Processing of Non-Metals
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Module - 3
Glass: Properties and Processing
Lecture - 7
Ceramics: Secondary Processing

A warm welcome to all in this seventh lecture of module three. The title of today's lecture is ceramics and we are going to discuss the secondary processing aspects of ceramics. So, today's is the last discussion on the module three that is on the topic of ceramics. So, before we windup our discussion on ceramics, let us first revise what we have covered in the previous six discussions or previous six lectures. We have highlighted the basic aspects of ceramics that what ceramics are from where they are derived, how the ceramics can be classified, we have seen that the ceramics can be classified broadly into two categories on the basis of their composition and on the basis of their applications.

On the basis of the composition, we have seen that there are silicates, there are oxides, non oxides, and there are glass ceramics. Within these there can be other categories of ceramic materials. We have seen on the basis of applications, we can have cement and concrete, we can have advanced ceramic or advanced performance, ceramics we can have clay's, we can have different types of applications of ceramics. Then we have seen the properties of ceramics that the prop the ceramics posses certain distinct properties which makes them different from the metals. We have even seen a table in which the ceramic were compared with metals and polymers for a wide verity of properties.

Then we have (( )) started the discussion on the preparation of ceramic powders. Two lectures were engaged on the topic of preparation of ceramic powders in which we have seen that how the methods that are used for preparation of ceramic powders, we classified. We have seen the two broad categories can be there. The mechanical route of processing the ceramic powder, and the chemical routes for processing the ceramic powder. Once the ceramic powder is ready, then we go for the second stage of processing of ceramic parts, that is mixing up of the ceramic powder will certain

additives to impart some special characteristics to the raw material, that is the ceramic material.

So, once the raw material is ready the final stage is that of giving the shape to the ceramic product. Now, depending upon the shape for example, we want to make a roof tile or we want to make a floor tile or we want make a dinner wear or we want to make a decorative item or we want to make a bio ceramic or we want to make a space shuttle product. So, depending upon the requirement of the shape we will give the shape to the ceramic raw material. Now, how the shape can be given that we for that we have seen that we can do the pressing of the raw material. The raw material is a ceramic powder which has been added with certain additives.

So, this raw material we would press. There are different methods of pressing that can be used for giving shape. We have seen that they we can do dry pressing, we can do wet pressing, then we can go for isostatic pressing and even we can go for hot pressing. So, pressing is one of the techniques which is used for giving shape to the ceramic raw materials. Then we can give shape to the ceramic raw materials by using the slip casting technique which is also called drain casting. In our previous lecture we have seen the fundamental or the basic aspects that how the slip casting is done and what are varies steps involved in slip casting process.

Then we have seen injection molding or more specifically ceramic injection molding and the extrusion process. So these two process is also used for giving shape to the ceramic raw materials. Now, once the shape has been got then we have to do certain additional process is in order to give strength and hardness to the final ceramic product. Now, we do the firing, drying and firing that is or firing we can also call as sintering. So, we will dry the product which we have made by any of these processes that is the shape has been made. Now, that shape would be subjected to higher temperature in order to do the sintering and finally, the product is ready.

But before the product is put to use many a times we have to put some additional glassing or some additional surface finish or sometimes we want some additional details of dimensional accuracy. We require a certain tolerance levels, so for those to attain all these special characteristics we have to sometimes go for secondary operations. Mainly secondary operations are done for certain specific purposes that we are going to study

today. But before we start today's discussion as we have already seen what has already been covered in this particular module.

We are going to first highlight the importance of secondary processes because secondary processing is a new word. So, basically we can do primary processing and the secondary processing. So, the total processing steps can be divided into primary processing steps and the secondary processing steps. So, in primary processing we will see that we can make the ceramic powder using any of the techniques that we have discuss. We can make the blend or we can do the mixing up of the ceramic powder with certain additives that would also be a primary forming process or a primary forming step.

Then we will do slip casting or extrusion or injection molding or pressing of this mixture to get a desired shape. So, once the desired shape has been got and the shape has dried down into a solid product the primary processing steps are over. Many a times sintering is also considered as a primary forming step and we get a final product in the form of ceramic part. But this ceramic part may sometime require a specific color or a specific surface texture or may require certain holes or may require certain trimming from the edge. So, all this processes that is making up of holes, trimming of the product, giving a specific surface texture, giving a specific surface finish or even coloring the surface of the ceramic part with different color.

All these will fall under the secondary operations. Secondary operations are important because our last module of this particular course would also focus on the secondary operations which are related to the advanced materials like polymer matrix composite or ceramic material composite. So, that module we will discuss towards the end of this particular course. But today our focus is that, what are the secondary operations that are done on the ceramic parts in order to make them more usable or to satisfy certain important (( )) specific design requirements?

So, with this introduction and highlighting the importance of secondary processing in context of ceramic processing, let us now start our discussion with an important aspect that is sintering. But before going to the sintering we will just revise that what are the basic steps involved in the processing of ceramic part and what in context of those steps what we are going to discus today and what we have already discussed.

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So, this slide again I am showing just to correlate the things that we have discussed in our previous lectures and the things that we are going to discus today. So, the processing of ceramic parts generally involves three basic steps. Now, what are these three basic steps. We are not going to going to the detail of these steps again, but just to revise that what are the steps involved in processing of ceramic part.

We can see that first and foremost step is the ceramic powder preparation. Now, ceramic powder preparation can be done by crushing, Milling, grinding or by varies chemical methods that we have already discussed. So, once we get a very high quality, high purity ceramic powder available with us we can further go to the next step. That is the mixing this powder particles with the additives. Now, once a high quality, high purity powder is available with us it is mixed with certain binders and additives in order to impart certain special characteristics. Once this raw material now is ready with us we will just give it a particular shape or which we are making the ceramic product.

Now, depending upon the requirements suppose we want make a flower vase out of this raw material we will give it the shape of a flower vase. So, next stage or the third stage is shaping. So, we can give a shape to the raw material using any of the techniques like pressing, slip casting, extrusion or injection molding. And there can be other processes also like jiggering is another processes which we have not covered. But there are number of processes which can be used to give shape to the ceramic raw materials. Then the next

step is the drying in which the moisture can be removed or certain binders that we do not want in the final product can be removed during the drying process.

Finally, the firing in order to improve the properties of the final product. Firing is also called sintering. And what are the important characteristics or what are the important achievements that we get after doing the sintering process that we are going to discus in today's lecture. So, these are the three basic steps involved in processing of any ceramic part. So, again just to revise the three steps ceramic powder preparation, mixing up of the powder with the additives and finally, the shaping drying and firing of the ceramic part.

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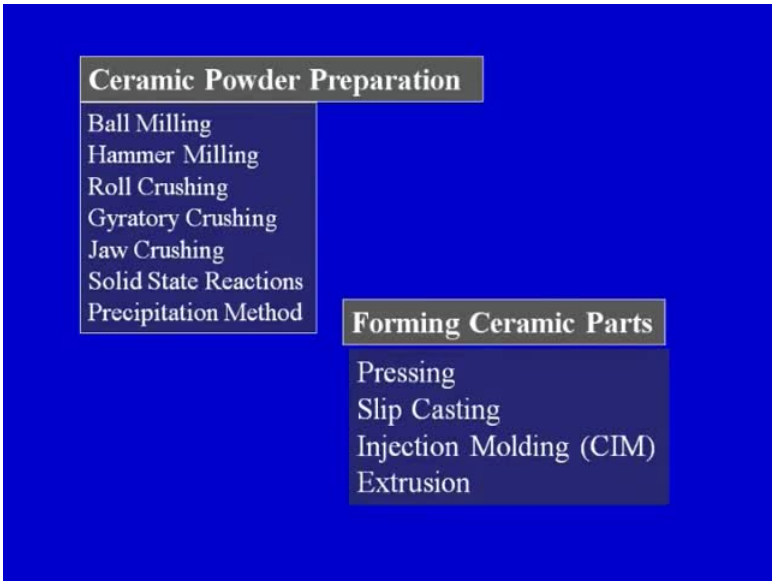

So, now with this particular background we can move on to the another important revision aspect. That is the ceramic powder preparation, how the ceramic powder pre powders can be prepared or can be synthesized. We can go for ball milling, hammer milling, roll crushing, gyratory crushing, jaw crushing, solid state reactions and precipitation method. The first five techniques which are mentioned in ceramic powder preparation on your screen, that is ball milling, hammer milling, roll crushing, gyratory crushing and jaw crushing falls under the mechanical route for preparing the ceramic powders. And solid state reactions and precipitation method fall under the chemical method of processing the ceramic powders.

So, we can process the ceramic powders or prepare the ceramic powders either using the mechanical methods or using the chemical methods. So, once the ceramic powders have

been prepared we will go for forming of the ceramic parts. So, we can go for pressing, we can go for slip casting, injection molding, more specifically ceramic injection molding which is used for precision castings or precision moldings and finally the extrusion. So, these important techniques can be used for giving shape to the ceramic raw materials. And then we will go for the next step once the shape is ready it is in the solid form next step is the sintering process.

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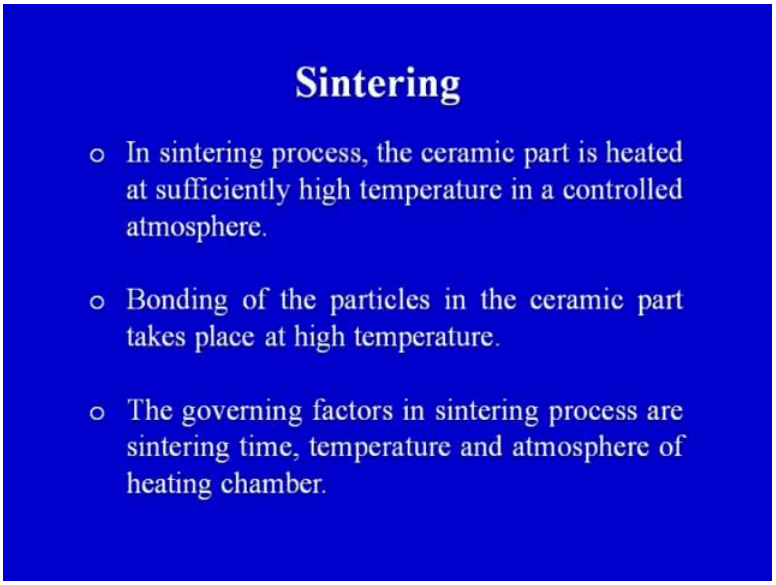

Now, let us go to the sintering process. Now, sintering is a we can say a process which is done at an elevated temperature and it has got certain specific objectives. Now, what are objectives of doing the sintering process that we are going to understand. Now, let us see what are there what is there on the screen or what are the important points that are mentioned on the screen. Point number one, in sintering process the ceramic part is heated at sufficiently high temperature in a controlled atmosphere. So, two important process variables have been highlighted in this particular point. That is the temperature and the controlled atmosphere.

So, sintering is done at a sufficiently high temperature. So, it is a high temperature process that is point one to be highlighted. Point number two that it is done under the controlled atmosphere. And what is sintered, that is the part which has been already produced using any of the methods that we have discussed in the previous slide that is slip casting or pressing or extrusion or injection molding. So, we have already got a

ceramic part. Now, we want to sinter that part or we want to further do the next step of processing on that part.

Why sintering is done we will just see. In case of sintering the bonding of the particles in the ceramic part takes place at high temperature. So, individual particles get bonded and therefore, the density improves or the porosity reduces. That we are going to see in the next slide, but first we need to understand two or three important points. That sintering is a process that is done at elevated temperature under controlled atmosphere which is point number one. Point number two, the bonding between the individual ceramic particles takes place when sintering is done.

Now, what are the governing factors in sintering process? Those are the sintering time for how long that temperature should be maintain because this is being done at an elevated temperature at a higher temperature. For how long what is the period or the duration for which this temperature has to be maintain or the ceramic part has to be subjected to an elevated temperature, for how much time?

So, first important variable is the sintering time. Another important variable is the sintering temperature, that at what temperature the process has to be carried out? And the next is the atmosphere of the heating chamber. So, that we have already seen that it has to be performed under the controlled atmosphere. So, two three important points have to be taken into account. That is a sintering temperature, the duration for which the temperature is maintain and finally, the atmosphere under which the sintering is being carried out.

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Now, mechanism of sintering process is complex. Now, how the sintering is going to takes place because if we take example of two individuals ceramic particles, how they are going to bond together? So, that is important to understand and there are different types of mechanisms that are in place when the temperature is increased. So, under elevated temperature or high temperature the bonding takes place between the individual ceramic particles. In a particular mechanism, if we take two spherical particles center to center distance is maintained constant.

The point of contact of these two spherical particles, there would be a bonding that would take place between these two particles by the formation of a necking zone or a necking reason. So, that is basically if we want to explain in a very simplistic manner. If we take two tennis balls as the two ceramic particles and bring them close to each other at the surface of contact at elevated temperature a solid solid bonding may take place. So, there are different mechanisms of sintering process that depends upon the varies types of control variables that can be controlled during the sintering process, that how the bonding is going to take place among the ceramic particles. So, the mechanisms can be different.

Bonds are developed between the ceramic grains which is accompanied by densification and reduction of porosity in ceramic part. This point I have already highlighted that when the bonding would take place among the ceramic particles during the process of

centering the density would increase and the porosity would decrease. So, the bonding is accompanied by densification of the ceramic part and which leads to the reduction of the porosity in the ceramic part. So, if there are certain applications of this ceramic part where we do not want the porous structure of the part, then we can go for sintering to increase the density of the part. So, otherwise also sintering is an important step in the processing of ceramic parts.

Finally, we can see that research and development work is going on in the field of microwave sintering. So, microwave sintering is another field which is very upcoming and the ceramic parts are being processed using the microwave sintering process. In microwave sintering also we can have different control variables, that is the wattage that we can control the power rating and we can control the time for which the microwave are going to impinge the ceramic part. So, there also we can control the operating variables and we can see the effect of change in wattage and the change of exposure time on the sintering process of the ceramic parts.

So, basically to summarize what do we mean by sintering? Sintering is a process which is done towards the end of the ceramic parts processing in order to improve or increase the density of the part, in order to improve the bonding between the varies ceramic particles and in order to reduce the porosity of the ceramic part. It is done at an elevated temperature under the controlled atmosphere. So, sintering is important from certain points of view. It is an important process in the total fabrication of ceramic part. So, it is an important step in the processing of a ceramic part from the ceramic powder into the final product.

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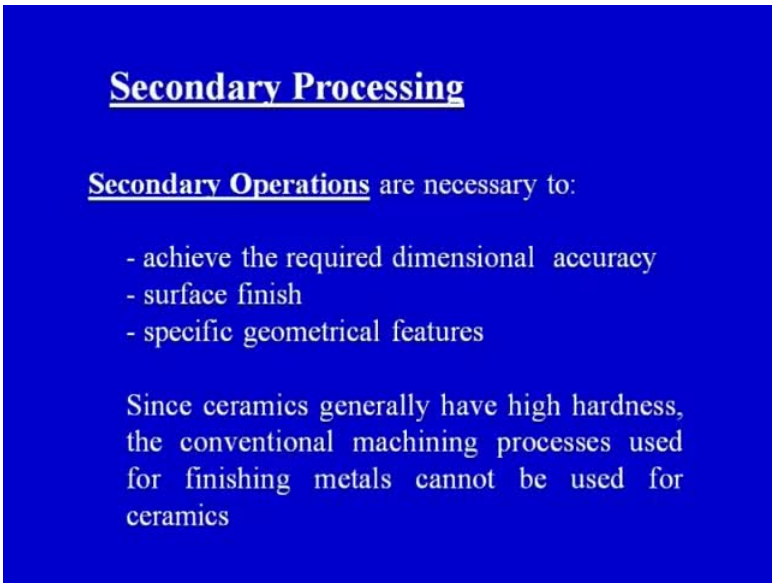

Now, we come on to the other important secondary operations that are done on the ceramic parts. So, let us see that what are the other secondary processing operations that are done? Before we go for the different operations, let us first see that why the secondary operations are necessary? So, secondary operations are necessary too. There are three important highlights which gives us an indication that yes the secondary operations are required on the ceramic parts. Now, what are these? First is to achieve the required dimensional accuracy. Suppose the final product that we have got is does not have is not having the desired accuracy.

So, the dimensions are slightly on the higher side, what we can do we can do the machining operation. So, to achieve the required dimensional accuracy sometimes we require secondary operations in terms of machining. Second is surface finish. Many a times the surface finish is going to dictate the in service performance of the ceramic part. And the surface finish that we have achieved during the processing of ceramic part is not up to the desired specification. Therefore, we may be required to go for secondary operations in order to improve the surface finish of the ceramic part. Finally, the specific geometrical features.

We may be requiring certain holes in the final product or some (( )) may be required. So, depending upon the final product or the design of the final product we may require to have certain additional geometrical feature which could not be incorporated in the

processing, during the process of giving shape to the ceramic part, because we have seen that there are different methods of giving shape to the ceramic part. What are those methods? Slip casting, we can see dry pressing, hot pressing, isostatic pressing, extrusion, injection molding. So, there are different methods of giving shape to the ceramic part.

So, when different shapes are being given we are not able to somehow incorporate these specific geometrical features into those methods or into those processing steps. So, finally, once the product has been made by any of these method we go for subsequent machining of this geometrical features into the product. So, basically to revise that why secondary operations are required? Secondary operations are required to achieve the required dimensional accuracy. Or to improve the surface finish as well as to incorporate or to produce certain specific geometrical features like holes into the final ceramic product.

Since ceramics generally have high hardness which is already known to us. And in our lecture one and lecture two of module three on ceramics we have seen that ceramics have high hardness. Conventional machining process used for machining metals, cannot be used for ceramics. So if you remember that in conventional machining one of the important principles is that the hardness of the cutting tool should be more than the hardness of the work piece material. And in this case work piece material is a ceramic material which has got very high hardness. So, the conventional machining process is that are used for machining of metals cannot be used for machining of ceramics.

Another important limitations of ceramics that makes them difficult to machine is their brittle nature. Because of the brittle nature of ceramics, it is very difficult to machine the ceramics by the conventional methods of machining like drilling or turning. So, we have to go for certain advanced or non conventional methods of machining in case of ceramics. So, this particular slide highlights important aspects that why secondary operations are required. So, secondary operations are basically required for three important purposes.

To achieve the desired dimensional accuracy, to improve the surface finish of the ceramic part and to give the certain specific geometrical features to the final ceramic product. So, we have seen that although we are able to get a near net shape by any of the

processes which we have already discussed in our previous lecture. But still in many cases secondary operation is required in order to make our product more usable and in order to make it more marketable or in order to improve the sales appeal of our product.

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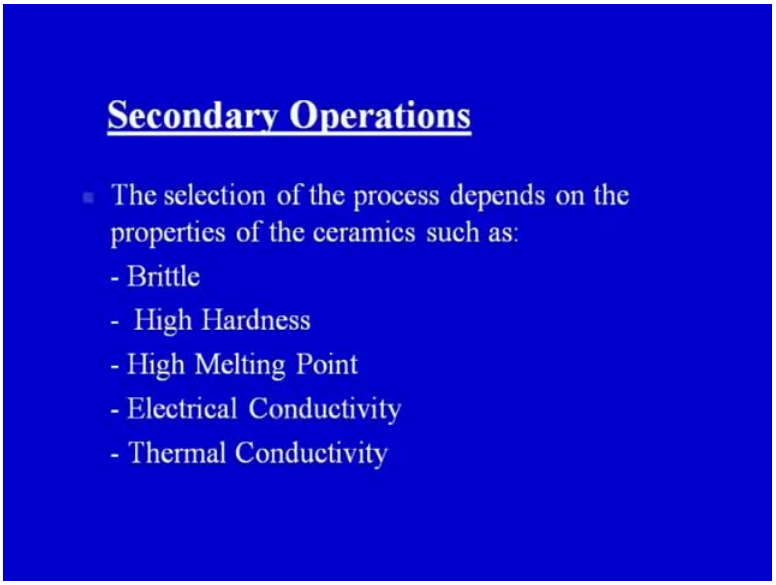

Now, what are the secondary operations? That we will see in the previous slide, but before understanding that. What are the secondary operations we should understand? That what are the properties of the ceramics that have to kept in mind before advocating the use of certain secondary machining operations? So, the selection of the process, which process? The secondary process that we have to carry on the ceramic products. So, the selection of the process depends upon the properties of the ceramics such as. Now, what are the properties of the ceramics which have to be taken into account before selecting a particular secondary operation?

Those are highlighted on your screen and why do we need to understand these properties because a blind application of any of the conventional methods of machining on to the ceramic part is certainly going to damage the ceramic part. And is not going to be able to give us the geometrical feature that we want to create in our final ceramic product. So, basically if we understand these properties of ceramics and use the secondary operation judiciously, and chose the secondary operation judiciously we would be able to generate the specific geometrical feature into the ceramic part in a most efficient and effective manner.

So, basically let us first read that what are the important properties that have to be kept in mind? First is ceramics are brittle in nature, ceramics have high hardness, they have high melting point, electrical conductivity is not so good for ceramics, as well as the thermal conductivity is not good for ceramics. So, they are highly brittle, nature high hardness, high melting point, poor electrical and thermal conductivity randers them to certain specific operations only. All the operations or machining operations cannot be directly applied on the ceramic part.

So, we would like to understand now what are the important operations or machining operations that can be used to generate certain geometrical features into the ceramic parts. But before going to the operations let us first try to understand that what would be the problem that would be generating if we are applying the conventional methods of machining to machine the ceramic parts. Because of the brittle nature we will not be able to generate the specific geometrical feature. For example, we try to make a hole inside a crucible using the conventional drilling tool. We have a conventional drilling tool and we want to make a hole inside the crucible.

As soon as the drill point will contact the crucible, the crucible is a ceramic material and which a which is brittle in nature. As soon as the drill would encounter the crucible or drill would come in contact with the crucible, the forces would be generated and the crucible may have a brittle fracture. Whereas if non contact type of machining operation is used, when the tool is not in direct contact with the crucible we may be able to generate a hole inside a crucible. So, the contact type of machining operations where a large amount of forces are being generated may result into the failure of the ceramic part. Therefore, the judicious application of the non conventional methods of machining is advocated for the machining of ceramic parts.

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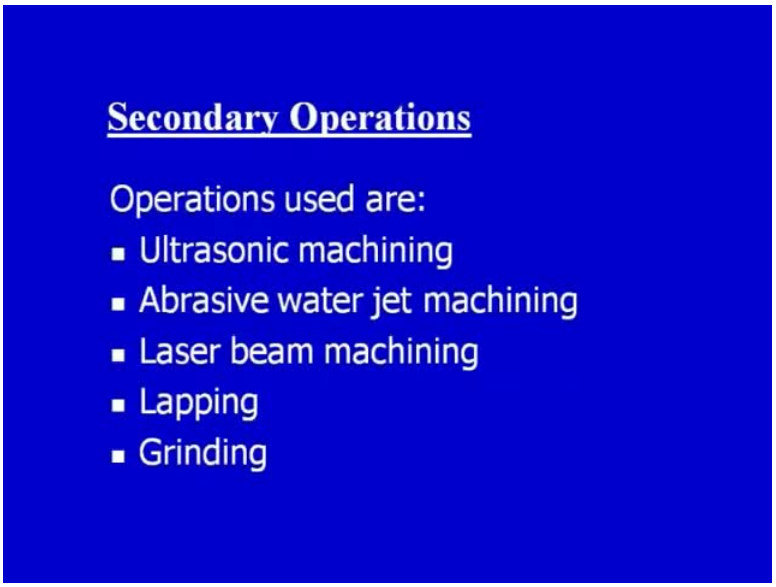

Now, what are the varies types of non conventional operations that can be done that is highlighted in the next slide. So, the secondary operations that can be done are the ultrasonic machining, abrasive water jet machining, laser beam machining. Then there are conventional operations like lapping and grinding in which very less forces or the magnitude of the forces that are generated as the result of the cutting action are not very high. Therefore, lapping also be done and grinding can also be done in order to improve the surface finish. But whenever we want to do the machining in those cases, we will not go for the conventional machining in case of ceramics.

We will always go for unconventional methods of machining such as ultrasonic machining, abrasive water jet machining or laser beam machining. In ultrasonic machining basically the tool vibrates at a very high frequency and the tool is not in contact with the work piece. There is a slurry or abrasive slurry which forms, we can say medium in between the tool and the work piece. The abrasive particles in the slurry come in between the tool and work piece. By impinging of these ceramic particles the material is removed from the raw material or the work piece in which we want to generate a whole or cut cavity.

So, basically ultrasonic machining, abrasive water jet machining and laser beam machining in this particular, in these particular machining operations no forces would be generated because the cutting mechanism is entirely different from the conventional

machining in which the tool and work piece comes in direct contact. Where as in case of ultrasonic machining and aggressive water jet machining, no such forces are or no we can say damaging forces are generated or the forces generated are negligible, and does not result into the failure of our product or the products specifically the ceramic product.

So, again we can just conclude that in case of ceramic products the secondary processing is required in order to improve the dimensional accuracy of the part. In order to improve the surface finish of the ceramic part as well as in order to generate or create certain geometrical features in to the ceramic part. And as such the conventional machine operations cannot be applied directly or blindly on to the ceramic parts because ceramic are brutal in nature. Therefore, the unconventional technique of machining like ultrasonic machining, abrasive water jet machining, laser beam machining can be successfully used for creating or generating the cavities or a specific geometrical features in the ceramic parts.

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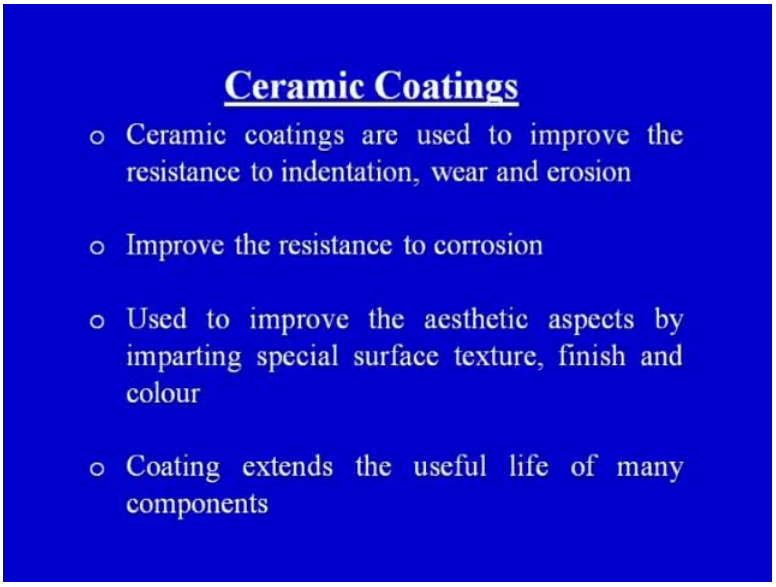

So finally, when we want to do the machine finishing of the ceramic part we can go for lapping and grinding because in these cases also, the amount of forces that are generated of the action of grinding or lapping are negligibly small or very, very small. And therefore, these important processes can be applied on ceramics. Now, coming on to the another important aspect of ceramics, that is the ceramic coatings. This is also one of the important aspects and should not be left because ceramic coatings are being used

worldwide, widely for improving the surface characteristics of many applications. So, ceramic coatings, why they are used, what is the importance of ceramic coatings?

So, ceramic coatings are used to improve the resistance to indentation, wear and erosion. So, basically we do not want that the wear of the surface should take place or a indentation on the surface should take place. We want a surface, a very hard surface. So, a coating of ceramic is imparted on to the surface in order to improve its resistance to indentation and wear as well as erosion. Also to improve the resistance to corrosion because we have seen in our previous lecture that ceramics have the ability of resistance to any type of chemical attack and they are corrosion resistant.

So, ceramic coating on the top of the substrate would prevent the substrate from corrosion. So, ceramic coatings have the advantage of resistance to corrosion. Then first important point is the ceramic coatings are used to the resistance to indentation, wear and erosion. Ceramic coatings are also used to improve the resistance to corrosion. Also they are used to improve the aesthetic aspects by imparting special surface texture finish and color which is not that relevant because we have to justify the cost effectiveness of the process also, because when we are imparting the coating on to the substrate to see that how much cost is involved. And if only giving color, it can be done by other coloring mechanisms or coloring methods also.

So, basically the two important aspects of providing the coating are point number one or two the two important advantages to providing ceramic coatings on the substrate are that it provides resistance to indentation, wear and erosion, as well as it is provides corrosion resistance. There can be other examples also because the ceramic coatings often to an extended life of the product because it has the very good surface finish the chances of flaws are less. And under cycling loading the flaws may not get propagated and the product may not fail if there are no flaws on the surface.

So, when we are providing a coating which has uniform thickness and which has good mechanical binding with the substrate, in those cases the life of the product with coating would be higher as compared to life of the product which is not having the coating. So, two important aspects of providing the coating are already mentioned. One of the additional aspect or secondary aspect is also mentioned to improve the surface structure or to improve the aesthetic aspects of the surface. So, that is another important aspect,

but it is slightly less important as compared to the first two important points that are mentioned. Coating extends the useful life of the many components which I have already highlighted.

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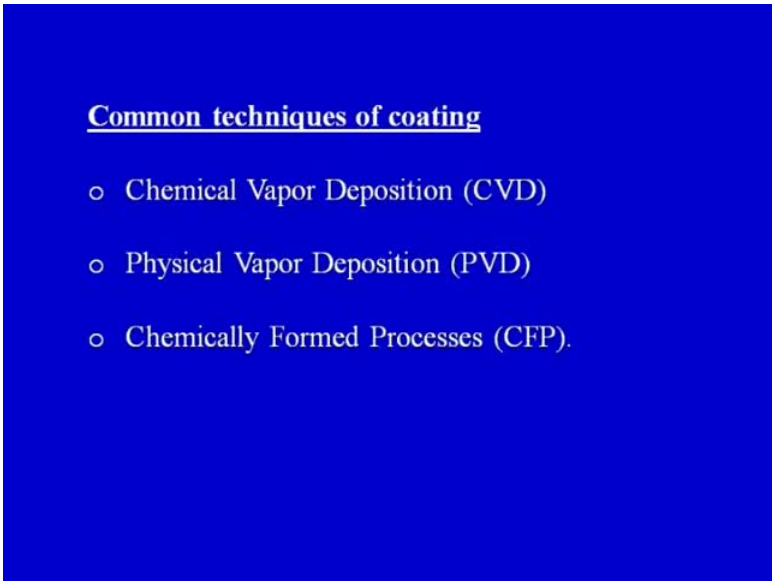

So, basically the coating helps us to improve or increase the life of the component on which the coating has been done. So, there are number of techniques which are used to coating. So, ceramic coating can be put in a number of ways, but chemically a chemical vapor deposition is important. Otherwise, we can go for chemically formed processes or physical vapor deposition. But we are going to discuss chemical vapor deposition which is one of the important techniques of depositing the ceramic coating on the substrate. So, the substrate material also can be the different and coating material can also be different. But basically we would like to understand that how was ceramic coating can be put on top of a substrate.

So, basically the principle is simple. Let us first try to highlight few points related to the chemical vapor deposition. Otherwise, there are number of techniques which are in use for depositing that coatings on to the substrates. But our focus is on ceramic coatings and therefore, we are going to discuss the chemical vapor deposition technique for depositing the ceramic coating on to the substrate.

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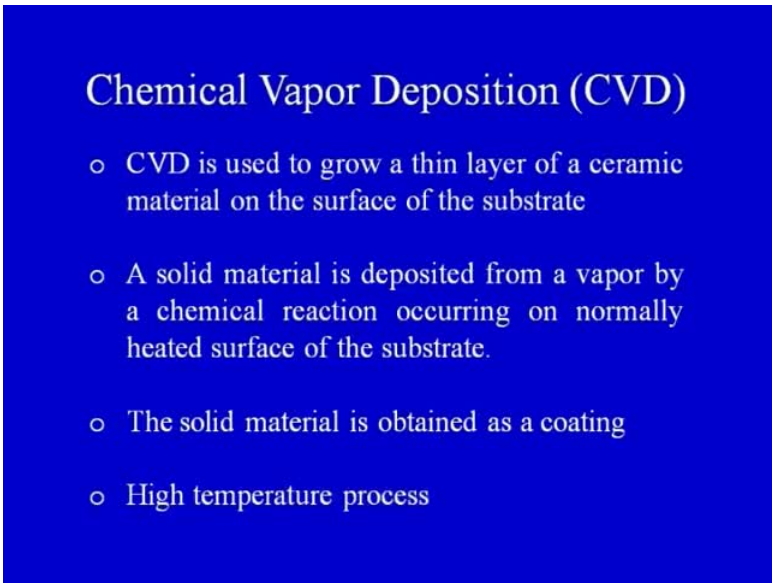

Now, chemical vapor deposition CVD is used to grow a thin layer of a ceramic material on the surface of the substrate. So, basically they are would be a coating they are would be a substrate. The substrate is a heated substrate because CVD is process which is carried out at an elevated temperature. So, basically we have a substrate. On that substrate surface we have to generate or create the coating and the coating would be a ceramic coating. So, a solid material is deposited from a vapor by a chemical reaction. So, basically the coating would be a solid material coating.

So, it would be a solid material coating and would have a certain thickness. So, solid material is deposited from a vapor. So, the raw material or we can say vapor would come which has got certain chemical which would react on the surface and deposit the solid material on the surface. So, solid material is deposited from a vapor. So, we will have gaseous reactants that would come and react on the surface, and provide a coating on the substrate. Solid material is deposited from a vapor by a chemical reaction occurring on normally heated surface on the substrate.

So, we have a heated substrate and on the surface on the substrate the chemical reactions takes place and the solid coating is deposited on to the surface of the substrate. The solid material is obtained as coating and it is reaction product of the reaction that is taking place on the surface. This is the high temperature process. So, we will try to understand

this with the help of a diagram. On your screen you can see I am going to draw a very simple diagram of a chemical vapor deposition process.

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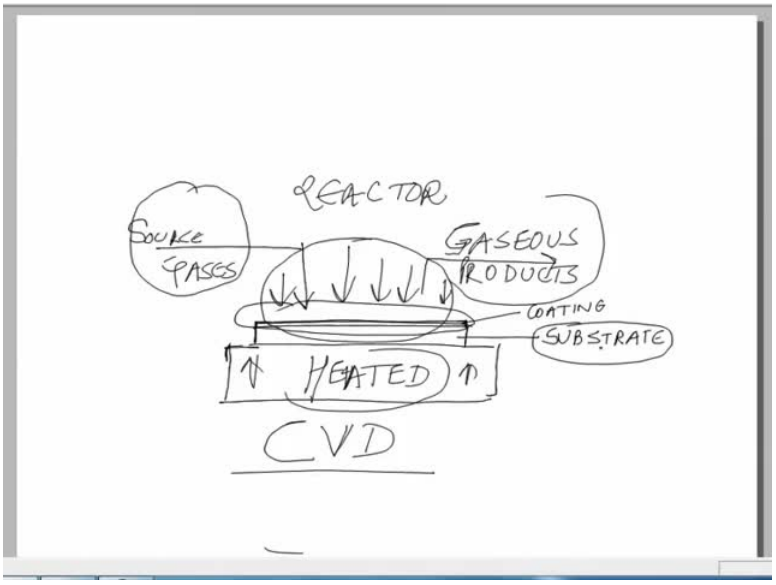

So, basically this is our substrate and on substrate we want to provide a coating. So, on your screen you can see that we already highlighted to the substrate. And this is the coating that we want to generate. So, from this side that I have already told that the source, the gases carrying the chemical would be coming. So, basically this is the source through the which the input is coming and finally, the reaction is going to take place in this zone. So, we can call this as the reactor where the actual reaction is taking place and the final gaseous product would be going out. So, we can see that the final gaseous product are going out. So, we are we are having a input, that is coming and we are having a output.

The final reaction is taking place on this surface as I am highlighting and a coating is being deposited on the substrate. This is a substrate which is heated, it is a heated substrate. So, heat is coming from here this is source of heat and the substrate which we have already highlighted is here heated. So, we have a heated substrate and top of that substrate the chemical reactions are taking the place. The gaseous reactants coming and because of the chemical reaction taking place on the surface of the substrate the solid coating or the solid ceramic coating is being deposited on the surface and the gaseous

products are going out. And the point we are the reaction is taking place is that we can call as the reactor.

So, this is we can say a very simple representation of the CVD process, that is the chemical vapor deposition process. So, now we will try to again understand some of the other final details of the process. So, chemical vapor deposition just let us revise we have already seen with the help of the diagram that how the input is coming, the vapor is coming, where the reaction is taking place substrate is heated. And the byproducts or we can see the gaseous products are going out in the reactor, it is a imaginary reactor where the reaction is taking place.

Finally, the coating of uniform of thickness is being deposited on the substrate. So, different types of materials can be chosen as the substrate and different types of coatings can be provided on these substrate. And ceramic coating can also be provided with the help of the CVD process or chemical vapor deposition process, one of the examples we are going to see in the subsequent slide.

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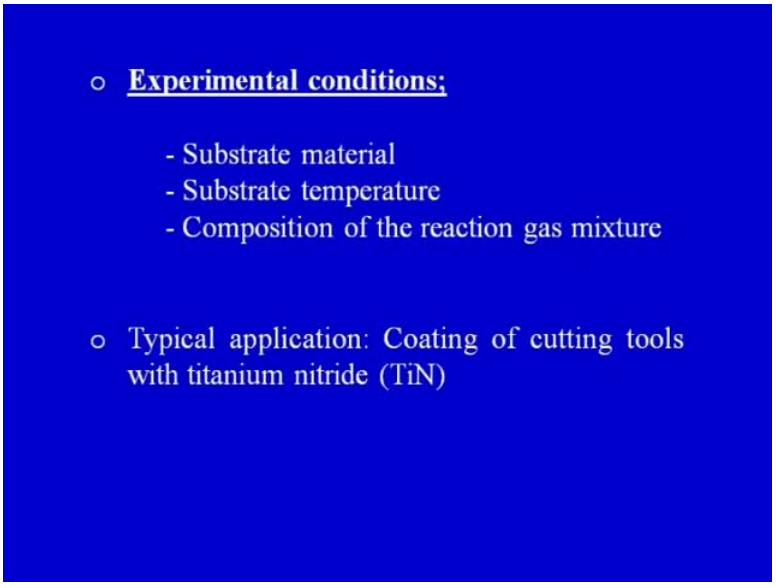

So, let us see. Now, what are the important conditions that have to do taken care of, that what is the substrate material, substrate temperature because we have seen the substrate is being heated from below and the substrate is an elevated temperature. So, the substrate on top of on which we want to generate the ceramic coating, what is the material of that substrate, how it will bind with the ceramic coating that is a in other important point to

taken care of. Then the substrate temperature, at what temperature the substrate has to be maintained so that we are able to generate a very good quality coating on top of the substrate. And bond between the coating and the substrate is very, very strong that we have to ensure in order to have a good quality product.

Finally, the composition of the reacting gas mixture because we have seen the gas or the vapor is coming as an input and the reactions is taking place on the surface of the substrate. So, we have to see what is what should be the ideal composition of the reacting or the reaction gas mixture because that would dictate the type of coating that we would get or the chemical composition of the coating that would be deposited on the substrate. So, these three important points have to be borne in mind. That is what is the substrate material, what is the substrate temperature and the composition of the reaction gas mixture.

Now, one of the typical applications of the coating of cutting tools with titanium nitride. So, one of the typical application is coating of the cutting tool with titanium nitride. Now, why the coating on the cutting tool is desired or required? Because we have already discuss in the secondary machining operations for ceramic part, we have told we have seen that ceramics have very hardness. Therefore, the hardness of the tool should be more than the hardness of the ceramics, if we want to use that tool for cutting the ceramics. Because ceramics have high hardness and hardness of the tool should be more than hardness of the work piece.

And in many cases in order to improve hardness of the cutting tool we would deposits certain coatings on the cutting tools so that the hardness is increased. As we now that titanium nitride has got high hardness and therefore, titanium nitride is deposited on the cutting tool in order to improve the hardness of the cutting tool so that can be used for even harder work pieces. This is not the only example of deposition of ceramic coating on the cutting tool. There are other examples in which the hard ceramic coatings are deposited on the cutting tool in order to increase their hardness. This is one example ceramic coating which improves the hardness of the cutting tool.

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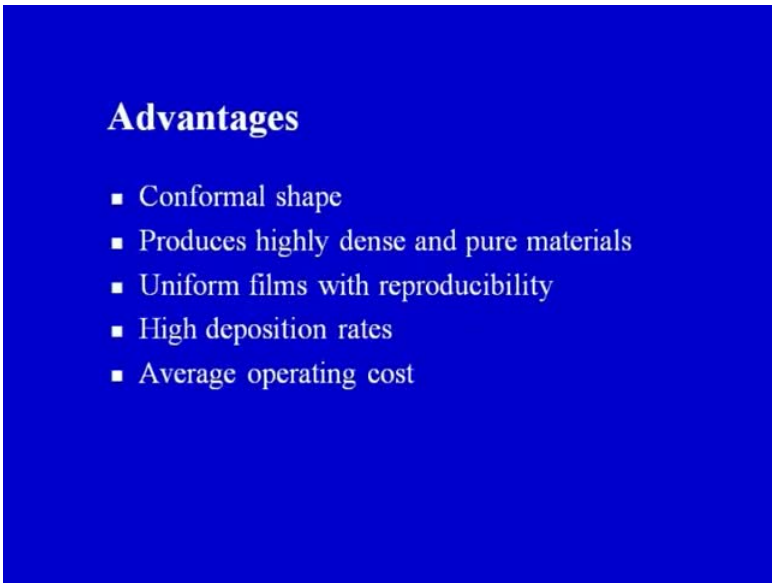

Now, what are the advantages of we can say the CVD process. First important advantage is conformal shape. Now, suppose we have a contour on the surface on which we want to deposit the ceramic coating. Now, using the CVD process or chemical vapor deposition process we will be should be able to generate a coating on that contour. In case of a flat surface it is easier to deposit a coating, but slight difficulties are seen or observed when there is the contour. And CVD has this advantage that even if surface has a contour, in that case also the CVD process would be able to generate a uniform coating on to the contour surface also.

Therefore, the conformal shape coating can be generated using the CVD process. Once again I want to highlight this point that in our example the diagram that I have drawn I have taken of flat surface on which the coating has to be deposited using the CVD process. But instead of a flat surface I would have contoured surface on which I want to produce or generate the coating or the ceramic coating. Then also CVD process can be used to generate a coating on to the contoured surface. Therefore, it would, the coating would conform to the shape of the final surface. Therefore, it has the advantage to conform to the shape of the contour on which we want to generate the coating.

Second point it produces highly dense and pure materials. So, the chemical composition of the coating is pure and the density is also very, very good. Another important advantage is that the uniform films can be generated using the ceramic, sorry chemical

vapor deposition and the reproducibility also good. Again and again we use the CVD process, we would be able to reproduce the similar type of coating. Then the high deposition rates are there, CVD also has got number of variants.

Basically, we are discussing basic type of the chemical vapor deposition process. Otherwise there are number of variants of chemical vapor deposition processes also. And within this variants the deposition rate would be vary, but in case of standard CVD process we can get a high deposition rate. So, deposition rate is high, uniform films can be or uniform coatings can be got, purity of the coating is high, highly reproducible technique and at an average operating cost.

So, the operating cost is not that high in case of CVD process. So, once again we can revise just revise, that what are the important advantages of the CVD process. The important advantages are that we can conform to the shape of the contour in case of CVD process. The coating can be deposited on a contour surface satisfactorily and successfully. High purity materials are generated during this process, uniform thickness or uniform films can be got in a highly reproducible manner. Deposition rates are high and cost involved is not so high in case of CVD process.

So, CVD is an important process which is used for deposition of ceramic coating on to the substrate. And why the ceramic coatings are be generated or created on to the substrate, that also we know. In order to improve the indent resistance to indentation, wear or erosion, as well as to improve the corrosion resistant resistance of the surfaces. So, ceramic coating have got certain important applications, and one of the typical application we seen the deposition of titanium nitride coating on to the cutting tool in order to improve the hardness.

So, ceramic coatings are important and we should know that how the ceramic can be deposited on to the different types of substrates. So, with this we come to the end of our today's discussion, that is lecture number seven in module three and also we come to the end of module three that was related to ceramics. I feel that this discussion would be helpful to audience who are interested in discussing or in understanding the basic aspects of ceramics. During the course of this module we have try to understand the basic aspects of ceramics, the classifications of the ceramics the basic properties of the ceramics, comparison of ceramics with metals and polymer.

Then we are focused our attention because our course is on processing of non metals. We have focused our attention mainly on to the processing of ceramic parts. And for that we have discussed in two important lectures that what are the various methods of preparation of ceramic powder? Once the ceramic powders have been made we have seen that how these powder can be given various shapes and what are the important techniques which are use for giving shapes to the ceramic powders like slip casting, pressing, extrusion and injection molding.

And finally, we have seen that what are the important secondary operations which are required in order to make ceramic products even more usable. And towards the end we have seen that what is the importance of ceramic coating which are deposited on to different types of substrates. So, with this we close our module three and in our next module we would be discussing the basic as as well as the processing aspects of the polymers. I feel that the discussions that we have had in module three are useful to the listeners and the different types of practitioners who have shown interest in these lectures.

Thank you.