Manufacturing Processes - 1

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Module - 01
Lecture - 03
Powder Metallurgy – 3

Welcome to the third session on powder metallurgy. Already we have gone through two sessions on powder metallurgy namely, powder metallurgy 1 and powder metallurgy 2. In powder metallurgy 1 and powder metallurgy 2, we have discussed regarding the introduction to basic manufacturing processes, introduction to powder metallurgy, importance of powder metallurgy as a manufacturing process. Discussion was there on different types of metal powder geometrical characteristics like particle size, particle shape, aspect ratio, etcetera, and then we discussed regarding the properties of metal powders.

Later on we went on to discuss regarding the various manufacturing strategies or various manufacturing techniques of metal powders. After that we discussed the basic process or the basic line diagram for powder metallurgy was discussed. Later on we started, to discuss the process of powder metallurgy step by step. In the last lecture that is on powder metallurgy 2, we discussed regarding the compaction cycle. The different compaction techniques were you seen there, we have seen that it the compaction can be done, either by die punch type of arrangement or it can be done by hot isostatic pressing or cold isostatic pressing.

After that we saw, what are the different types of die materials, and what are the importances of different types of die materials in large production or small production. So now, after the compaction process, the next step in the manufacturing of a powder metallurgy part is of sintering. Now, we will discuss regarding the sintering, aspects after that we will discuss regarding the economic and design aspects of powder metallurgy parts. Later on, towards the end of this session and towards the end of discussion on powder metallurgy, we will discuss regarding the advantages and limitations of powder metallurgy parts.

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Now, coming on to the other compacting and shaping processes, already we have discussed, the metal can metal powder can either be compacted with the help of a die punch of type of arrangement, compaction cycle was very clearly depicted with the help of diagrams in powder metallurgy 2. Then isostatic pressing was shown with the help of diagrams, cold isostatic pressing and hot isostatic pressing. So, there are other compaction processes as well, just to name a few these can be metal injection molding, rolling, extrusion, pressure less compaction, spray deposition and with the help of ceramic molds.

So, metal injection molding is one of the most important processes that is used. So, the basic principle is the same as injection molding of plastics there is a die cavity, one half of the die cavity is fixed, the other one is movable. So, the injected plastic takes the shape of the die, so before injection the plastic is melted with the help of a screw type of arrangement, and outside the screw type of arrangement there are heating coils. So, heating coils will heat the plastic and the molten plastic will then flow into the die cavity.

So, this basic cycle is that the two mould cavity part or the two mould cavity halfs will join together and form the die cavity in between. So, the die cavity that is formed in between the two die halfs will then be injected with the help of a molten plastic, and the molten plastic will take the shape of the die cavity, which has been made in between the two joint halfs. After the cooling of that molten plastic has taken place, the die cavity will open, and in between there will be the part that has been made, which can later only plugged in a bend.

Similarly, in metal injection molding also, for similar process is followed there is a die cavity, which can be made into two halfs, when the two halfs will join together it will form the complete die cavity in between the two halfs, the metal is injected. And later on, there are subsequent processes that we will see in the subsequent slide, which are done to get the final powder metallurgy part. So, we will discuss in detail the metal injection molding, and quickly run through the other compaction and shaping processes like, rolling, extrusion, pressure less compaction, spray deposition and ceramic molds.

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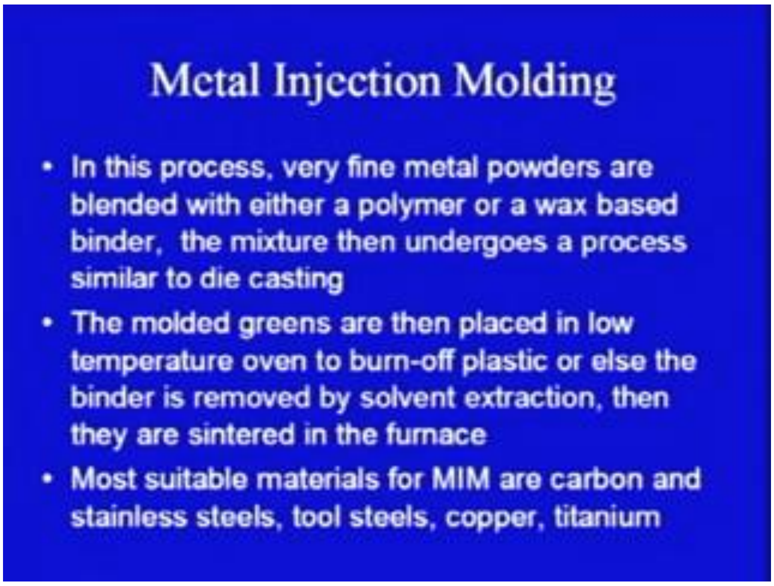

So, metal injection molding, what is this process like, in this process very fine metal powders are blended with either a polymer or a wax based binder. So, we are not going to use the metal powders as produced, but we are going to blend them with either a polymer or a wax based binder, the mixture then undergoes a process similar to die casting. The molded greens are then placed in a low temperature oven. So, the molded greens are the green compact that we get after the process of injection.

The green compact that we get though were called the molded greens, are then placed in a low temperature oven to burn off plastic or else, binder is removed by solvent extraction. So, initially we have seen the metal particles are coated either by a wax or by the help of any polymer or this has to be removed later on, how this will be removed?

This will either be removed by heating it in a small oven or it will be removed with the help of a solvent extraction, then they are sintered in the furnace.

So, the green mold or the molded greens that are made are then sintered in the furnace. So, most suitable materials for MIM that is metal injection molding are carbon and stainless steels, tool steels, copper, and titanium. These are the materials which are most suitable for use, under the metal injection molding or the MIM compaction process.

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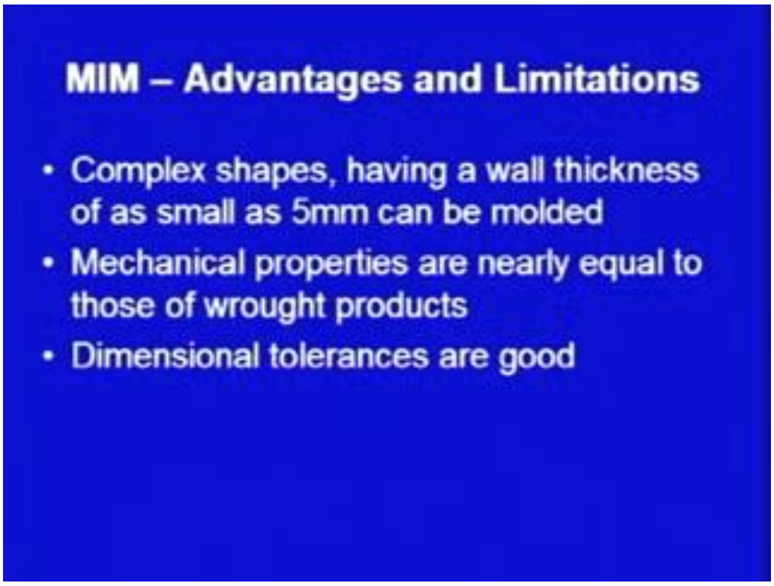

So, MIM has certain advantages and limitation, so just to have a brief overview of advantages and limitations of metal injection molding compaction process. We will just run through the advantages and limitations. So, complex shapes having a wall thickness of as small as 5 millimetre can be molded using MIM. Mechanical properties are nearly equal to those of wrought products. So, wrought products are basically isotropic in nature, so the mechanical properties of the P/M parts made by this metal injection molding are equal to the wrought products. So, the dimensional tolerances are also very good.

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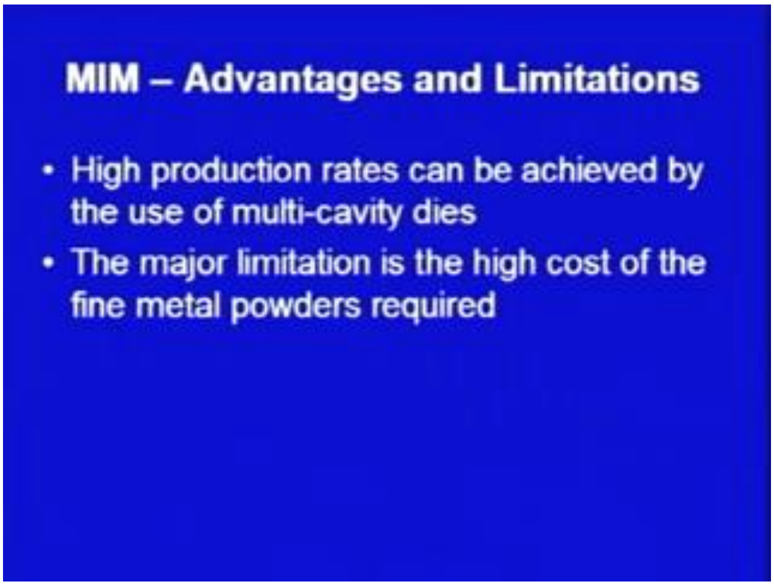

High production rates can be achieved by the use of multi cavity dies, so the die can I either have a single cavity or the die can have a multi cavities. If multi cavity is there, the powder or the powder blended powder we can say, which has in blended either with a wax or a polymer based lubricant can be injected into a number of cavities, and the production rate subsequently can be very, very high. Then the major limitation is the high cost of the fine metal powders required. So, the size of the powder required here is very, very fine.

So, fine powders will add to the cost of the process. So, the major limitation of metal injection molding is that, we the cost of metal powder is required for this process is comparatively high. The other compaction processes are rolling, in rolling the molten not the molten metal powder, it is the powder mix or the product mix, which has been made by blending the different powders together with the lubricant is passed through the rollers. And we get a sheet of the P/M part or the powder metallurgy part. So, this sheet can be made use of in making the coins that we use as a currency or for other operations.

In case of extrusion, the powdered metal particles are pressed with the help of a ram and are extruded out. So, these extruded green compacts can later on be sintered to get the final product. Then coming on to the other compaction process like, spray deposition, in spray deposition there is a rotating pre form on the rotating pre form, the metal powder are spread, and then they are sintered accordingly. So, there are different compaction processes as we have seen, but we have given a special emphasis to metal injection molding, which is one of the most important compaction process being used today.

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Now, coming on to the basic concept of sintering, the sintering it is a process whereby green compacts, which have been got after the process of compaction are heated in a controlled atmosphere, to temperature below the melting point, but sufficiently high to allow bonding of individual particles. As we have been discussing in the last two lectures also, that the temperature for sintering is less than the melting point of the metal.

Suppose we are making use of titanium or a tantalum or any other metal powder, so the sintering temperature for that metal powder will be less than the melting point of the metal. So, the basic process here is that we are not going to melt the metal powders, they will be used in the solid state only. So, why heating is required? So that, metal powders are heated to a temperature below the melting point, but sufficiently high to allow bonding of individual particles. So, in the process of sintering, we will see this concept or the mechanism of bonding with the help certain diagrams.

Here, the metal powder green compacts are heated to a elevated temperature lesser than the melting point. So that, the bonding between the individual particles takes place, and the density of the green compact improves. The principal variables in sintering are, temperature, time, and the furnace atmosphere. The furnace atmosphere sometime it is required, it should be the inert atmosphere and the time for which we are going to leave the green compact, under the sintering temperature. So, all these points have to be taken care of when we go for the process of sintering.

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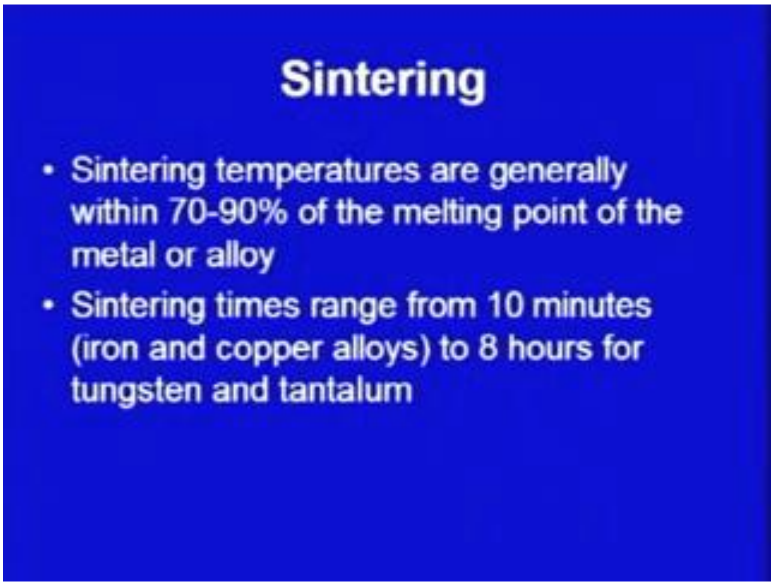

Sintering temperatures are generally within 70 to 90 percent of the melting point of the metal or alloy. Already in the previous slide also we have discussed that it is never equal two or more than the melting point of the metal, it is always 70 to 90 percent of the melting point of the metal. So, sintering temperatures will always be less than the melting point of the metal. Sintering times range from 10 minutes, typical examples we can take iron and copper alloys required 10 minutes of sintering, and this can go up to a sintering time of 8 hours for tungsten and tantalum. So, tungsten and tantalum require 8 hours of sintering, whereas iron and copper requires only 10 minutes of sintering.

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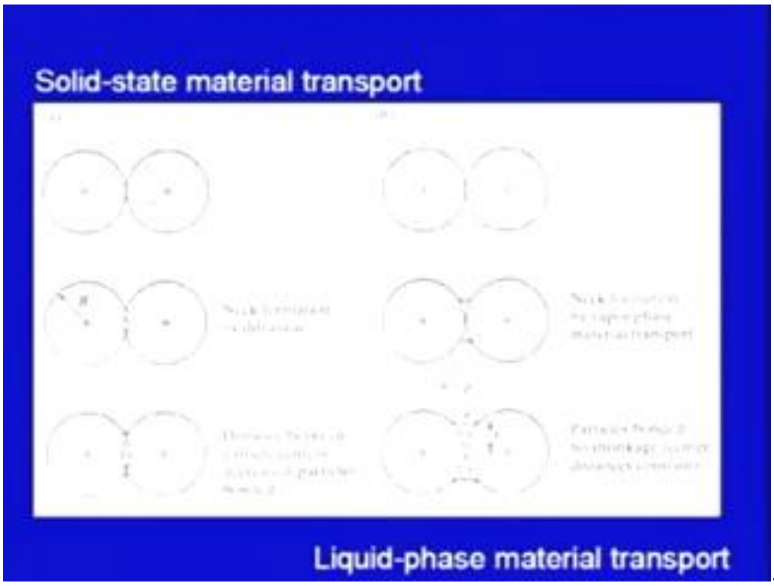

Now, this is just to have brief overview, what is the basic mechanism of particle to particle bonding during the sintering process. We can see there are two different types of mechanism, first one is the solid state material transport, another one is the liquid phase material transport. In solid state material transport, we can see there are two individual metal particles, which we can see on your screen you can see there are two different metal particles. These two metal particles when they come close to each other, there is a neck formation by diffusion.

So, diffusion process takes place, where the two metal particles are meeting each other, and the distance between the particle centres decreases, particles get bonding. So, solid state material transport takes place in this zone, and the distance between the two centers will decrease in solid state material transport, whereas in case of liquid phase material transport these are the two metal particles which are coming together. These two metal particles are having forming vapour phase here, so next formation by vapour phase material transport.

So, in this zone there is a neck formation with in the form of a vapour phase material transport. So finally, we get the bonding between the two metal particles. So, particles get bonded no shrinkage or centre distance is constant. So thus, there is no shrinkage that is taking place, and the centre to centre distance between these two spherical particles always remain constant, in case of liquid phase material transport. So, these are two mechanisms of the particle to particle bonding during the sintering process.

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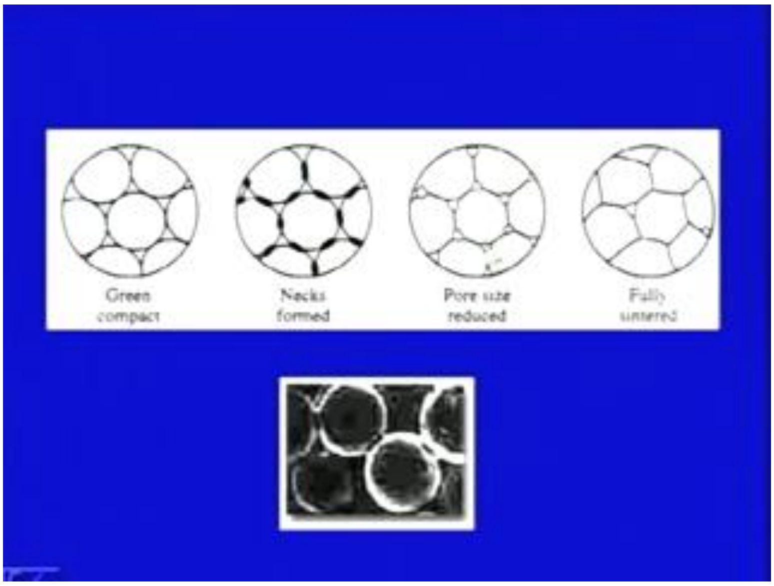

This has been explained with the help of another diagram; here we can see this is a green compact, all the spherical balls have been shown. Inside we can see there are certain voids, these are voids that are present in between the spherical metal particles. So, when we heat it that is when we subject, this type of a green compact to the sintering temperature. We can see the neck formation is taking place, wherever the two metal particles are meeting. For example, these two metal particles are meeting over this phase, and here we see that there is a neck formation taking place.

So, the pore size here we can see this is the pore size here, here the void size or the pore size there pore size. This has been reduced, and the particle to particle bonding has taken place, and this is the total length of the bond that has been developed between two metal particles. So, the pore size gets reduced, and then in the finally and the fully sintered product we can see the pore the number of pores is less, so the density has improved. This is basically the diagram, we are there are the different metal particles, and they are bonded to each other during the process of sintering.

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So, this gives us a typical sintering temperature and times for various metals. We can see for molybdenum it is the temperature is 2050, and the time is 120 minutes, 2050 degree centigrade and 120 minutes. Similarly, for tungsten we can see the temperature is 2350 and the time is 480 minutes. So, it requires around 8 hours of sintering as was shown in the previous slide. Similarly, for tantalum the temperature is 2400 degree centigrade and the time required is again 480 minutes that is approximately 8 hour sintering is required for tantalum.

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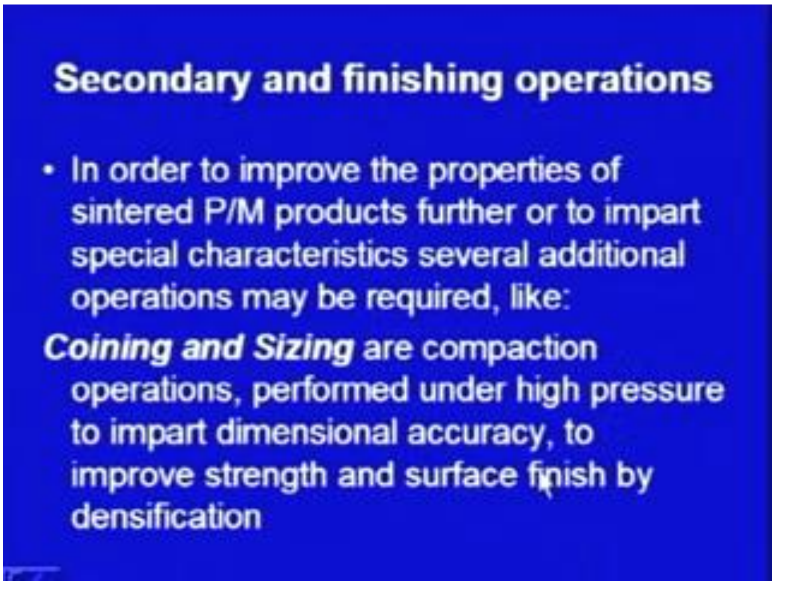

So now, we have seen that in the basic powder metallurgy process, we make the powders then we blend the powders together for certain properties of the final product, then these are compacted. After compaction sintering takes place, in which the particle to particle bonding takes place density improves, porosity is also affected by the sintering process. Later on, now we enter into another phase of the manufacturing process of powder metallurgy that is the secondary and finishing operations. So, secondary and finishing operations may be required, may not be required. So, this depends upon the final properties or the final mechanical properties of the component that we are making of powder metallurgy.

So, if required we have we can go for these secondary and finishing operations to give the desired property to the powder metallurgy part. So, in order to improve the properties of sintered powder metallurgy product, further are to impart special characteristics, several additional operations may be required. So basically, if we want to enhance the properties or if we want to impart the special characteristics to the powder metallurgy part, we need to go for secondary operations.

So now one by one, we will go through what are the secondary operations in powder metallurgy. So, the first secondary operation is coining and sizing. Coining and sizing are compaction operations performed under high pressure to impart dimensional accuracy to improve strength and surface finish by densification. So basically, if you want to improve the dimensional accuracy and we want to improve the strength of the powder metallurgy part, we can go for the process of coining and sizing.

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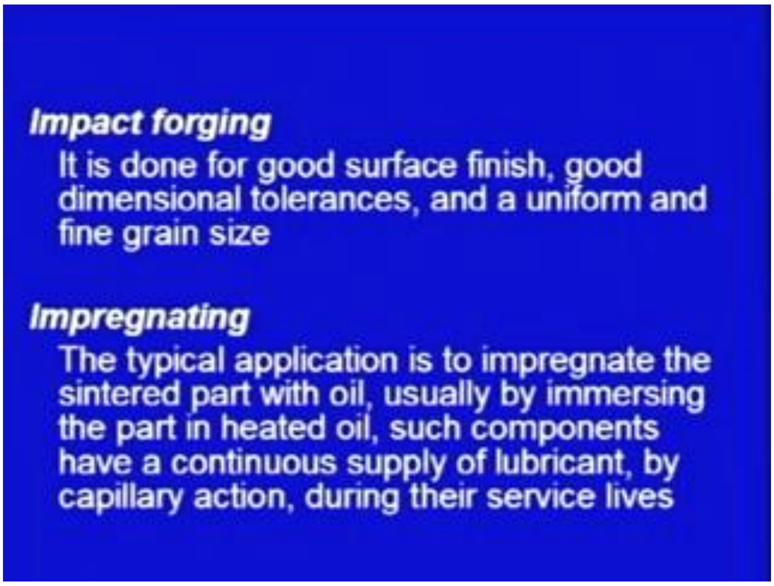

Then we can go for impacting forging, what is impact forging? Impact forging is done for good surface finish, good dimensional tolerances and a uniform and fine grain size. So, if you want to have good surface finish, good dimensional tolerances, and if the grain size required is fine, then we may go for impact forging. The third important secondary operation is impregnating, impregnating basically is to impregnate the sintered part with oil, usually by immersing the part in heated oil.

Such components have continuous supply of lubricant by capillary action during their service lives. Basically, if we want to make self lubricating type of bearings, which will supply the lubricant during their operation, then we will go for the process of impregnation. So, impregnation basically involves, keeping the porous powder metallurgy part in the oil for some time leaving the part for some time, under certain condition.

So that, the powdered metal product helps the oil to go inside or the oil go inside the powdered metal product, so that, the oil is present inside the bearing, when it is under use. So, impregnation basically is the filling of the pores in the powdered metal product with the oil. So, whenever in service life, this product is been used, when under pressure or under temperature the oil will automatically come out, because of the capillary action, and will act as a lubricant.

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Then the another process is infiltration, infiltration here a slug of lower melting point metal is placed against a sintered part, and then the assembly is heated to a temperature sufficient to melt the slug. Basically, in this whatever porous product that has been made using powder metallurgy, we need to improve the density, we need to improve the strength of the powdered metal product that has been made using the process of powder metallurgy. We will encircle it or we will put some metallic slug outside it, whose melting point is less than the melting point of the metal that has been used for making the powdered metal product or the powder metallurgy product.

After heating, the slug will melt and the molten metal will infiltrate the pores by capillary action to produce a relatively pore free part having good density and strength. One of the example, we can co adhere is, that infiltration of iron based compacts by copper. Suppose, we are making powder metallurgy part of iron base, then the pores can be filled using copper. So, copper will act as a slug, which will be melted and the molten copper will enter into the pores that are there in the iron based powder metallurgy product.

The hardness and tensile strength is improved, and the pores are filled which prevents moisture penetration. So, one of the advantage of infiltration is that, sometimes when the product made per outer metallurgy has to be used in certain pressing environments. There the moisture can enter in to the pores and can cross certain types of corrosion, so in order to avoid that corrosion in order to avoid the infiltration of moisture into the pores of the powder metallurgy part. We can preamp the problem, and we can fill the pores with the help of another metal, which do not react with the metal of out of which the powder metallurgy part has been made.

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Now, we come on to plating, why plating is required? In the first lecture also I have told that surface finish or the characteristics of the surface or the packaging of the component is very, very important. So, in order to improve the surface finish or in order to give certain important characteristics to the surface, we go for the process of plating. Now plating is given for pleasing appearance and protection from corrosion, inner porosity has to be taken care of before plating and has to be eliminated.

Suppose, we do not remove the inner porosity of the powder metallurgy part then this, there may be certain corrosion, certain types of deterioration within the pores that may take place. Now, impregnation with molten metal will help, as we have seen we can fill the pores with the help of lower melting point slug, but galvanic corrosion is likely between dissimilar metals. So, if we are filling the metal, which is dissimilar to the metal that we have used to make the powder metallurgy product, there are chances of galvanic corrosion.

More over difference in the coefficient of expansion and contraction may lift the plating material. So, if the powder metallurgy product that has been planted by some other metal is subjected to higher temperature or is subjected to certain conditions, there it may expand or it may contract. So, difference in coefficients of expansion and contraction may result in the lifting up of the plating material. So, how do we overcome this problem, we cannot fill it with the dissimilar metal because of the galvanic corrosion.

So, in order to overcome this problem, impregnating the part with the plastic resin will overcome most of these difficulties. So, before plating we can impregnate it with the help of a plastic resin. So plastic resin will in the molten form or melted plastic resin will enter into the pores. And later on when this impregnation is completed, we can go for the plating process.

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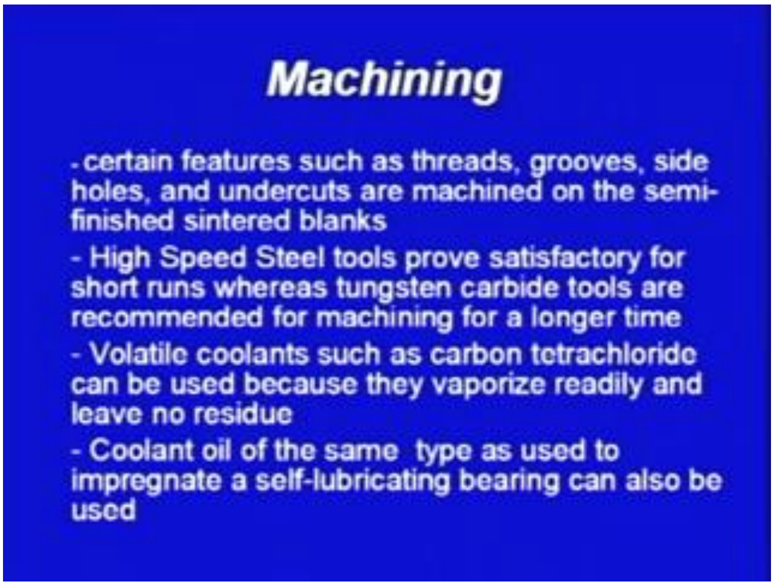

Now, coming on to machining, machining is other optional process if required we can go for machining, if not required we can avoid the machining process also. So, certain features, such as threads, grooves, side holes and under cuts which are present in the final powder metallurgy part can be machined on the semi finished sintered blanks. Similarly, high speeds tool prove satisfactory for short runs, whereas tungsten carbide tools are recommended for machining of longer time. So, if we have to machine for a longer period of time. So, we need tungsten carbide tools, why we need tungsten carbide tools?

Because, tungsten carbide tools have high hot hardness, and they have lesser wear as compared to high speeds steel tool. So, if we are making these of high speeds steel tools, these can only be used for a shorter period of time, because they will wear out very fast. Moreover, there is also a restriction on the use of the coolant, so coolant may need some residue, and may later on cause rust or corrosion. So, volatile coolants such as carbon tetrachloride can be used, because they vaporize readily and leave no residue. So, carbon tetrachloride is recommended coolant or recommended cutting fluid for machining of powder metallurgy parts.

Moreover, coolant oil of the same type as used to impregnate a self lubricating bearing can also be used. So, oil based lubricants are the coolants can be used, which are similar to the self lubricating oil that we are using for making a self lubricating type of bearing. So, till now we have discussed the secondary operation. So, these secondary operations basically are, if we start from the beginning, these are infiltration, impregnation, machining. And there are other number of operations which can be done, if we want to impart special characteristics to our powder metallurgy part.

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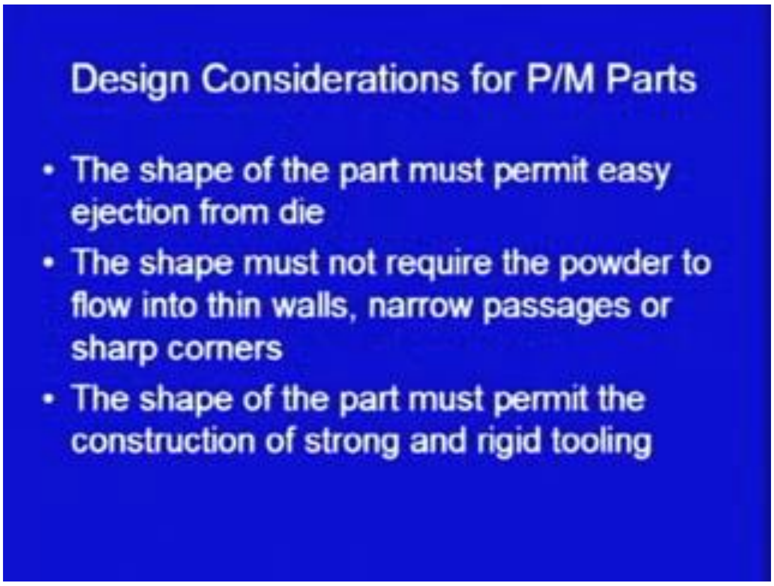

Now, the next section of this lecture will dedicate towards the design aspects of powder metallurgy parts. So, the design consideration for powder metallurgy part, first we will see them in plain English. And try to understand what are the design considerations? Then with the help of the diagram, we will try to understand that what are the design considerations required for powder metallurgy parts? The first point in the design consideration for powder metallurgy part is the shape of the part must permit easy ejection from the die.

So, the shape of the part is an important characteristic, we have to make a die in order to make a powder metallurgy part. So, the shape of the die is also limited, so the shape of the die should be such that the part should get easily ejected. If the part is not getting easily ejected, then there are chances of breakage of the part, moreover the parts made by powder metallurgy are sometimes brittle. So, if the ejection is not proper there are every chances or there is every chance that the part may break. So, the shape of the part must permit easy ejection from the die.

The second point to be discussed here is the shape must not require the powder to flow into thin walls, narrow passages or sharp corners. So, first of all to make a die, which is having narrow passages thin wall is a difficult task. The next point is to let the metal or the metal powder or the product mix or the blended powder to enter into these thing sections or narrow passages is itself a difficult task. One of the important properties of the powered metal or the metal powders that we have discussed is the flowability.

So, if the metal powders do not have the adequate flowability, the powdered metal will not be able to enter into the thin walls of the narrow passages. So, the while designing a powder metallurgy part, we should take care of all these aspect, so that, the shape must not require the powder to flow into the thin walls, narrow passages or sharp corners. Otherwise the final product that we will get may have certain areas, where the powdered metal has not reached.

The third point took over here is, the shape of the part must permit the construction of strong and rigid tooling. Already, I have told to make dies is an important tasks for powder metallurgy. So, if powder metallurgy process has to be successful, the dies have to be very, very strong, as well as they have to be having very good dimensional tolerances, and the great etcetera everything has to be taken into account. So, the shape of the part must permit the construction of strong and rigid tooling, the dies must be strong and rigid. If we go into small parts or small cavities then strength, as well as the rigidity of the die, may not be that much.

So, the shape of the part must permit the construction of strong and rigid tooling. Another important point is the shape of the part should have fewest possible changes in the cross section, why because if there are too many changes in the cross section, then the density may vary, when we compact the product using the die and a punch. So, when the punch will press the product or the green compact, we will not be able to get a uniform density distribution, if there are too many steps or too many geometrical changes in the cross section of the product.

The special capabilities afforded by powder metallurgy to produce certain part forms should be utilized. So, the special capabilities, which are possible with powder metallurgy should be utilized to make parts. The design should never contain holes, whose axis are perpendicular to the direction of pressing, this will be explained with the help of a diagram, where it will make it absolutely clear, that axis of the holes should never be perpendicular to the direction of pressing. Otherwise, the roundness of the hole or the circularity of the hole that we are getting may be disturbed.

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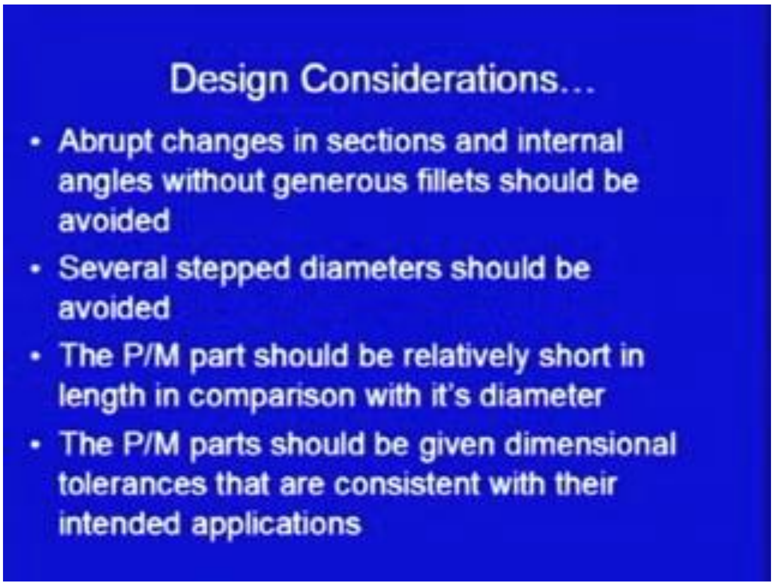

Now, further design considerations are abrupt changes in sections, and internal angles without generous fillets should be avoided. Now, the cross section or the section of the powder metallurgy product that we are designing, in that abrupt changes should not be there, abrupt changes like, the diameter in one section is very, very large. And in the subsequent or the adjoining section is very, very small, so abrupt changes in the cross section, should be avoided.

Similarly, internal angles without generous fillets should be avoided, so we should be very generous in giving the fillets. We should use fillet radius, if fillet is not there, fillet radius is not there. If we are making sharp edges or sharp corners, then there are chances that the abrasion may take place over on those edges. And, we may not get that desired quality of the powder metallurgy product. Then the next design consideration is several stepped diameters should be avoided, why? Because, the density gradient will be there, the density may not be uniform throughout the bulk of the powder metallurgy part.

The powder metallurgy part should be relatively short in length in comparison with it is diameter. This I will show or I will explain with the help of a diagram, the powder metallurgy parts should be given dimensional tolerances that are consistent with their intended applications. As we have discussed, the powder metallurgy parts are near net shaped parts. So, the products that we are getting out of powder metallurgy process, can be used as it is without any secondary manufacturing process.

So, the dimensional tolerances should be such that, it should match with the intended application of the product. So, if the intended application is that our dimensional tolerances should be less, it should be less. If we one dimensional tolerance to should be more, then we can go for some subsequent or other optional processes to improve the dimensional tolerances.

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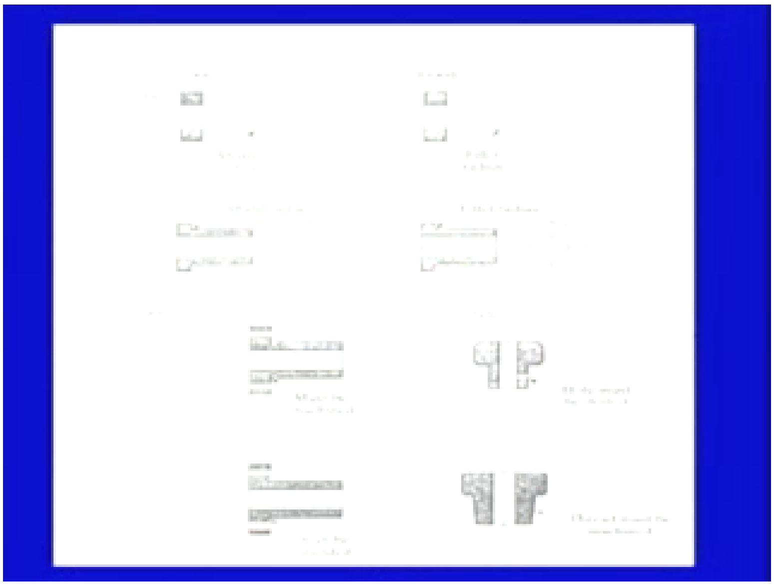

Now, here in this diagram we can see that, if sharp radius is there, it means that the product will not be of the desired quality. It is clearly written this is the pure design, on the other hand this is a good design, where there are there is a fillet radius. So, if there is no fillet radius or a sharp corner is there or a sharp radius is there, there are chances that the product may not be of the desired quality. On the other hand, if fillet radius is given the product will be of the good quality.

Similarly, sharp radius should not be there, we should always go for fillet radius. So, fillet radius is provided, we will get a product of a very good quality. Moreover, if this type of a cavity has to be formed inside the powder metallurgy part, it must be machined. On the contrary, if any cavity has to be formed in this section at the t point like this, it can be moulded during the powder metallurgy process. Similarly, if we want to make a hole like this, now we can see the pressing direction here is this.

The compact will be pressed in this direction, and this is the hole with whose axis are perpendicular to the direction of pressing. Now, this is the direction of pressing and this is the axis of the hole, perpendicular to the direction of pressing. So, the hole must be drilled and it should not be moulded ((Refer Time: 33:26)) we should make the green compact, and then later on we should drill this hole. Moreover, if we want to make threads here in this section, these threads must be machined. We should not try to mould these threads or try to develop these threads during the die punching operation.

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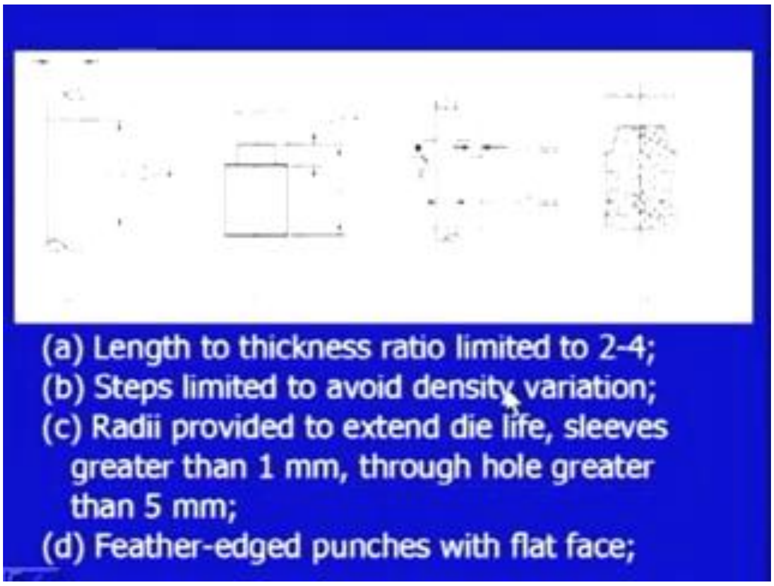

Moreover, other design considerations can be, as I have already told in the design consideration for powder metallurgy parts, that h by d ratio should be to the tune of 2 to 4. It means, that the height or the length of the part should be 2 times or 4 times to the maximum 4 times to the diameter. Now, this is the dimension d shown, now d can be h, this is h. Suppose, h should be 2 to 4 times the d, it means that if it is more there are chances that the product may break from in between or there are chances of buckling. So, h by d ratio should be 2 to 4.

Similarly, length to thickness ratio limited to 2 to 4 this is part a, this is part a the explanation is given here. Similarly, for part b we can see, the steps limited to avoid density variation, so there are two steps here, first and second. These steps should be limited in order to avoid the density variation. So, there also certain design guidelines have been given, but h by 4 this should be less than equal to h by 4 the height of this particular step should be less than the height of the, the total height it should be less than h by 4.

Similarly, we have we can always provide a sleeve of greater than 1 millimetre, if the size of the radii provided to extend the die life this is the radii, which is provided to extend the life of the die. Moreover, if we want to make a hole greater than 5 millimetre like this, we can provide a sleeve of greater than 1 millimetre. Moreover, feather edged type of punches like, feather edged punches with a flat face. If you want to make a powder metallurgy part this is the powder metallurgy part. If we want to make it of this shape, we can use a feather edged type of punches. So, see these are some of the design guide lines that should be taken care of when we design the part.

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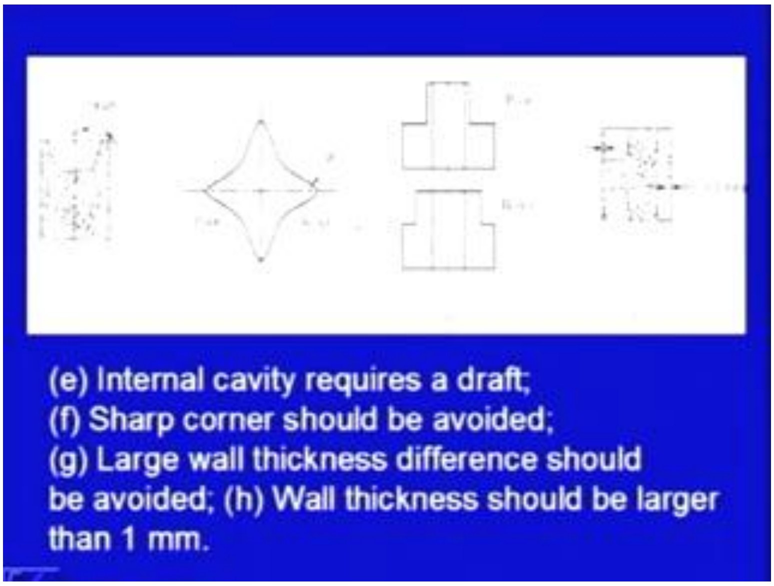

Then coming on to other design guidelines, if internal cavity is there, this is some internal cavity in the powder metallurgy part, this blank portion here. And the later on, other position is filled with the powdered metal. So, if these kinds of a design have to be developed, then some draft should be given to the internal portion edges. So, internal cavity requires a draft, so this is the internal cavity and it requires certain drafts. So, this draft, usually is given in terms of certain degrees 0, it can be 2 degrees or 3 degrees or 5 degrees depending upon the requirement.

Similarly, sharp corners should be avoided. In this design we can see that this is a sharp corner. So, these type of sharp corner should be avoided, it is very clearly depicted here, it is poor design. So, in order to improve this design, we can give a radius and we can make the design better. So, sharp corners should always be avoided in powder metallurgy parts. Similarly, in this portion we can see in this design aspect, the large wall thickness difference should be avoided; large wall thickness difference should be avoided.

Now, here we can see, the wall thickness is this much and the wall thickness in the adjoining section is this. So, this is a better design, on the contrary the pure design is this is the wall thickness here, and the wall thickness here is relatively much smaller as compared to the wall thickness here. So, the large wall thickness differences should be avoided. So, we should always go for better and best design. This type of wall thickness differences should be avoided.

Similarly, the wall thickness should be larger than 1 millimetre. So, if we want to make this type of a product, so this wall thickness here should always be greater than 1 millimetre. If this is less than 1 millimetre that type of the product, that we get will not be according to our specifications, and according to the geometric dimensions that we want to have in our final product. So, all these design guidelines should be taken care of, when we design any product, which has to be manufactured using the technique of powder metallurgy.

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Now, powder metallurgy products, till now we have seen that powder metallurgy is used for making different types of products. So, powder metallurgy products can be off, different dimensions or different application products bearings and filters, then the products of complex shapes that require considerable machining like gears. So gears, if we want to make use of any other manufacturing process, like machining or casting. They will subsequently require number of machining like, if machining is being done, then machining will result in wastage of too much of material.

If casting is done, the quality that we may get may not be according to our desired levels. So, subsequent machining, there also is required. So, where complex shapes are there, which require machining, we can go for powder metallurgy and it can be made in a single shot. So, porous products can be made using powder metallurgy. Moreover, the parts which require high level of machining or too much of machining can be made out of powder metallurgy.

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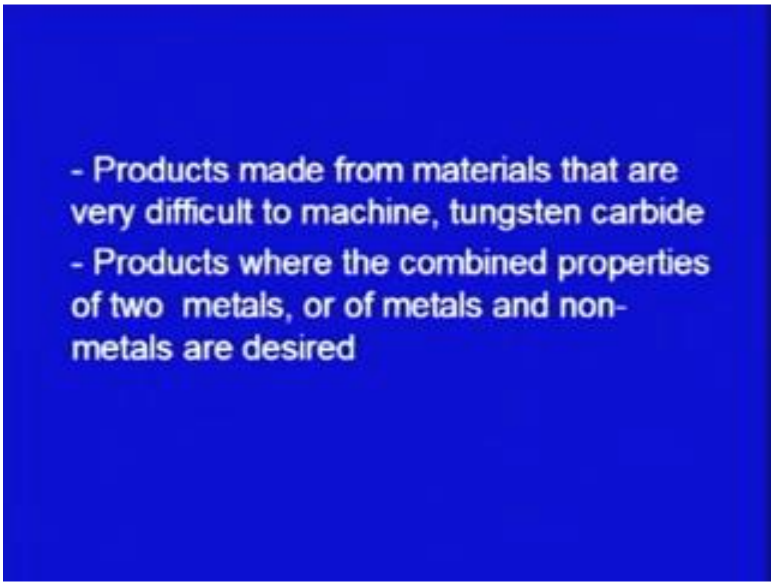

Then products made for materials that are very difficult to machine, like tungsten carbide. So, materials which are hard to machine can be made using the process of powder metallurgy, then products where the combined properties of two metals or of metals and non metals are desired, can be made out of powder metallurgy. Already we have discussed, in the blending stage we can take two different types of metal powders, and blend them together to get the desired mechanical properties of the final product. So, wherever we want to have a combination of properties of different products, we can go for powder metallurgy.

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Then coming on to the application areas of powder metallurgy, now the first application is metal filters, what are metal filters? Metal filters are used for filtering, diffusing, controlling, the flow of gases and liquids, separating liquids from of different surface tensions, removing moisture from airstreams, acting as sound deadeners. So, metal filters can be made, which property of powder metallurgy products is being used here? It is the porosity, because metal powder products made by powder metallurgy are porous, they have pores inside. So, these pores sometime acts as the arresters of moisture.

Suppose, we want to remove the moisture out of airstream, we will pass the airstream with moisture through this metal filters, the moisture will be arrested and only the air will pass. Similarly, these can act as sound deadeners, moreover we can separate liquids having different surface tensions also using metal filters this can be explained with the help of a diagram.

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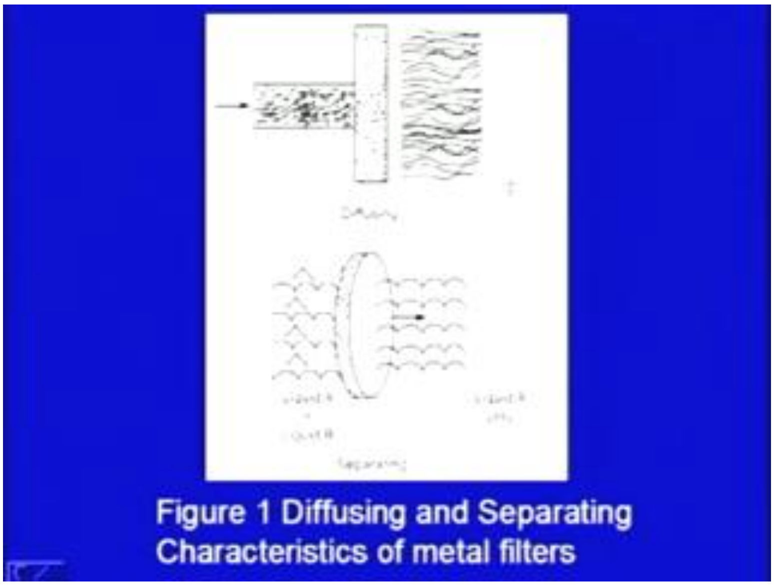

Figure 1 Diffusing and Separating Characteristics of metal filters

This is in the diagram it is very clearly seen, here it is liquid a and liquid b, and we are passing it through a metal filter, and here we are getting only liquid a. Similarly here, the diffusion is taking diffusing is taking place. We have some air stream, here we get the different types of a air stream, where the moisture may be arrested by this metal filter. So, diffusing and separating characteristics of metal filters has been depicted,, in this application of powder metallurgy product.

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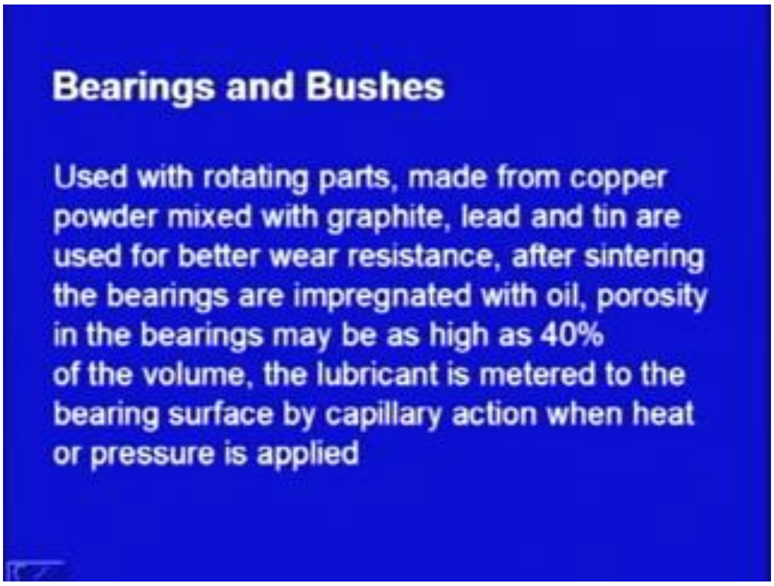

Then the second application for powder metallurgy products can be bearing and bushing. So, bearings and bushings are used, where we have rotating parts these are made from copper, the copper in the powdered form mixed with graphite, lead and tin, and it is user for better wear resistance. Lead and tin basically are added for better wear resistance. So, after sintering the bearings are impregnated with oil.

The process of impregnation already we have seen in the secondary techniques or secondary manufacturing processes for powder metallurgy part. So, in secondary manufacturing we have seen either it can be impregnated or it can be infiltrated or it can be machined coining and sizing, impact forging. Different types of processes are there, out of which one of the most important process was of infiltration or impregnation. So here, the oil can be impregnated into the porous bearings, and which will give them the property of self lubrication.

So, porosity in the bearings may be as high as 40 percent of the volume, and the lubricant is metered out to the bearing surface by capillary action, when heat or pressure is applied. So when, the self lubricating bearing is in the service condition on the application of pressure or heat. The oil that is impregnated during the impregnation stage of the manufacturing process, the oil will come out using the capillary action and will act as the lubricant.

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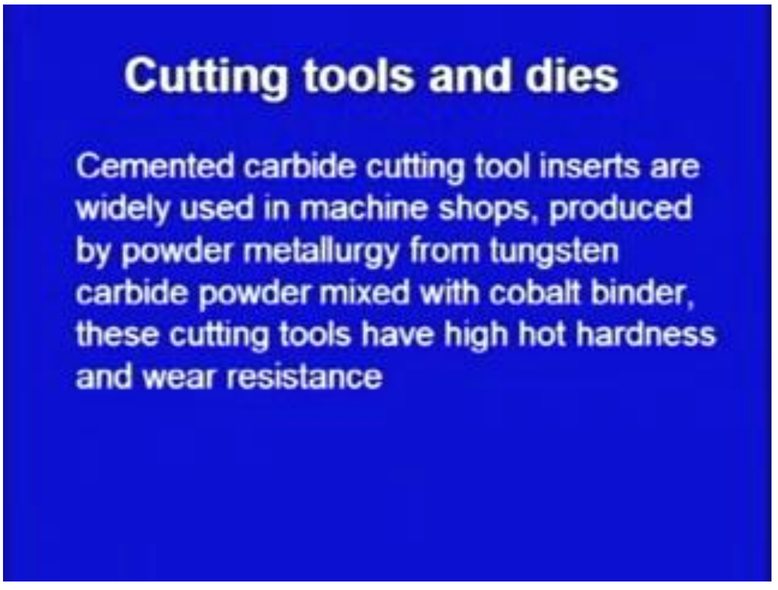

Then cutting tools and dies, so cutting tools and dies of cemented carbide can be made using powder metallurgy. These are produced by powder metallurgy from tungsten carbide mixed with cobalt binder. So, the metal powder use of tungsten carbide and it is mixed with the cobalt binder. So, these cutting tools have high hot hardness and wear resistance, so what is hot hardness? During the machining operation the temperature rises substantially. So, the tool material should retain it is hardness, at that elevated temperature.

The temperature may go depend go up to a level depending upon the combination of the tool material, and the work material. So, the material of the tool should be such that, it should withstand the high temperature generated during the cutting operation. So, these cutting tools made up of cemented carbide have this property of hot hardness and wear resistance. And how these cutting tools are made, these cutting tools are made from the process of powder metallurgy in which cobalt acts as the binder.

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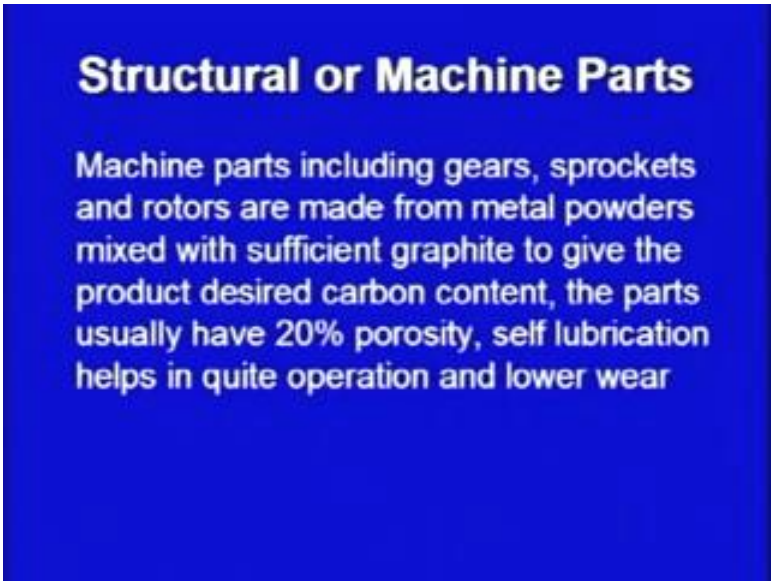

Now, structural or machine parts can also be made out of the process of powder metallurgy, what are the special characteristics of structural or machine parts? So, machine parts including gears, sprockets and rotors are made from metal powders, mixed with sufficient graphite to give the product desired carbon content. The parts usually have 20 percent porosity; self lubrication helps in quiet operation and lower wear. So, this porosity can again be utilized, and can be made these can be impregnated again with oil and the self lubricating property can be utilized, for quiet operation and lower wear of the machine parts or the structural components.

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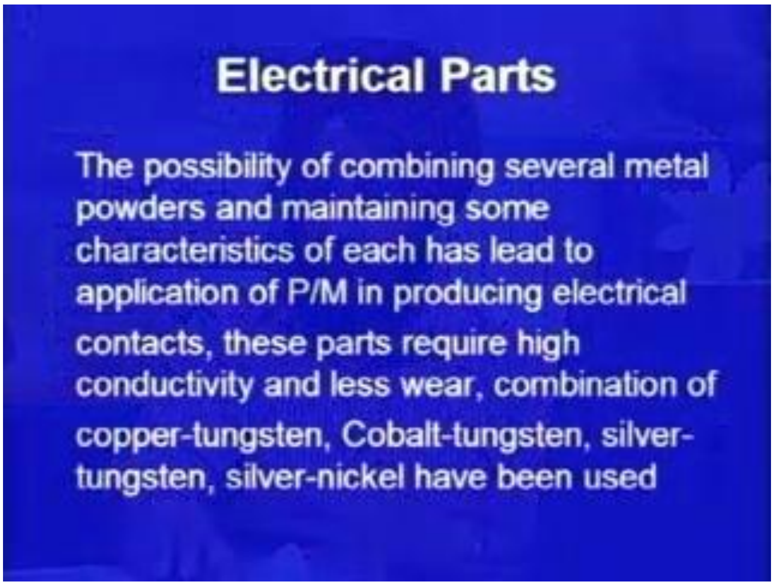

Electrical parts can also be made out of powder metallurgy, so the possibility of combining several metal powders and maintaining some characteristics of each. So, we can combine several metal powders by retaining some characteristics of each, this has lead to the powder metallurgy producing electrical contacts. These parts require high conductivity and less wear. Combination of copper tungsten, cobalt tungsten, silver tungsten, silver nickel have been used, different combination have been used to make electrical parts, out of the process of powder metallurgy.

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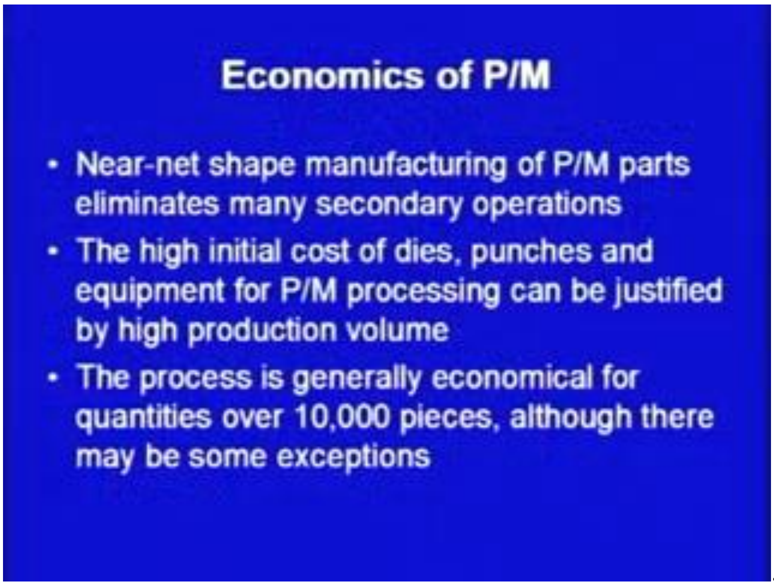

Now, coming on to the economics of the powder metallurgy, now how economic the process of powder metallurgy is as compared to the other manufacturing process. Already we have discussed, the process has to be competitive, so that the products made by that process can compete with the products made by other processes in the market. Now, what are the economic aspects of powder metallurgy, because of the near net shaped manufacturing of powder metallurgy parts, this eliminates the secondary operations, so no secondary operations generally are required.

The high initial cost of the dies, punches and equipment for powder metallurgy processing can be justified by high production volume. We have seen that, the production volumes in case of powder metallurgy are considerably high. So, the high cost of the die will be spread over the initial cost of the products that we are making. So, if we are making large number of products the high initial cost will be spread over the large number of products. And it will be economical viable, economically viable to make product out of powder metallurgy.

The process is generally economical for quantities over 10000 pieces, although there may be some exceptions so there may be some exceptions. The some of the powder metallurgy process, for certain parts may be economical, economically viable less than 10000 pieces also. So, the break event may come, earlier also the break event make come later on also, but general discussion can be that, if we are able to make 10000 pieces, we can economically justify the use of powder metallurgy process.

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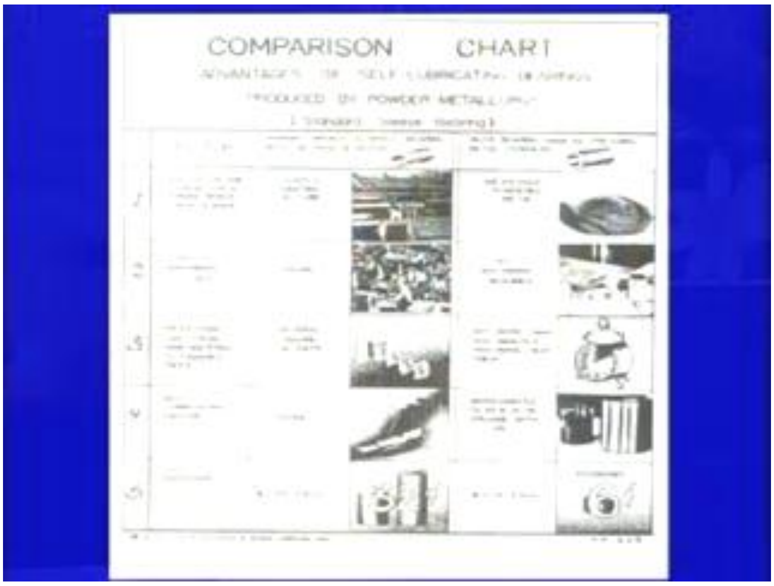

Now, this is one comparison chart, which shows that an ordinary bronze bearing is made, bronze or brass bearing is made, and there is a bearing that is made by powder metallurgy. So, first point is the cost of black basic piece from which piece the bronze or the brass bearing has to be made, so it is costly casting or tube. On the other hand, if we take this as the powder metallurgy root, in powder metallurgy root inexpensive powdered metal will be used. So, we can see basic manufacturing processes, it is either costly casting or tube.

On the other hand here, it is a inexpensive powdered metal, cost of machining is usual, here no machining is required. Processing time here several hours or days, in case of powder metallurgy not more than 10 minutes including heat treatment. Moreover here, the self lubricating factories not there, in case of powder metallurgy, the self lubricating characteristics are present in the powder metallurgy part.

The cost also here is comparatively more as compared to the powder metallurgy part. So, starting from the raw material to the final part through the sequence of operations, we can see the powder metallurgy initial cost is also less. Moreover, the final product that we are making is also cheaper as compared to a product that is made up of normal or the basic manufacturing process.

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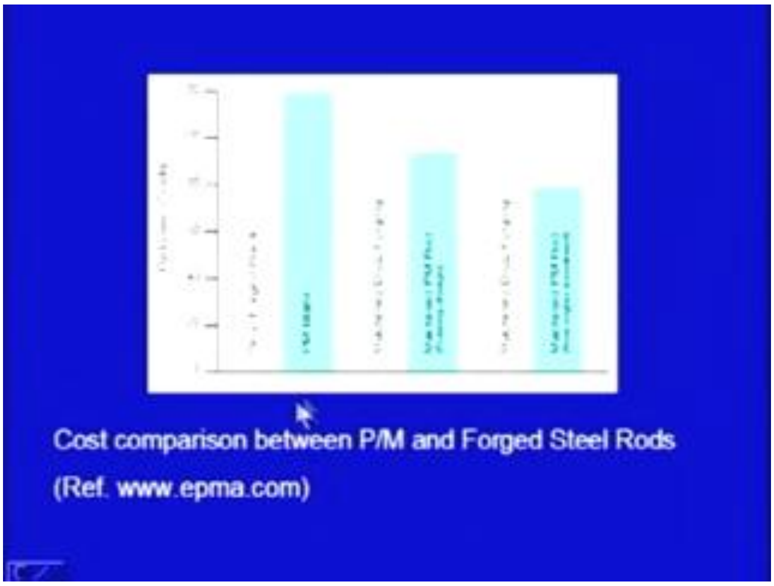

So, this is another comparison, the relative costs of making the product. This is the drop forced blank this is the P/M blank. Although the powder metallurgy blank is initially, it is costly, but subsequent when it goes through the process of sequence of operations of the process of powder metallurgy. The final machined powder metallurgy rod is cheaper as compared to the rod that is made up of the other or the basic manufacturing process.

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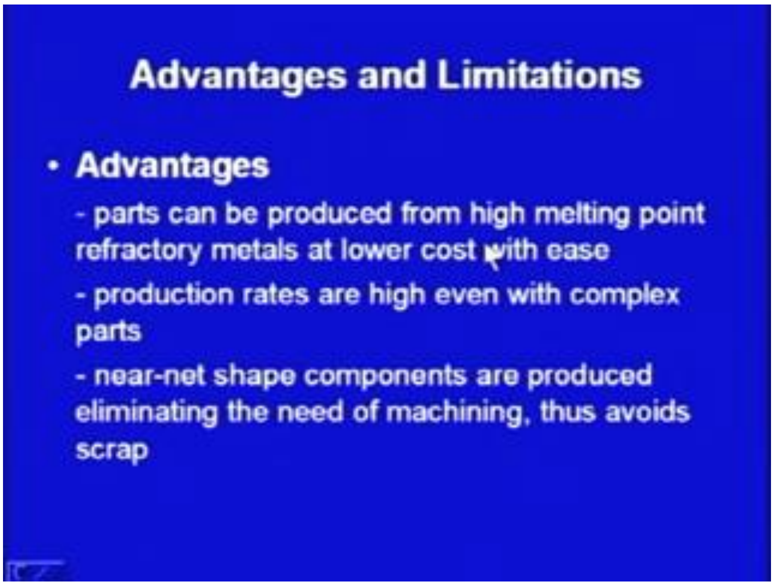

Now, coming towards the last session or the last section of our discussion on powder metallurgy, the advantages and limitations of powder metallurgy, so the advantages, first of all we will discuss the advantages of powder metallurgy. Then we will go towards the limitations of powder metallurgy. So, advantages are, the parts can be produced from high melting point refractory metals at low cost with ease, so the cost is also justified; the ease of the process is also justified. And the melting point, where the metals are very high melting point, we can make break them down into powders and make the part out of those metals of high melting point using the process of powder metallurgy.

Similarly, production rates are high even with complex parts, so the parts geometry may be complex, but the production rate is extremely high with powder metallurgy. So, near net shape components are produced, eliminating the need of machining. So, sometimes machining is not required, we get the product in the final form as useable form. So, thus powder metallurgy avoids scrap and thus the process is economically justified.

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Parts can be made from of a wide variety of combination, thereby having desired mechanical and physical properties such as density, hardness, toughness, stiffness, damping and specific electrical and magnetic properties. So, we can blend metal powders of different metals together, and can get the desired properties in our final product. So, parts with controlled porosity can be produced, so this property of porosity can be used in making self lubricating type of bearings. So, skilled machinists are not needed, labour cost generally is low, because the process is automatic process.

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Another advantages of powder metallurgy are, the parts can be produced with impregnation or infiltration of other materials to obtain specific characteristics needed for specific application. The simple example can be of, self lubricating type of bearings. Then bi metallic products, sintered carbides and porous bearings can be produced by powder metallurgy. So, the products that are difficult to produce by the basic manufacturing processes can easily be made by using the technique of powder metallurgy.

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Instead of having, so many application areas, so many advantages there are certain limitations, that are typical to the process of powder metallurgy. So, what are these limitations? So, high cost of metal powders as compared to raw material used in forging and casting. So, the metal powder production for using it as a raw material in the powder metallurgy process is important. And the cost is more as compared to the raw material used by the basic manufacturing process. So, few powders are difficult to store without deterioration.

In our section on hazards with metal powders, we have seen that metal powders are sometimes hazardous, and they make undergo deterioration or contamination, so that has to be avoided. Moreover high cost of tooling and equipment, particularly important when production volumes are small, so we have seen, we have quoted a figure also. Depending upon that figure, we can say the break event can come earlier also or it can come later also.

So, high cost of tooling and equipment has to be justified by the production volume. So, if the production volume is relatively small, then we have to justify the higher initial cost of the dies, as well as of the equipment. The other limitations of powder metallurgy process are very large and intricate shapes are a limitation. If we want to make a very large shape, and the geometry of the shape or the geometry of the product that we are, that we want to make is very, very complicated, then it acts as a limitation to the application of powder metallurgy for making that product.

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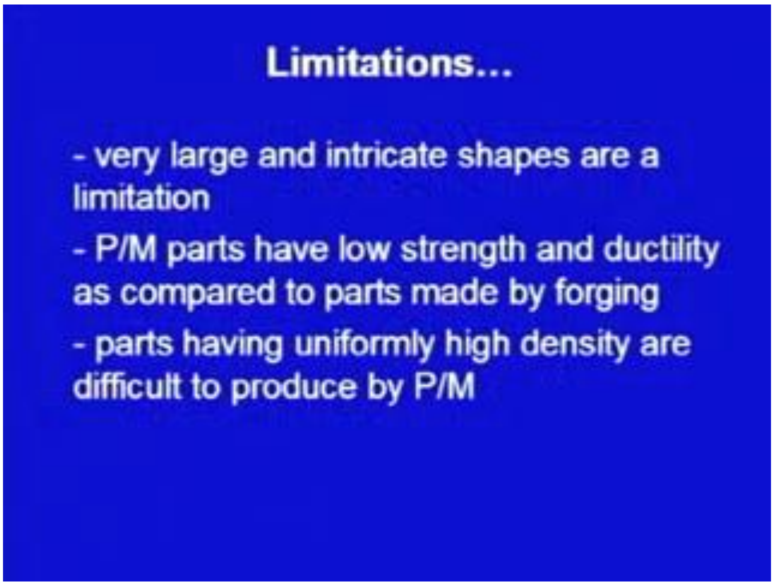

P/M parts have low strength and ductility as compared to parts made by forging. So, the strength of powder metallurgy parts is less, as well as the ductility of powder metallurgy parts is considerably less, as compared to the parts made by the basic manufacturing processes like forging. Parts having uniform density are difficult to produce the powder metallurgy. So, parts having uniformly high density are difficult to produce by powder metallurgy.

So, if we want to have a distribution of other density gradient minimum, and we want that the product should have uniform density throughout it is bulk, then it is difficult to form using powder metallurgy. Parts having uniformly high density are difficult to produce by powder metallurgy, so there is the density gradient sometimes in the powder metallurgy part. So, to have uniform density it is difficult to form using the process of powder metallurgy.

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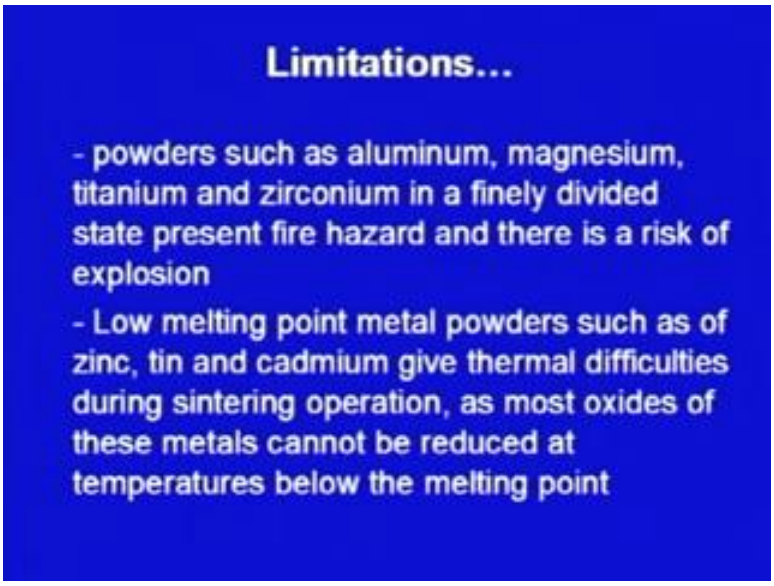

So, powder such as aluminium, magnesium, titanium and zirconium in a finely divided state present fire hazard, and there is a risk of explosion, already we have discussed this thing in detail. Finally, low melting point metal powders such as of zinc, tin and cadmium give thermal difficulties during sintering operation, as most oxides of these metals cannot be reduced at temperatures below the melting point. So, now we come on to the end of three sessions on powder metallurgy, we have basically covered powder metallurgy in different phases.

We have seen different techniques of metal production, we have seen the various stages of powder metallurgy process like, compaction, sintering. We have seen the design aspects of powder metallurgy, well economic aspects of powder metallurgy. And finally we have seen, what are the application areas of powder metallurgy? And later on we came on to discuss the advantages and limitations of powder metallurgy. So, I feel that in these three sessions, you might have got an insight into the basic concepts of powder metallurgy.

Thank you.