Manufacturing Processes -1

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Module - 01
Lecture - 02
Powder Metallurgy – 2

A very warm welcome to you to the second session on powder metallurgy. At the onset, I would like to wish you a very good morning. So today, we are going to start the second session on powder metallurgy. In the previous session that was powder metallurgy 1, we discussed regarding the details of basic manufacturing; after that we discussed the basics of powder metallurgy. After powder metallurgy, we saw what is the basic concept of powder metallurgy? Later on we moved on to the production of metal powders. Before that we discussed, what are the different types of geometric characteristics of the metal powder.

So, last session ended when we were discussing regarding the powder metallurgy, metal production techniques. So, we have discussed 3 different techniques of metal production that was; the first one was atomization, the second one was reduction, and the third one was carbonyls. So, today before we go on to the second session powder metallurgy, a brief review of what we have discussed till date.

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We have discussed in our first session introduction to basic manufacturing, then we have discussed introduction to powder metallurgy, then we discussed importance of powder metallurgy as a manufacturing processes. After that we discussed, what are the metal powders. What are the different shapes of metal powders? How these shapes influence the properties of the final product. Then we discuss the various characteristics like apparent density, chemical properties, purity.

Later on, we went on to discuss the production of metal powders. In production of metal powders, we have already discussed atomization, reduction and carbonyls techniques for making of metal powders. So, this was to be continued in powder metallurgy tool. So today we are here to start our discussion on powder metallurgy tool.

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So, the fourth technique for making the metal powder is comminution. So comminution is basically known as mechanical pulverization. This involves crushing, milling in a ball mill or grinding brittle or less ductile metals into small particles, brittle materials produce angular shaped particles, while with ductile materials particles are flaky, not particularly suitable for powder metallurgy applications. This we have already seen, when we discussed regarding the shape of the metal powder particles.

We have seen the needle like or flake like particles have the aspect ratio, which is one of the characteristics to define the shape of a metal powder, the ratio is aspect ratio for flake like particles is around 10. So, when we use this flake like particles, we it is very difficult to get adequate density and porosity in the powder metallurgy part. So, the particles that are flaky are not particularly suitable for powder metallurgy applications.

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We will see this mechanical pulverization with the help of some diagrams, so these are some of the diagrams of mechanical pulverization process. Here we can see that there are three different types of processes that come under the category of mechanical pulverization. As we can see, the first one is the roll crushing there are two rolls that are rotating, and bigger matter particles are been crushed into smaller tiny particles.

Second is the ball mill, in ball mill we can see there are number of balls these balls can be made up of steel which is very, very hard. So, the hard steel balls, when they are rubbing against under the rotating action, they wear very less as the steel has the property that is stainless type of steel is there or different types of alloy steels are there, which have this property that they wear very less. So, when they rub against the metal particle they break the metal particles into smaller size particle.

The third category here to discuss is the hammer milling, in hammer milling we can see there is a rotation taking place. We are there are two hammers, so these two hammers, when they strike against the metal particle, these metal particles bigger metal particles are broken down into smaller metal particles. So, these are three different types of mechanical pulverization processes that are used to make metal powders.

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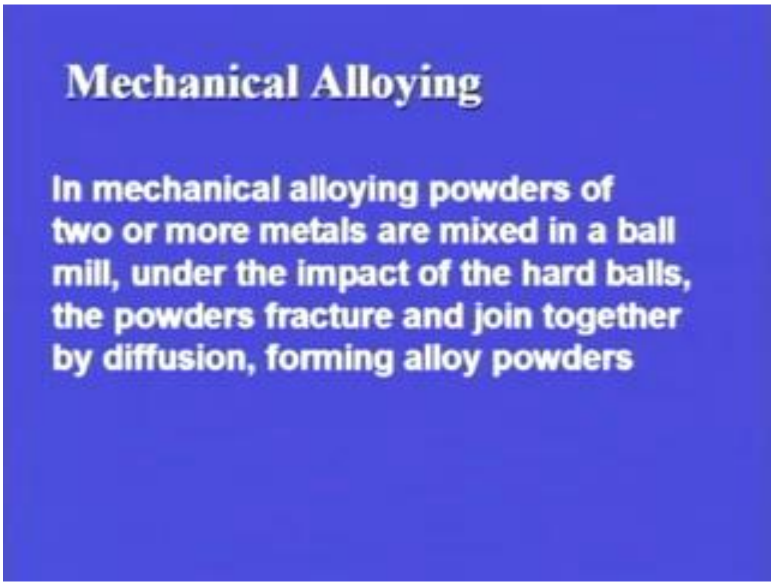

Then the fourth process is mechanical alloying, already we have discussed in our first lecture, that we the basic property of powder metallurgy or the where powder metallurgy find it is most importance is that. It has the tailor made raw materials, you know tailor made raw materials mean, that we can group different types of metal alloys or we can group different types of pure metals, make the powder and blend them together in the blending process.

So, when we want to alloy two different pure metals to whether we can go for this process of mechanical alloying. So, what is the basic concept of mechanical alloying? In mechanical alloying powders of two or more metals are mixed in a ball mill, under the impact of hard balls. Already I have told in ball mill, we make use of very hard balls, which may be made up of any kind of alloy steel. The powder fracture and join together by diffusion forming alloy powders.

So, these alloy powders, why do we require these alloy powders, because sometime some particular powder metallurgy parts having some applications. They require certain properties, certain properties are desirable in the final product to have certain mechanical properties, to have certain physical properties. So, when the final product has some specification regarding the mechanical and the physical property, we need to blend the different metals together to get the final property. So, we need to go for the process of mechanical alloying.

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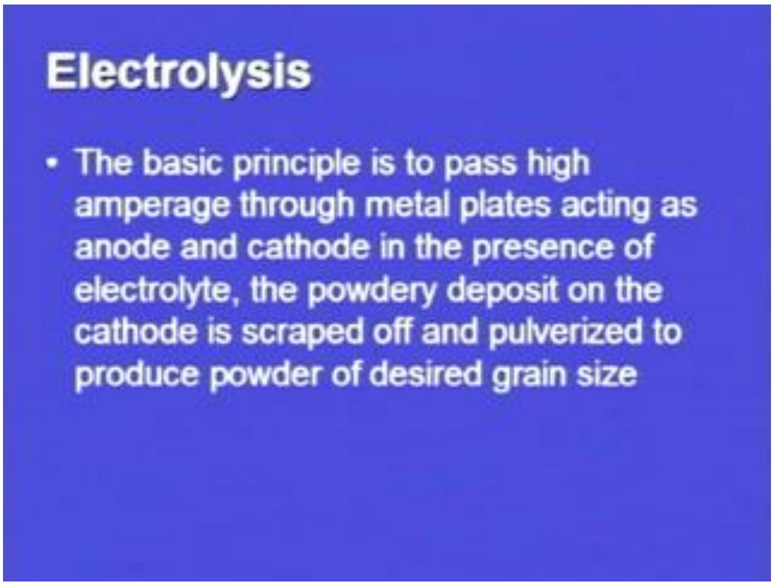

Now, coming onto the next process for making metal powders, this is electrolysis. What is the basic principle? The basic principle anybody who has studied chemistry knows the basic principle of electrolysis. So, the basic principle here also remains same, this is another form of electro plating, here the basic principle is to pass high amperage through metal plates acting as anode and cathode in the presence of electrolyte. It means there by electrolyte is present, and there are two electrodes, one acting as the anode, other one acting as the cathode. The powdery deposit on the cathode is scraped off and pulverized to produce the powder of desired grain size.

So here, we do not get the metal powder to be directly used, whatever is deposited on the cathode, we remove that and then we pulverize it. So, pulverization already we have seen there are three different processes for pulverization, that is hammer milling, ball mill or roll cursing. So, we can use any of these three processes. And finally, make a powder of the desired grain size. So, till now, just to summarize three different processes for metal powder production, we have seen that we can make metal powder either by mechanical pulverization or we can make it by electrolysis or we can make it by any of the processes that we have discussed in the first lecture.

Now, there is another category of powder that is nano powders, usually the powders that we make out of any of the manufacturing processes for powders. The size ranges from a few microns to may be going towards the maximum of one millimeter, but sometimes we need powders of nano size also nano size means 10 to the power minus 9 or smaller than that.

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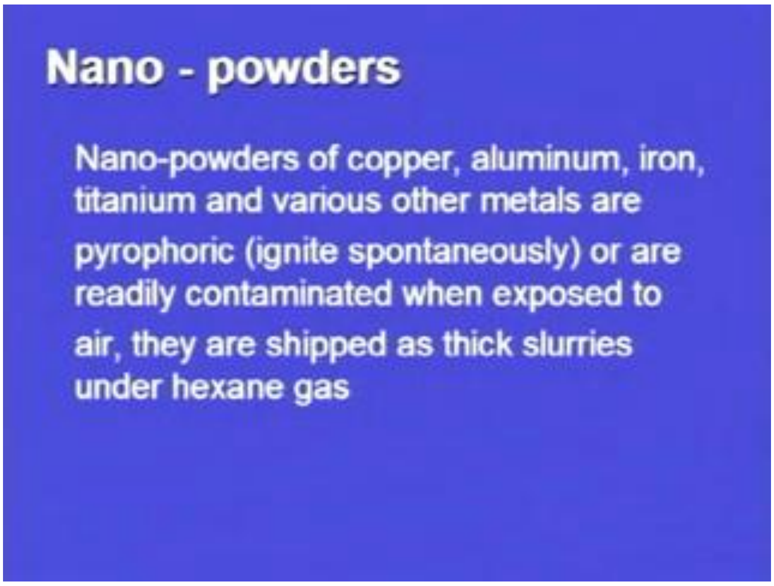

Then this nano powders of copper, aluminum, iron, titanium and various other metals are pyrophoric, pyrophoric means they ignite spontaneously or are readily contaminated when exposed to air, they are shipped as thick slurries under hexane gas. So, these nano powders all though there is no limitation on the size of the powder that we make, using any of the metal production techniques. But, if we make powder of a very small size, then these kind of problems of contamination or pyrophoric ignite spontaneously type of problems may come into picture.

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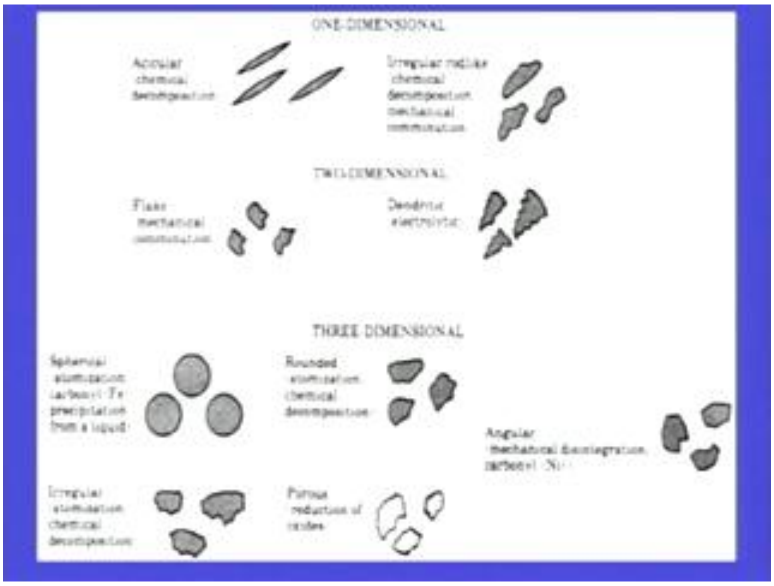

Now, these are certain shapes that are made by using any of the manufacturing process for metal powders, like the first one is the one dimensional, acicular type of shape is made by chemical decomposition. So, we can see that this is the acicular type made by chemical composition. Then there is irregular rod type which can be made these are the irregular rod type of metal particles, which can be made either by chemical decomposition or by mechanical comminution. Already we have seen mechanical comminution or mechanical pulverization.

Then two dimensional types of particles can be made by mechanical comminution, this is flake these are different types of flake like particles. These can be made by mechanical comminution or there are dendrites, dendritic type of particles these can be made by electrolytic process. Now, dendrites if you see, if you study casting and we see the solidification phenomenon of casting process, then these dendrites formation takes place during the solidification of different metals. So, these are different kinds of dendrites that are formed in metal powder production also.

These are some of the two dimensional shapes, produced when we make use of electrolysis as one of the manufacturing processes for making powders. Then there are three dimensional types of metal powder particles like, this is spherical. As we have seen in the scanning electron microscope in the first lecture, there was the photograph which was shown in which the spherical particles were made. So, these spherical types of particles can be made by the processes of atomization or it can be made by the processes of carbonyls, precipitation from a liquid.

Different processes are there carbonyls, atomization or precipitation from a liquid, in which we can get the spherical particles. Similarly, these rounded particles can be made these are the some kind of rounded particles, these rounded particles can be made either by atomization or these can be made by chemical decomposition. Similarly, angular shape of particle, these are angular shape of particle we can see, these can be made by mechanical disintegration or by carbonyls. Here, we can see that, irregular shaped particles where there is no regular shape of the particle, here these can be made by atomization or chemical decomposition.

If you want to have porous type of particles then porous particles can be made by reduction of oxides. So, we have seen that there are different processes for making metal powders like, atomization, reduction, carbonyls, mechanical alloying, and then there is mechanical pulverization, electrolysis. So, different types of processes can be used to make different types of metal powders of different shapes and sizes. So, these processes can be chosen, according to the final shape of the particles that we want.

So that, these particles will influence finally, the density as well as the porosity of the final product that we make out of powder metallurgy. So, the selection of a metal production technique also influences the final properties that is the physical and the mechanical or the chemical property of the final powder metallurgy part. Now, we have one, once we have made this metal powders, then different metal powders had to be blended together to get the desired property of the final powder metallurgy part.

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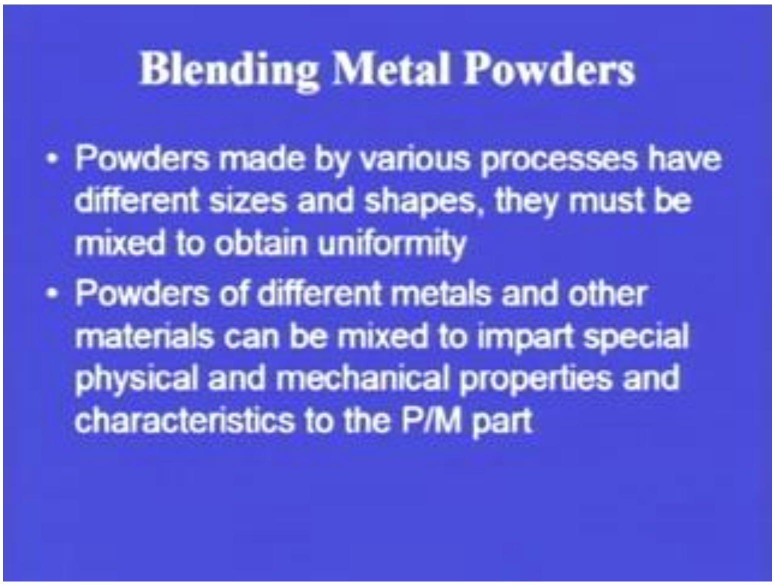

So now we come onto the blending of metal powders, so we have already seen the powder metallurgy, basically is making the metal powders blending them, then compacting them sintering, and finally the other optional processes. So, we have till now seen that how to make a metal powder, what shapes can be made using different metal powder techniques, metal powder production techniques. So, now we come onto the second stage of powder metallurgy that is called blending, so now blending of metal powders made by various processes have different sizes and shapes.

As we have already seen in the previous slide that we can make different size and different shapes particles using the various processes. They must be mixed to obtain the uniformity. So, we need to have some kind of uniformity in the powder mix, so we need to blend the different sizes and different shapes of particles together to have the uniformity in the final mixture that we are going to use for further processing. The second point to mention here, in blending metal powders is powders of different metals and other materials, can be mixed to impart special physical and mechanical properties and characteristics to the powder metallurgy part.

So, one thing to mention here, where we use this P slash M it says that it is a powder metallurgy, it is a small form of writing powder metallurgy. So, second point states that, if we have to blend that, if we need to have certain important properties in our final product, then we need to blend different types of metal powders together. So, powders of different metals and other materials used to imparts special property to the final product that is why we need to blend different particles together, different particles of different metals together.

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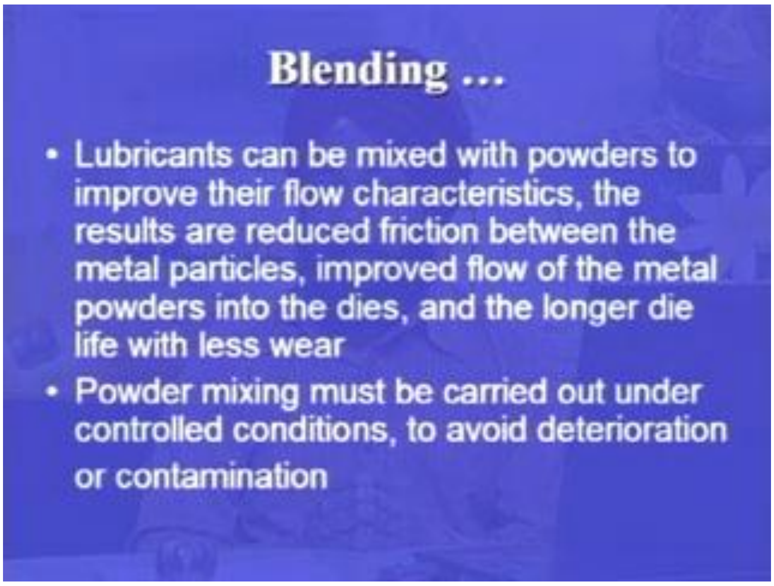

Then coming onto the third point for blending, third important point for blending is, lubricants can be mixed with powders to improve their flow characteristics. The result are reduced friction between the metal particles, improved flow of the metal powders into the die, and the longer die life with less wear. So here, there are three important points, why do we need to add lubricants, while the blending process into the metal powders. So, the first point is, the results are reduced friction between the metal particles. So, if a lubricant is present in between the metal particle, so the flow of the metal particle will be very smooth within the die.

As we have already seen in the characteristics of metal powder, that flowablity of metal powder particles is one of the most important characteristics. So, the flowability will be improved if we use the lubricants. So, first point, the results are reduced friction between metal particles, so this will add into the property of flowability. The second is improved flow of metal powder into the dies that is already I have told, that the friction will be less between the metal particle, and the flowability will be good. And the longer die life with less wear.

So, then lubricant will be there, these metal particles sometime tend to be abrasive in nature, so then this abrasive particles will rub against the die wall, there are chances that the die wall will have certain amount of wear. So, if we add lubricant into the metal powder at the very onset on the during the blending stage, then the friction between the die surface as well as between the metal particles will be reduced. And this will add to the longer die life with lesser wear to that die surface. The next point is powder mixing must be carried out under controlled condition to avoid deterioration or contamination.

Already we have seen certain metal powder have the property, that they are pyrophoric they ignites spontaneously. So, in order to avoid any form of contamination or deterioration, the powder mixing must be carried out under controlled condition may be these can be carried out under inert conditions, where there is no atmospheric oxygen, etcetera available.

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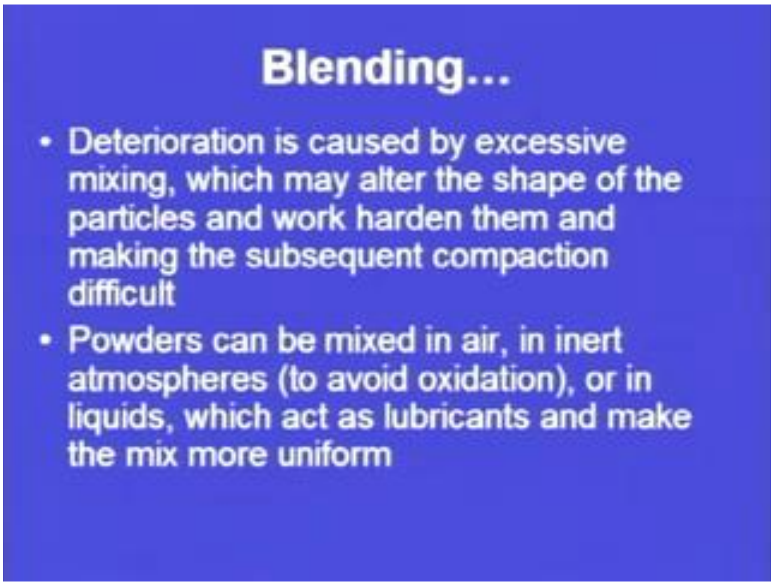

So, coming onto another point an important points of blending, deterioration is caused by excessive mixing, which may alter the shape of the particles and work harden them, and making the subsequent compaction difficult. So, work hardening may take place of the metal powders, because of the rubbing which is more as desirable. So, deterioration is caused by excessive mixing, which may alter the shape of the particles, a shape of the particles may also be altered. Now, while designing a powder metallurgy part, we feel that this is the shape of the particles, we should use so that we get the desired property of the final product.

We select a manufacturing process for powder depending upon the shape that we require, shape of the particles that we require in the final product, but during the blending, if we go for excessive mixing, the shape of the particle will change. And if the shape of the particle will change then the final properties that are desired in the final powder metallurgy part or the powder metallurgy product will not be there. So, deterioration is caused by excessive mixing, which should be avoided.

The next point to be considered in blending stage is that powders can be mixed in air in inert atmosphere to avoid oxidation or in liquids which act as lubricants and make the mix more uniform. So, the mixing of the powders can take place in air, it can take place in inert atmosphere or it can take place in liquids though already in the blending section only we have discussed that we need to add certain lubricants, to improve the die life as well as to improve the flowablity characteristics of metal powder.

So, these can be mixed in the presence of a lubricant, which can later on in the presence of a liquid, which can later on act as a lubricant during the compaction and the sintering processes. So, now already to summarize we have seen that, why blending is required, and what are the important points to be taken care of, while we blend the different metal powders together.

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Now, we come onto the hazards with the metal powder, so metal powders already told that it is they ignites spontaneously some time. So, these are some of the hazards which have to be avoided, so what are the points to be taken care of while we discuss the hazards of the metal powders. The first point to be consider here is that the surface area to volume ratio for metal powders, makes them very explosive. The high surface area to volume ratio that is the surface area is more and the volume is less. This results into sometimes explosion and sometimes some kind of deterioration of the metal powder, so this has to be avoided.

So, some of the metal which have this kind of characteristics are aluminum, magnesium, titanium, zirconium, and thorium, so these particular metals are particularly explosive, because of the high surface area to volume ratio. So, great care must be exercised both during blending and in storage and handing, so it is not that we make a metal powder of a very metal particle of very small size. And then we use those metal particles as it is, we have to store them very carefully, and we have to handle them particularly having a lot of giving, lot of emphasis on their pyrophoric characteristics.

So, they should not explode and cause certain damage to the human life or to the equipment. So, precautions what we need to take precautions include preventing sparks, there should be no sparks, wherever we are storing or we are handling our metal powder, no sparks should be allowed in that area, then open flames etcetera should not be allowed, and chemical reaction should not be allowed. So, we have seen that metal powder once they are made, they are having certain advantages, but the limitations is that there are certain hazards also associated with the metal powders, which have to be avoided.

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Now, we come onto the powder metallurgy processes, so already till now we have seen, that we can make metal powders using different processes, and there are certain hazards related to the metal powders. Before that we have seen that metal powders of different metals need to blend it together, to give the final mechanical as well as the physical properties to the powder metallurgy part.

Now, powder metallurgy processes an overview, the powder metallurgy process normally consists of four basic steps. Four basic steps already in the first lecture we have seen, just to point out once again. These four basic steps for powder metallurgy processes are, producing a fine metallic powder, mixing and preparing the powder for use, pressing the powder into desired shape, heating that is sintering the shape at an elevated temperature.

So, till now we have seen, that how to produce a fine metallic powder, some of the processes we have discussed with the help of certain diagrams we have seen, how metal powders can be made? Mixing and preparing the powder for use, already it has been discussed, why blending is required? What are the important points to be taken care of while blending a metal powder? The third point is pressing the powder into desired shape this is also called compaction, which will be seen now.

Another point in the processes are the designed cycle or the production cycle of a powder metallurgy part are heating and sintering the shape, at an elevated temperature. So, we these two important points we are going to discuss in detail, in the coming session. Now, other processes are required for special results, other processes already in the diagram we have shown and we have seen that other processes are like, infiltration, impregnation, machining, winding, sizing. So, all those processes will be discussed in the present session.

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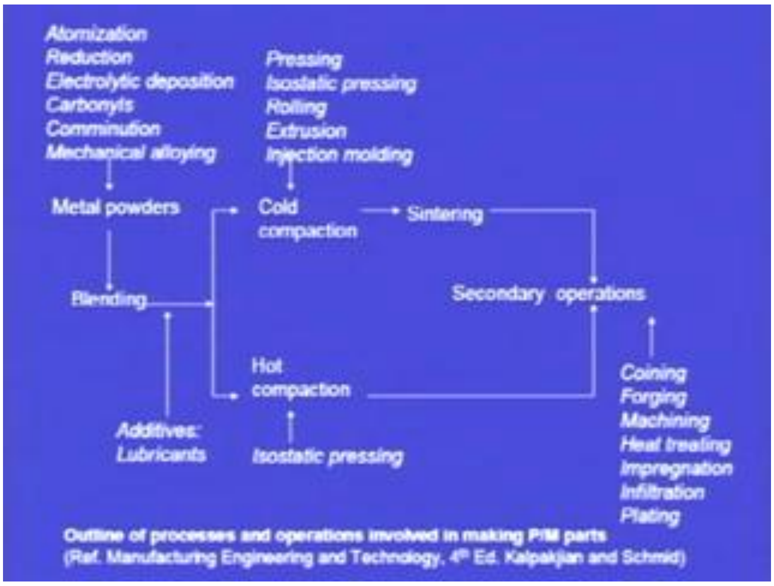

Now, this is the very we can say a very detailed diagram of the processes of powder metallurgy. So, we can see with the help of the arrows, just first of all I will talk about the important steps in the processes of powder metallurgy. And then we will discuss each step, as we go into the further session. So, the first point is metal powders, second point, the metal powders once we have made the metal powder then we blend the metal powders together, in the blending we add certain additives these additives can be lubricants.

After the blending has been completed, there are two ways we can make a final product, either we can go for cold compaction process or we can go for hot compaction process. After cold compaction, we go for sintering and after hot compaction directly we go for secondary operations. So, basically the importance steps included here are, metal powders, blending, cold compaction, hot compaction, sintering and the secondary operations. Now, coming onto the further sub classification, metal powders can be made using atomization, reduction, electrolytic deposition, carbonyls, comminution and mechanical alloying.

All these processes we have already discussed, when we make the metal powders then we blend them together add lubricants, why they are required already we have seen. Now, cold compaction can be done using simple pressing, isostatic pressing, rolling, extrusion, injection molding. Hot compaction can be done using isostatic pressing, then we sinter the cold compaction product that we call as green compact. So, green compact that is made after cold compaction is then sintered. And then finally, we go to the secondary operations, so what are the secondary operations?

Secondary operations basically are, coining, forging, machining, heat treating, impregnation, infiltration and plating. So, if required we will go for the secondary operation, if the product does not demand all these processes, then we can even omit these secondary operations. This depends upon the specifications of the powder metallurgy product that we are making, if required we will go for these processes, if not required we can omit these processes from the production cycle.

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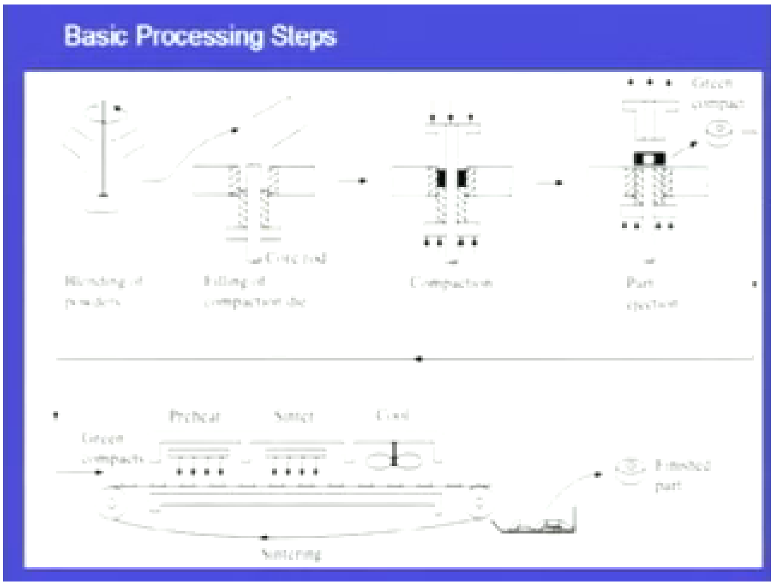

Now, this gives a line diagram of the basic processing steps, so we can see that this is the blending of the powders, so this is one shape Y shape kind of all equipment in which we put the different metals, whose powder have to be made the powders have already been made, we put them for blending processes here. So, different powders will be put here and this will be rotated as is shown in the diagram, this is the rotation taking place. So, this will be rotated at a predefined speed, and the metal powders that have been put here will be mixed thoroughly.

So, once we make the metal powder mixture here, the powder mix I can say, once the powder mix is ready, this powder mix then will be put in the compaction die. So, this is the compaction die, in this we have a core rod here. If we want to make a hollow product which is hollow from inside, we will use a core rod if we want to make a solid product then this core rod will not be require. So, this step means filling of the compaction die, the first step was blending of the powders. So, different powders will be put and will be blended here with the lubricants, if we want to add the lubricant.

After that, we will use this compaction die in the compaction die we will put the metal powders in the form of the mixture that we have made in the blending stage. After that, the compaction is taking place, these array show that the pressure is been applied, this the solid black portion here shows us the product that is being made. So, the powder that has been put here has filled this cavities that I cavities, and then there is a pressure been applied, so this is a processes of compaction. After compaction, the part ejection, part ejection means the part that has been made is taken out.

Now, we can see this solid black portion, which is this is the final shape this is the two dimensional diagram shown, this is a three dimensional green compact which has been made. So, now this green compact that has been made after the cold compaction process is then sent for the sintering processes. So, the green compacts are sintered and here we can see there is a continuous type of arrangement, belt type of arrangement. The continuous belt is moving like this, and the green compacts are put here on the belt.

So, when this green compacts come on the belt, they are first pre heated up to a certain temperature, after pre heating they are sintered, that is a sintering temperature which is less than the melting point of the molten the melting point of the metals, that we are taken in the powdered form. So, if it is equal to or more than the melting point, there are chances that the powders we have taken may melt. So, the temperature is always kept less than the melting point of the molten melting point of the metals that have been used for making the powders.

So, the sintering is taking place here at a pre specified temperature, which is less than the melting point of the metals that are used for making the powder metallurgy part. Then the cooling process is taking place, and finally we get the finished part. So, this finished part if required this can go for any of the subsequent operations like coining and sizing, it can go for machining, it can go for infiltration, impregnation. So, if required other optional manufacturing processes can be carried out on this finished part.

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So, what is basically compaction? Now, we will discuss compaction and sintering, so what is compaction? So, compaction is the process in which the blended powders are pressed into shapes in dies. So basically, we apply some pressure we put the metal powder into the die cavity. And then we apply some pressure, so when the pressure is applied, the powder takes the form of the die cavity. So whatever product we want to make, we will make exact replica of that product into the die cavity. And the die cavity will be filled with the metal powder and then it is pressed. So, the process of these pressing is called as compaction. So, the purposes of compaction what is the purpose of compaction?

The purpose of compaction or the purposes of compaction are to obtain the required shape as I have already told, it will take the powder will take the shape of the die. Density and particle to particle contact and to make the part sufficiently strong for further processing, so during the process of compaction, we get the required shape, we get the required density and we get the particle to particle contact. So, that the particle, the product that we are making is of sufficiently strong strength or the strength of the particle, not of the particle the strength of the product is sufficient to go for further processing strengths.

Now, whatever product we are making, the green compact is the product of the compaction process. So that, green compact has to be used for further processing, already we have seen the compaction process, after the compaction process whatever green compact we are getting; that green compact is sent to the sintering process. After the sintering process, other optional processes may be required; sometimes we may need to machine the product.

So, when machining is there if the strength of the product will not be sufficiently high, it may if it is brittle or if it is porous then it may break also. So, we need to have that the strength of the green compact should be sufficient to and to with stand the forces or to withstand the processes that are subsequent to the process of compaction. So, the purpose of compaction basically is to get the required shape that is the shape of the die, then the required density and particle to particle contact.

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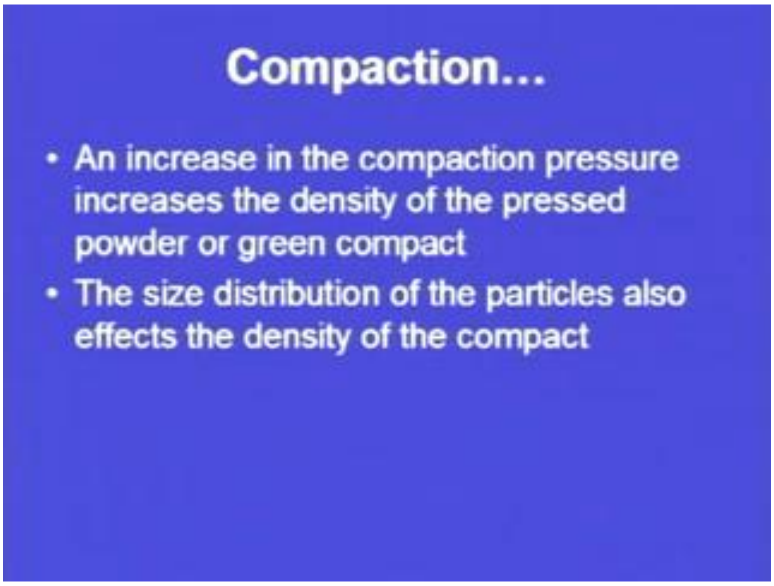

So, as we have seen that the strength of the green compact is also important for further processing of the green compact. So, now the third point to be considered in compaction is, an increase in the compaction pressure increases the density of the pressed powder or the green compact. So, if we increase the compaction pressure, the density of the pressed product or green compact will improve. So, increasing the compaction pressure will increase the density of the pressed powder or of the green compact. So, we need to have adequate density of the green compact. So, density as well as porosity these are the two important properties of the powder metallurgy part.

So, increasing the compaction pressure will increase the density of the powdered compact. Then, the size distribution of the particles also affects the density of the compact. Already I have told these has been discussed in the previous class also, if we put the tennis balls of same size into a box, then there will be some porosity inside, and the density will be depending upon the shape of the balls, as well as the pores that are present in the box, after filling the balls. So, the size distribution of the particles also affects the density.

So, if all the balls are of same size, the density will be comparatively less, but if there is a distribution of the size of the particles, then the larger particles will take certain space and the smaller particles will fit into the interstices or the voids that have been created in between the bigger particles. So, they will fit into the smaller voids, and the density will be improved. So, the size distribution of the particles also affect the density of the compact.

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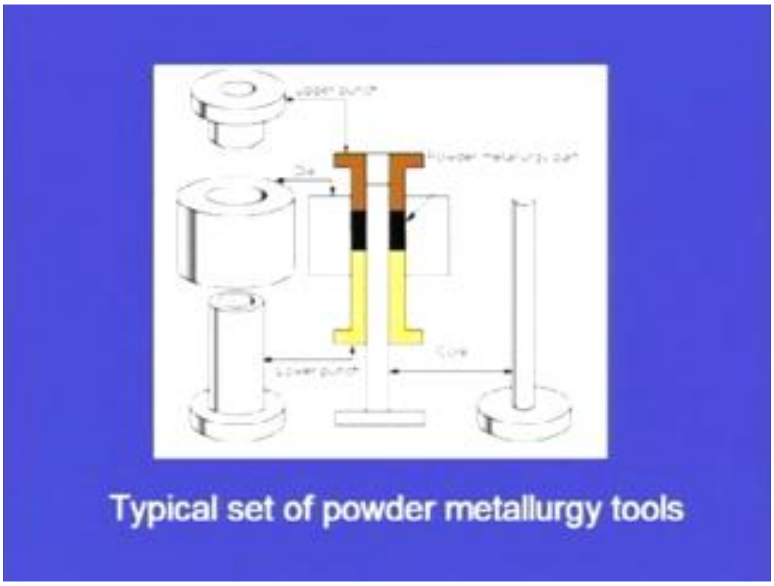

So, now this the very basic diagram just to show the whatever the typical set of powder metallurgy tools, this is the very primitive type of diagram very simple diagram, to explain the student, what are the various type of basic powder metallurgy tools. So, you can see here there is the upper punch, shown here this is the upper punch, there is a lower punch, it is of different color you can see. Then there is a die, three dimensional shape as well as the two dimensional representation is also shown. The three dimensional shape you can see of the upper punch is like this, this is the circular shape, then the die is also circular, then there is a lower punch like this. And then there is a core rod, which is shown here.

So, solid black portion gives the powder metallurgy part, so all these parts typical set of powder metallurgy tools, then they will be used in consumption. Then we will be able to make a part that is the solid black portion, this kind of part can be made use of using this typical set of powder metallurgy tools, how it will be done? What are the various steps involved that we will see in the subsequence slide.

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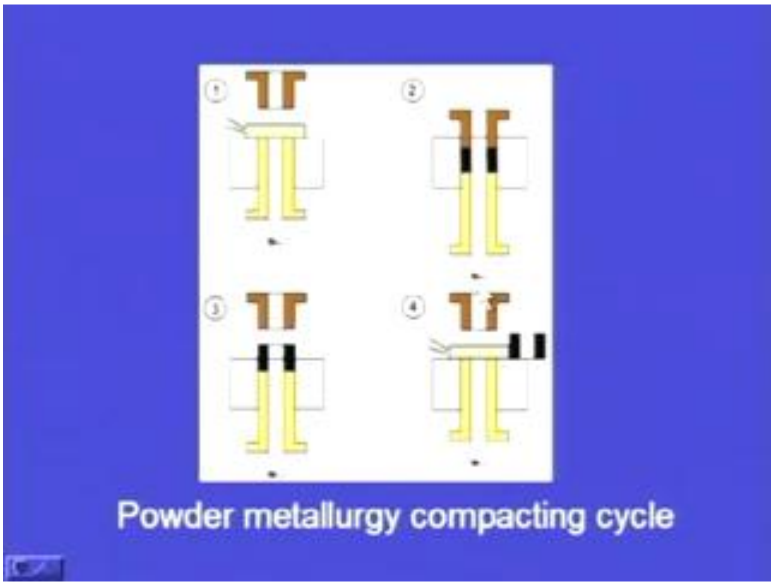

So here, we can see this is a delivery of the metal powder, so this metal powder will be delivered here. So, this metal powder in the first step is the delivery of the metal powder upper punch and lower punch are in a withdrawn position. Then when the metal powder has been supplied here, these to punches will excite certain pressure. And this is the processes of the compaction where we are applying pressure on the metal powder to give it the shape of the die. So, the die is there, within the die there is a shape, there is the core rod the core rod is being used, because we want to make a hollow product.

If we want to make a solid product in which we do not need any kind of cavity or any kind of hole then this core rod will not be required. Then this is the third processes, the third step which is the ejection, any ejection this is sort of withdrawn position, upper portion of the upper punch. And then the lower punch will push the part, so this is the part which is later on removed like this. So, this is a cyclic process, first of all it is the metal powder is delivered here, after the metal powder delivery it is compacted, it is ejected.

And then it is moved to the next chamber, next process and the delivery is again, they are for the metal powder. So, basically metal powder is delivered here and here, and before the in between there are these two steps of compaction and ejection. So, this is the powder metallurgy compaction cycle, so whatever we have seen in this diagram, we will just summarize it in the form of simple English sentences.

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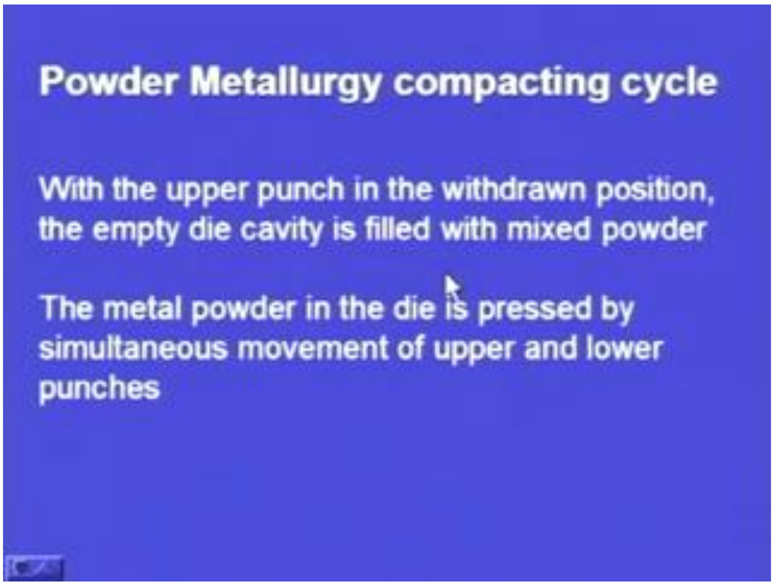

So, we can see powder metallurgy compaction cycle, the first point is with the upper punch in the withdrawn position, the empty die cavity is filled with the metal powder. So, upper punch in the withdrawn position, the die cavity is filled with the metal powder. The metal powder in the die is pressed by the simultaneous movement of upper and lower punches. So, this is simultaneous movement of upper and lower punch, and the metal powder is been compacted inside the die. Now, when the metal powder has been compacted inside the die that is the step two, then we go onto the step three. So, what is basically step three?

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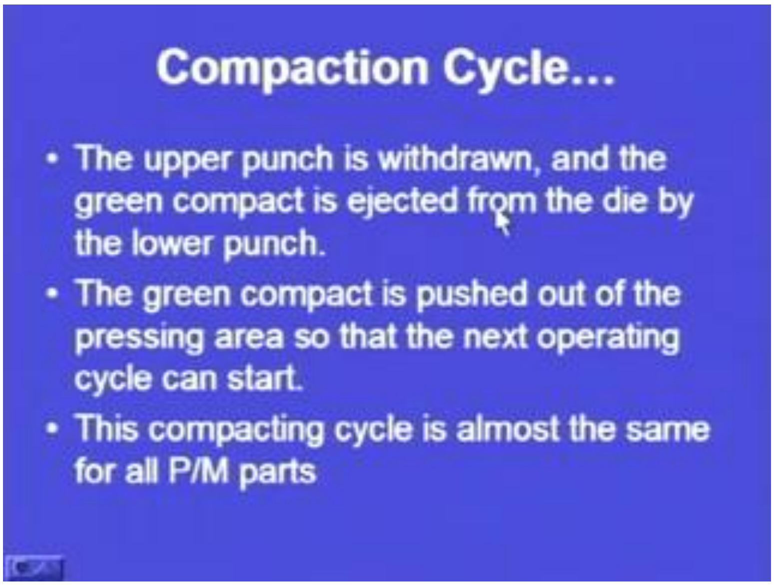

The upper punch is withdrawn, and the green compact is ejected from the die by the lower punch. Now, step three we can see the upper punch is withdrawn, and the green compact these black portions are the product that we are making is withdrawn with the help of the lower punch. The green compact is pushed out of the pressing area, so that the next operating cycle can start.

So, now whatever, green compact we have made here, after the pressing as well as after the ejection is pushed into the next station or the next stage, so that we are ready for the next processes or the next cycle. So, as we have seen, this is for the delivery of powder mix here, again we will supply the powder mix here, and this powder mix or the blended powder then will be compacted, and after compaction it will be ejected.

So, this is the basic powder metallurgy compaction cycle, so this compaction cycle is almost the same for all powder metallurgy part. There will be some variation depending upon the change in the shape of the die, depending upon the way in which we press the powdered mix to make a green compact. But, the basic process for making a powder metallurgy green compact or a final powder metallurgy product will be same, this compaction cycle the basic step will be same.

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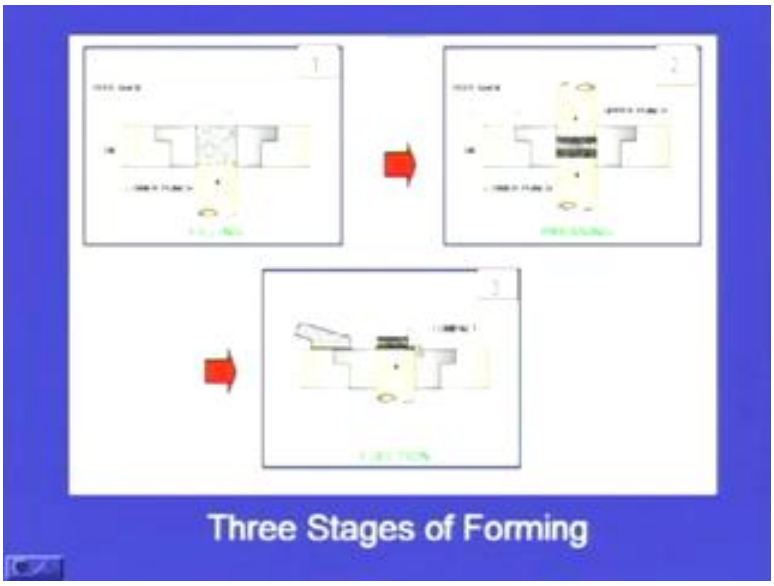

Now, this is another diagram to explain how we can make a powder metallurgy part, so here also there are 1, 2 and 3 stages. As we can seen in the first stage there is a die, this is the die this light grey position, then there is the punch that is here, this is the feed stock or the feed shoe from here we are going to feed the metal powder. So, this is basically the metal powder of which we want to make the final product, the shape that we are going to get will depend upon the shape of the die.

So, here we can see that there is a cylindrical type of shape that we want to make, so the die is of a cylindrical shape, here there is a lower punch this the lower punch, and this is the feed shoe. So, the feed shoe is going to supply the metal powder. So, once the metal powder has been supplied in the first stage, then we go on to the second stage. In second stage we can see there is a lower punch, there is a upper punch, there is a die and then these two are as we can see with the help of arrows, these two are pressing the metal powder which has been supplied here into the green compact.

After the pressing has been done there is the process of ejection. In ejection the upper punch has been withdrawn, the lower punch then pushes the green compact outside, here it is written compact. So, this is the green compact that has been made. So, basically to summarize there are three stages of forming, first one is the filling the filling of the metal powder, the second one is the pressing the pressing of the metal powder or the powder mix between the upper and the lower punches, and the third one is the ejection in which the green compact is finally ejected out of the dies.

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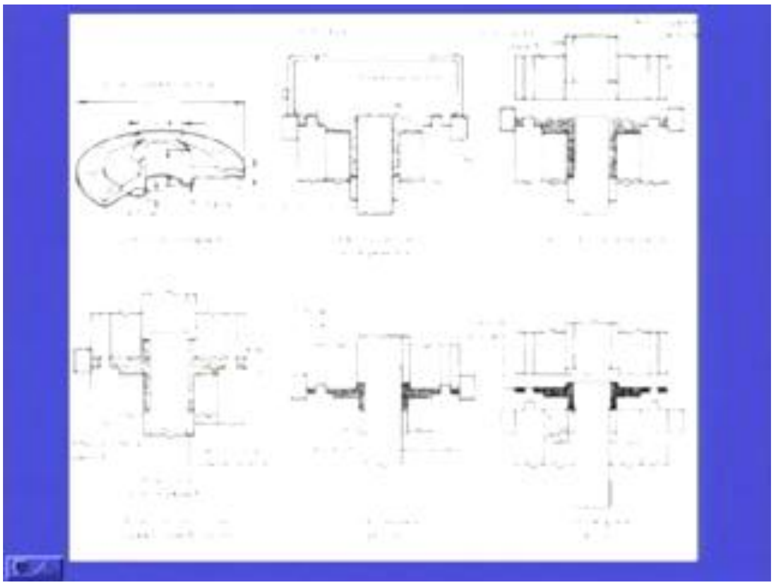

So, this is another diagram which seems to very complicated, but it is not that complicated, these also shows the very basic process of making a green compact. So, this is the shape suppose we want to make. We make a die, we put the metal powder this is the loose metal powder which has later on been smoothened like this, there is a upper punch, there is a lower punch. And then, the upper and lower punch will press against each other and in between this black portion is the metal powder which has been pressed together, and later on this black portion has been ejected.

So, three diagrams have been shown to illustrate the process of compaction, there is a lower punch, upper punch, feed of the metal powder or the powder mix. And then this powder mix is then formed into a form of a green compact, which is later on ejected with the help of a lower punch. So, there may be sometimes problem in cold compaction, what are these problems? We will here discuss only one basic problem.

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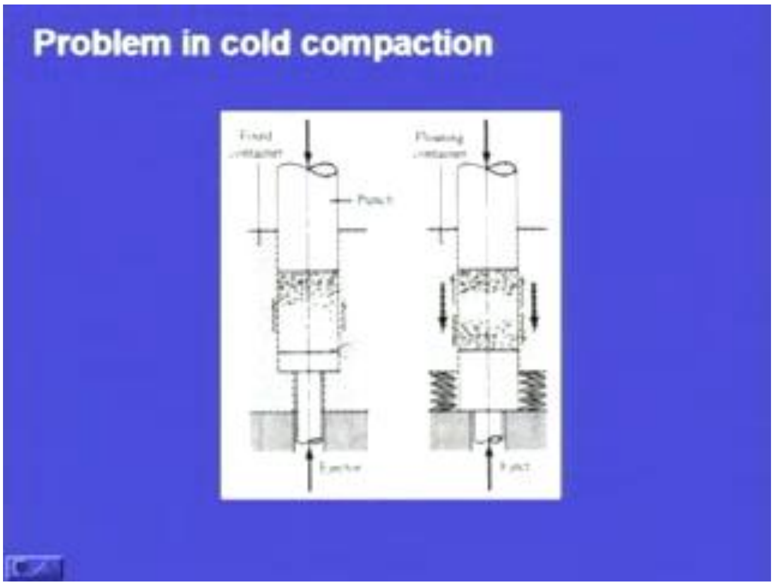

The basic problem arises here, this is the powder mix which is being pressed, this is a punch which is pressing it. This is the die walls or we can see this is the die. So, we can see that this particular portion, upper portion has more density as compared to the lower portion. We can see the darker portion; we can assume that the darker portion here will have more the density as compared to the lower portion, because here applying the pressure from this side only. So, the density variation is there, so when we will use this product, some portion will have more density as compared to the other portion.

In some of the application this density variation or the density gradient within the product may not be required. So, when this density gradient is not required, we need to have uniform density throughout the product, throughout the bulk of the product. Then this problem has to be avoided somehow. So, how it will be avoided, we can have two counter acting punches like this, and here we can see that there are two dark portions on the top, as well as towards the bottom also.

And there is a floating type of a die, two counteracting punches and the floating type of die, here we can see there are spring type of arrangement. So, this problem that arises, because of the single acting punch can be avoided by using double acting or counter acting punches with a movable die. So, whatever we have seen here, we will simply see it in the form of a very simple English text.

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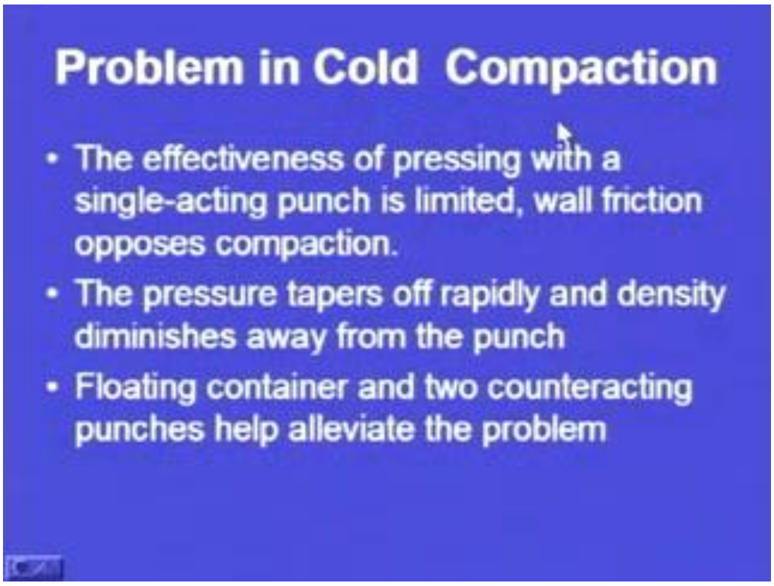

So, the problem in cold compaction already discussed in the previous slide, the effectiveness of pressing with a single acting punch is limited, wall friction opposes compaction. So, the wall friction will also oppose the compaction processes. Then the pressure tapers off rapidly and density diminishes away from the punch. As already I have shown, the density is very good towards the periphery of the punch or at very close to the punch, the density is very good, but at a distance the density is comparatively less. So, floating container and two counteracting punches help alleviate this problem, so the floating container and two counteracting punches. This is the floating container and these are two counteracting punches these will help to solve this problem, the problem of cold compaction.

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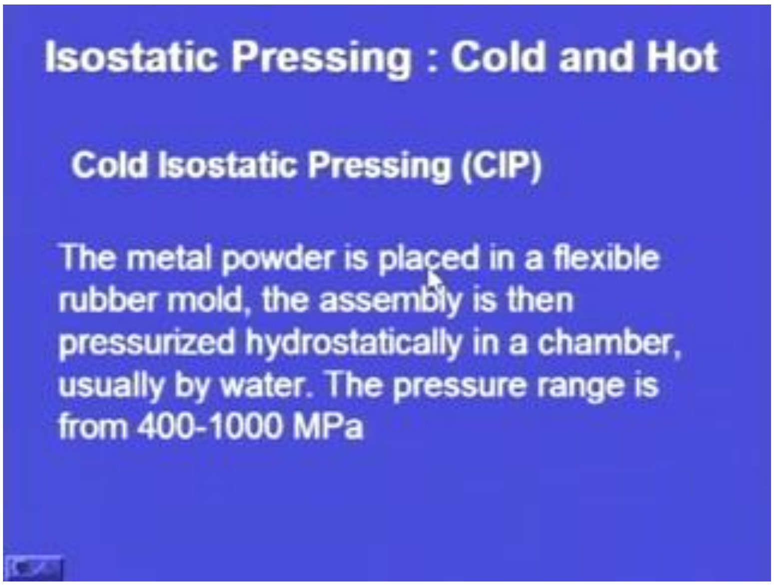

Now, there is another way in which we can counteract this problems, these are by isostatic pressing, so isostatic pressing can also be carried out either in cold condition or it can be carried out in hot condition. So, what is basically cold isostatic pressing? This we will also see with the help of a diagram, what is cold isostatic pressing, cold isostatic pressing? Which is also called CIP? What is CIP? The metal powder is placed in a flexible rubber mold; the assembly is then pressurized hydrostatically in a chamber usually by water. The pressure range is from 400 to 1000 mega Pascal.

Normally, we have seen in compaction there is a die punch type of arrangement, the upper punch and the lower punch press the metal powder and a green compact is made, but it has certain limitations which are overcome by the isostatic pressing. So, what is the basic principle of isostatic pressing? The metal powder is placed in a flexible rubber mold; the assembly is then pressed hydrostatically, usually by water the pressure range typically is given as 400 to 1000 mega Pascal.

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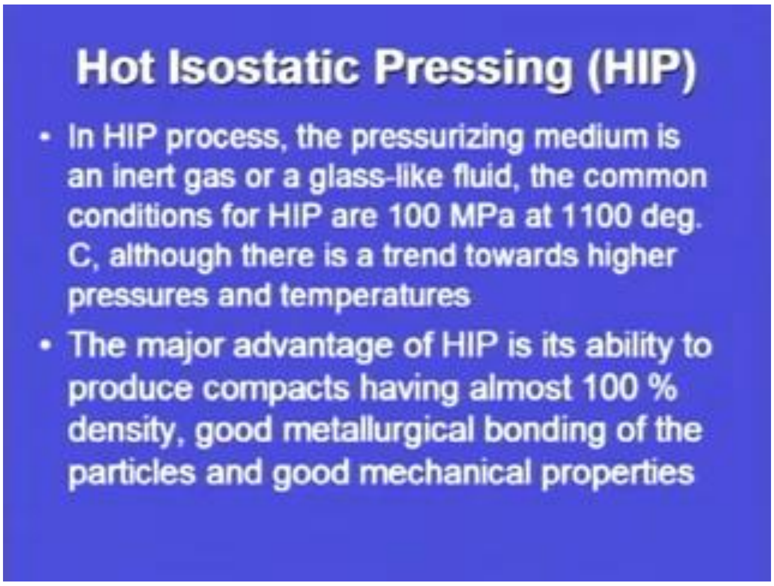

Now, coming onto hot isostatic pressing, what is hot isostatic pressing? Already we have seen cold isostatic pressing, isostatic pressing means that we are pressing the compact from all the sides. In hot isostatic pressing or HIP, in HIP process the pressurizing medium is an inert gas or a glass like fluid, the common conditions for HIP are 100 mega Pascal at 1100 degree centigrade, although there is a trend towards higher pressures and temperatures. As we have seen in cold isostatic pressing, we are pressurizing with hydrostatically in a chamber usually by water.

In hot isostatic pressing, we are pressurizing with the help of an inert gas or a glass like fluid, the common conditions for hot isostatic pressing are 100 mega Pascal at 1100 degree centigrade. So, the major advantage of hot isostatic pressing is, it is ability to produce compacts having almost 100 percent density, good metallurgical bonding and good mechanical properties. So, although we can make use of process of die and punch type of arrangement, but still isostatic pressing has its own advantage. The advantage is in terms of good density that is that can go up to the tune of the 100 percent. Then it has good metallurgical bonding of the particles and good mechanical properties.

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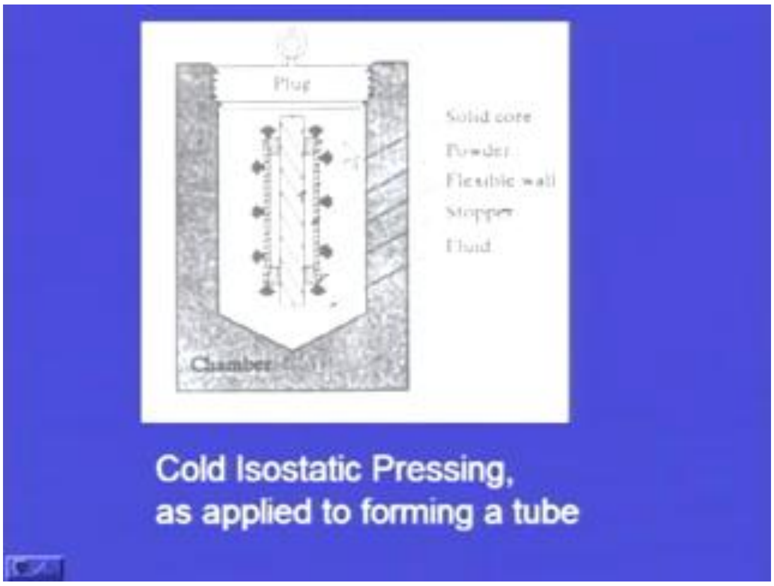

Now, this is simple diagram of cold isostatic pressing as applied to forming a tube. So, if we want to form a tube using the process of powder metallurgy, then pressing can be done in cold isostatic pressing conditions using this kind of a diagram or this kind of a setup. So, we can see there is a this hashed portion is a solid core, solid core why solid core is required? Solid core is required, because as already it is shown here as applied to forming a tube, this process is being applied for forming a tube. So, tube is hollow from inside. So, in order to have that hollow portion inside we are using a solid core, then there is a powder which has to be pressed, after around it there is a flexible wall there is a stopper and a fluid.

So, when with the help of a plug, when this is pushed down the water or the fluid that is there will press against this flexible wall. And the powder which is their inside will be pressed from all the direction. In with die and punch type of arrangement, sometimes there is a variation in the density profile,along the length or the depth of the product. But, in this case as we can see the pressure is being applied from all the direction, so we will get a uniform density throughout the bulk of the product. So, density may go up to 100 percent of the final product. So, this is the basic diagram of cold isostatic pressing for forming the tube.

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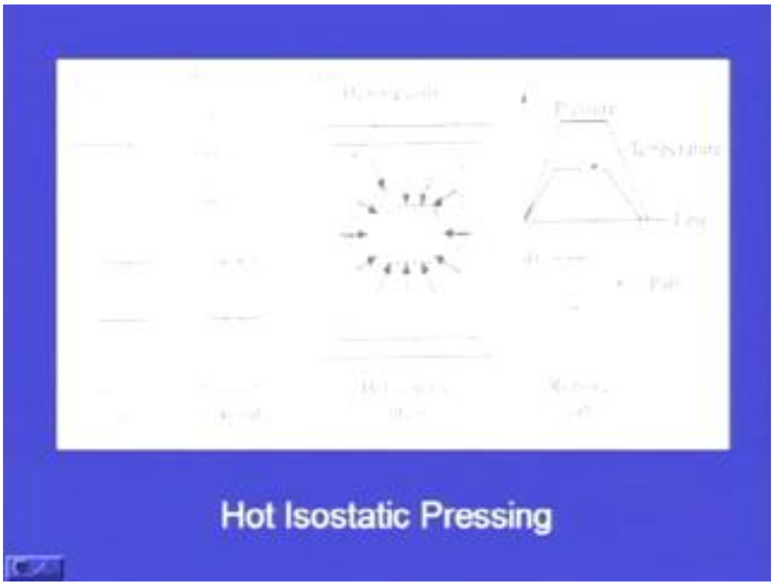

Now, this is the simple diagram for hot isostatic pressing. In hot isostatic pressing we have heating coils also, because the compact is heated up to a temperature of 1100 degree centigrade, as well as the pressure is applied. So, the pressure here is applied in the form of a inert gas or a glass like fluid, the pressure is applied with the help of a inert gas here, and there are heating coils. So, there are different steps, first steps is the filling the can, the can is filled with the metal powder or the powder mix, then there is a vacuum ((Refer Time: 46:38)) then heating coils are used to heat as well as the pressure is applied from all the direction.

The pressure and temperature profiles with time are shown here. So, the first the pressure is increased, then it is maintained at a certain level, and then finally it is released. Similarly, the temperature profile also the temperature is increased maintained at a certain pre specified level, and then this is decreased. So, then we get the final product in this form. So, this is the final, this is the initial product where the metal has been core, the metal has been put or the powder mix has been put here, the blended powder is put here, vacuum wake out. And then it is pressed in the presence of temperature, and then finally we get the final product.

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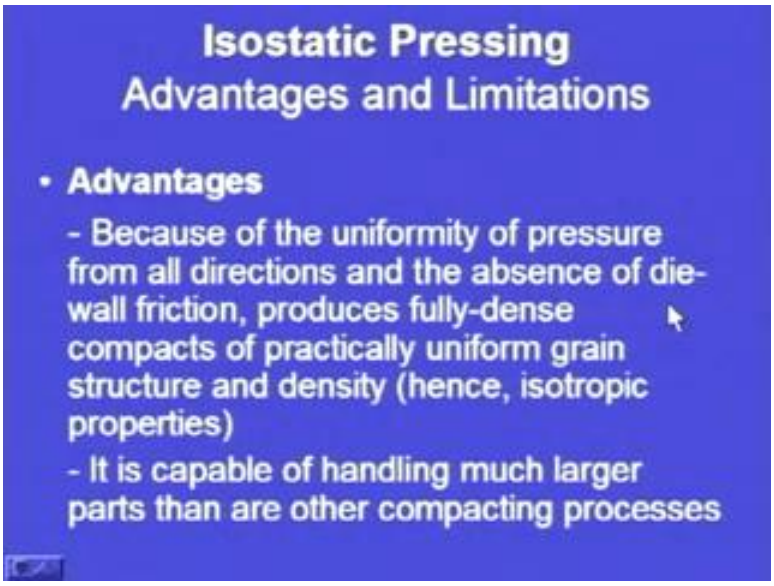

So, isostatic pressing as discussing cold isostatic pressing and hot isostatic pressing, we have discuss certain advantages of the processes of isostatic pressing. But now, just to summarize these advantages, we can say that isostatic pressing has certain advantages and certain limitations. So, what are the advantages? The advantages are, because of the uniformity of pressure from all the directions, as we have seen in the diagrams for HIP and CIP. There the uniformity of pressure from all the directions, and the absence of die wall friction.

As we have seen in going for the compaction processes with die and punch type of arrangement, there is a friction between the powder as well as the die surface. So, here in case of isostatic pressing, the absence of die wall friction is there. So, this produces fully dense compacts of practical uniform grain structure and density. So, hence isotropic property, so density gradients is not there in the bulk of the product, and we get a quasi isotrophic type of property. Secondly, it is capable of handling much larger parts than other compacting processes, so the size of the part is also important. So here, we can handle much larger parts as compared to the other compaction processes.

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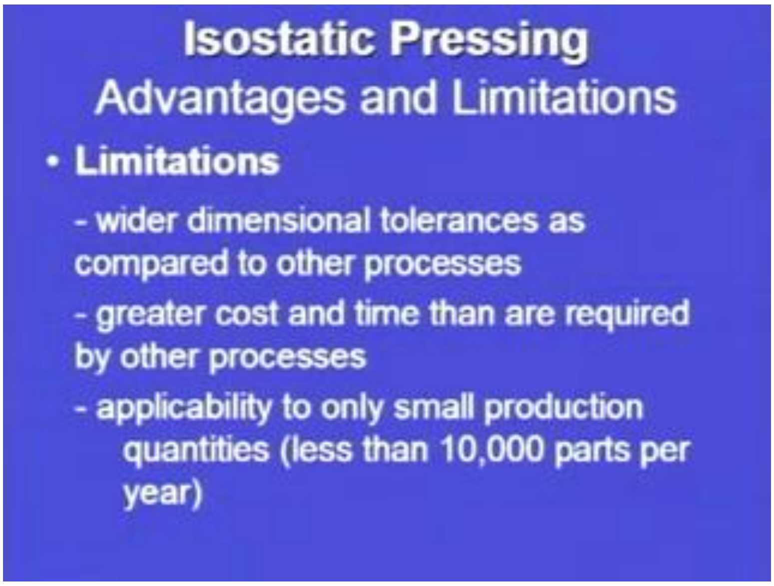

Then the limitations of isostatic pressing are wider dimensional tolerances as compared to other processes. So, the dimensional tolerances that we get in isostatic pressing are towards the higher side as compared to other compaction processes. And greater cost and time, then are required by other processes, so the cost required here is higher and the time also is more. So, the lead time for making a powder metallurgy product will be more, if we are opting for hot isostatic processing or cold isostatic processing.

Then the applicability to only small production time, as the time required for HIP and CIP is much more as compared to the our compaction processes. So, the final production volume that we can get is comparatively less. So, there are 7 advantages uniformity and density, and uniformity in pressure, and then die wall friction is also reduced. But there are certain limitations also which are the high, the more time is required, higher cost,as well as the lighter dimensional tolerances.

So, if you want to go for hot isostatic or cold isostatic processing, we have to make a tired of between the advantages as well as the limitation. We have to see whether the advantages are more or the limitations are more, and then we have to make a final decision, whether we have to go for hot isostatic pressing or cold isostatic pressing or we have to go for general compaction processes like, die and punch type of an arrangement.

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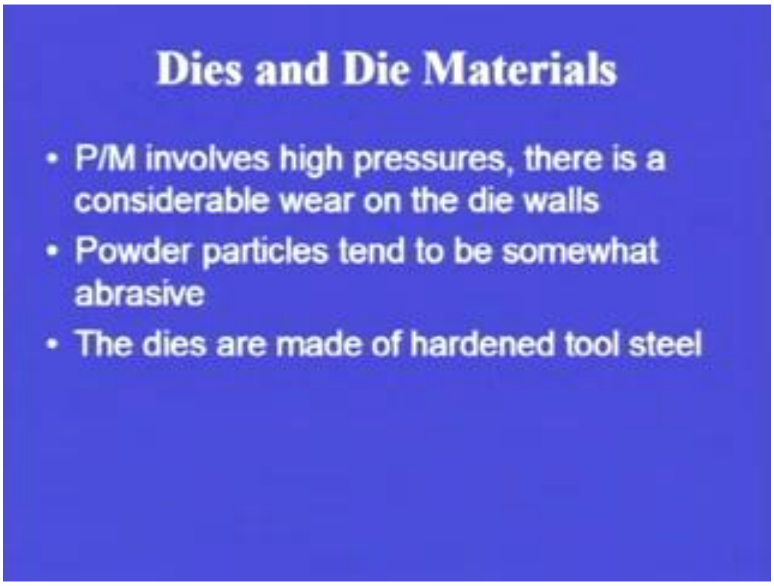

Now, die and die materials, as most of the times I have been mentioning regarding the die, the die is used the die surface as have should have anterior property. So, what are the different types of materials that are used for making dies, we will see in this section. So, die and die materials, so powder metallurgy involves high pressures, already we have seen the compact has to be pressed. There is a considerable wear on the die walls, powder particles tend to be somewhat abrasive.

So, powder particles that are we are that we are using, sometimes they have plate like shapes, sometimes they are irregular shapes, so they sometimes tend to be abrasive in nature. So, these abrasive metal particles sometime may abrade the die surface, so that has to be avoided. The dies are made up of hardened tool steel. So, tool steels are used to make the dies, because of their anterior characteristics.

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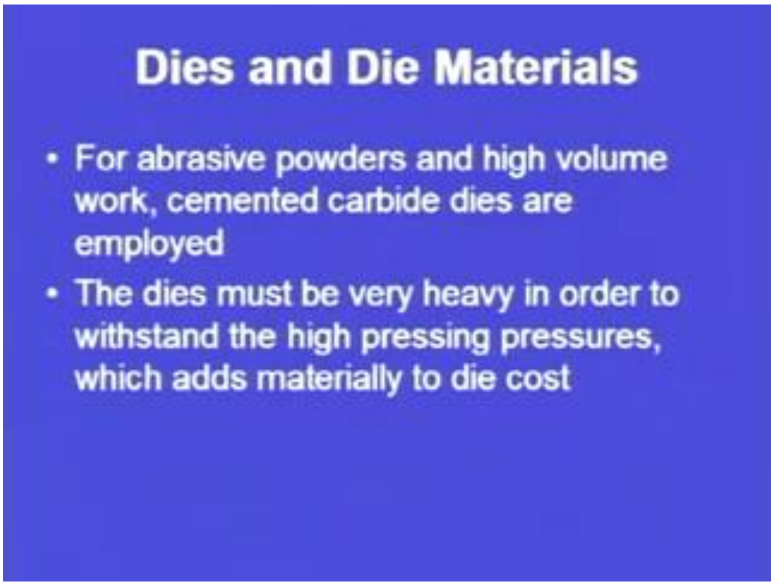

For abrasive powders and high volume work, cemented carbide dies are employed. So, already in the previous slide we have seen tool steels can be used. Last point, the dies are made up of hardened tool steels, so we can make dies of hardened tool steel also. And for abrasive powders and high volume production, we can go for cemented carbide dies. The dies must be very heavy in order to withstand the high pressing pressures, which adds materially to the die cost. So, die cost is considerably high, because the size of the die should be big, moreover the material of the die should have the anterior characteristics.

So, this two important points lead to the lead towards the high cost of the die, but the high cost of the die can be spread over a large number of parts that we are producing over a period of time. So, if we the die is costly initially that if it is used for making a large number of parts, then the total cost of a die is spread over the cost of making all those parts. So today, we come to the end of the second session on powder metallurgy that is powder metallurgy 2. To briefly summarize what we have discussed today, we started with our discussion on production of metal powders.

We have seen today two processes for making metal powders, the first one was mechanical pulverization, the second one was electrolysis. Then we stared our discussion on the basic process of powder metallurgy going step by step by step, we have seen that metal powders are made blended then compacted, sintered and finally other optional processes are used. So, today we stared our discussion on compaction, we have seen die punch type of arrangements can be used for compacting the metal powders.

And there can be isostatic pressing. In isostatic pressing we saw that we can go for either hot isostatic processing or cold isostatic processing. The advantages and limitations of both hot as well as cold isostatic pressing were discussed briefly. Then we went on to discuss that the importance of the die materials, though importance of die material as well as the anterior characteristics and the cost of the dies was discussed briefly. Next lecture we will discuss regarding the sintering aspects of the powder metallurgy process, and the design and economic aspects of the powder metallurgy parts.

Thank you.