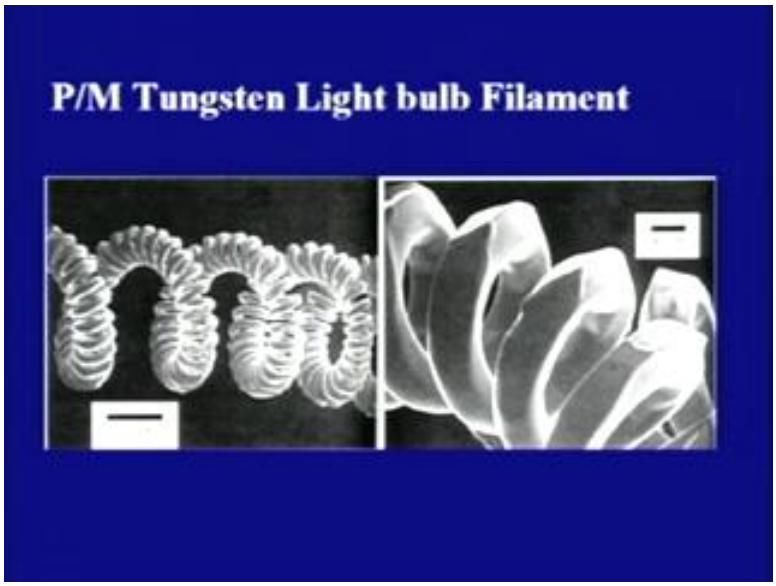

So, coming on to the this is just to have a look at the tungsten light bulb filament. So, this has been shown at 300 micron and 40 micron. So, you can see that at a magnified image this is the, how the tungsten light filament looks like.

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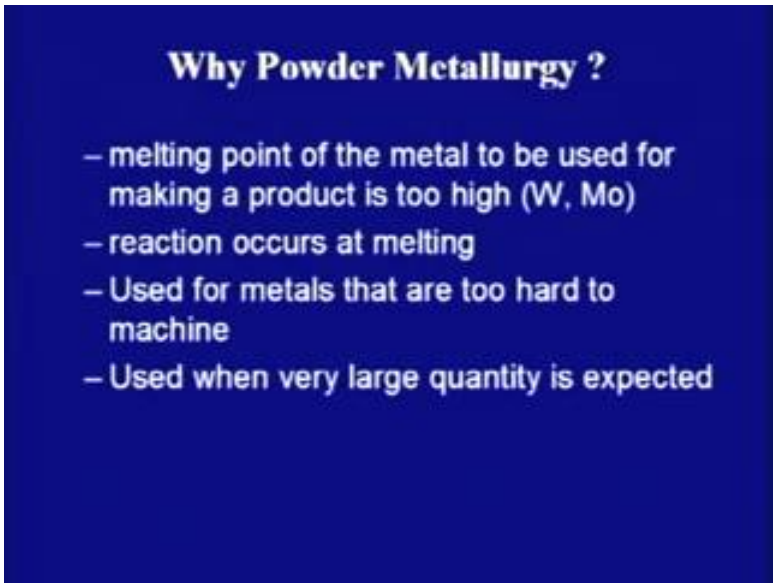

Now, why powder metallurgy is important, so there are certain points that we would like to address as a importance of powder metallurgy as a manufacturing process. Now, first one is the melting point of the metal to be used for making a product is too high, example is given tungsten, when we have to make a product of any metal which has a very high

melting point. Now, suppose the first manufacturing process that we have considered very basic manufacturing process was casting.

Now, what do we do in casting, in casting we melt the metal in a furnace, different types of furnaces are available like, induction furnace, cupola furnace, electric arc furnace, different types of furnaces are there, though not electrical furnace electrical induction furnace. So, different types of furnaces are there, which melt the metal, but none of the furnace can melt a metal which has a melting point as high as tungsten. So, there may be some specified, some special furnaces which can be used for melting tungsten, but its not usual or not of the self available furnaces.

Now, as we can see that if the metal the melting point of metal is very, very high, then we cannot use casting process, because we do not have furnaces to melt those types of high melting point metals. So, we can make the powder of that metal, and use it as a power metallurgy raw material, and use the process the various steps of powder metallurgy to make any product out of that metal. So, the metals which have a very high melting point can be utilized as a raw material for powder metallurgy applications.

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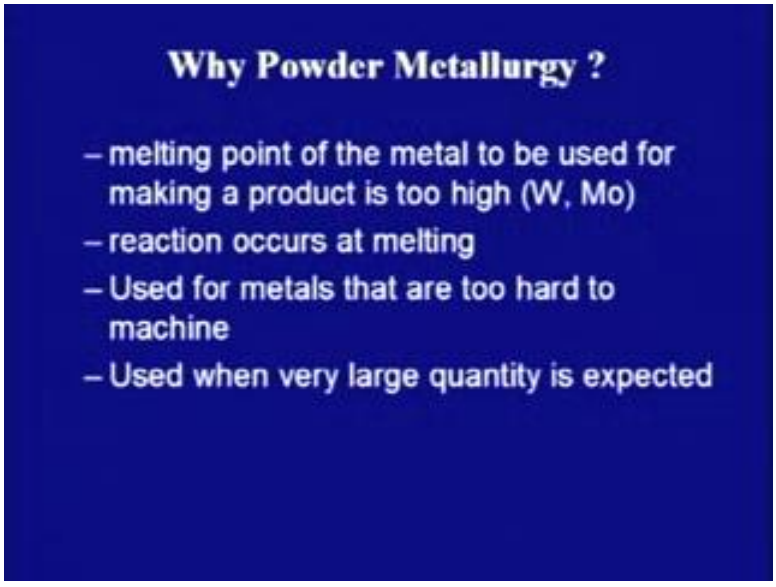

Similarly, the second point to be mentioned here is reaction occurs at melting; they are certain metals, which react when they melt. The reaction may take place with their environment, it may take place with that atmosphere or it may take place with their furnace in which that is in melted. So, when the reaction takes place on melting, the

metal cannot be used, because some contaminants may add in to the metal. Similarly, the third point is used for the metals that are too hard to machine, now tungsten if you walk to machine tungsten, machining basically the basic principle is of relative hardness.

If I want to machine something, I needed tool which should be harder than the work peace. Now, tungsten is harder than most of the steels, now to machine tungsten I need to have a diamond tool, now diamond is very, very costly tool material and it cannot be used as versatile as versatility as possible. So, it is use for metals that are too hard to machine, then it is used when very large quantity is expected. The production rate of power metallurgy is quite high, so whenever we need to produce the metals or produce their final products at a very fast phase, we can go for powder metallurgy.

So, just to have a brief summary were powder metallurgy gains it is important. The first point is, it is used for metals which have a very melting point, which cannot be processed by the basic manufacturing processes, then it can be used for those metals, which react on melting. The third point is it is used for metals that too hard to machine, and then finally it is used were the production volume is very, very high. So, these are the four basic important areas, where powder metallurgy has found it is application.

There are other manufacturing process also, which has under special conditions can be used for this important conditions, but powder metallurgy is most suited, where we encounter this four important conditions. If this four important conditions are encounted, straight forwardly we should choose powder metallurgy as the basic manufacturing process for these conditions.

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Now, coming onto our next topic of discussion that is how it competitive powder metallurgy is. Already we have seen that powder metallurgy is a important manufacturing process, it has a certain application areas, where it has certain advantages as compare to the basic manufacturing process. So, how competitive it is, now competitive on the basic of the economics, though powder metallurgy can be used for metals which have very high melting points, but sometimes the cost of the process also has to be taken in to the account.

If the process is too costly, we cannot use powder metallurgy as a manufacturing process for making final products. We have to upgrade our basic manufacturing process, so that we are able to produce the product at a relatively cheap price. So, how competitive is powder metallurgy as compare to the other manufacturing process, here we have certain points like, what makes process attractive for producing a wide variety of product. The first point to discuss here is the availability of wide ranges of powder combinations, here this property we can call it as the ((Refer Time: 27:49)).

Now, whatever final properties we want these final properties can be the mechanical properties, this can be the chemical properties, so depending upon the requirements of the final product. We can tailor our raw material like, suppose we make a product of pure aluminum, it will have certain properties, certain specifications and it can be used in certain application areas only, but if our application areas change. We need to change the

raw material, so we can make a powder of aluminum, we can make a powder of some other metal, which can be blended with aluminum in the mixing and blending stage. And then, we can again make a product, now this product may be superior to the earlier product, which was made of pure aluminum. Now, depending upon the final requirements, the final requirements may be depending upon the mechanical properties, like tensile strength, here strength or it can be bulk modulus, young's modulus. Different types of requirements may be there, mechanical requirements or different specific application requirements, like self lubricating type of bearings or there are sound ((Refer Time: 28:58)), so different types of requirements are there, depending upon the different types of requirements, we can tailor our raw material here.

Tailor our raw material means, we can blend different types of metal powder, depending upon the requirements of the final product. So, just to give you some examples, led and copper for bearing surfaces, steel and copper can be blended to make a self brazing type of an alloy. So, the first important point which gives a very good competitive advantage to powder metallurgy as a manufacturing process are, availability of a wide range of powder combination.

Then the second point is the ability to produce parts to net dimensions. So, this is another important aspect of manufacturing that is net shape forming. Already in the basic manufacturing process, we have seen machining is one of basic manufacturing process, what do we do in machining? We get a raw material, we remove some of the material in the form of chips, and then we get the final product, but here using the die and punch type of arrangement, whatever shape we want to make we can make it directly, after that no machining is required.

Although we have mentioned machining as one of the other optional manufacturing processes for powder metallurgy part, but it is seldom required. Depending upon the shape of the die; depending upon the finish of the die the internal surfaces, the finish of the internal surfaces of the die, we can make a product which is ready to use, ready to use means it is a net shaped product, you does not require any subsequent processing. So, another competitive advantage of powder metallurgy is the products that we make out of powder metallurgy can be directly used, means do not require any further finishing, plating or coating requirements.

So, if certain application specifies important characteristics like the plating should be there or coating should be there, only then it is required, otherwise after centering directly we can use the product into the application area. Now, the last point is the economics of the overall operation, so here I am not going to elaborate on the economics aspect of powder metallurgy, because we have a complete chapter or a lecture denoted towards the design, and the economic aspects of overall operation of powder metallurgy.

So, powder metallurgy till now we have seen that it is a competitive process, it has certain applications spectrum, we are powder metallurgy has a advantage over other basic manufacturing processes. And it has a competitive add advantage over basic manufacturing process in certain applications spectrum. Now, coming on to the metal powders, all of us may think metal making the metal powder is very easy, take any metal powder use a hammer and try to strike it on the metal. And we can make metal powder it is not that easy, it is the very sophisticated very important engineering process.

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So, metal powders are highly engineered materials, metal powder we cannot make metal powders directly in our room or in our lab, it require certain sophisticated processes certain well control processes, where there are different control parameters. Under those parameters, we subject the metal or the molten metal, and then we made the metal powders. So, it is a highly engineered process or highly engineered spectrum of manufacturing process. So, metal powders are highly engineered materials.

Now, coming on to what are this metal powder? What are the important aspects of this metal powders, which affect the final properties of the powder metallurgy part? So, these are the first is the particle size, the distribution and shape of the metal powder affect the properties of the compacted product. Now, if you see this on sentence, there are three important points that have been mention in this simple sentence. The first one is the particle size, then the distribution of the particle size and the shape of the metal powder. So, all these three important points, affect the final properties of the powder metallurgy part.

The particle size, suppose we take an example, the particle size if all the particles are of very big size or we can say these are courser in mature. So, if the particle size is course and they are uniform in size, the size is very big there are go bound to be certain pores within the metals. Now, simple example can be taken, if we found to fill the tennis balls in a box, we take a box put the tennis balls in that box, in between we will find there are too much of open spaces. So, this open space basically gives the porosity to the box, if we calculate the total volume will be the total volume of the balls, divided by the total volume of the box.

So, in this way if the size of the particles will be very, very large, there are going to be lot of porosity, as well as the density will also be less. If the particle size is very, very small, then the density will be good and the porosity will be less. Now, depending upon that what type of properties do we want, we have the we can choose the particle size. Similarly, a distribution of this particle size as we are going to further going our lecture, we will see they are different techniques for making the metal powders. So, the metal powders that we get out of these different techniques are of different sizes. So, there is the distribution of the size of the particle.

Similarly, the shape of the metal powder, the shape of the metal powder can be middle like it can be spherical; it can be any random shape. So, there at different manufacturing methods or different methods for producing the metal powders, which can be used to made the metal powder. So now, these make these processes, make the metal powder and the shapes of the metal powder depend upon the method by which it has been made. So, three important points have been discussed particle size, distribution and the shape of the metal powder.

The shape of the metal powder also depends upon the manufacturing method, use to make the metal powder. And all these three important aspect will defined the properties of the final product, the properties like density, porosity, compressibility. Then coming on to the particle size, the particle size is usually measured by screening. Now, what is this screening process? Anybody who has certain idea regarding the casting, sand casting in particular, in sand casting we make use of sand, the sand has certain fineness, the sand greens are having the fineness. So, we calculate the green fineness number. So, there are different sieves through which the sand is passed and we calculate the green fineness number.

Similarly, in case of metal powders also, the metal powders also have size, this size is the size of the particle. So, this is found out using the very simple technique that is screening. Now, what is screening? If screening we pass the metal powder through a set of sieves, of various mesh sizes, mesh sizes give the size of the core or the size of the cavity inside the mesh. Now, larger the mesh size, smaller is the opening in the sieve, so using this kind of screening process we pass the metal particles through a set of sieves. And then we see how much weight of the metal powder is left on one particular sieve and on the bases of that, we get an idea that what is the size of the particles in this metal powder.

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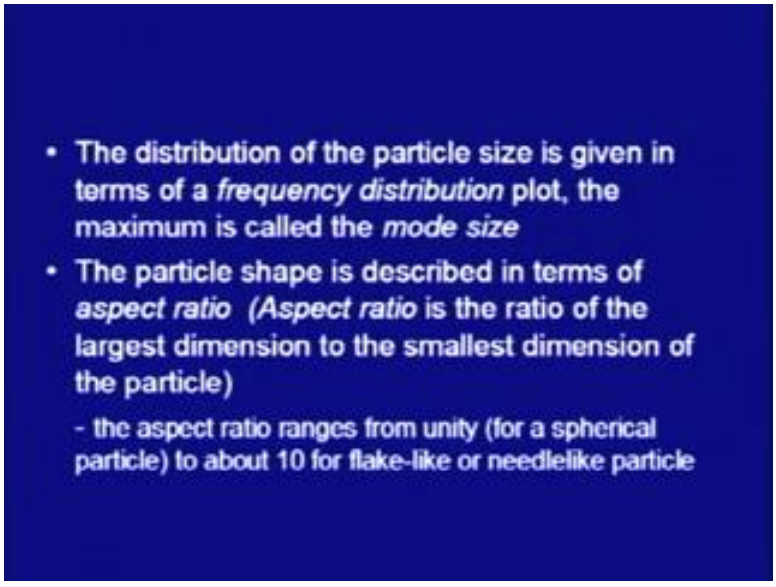

Similarly, we get the distribution of the particle size is given in terms of frequency distribution plot, the maximum is called the mode size. Now, it is not important to know that, what is the size of the particle for a particular metal powder, as I have already told, that there are different metal production method, so different metal production methods will make the metal powders, depending upon their properties. Now, some of the metal powders will have very big sizes, some of the metal powders will have very small sizes. Similarly, the size will be varying for one particular type of a metal powder.

Now, sometimes suppose we take a case of 100 percent, out of 100 percent 10 percent of the particles may be a one particular size; 20 percent of the particles may be of other particular size, and 50 percent of the particles may be different particular size; and the remaining can be of the different particular size. So, the particle size is vary over the total metal powder, total quantity of the metal powder. So, on the basis of what is maximum we say this is the mode size of this metal powder, 50 percent of the particles are of this size this I will explain with the help of some diagrams also.

Till now, we have seen two important aspect of metal powders, first one is the particle size, the second one is the distribution of the particle size. Now, coming on to the third important aspect that is the particle shape, the particle shape is described in terms of the aspect ratio. Now, aspect ratio is the ratio of the largest dimension to the smallest dimension of the particle, the largest dimension to the smallest dimension. If we take a case of a rectangle, now a rectangle has a largest larger dimension that we call as length, and smaller dimension that we call as breadth. So, length and breadth ratio of length and breadth will give the aspect ratio for the rectangle.

Similarly, as mention here the aspect ratio ranges from unity for a spherical particle to about 10 for a flake like or needle like particle. If you take a example of a sphere, sphere has only one particular geometrical entity that is it is we can say it can be specified with help of a radius. Now, radius is constant, if we take r by r maximum and minimum ratio, it gives us r by r, because r is equal to r, it gives are r well we have unity. Whereas l in a needle like or flake like particle, it will have certain length or if it has a round crop section, it will have certain radius or certain diameters.

Now, ratio of the length to the diameters will give us the aspect ratio, so these aspect ratios for needlelike or flake like particles may be 10 or even more or it can be less. So

now, we have three important aspects for metal powders, the first one ((Refer Time: 39:21)) the particle size, the distribution of the particle size that we call as the frequency distribution, and finally the third important point, that is the shape of the metal particle. So, all these three important points will affect the final properties of the powder metal product that we are going to make using the basic process of powder metallurgy.

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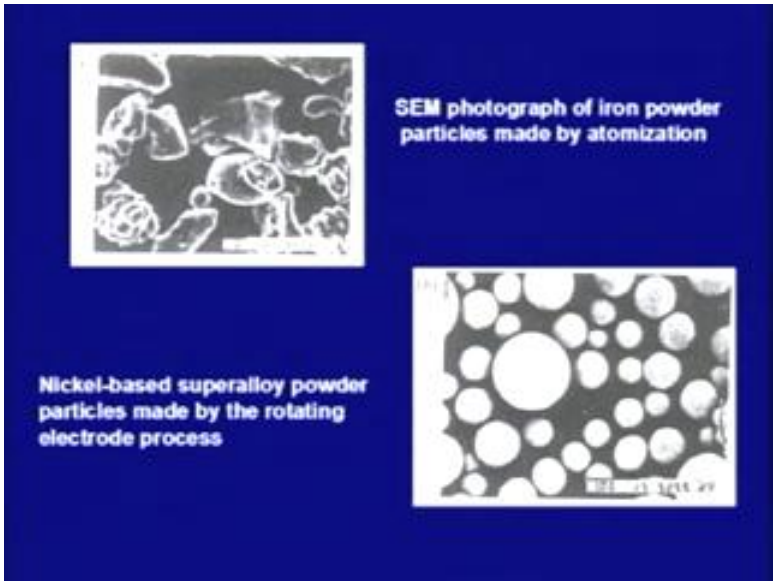

Now, here we can see two photographs has been shown, the upper one being the scanning electron microscopy photograph of iron powder particles made by atomization. Now, atomization may be a new term to all those students, atomization we will see what is this process of atomization? In the course of this lecture only, and the second photograph shows the nickel based super alloy powder, particles made by the rotating electrode process, now rotating electrode process, we also a new term, but the powder particle is what we have been discussing till now.

So, here we can see in the second photographs these are the particles, the particle is of a very big size, there are other particles which are of relatively smaller sizes. So, we can see that the particle size is important, more over the distribution of the particle size is important. Now, if we count the number of particle having a very large size, this is very less, if we calculate the number of particle with this size, we can see that there are number of particles having relatively this size. So, we can say the distribution of this size in the metal powder is more as compare to this bigger size.

Similarly, the shape of the metal powder particles, here we can see the shape is random shape. So, if we want calculate the aspect ratio, we will see what is the largest dimension? Suppose, now this is the largest dimension, and this is the smallest dimension, so we can calculate the l by d ratio for this, and we will get certain value for that. So, we can get the shape of the particles, we can get the size of particle, and we can get the distribution of this size.

Now, sometimes this sizes maybe in larger number, sometimes this size maybe larger number. So, metal powders that will make, those are having three important characteristics, first one is the particle size, the second one is the distribution of the particle size, and the third one is the aspect ratio or we can say the shape of the metal particles.

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Now, this may not be too much clear, but just to name a few metal powders, metal powders can be made up of pure metals, it can be made up of alloys or it can be made up of compounds. So, we can get powdered metals of aluminum, antimony, bismuth, cobalt, led, tantalum, titanium, vanadium. Then we can make metal powders of certain alloys also like aluminum iron alloys, we can make metal powder brass, nickel copper, nickel iron, solder, stainless steel all these alloys can be made into a metal powdered form.

Similarly, there are certain compounds of which we can make metal powders, these are borides, these can be carbides like tungsten carbides, molybdenum disilicide can be used

nightrides can be used. So, there are difference types of categories, which can be used to make metal powder this can be pure metal means the powders of pure metal, the powders can be of alloys, all the powders can be of compounds. Coming on to the characteristics of the metal powder, till now we have seen the geometrical features of the metal powder like the particles size, the distributions of the particles size, and then the shape of the particles size.

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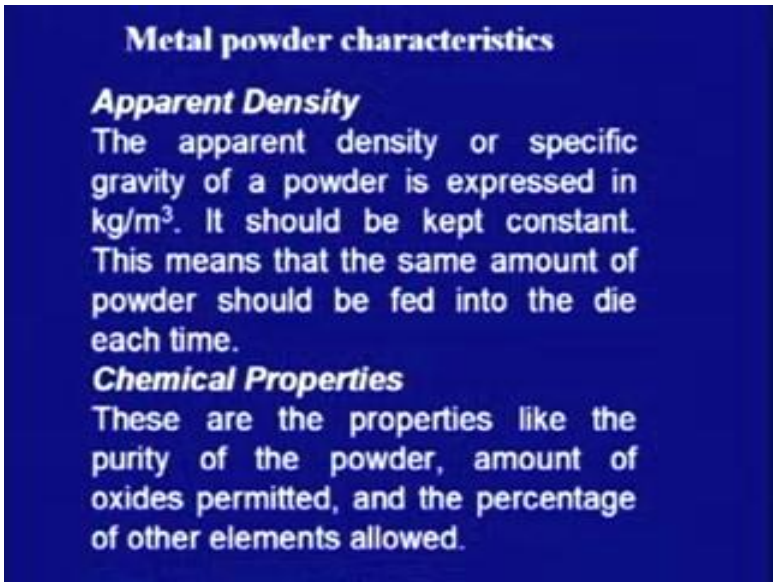

Now, it has certain characteristics, now the important characteristics will just briefly go through this important characteristic of metal powders. The first one being the apparent density, the apparent density or specific gravity of the powder is expressed in kilogram per meter cube. It should be kept constant, this means that the same amount of powder should be fed into the die each time. Now, this is important the same amount of the metal powder should be fed into the die each time, by because if more metal or less metal, we may not be able to get the exact shape of the final product that we want to make.

The second important characteristic is chemical properties, these are the properties like the purity of the powder. Already, I have told that metal powders can be made up of pure metals, the amount of the oxides permitted and the percentage of other elements allowed. Now, the amount of the oxides permitted, and the percentage of other elements allowed is important, because if we have too much of oxides in the metal powder or there are

other elements in the metal powder. So, when we compact this metal powder is always in contact with the die surface.

Now, if these particles are abrasive in nature or this we can say that this particles which are the other elements of the other oxides which are not required, these may abrade the die surface. So, we have certain points dedicated to the die materials also, which we will have been subsequent lecture, so that wear of the die is the very, very important. So, these important things, like the oxides or the percentage of other elements, may affect the surface of the die or may cause the wear of the die. So, there is a limitation on the percentage of oxides allowed, as well as the percentage of other elements allowed.

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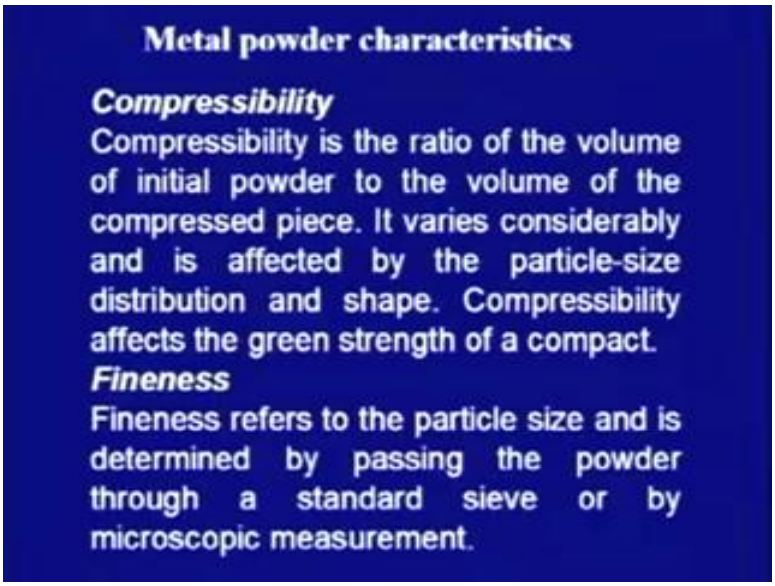

The third important characteristic is the compressibility, now what is compressibility? Compressibility is the ratio of the volume of initial powder to the volume of the compressed piece. It varies considerably and is affected by the particle size distribution and shape. Compressibility affects the green strength of a compact. Now, if the metal powders do not have this characteristic, we will not be able to a make compact or a green compact out of a metal powder. If it is compressible, we can compress it and applying certain pressure, in the step that is called compaction, and we can get a green compact.

If it is not compressible will not be able to that a green compact, even if we get a green compact, it will not a adequate strength to sustain the other operations that are subsequent to the step of compaction. After compaction also, we have to take into

account different steps, like we have to use that green compact for sintering, after sintering we have to use it for other optional manufacturing process.

So, the other important characteristic is fineness, the fineness refers to the particle size, and is determined by passing the powder through a standard sieve or by microscopic measurement. Already, I have told that we can calculate particle size using the screening process, which is mentioned here as passing the metal powder through a sieve.

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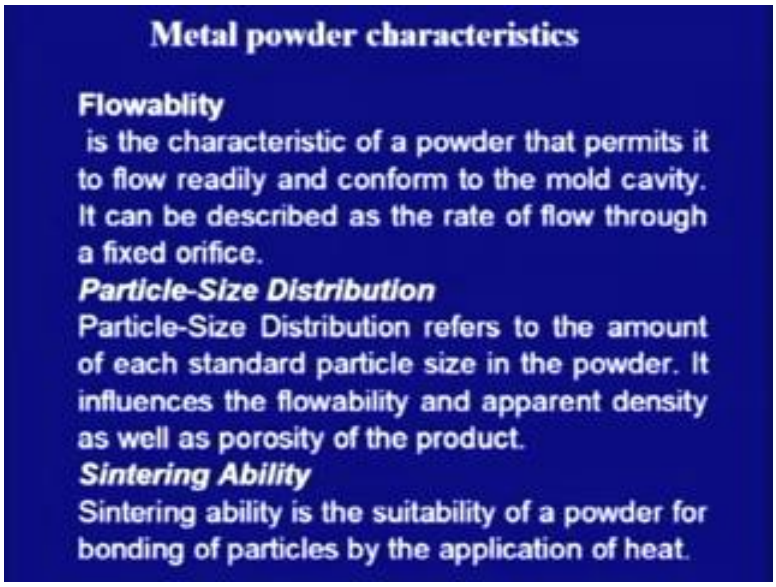

So, fineness is also an important characteristics of metal powder, then other important characteristics is flowablity, the metal powder should be having this property of flowablity what is flowablity? Now, flowablity is the characteristic of a powder that permits it to flow readily and conform to the mold cavity. As we will seen the subsequent lectures that we make them mold cavity of the shape, of which we want to make the final product. Suppose, we want to the make the final product in the form of these mouse. So, we will make a mold cavity or we can call it a die cavity of the shape and fill the metal powder in this.

So, if the metal powder has the flowablity characteristics, it will enter in to the mold cavity and will reach to the farthest corner of the die cavity or the mold cavity. If it is not flowable, it will not reach to all the corner of the die cavity and the final product that we get will be a defective product. So, the flowablity should is an important characteristics or metal powder should have adequate flowablity. It can be described as the rate of flow

through a fixed orifice. So, we can pass the metal powder through a fixed orifice and get a idea about the flowablity characteristics of the metal powder.

Another important point is the particles size distribution, which have already been discussed in the geometrical futures of the metal powder. So, the particle size distribution refers to the amount of each standard particle size in the powder, it influences the flowablity and apparent density, as well as porosity of the product. Example already I have given, filling that of the tennis balls of same size inside the box. So, there will be certain porosity will be there, if the size is less or more the porosity will be affected, accordingly.

Coming on to the next metal powder characteristics, it is the sinter ability or the sintering ability, sintering ability is the suitability of the powder for bonding of particles by the application of heat. Now, in sintering process, the different individual metal powder particles or subjected to temperature, and they from a bond with the adjacent particles.

So, if the metal powder have this properties of sinter ability, they get they will have form a bond, and they will improve the density of the metal powder. If do not have this type of characteristics though the bonding between the adjacent metal powder particles will not take places. And finally, the density and the porosity will be affected accordingly. So, the metal powder should have these characteristics of sintering ability.

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Now, we have discuss till now, some of the important characteristics of the metal powder, now we will see how this metal powders can be made, how this metal powders can be manufacture. So, there are certain processes to name them atomization, reduction, electrolytic deposition, carbonyls, comminution and mechanical alloying. So, with the help of diagrams or with the help of certain explanation, we will try to go through each one of these powder production techniques.

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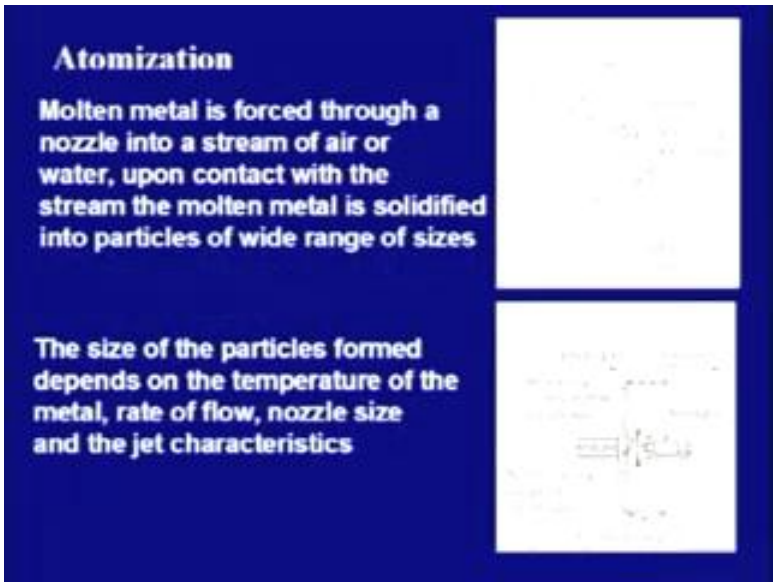

So, coming on to the first one that is the atomization, so the two diagrams are given here. Already when we saw two diagrams or the scanning electron microscopes for two different metal powder particles, we have seen that one of the ((Refer Time: 49:47)) was for atomization, the other one was for using the standard electrode method or the rotating electrode method. So, here we can see in the atomization process, just to label to read out what has been labeled in the diagram, there is a molten metal, there is a ladle, there is a atomizing water spray, there is a atomizing chamber, and there are the metal particles or the metal particles or the final particles that have been produced by the process of atomization.

So, the basic process here is the molten metal is forced through a nozzle into a stream of air or water, upon contact with the stream the molten metal is solidified into the particles of wide range of sizes. As we can see, the particles of wide range of size, so first coming on to process, the molten metal is taken it is passed through a ((Refer Time: 50:39))

through a nozzle into a atomizing chamber. In the atomizing chamber there is a atomizing water spray, it is not important that the water spray should always be a water, it can be of air also it can be of any other inert gas. So, under the applications of this atomizing spray, the metal particles that are coming out of the nozzle will form the different shapes.

So, we can see already it has been told that, it the molten metal is solidified into particles of wide range of sizes. So, the size that we will get out of this processes atomization will not be seen, the particles will be of a varied size. So, this is the first process to convert the molten metal into the metal particle passing it through a nozzle. Coming on to the second process that is the using the rotating consumable electrode. So, basically this is the application of a welding process only, here we can see that just to see what a what how the diagram has been labeled, there is a inert gas, there is a vacuum, that has been created in the chamber.

There is rotating consumable electrode, there is non rotating tungsten electrode, there is a collection port, where the metal particles will be collected, and there is a spindle to give a rotatory motion to the rotating consumable electrode. Now, in this process when this two electrodes, the rotating consumable electrode as well as the non consumable electrode are brought together are current passes through these two electrodes, and arc is set up between the two electrodes. Now, one electrode that is the rotating electrodes, which is the consumable electrode is rotating at a very high speed.

Now, under the centrifugal force is the metal, which is melted at the tip of this consumable electrode, forms into a type of a droplet, and that this droplet of metal powder falls into the collection port. So, this particular process makes use of the basic principle of welding, where we are bringing to whether two electrodes together and one electrode is a consumable electrode, another one is a non consumable electrode. So, this consumable electrode is the electrode made up of a material of which we want to make a metal powder. So, this will be consumed in the process, and we will get a metal powder by using this process. So, this is the first process for making a metal powder.

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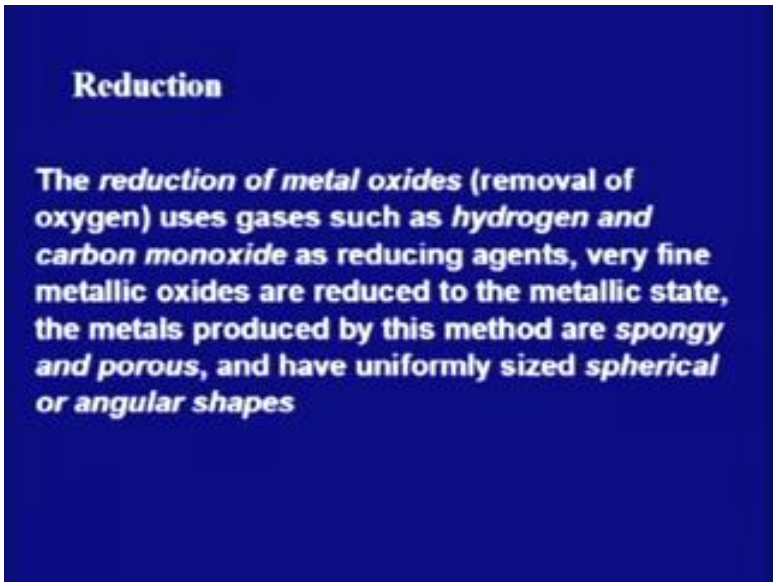

Now, the second process is the process of reduction, so what is this reduction? Reduction is any student of chemistry knows the process of reduction, the reduction of metal oxide, removal of oxygen, uses gases such as hydrogen and carbon monoxide as reducing agents. Very fine metallic oxides are reduced to metallic state the metals produced by this metal by this method are spongy and porous, and have uniformly sized spherical or angular shapes. So, important points here are the metals produced by this method are spongy and porous, as well as they have uniformly sized spherical or angular shapes.

Now, a shape has been given here, spherical or angular. Now, this shape of the metal powder that has been made by this process of reduction influences the final properties of the final product. So, if the uniformly sized spherical particles the porosity will be more the density maybe less, but depending upon the size of the particles, we can see also depending upon the size, as well as the shape of the particles. We can see whether these particles will form a dense product or this will form a porous product, depending upon the size these properties will be defined. The reduction is another process, where the metal oxides are reduced using reducing agents such as, hydrogen and carbon monoxide.

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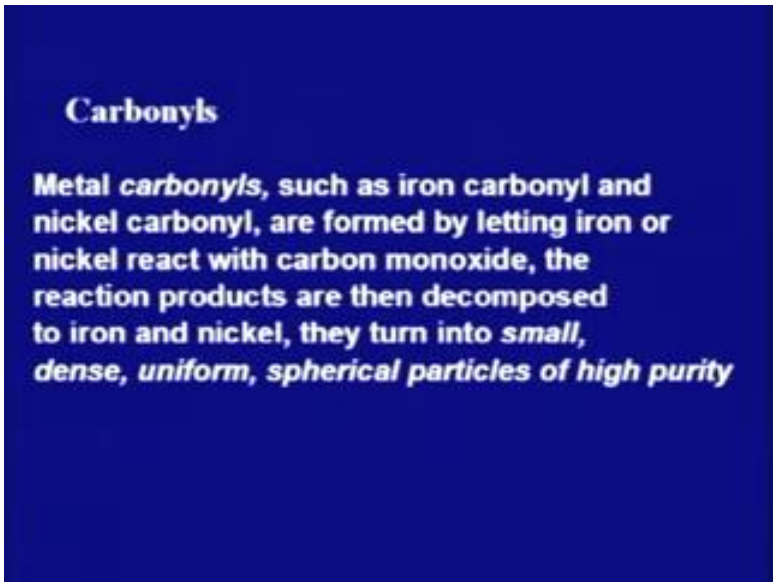

Now, the third process for making metal powder particles is carbonyls, metal carbonyls such as iron carbonyl and nickel carbonyl, are formed by letting iron or nickel react with carbon monoxide. The reaction products are then decomposed to iron and nickel, they turn into small, dense, uniform, spherical particles of high purity. Again here, we can see the emphasis is on the shape and size of the particles. We can see using this process of metal carbonyls, where iron and nickel carbonyl are formed, where iron and nickel react with carbon monoxide, and the reaction products are then decomposed to iron and nickel.

The final emphasis is on the process is there, but the final emphasis on how what are the types of, what is the shape of the metal powder that we are getting, what is the size of the metal powder that we are getting. The size is small and it is dense, it is uniform, uniform means as in atomization we have seen, the particles size is varying sometimes we may get bigger particles; sometimes we may get smaller particles. But here, using this process of carbonyls, we are going to get we are going to get small particles; we are going to get dense particles. The size of the particles will be pretty much uniform, the shape will be spherical and this will be particles of high purity.

So now, become to the end of first session on powder metallurgy, I will just try to summaries, what we have covered in this first section on powder metallurgy. We have covered the introduction to basic manufacturing processes 5 basic manufacturing processes have been addressed that is casting, forming and shaping, machining, joining

and finishing. Then we went on to the introduction to powder metallurgy, what are the various steps, basic steps of powder metallurgy. After that, we went on to cover the basic characteristics of the metal powders, what are the important properties of the metal powders.

And then, we went on to discuss some of the important metal production techniques, out of which we have covered atomization, reduction and carbonyls. Now, in our next lecture on powder metallurgy, we will start our discussion with metal production techniques, in which we will cover mechanical communition or which we can call it as pulverization. And after that, subsequently discuss the various steps that are used to make a product out of powder metallurgy.

Thank you.