Processing Of Non-Metals

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Module - 6
Ceramic Matrix Composites: Processing
Lecture - 4
Chemical vapour infiltration

A warm welcome, to all of you in this lecture on chemical vapour infiltration; let us first see where this particular topic is fitting into our complete course on processing of non metals.

As all of you know those who have seen the earlier lectures also that we are focusing on the aspects of non metals and our focus is on the processing aspects of non metals, we are not talking about the design or the chemical aspects of the non metals, but our focus is on the processing aspects of non metals the name of the course is processing aspects of the non metals.

In this particular course we are discussing various types of materials which have non metallic properties, if you remember we have seen that what are the various types of ceramics in a particular module, we have seen different types of polymers different types of techniques, which are used for processing of polymers, we have seen different types of techniques which are used for the processing of polymer matrix composites.

Now, we are into module 6 of our course and we are focusing on the techniques which are used for processing of ceramic matrix composites. Today we are going to discuss the technique of chemical vapour infiltration in respect to the processing of ceramic matrix composites, otherwise most of us know that chemical vapour deposition and chemical vapour infiltration chemical impregnation are the techniques which are used for processing different types of materials, but our focus primarily is to understand the usefulness of this particular technique for processing of ceramic matrix composites. So, in our broad course of processing of non metals, now we are discussing module number 6 in which we have already discussed 3 lectures, in which we have seen the basic aspects of the ceramic matrix composites, how the ceramic matrix composites are different from the monolithic ceramic, what properties are enhanced by putting a reinforcement in ceramic matrix, we have seen that how ceramic compared with the metals and we have also seen that how the ceramic matrix composite compared with the monolithic ceramics.

We have seen, in the various toughening mechanism that come into picture specifically in case of ceramic matrix composites and then we have seen that what are the various types of techniques which are used for the processing of the ceramic matrix composites also a broad outline was discussed in one of the previous lecture regarding the post processing techniques which are used for ceramic matrix composites.

So, this with this particular introduction now, we started the discussion on in the previous lecture, we have started the discussion on the various processing techniques for ceramic matrix composites and if you remember in the previous lecture we have seen the powder processing techniques for processing of ceramic matrix composites in which the reinforcement and the matrix is combined together and the cold pressing of this is of the combination is done sometimes, we make a green composite and then finally, compress it in order to give it a particular shape. So, all those details were discussed in the previous lecture the technique is called the powder processing techniques.

So, today we are going to discuss another technique for processing of ceramic matrix composite. So, our focus is not particularly on the basic aspects of chemical vapour infiltration our focus is on the application of ceramic sorry application of chemical vapour infiltration, in processing of ceramic matrix composite.

So, our we are not going to discuss the brief summary or we are not going to discuss the fundamentals behind the chemical vapour infiltration or the CVI process we are going to see how this technique can be applied for making ceramic matrix composite or for processing ceramic matrix composites.

In today’s discussion we will try to understand that how the ceramic matrix composite can be made by this technique of CVI of chemical vapour infiltration, we will try to understand that what are the important points that should be taken into account and all this we will try to understand with the help of few diagrams, in which we will see that how the ceramic matrix can be in filtered into the fibrous perform. So, all these details we are going to discuss in today’s lecture. So, with this introduction that where this particular discussion or this particular lecture falls in our total course, that is processing of non metals this falls under which module? That is processing of ceramic matrix composite and within this module what we have already covered a brief summary. I have already provided and what we are going to discuss in today's lecture is also been outlined. So, with this particular introduction and summary, let us now start our discussion on the chemical vapour infiltration of ceramic matrix composites.

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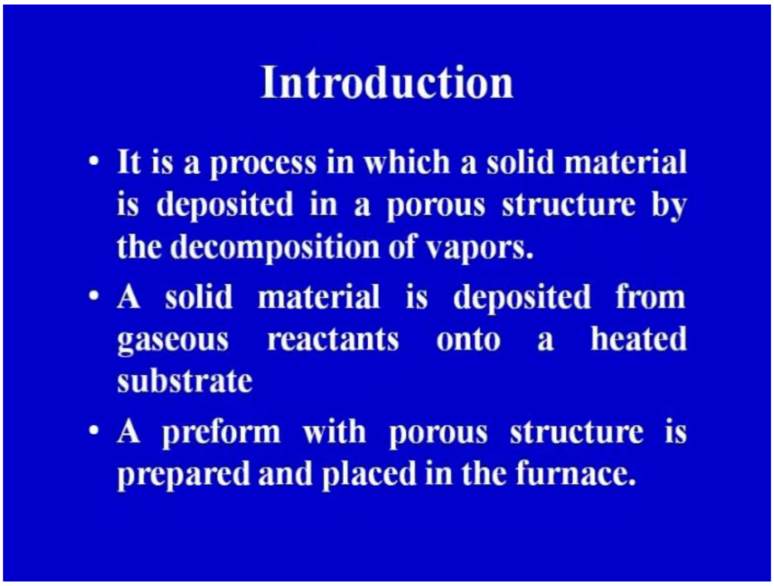

Let us, see the basic principle or the fundamental behind this process. It is a process in which a solid material is deposited in a porous structure by the decomposition of vapors. So, in this particular definition you can see, there are third important points let us try to understand these points one by one.

First important point is a solid material is deposited. So, in this particular case a vapour or there would be gaseous reactants, which would lead to the deposition of a solid material. So, the solid material can be any type of carbide or any other ceramic material basically in ceramic matrix composite let us see or let us revise that what is the matrix and what is the reinforcement. Although, this we have covered in the previous module and the discussion was quite detailed the roll of the reinforcement and the roll of the matrix, when we discuss the concepts of the composite materials in our module on polymer matrix composites, we have seen that the matrix can be having it can be of polymer, it can be of ceramic or it can be of a metal.

So, we can have a metal matrix composite, we can have a ceramic matrix composite and we can have a polymer matrix composite. So, in this particular case or module 6 our focus is primarily on the ceramic matrix composites. So, the matrix has to be the ceramic material and the reinforcement can also be a ceramic material. So, what we are going to get is the ceramic composite the matrix is also a ceramic the reinforcement is also a ceramic.

So, basically we are wanted to incorporate a ceramic matrix into and preform. So, basically in this particular point again I am coming on to the first point a solid material is deposited. Now, what is this solid material? This solid material is basically a ceramic material and it is a reaction product. So, there will be a reaction or there would be we can say deposition of a reaction product on a porous material; so, the porous structure.

Second point is porous structure point number one is a solid material is deposited where it is deposited on a porous structure; the porous structure basically is a kind of a reinforcement. So, this is a fibrous preform which is porous in nature and on top of that on in that we are depositing the solid martial from where the solid material is coming.

It is coming from the decomposition of vapors. So, you can see it is a process in which a solid material is deposited in a porous structure. So, you have two things one is porous structure which is already existing and then there is a gas, which is getting passed through that porous structure and in the mean while because, of the heat and the reaction that takes place the solid material is been deposited on the porous structure or the fibrous preform and how does this takes place because, of the decomposition of the vapors and the effluents will go out of the system or the process or the reactor. So, basically we are depositing the matrix in this particular case on the reinforcement and the matrix in case of ceramic matrix composite would always be a ceramic matrix.

Point number two again emphasizes point number one a solid material is deposited from gaseous reactants on to a heated substrate. So, the heated substrate in this particular case is the reinforcement and the matrix is coming from the gaseous reactants. So, basically if you remember the basic definition of composite is that we have a reinforcement and we have a matrix and the matrix and reinforcement combined together to make a composite. So, we have a matrix and a reinforcement and these to combined together to make a composite material.

The composite material has the properties which are superior to the properties of the individual constituents. So, in this particular case two important terminologies have been used for the reinforcement material that is the heated substrate the substrate can be a reinforcement material in the first case porous structure is a reinforcement material and from where the matrix is coming, the matrix is coming from the gaseous reactant. So, there is a gas that is passing through this porous structure or a substrate and it is getting decomposed, the gaseous reactants are giving the matrix material.

The solid material is getting deposited. So, that is the basic principle of the chemical vapour infiltration the chemical vapours are passing and they are infiltrating the porous structure and deposition of the solid material is taking place inside the porous structure and we are getting the combination of the reinforcement and the matrix. So, when these two things will combine together we will get a composite material.

So, we will try to understand this that how, actually this takes place with the help of few diagrams, but before going to the diagrams we should be able to understand that what is the matrix in this particular case and what is the reinforcement in this particular case. So, reinforcement can be in the form of a substrate or a porous structure and the matrix is been deposited by the vapours or the gaseous reactants. So, that is the basic important point that has to be understood.

So, the third point on your screen you can see preform with the porous structure is prepared and placed in the furnace. So, placed in the furnace means this particular process would takes place at the elevated temperature. So, the temperature is one of the prerequisites for the chemical vapour infiltration to in case of ceramic matrix composite to take place, in case of ceramic matrix composite, if we are going for a CVI process we have to put it in a chamber or a heated chamber. So, a preform that is a porous structure also you can call or a fibrous structure also you call or fibers are also made up of different material those can be made up of ceramic materials also. So, preforms which is a porous structure or a well we can say defined structure of fibers.

The fibers can be in one direction or they can be in bidirectional direction also. So, a pre form also with the porous structure is prepared. So, we have to first prepare the network of the fibers or that we can call as the preform. So, depending upon the requirement we can have different types of preform different materials can be used to make the preform or the fibers can be made up of different materials. So, we have a preform with the porous structure why porous because we have to infiltrate the matrix into this porous structure it is prepared and it is placed inside the furnace.

Now, one important aspect of the composite is ready. So, composite is the ceramic matrix composite or reinforcement is ready now or the matrix has to be put inside this reinforcement in order to get the complete composite. So, this is the basic fundamental aspect of making a ceramic matrix composite using the CVI process. So, we know now how the CVI process can be used for making the ceramic matrix composites and we will try to further understand, it that what are the various stages that are used for the fabrication of cmc's with the help of CVI process

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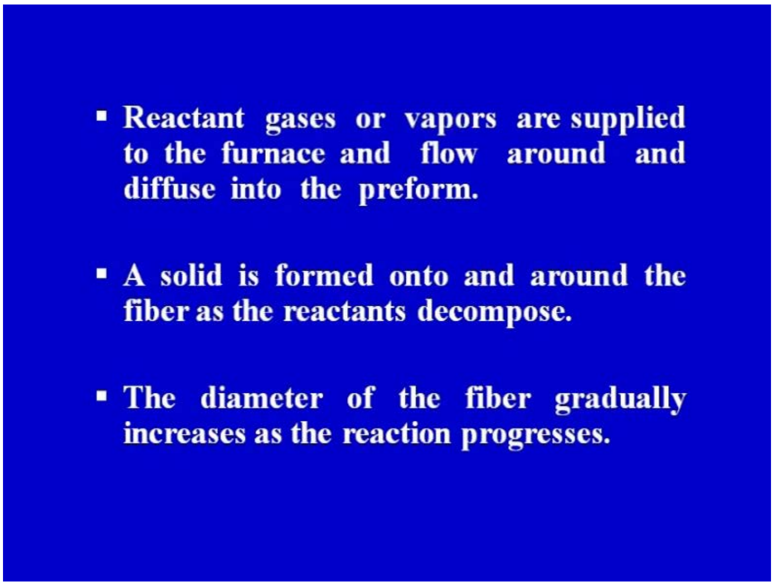

Other aspects related to the fundamentals of CVI application in case of ceramic matrix composites. Reactants gases or vapor are supplied to the furnace. Now, the last point in the previous slide was that we have a porous structure or a fibrous preform it is placed in the furnace, now in this furnace the reactant gases or vapors are supplied and these flow around and defused into the preform.

So, we have a porous structure and in that porous structure these gases will go and infiltrate inside and because, of the reactions takes place solid materials would be deposited on these fibrous preform and we will get a composite material.

So, a solid is formed onto and around the fibers as the reactants decomposed, again and again I am emphasizing that the gaseous reactants would decompose and a solid material would be deposited on the porous structure or the fibrous preform. So, a solid is formed onto means on top and around the fibrous as the reactants decomposed and the final point on your screen is the diameter of the fiber gradually increases as the reaction progresses as the reaction takes place more and more solid materials would be deposited on the fiber and the diameter of the fiber would increase. So, the fiber is made up of or it can be made up of a ceramic material. So, the fiber or the reinforcement is also a ceramic and the deposition of the matrix that is taking place is also a ceramic. So, we can get a ceramic composite by the CVI process. So, we have a fibrous reinforcement and the matrix is been deposited with the help of the passage of the gaseous vapor inside the porous reinforcement that we are using in case of the CVI process.

So, basically we have tried to understand that what is the reinforcement and what is the matrix in case of ceramic matrix composite and how these two can be blended together to make a composite material, if you remember in case of polymer matrix composite we have taken large number of lectures in which we have seen that how a polymeric matrix can be blended with different types of fibers and how the fibers and the matrix can be combined together to make a engineering material which can be used for number of engineering application.

So, in case of ceramic matrix composites also first and for most we should try to understand, that how the matrix and the reinforcement are been combined together in order to make a engineering material and these two sides have given us the clear amount of idea that how, a matrix is been infiltrated into the porous structure of the reinforcement. So, we have reinforcement in place and on top of that we are depositing and inside also we are depositing the matrix material. So, the matrix and the reinforcement are combining together to make a composite material.

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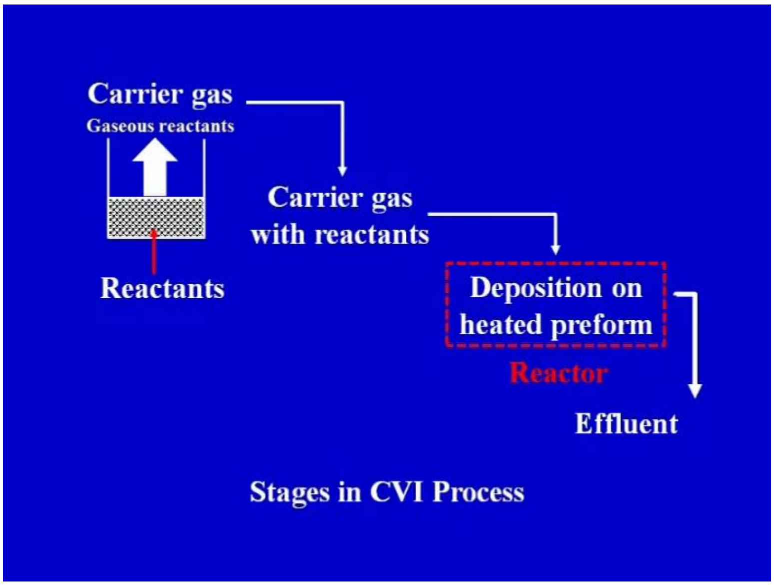

So, this is one particular diagram on your screen a very simple diagram just to explain what we have already discussed. So, these are the stages in the CVI process. So, you can see you have the reactants these are the reactants these are the reactants. So, the reactants will react and they will produce the gaseous reactants and these gaseous reactants will be carried by the carrier gas. So, basically first of all we have to produce the gaseous reactants and how the gaseous reactants are getting produces by the solid or the liquid reactants.

So, this particular green colored on your screen or this container contains the reactants and these reactants can be solid or liquid and when the reactions takes place gaseous reactants are produced and these gaseous reactants are carried by the carrier gas. So, this particular path is for the carrier gas along with the gaseous reactants. So, this is the carrier gas with the reactants and these reactants or the product of these reactants may be solid or liquid in nature. So, this carrier gas with the gaseous reactants is passed through the heated perform.

This red dotted portion, show the chamber where the preform has already been kept. So, the preform is porous in nature it is a network of the fibers and porous we can say characteristic it has porosity. So, this carrier gas with the reactants when it will passes through this porous structure or this is can be called as a reactor also. So, when this will pass through this porous structure they will deposit the reaction product on to the fibrous network.

So, the fibers diameter of the fiber would increase because, of the solid being deposited by the reaction of the gaseous reactant and finally, the effluents will come out of the reactor. So, basically what is happening, we have certain solid or liquid reactants these reactants are undergoing a reaction and they are producing the gaseous reactant and these gaseous reactants are been carried by the carrier gas and the carrier gas and the gaseous reactant are passed through a reactor. In this reactor we have already kept our reinforcement the reinforcement can be a fibrous preform or it can be a porous structure of the different types of reinforcement materials when this gaseous reactants will pass through this porous structure they will decompose and the solid matrix would be deposited on the fibers that are present in the preform. So, when this solid would be decompose or solid would be deposited not decompose.

The solid would be deposited on the fibers the diameter of the fibers would increase and the porosity would decrease because, of this deposition of this solid material if you remember in our first slide only we have seen that in this case the solid is deposited. So, this when solid material which is a reaction product would be deposited on the fibers, the diameter of the fibers would increase and the porosity would decrease. So, we will get a dense structure now because, of this solid deposition and the reaction products which are not useful would be coming out as the effluent.

So, basically a gas is passed through a porous material and the reaction product are been deposited on the porous structure and we are getting the more dense structure which we can call as a ceramic matrix composite. So, again just to revise what we have seen in this particular slide because, the various stages in the CVI process we also try to understand that what is the basic we can say construction of a reactor because in this particular slide we have just depicted the reactor with this red dotted chamber, but we will see, what is there inside the reactor and what can be we can in this particular case suppose the gas is flowing on its own, but we can force the gas through inside the porous structure. So, that we are able to reduce the total time of solid deposition. So, basically when it is a we can say without any forced gas flow when we are doing the process it may take lot of time, but specifically when we have to reduce the time of fabricating or processing of ceramic matrix composites using the CVI process, we can use the forced method, of passing the gaseous reactants through the porous media or the porous structure.

So, basically we can try to understand here because this is an important process for ceramic matrix composite is been used for making different kinds of ceramic matrix composites. We should try to understand that what is the basic fundamental behind the process and in this particular slide, it is shown that the solid or the liquid reactants reactions takes place gaseous reactants are produces, gaseous reactants are carried by the carrier gas and carrier gas with the gaseous reactants pass through the reactor in this reactor, we have already kept our preform which is a network of the fibers.

The fibers can be made up of different materials this can be ceramic fibers also. So, the carrier gas and the gaseous reactants when they pass through the reactor they deposit solid matrix material on top of the fibers and we have already the reinforcement the matrix is deposited by the gaseous reactant because on decomposition and finally, the effluent would be coming out of the reactor.

So, there are two or three important stages in the total CVI process. So, I think with this particular diagram one point is clear that what the reinforcement is where the reinforcement is kept and how the matrix is being deposited in the reinforcement and how the total composite is being made.

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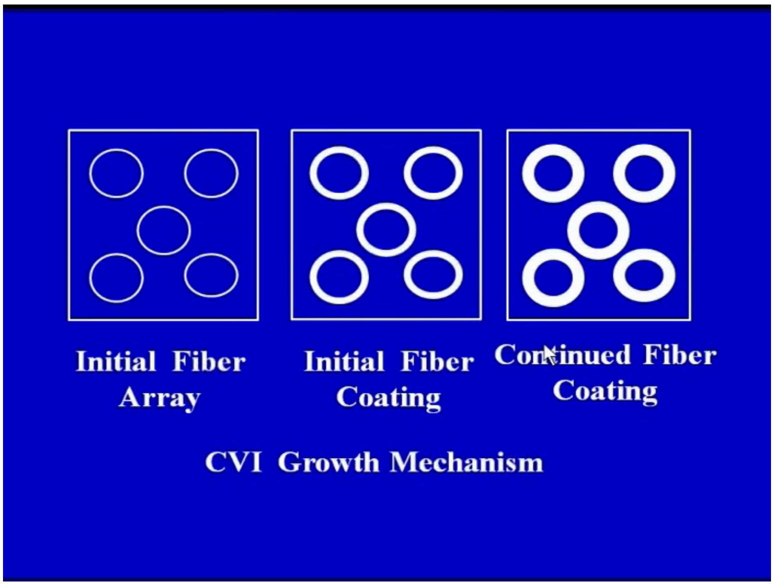

Now, here you can see the CVI growth mechanism that individual fibers are shown you can see, this is the porous preform these are the fibers one two three this is the fourth one fifth. So, we have different fibers, we have the porous this particular portion is porous when the gaseous reactants are passed through the porous medium or the porous reinforcement the diameter is increasing. Why? Because of the deposition of the solid materials which is from where the solid material is coming? It is coming from the gaseous reactants. So, from the gaseous reactant because of the reaction taking place the solid material is deposited on the fiber.

Here, you can see the solid material has been deposited all around the fiber here also the solid material has been deposited all around the fiber and with passage of time and flow of the gaseous reactant along with the carrier gas inside the porous media we can see diameter of the fibers is further increasing. So, what is happening basically the porosity is reducing and the diameter of the fibers is increasing which means the density of the total ceramic matrix composite that we are fabricating or processing is increasing.

So, we can see this is the initial fiber array or which has the porous structure, initial fiber coating by the material being deposited because of the gaseous reactants and continued fiber coating. So, we are increasing the diameter of the fiber the coating is taking place all around the fiber and the density of the composite, is increasing and the porosity is reducing. So, this is the CVI growth mechanism that in this particular process how the fibers are been coated, by passing the gaseous reactants through the porous media, the porous or the media or the preform is in the form of network of fibers which have been aligned properly depending upon the final product requirement.

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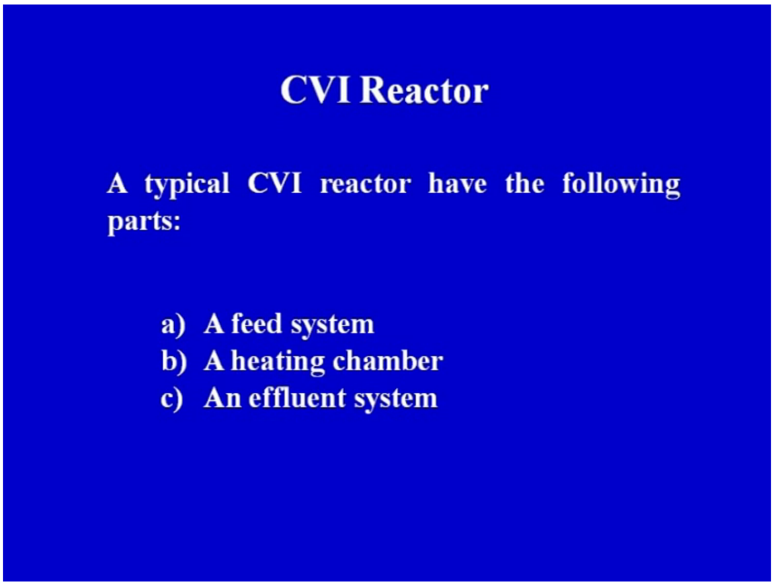

So, let us see now, in previous slide we have just seen the red box in which we have named as reactor, but this particular reactor has got a particular function and here the actually process is taking place, the gaseous reactant along with the carrier gas are coming and passing through the preform has already been kept in the CVI reactor and how the reaction takes place that we are going to see.

Basically, there are three important parts a typical CVI reactor have the following parts first one is the feed system from where the gaseous reactants would enter into the reactor, the second is the heating chamber where we are going to heat if you remember in our previous slides first or second slide only we have seen that the preform or the porous structure or the substrate is kept inside a heating chamber. So, basically this process is going to take place at an elevated temperature. So, we require a heating chamber.

First part is the supply system or the feeding system from where the gaseous reactants are going to enter into the reactor then we have a heating chamber where the preform has been kept and finally, the effluent system from where the gaseous effluents are going to come out after the reaction, which is taken place inside the reactor. So, there are these are the three important parts.

So, we will try to understand this with the help of a diagram.

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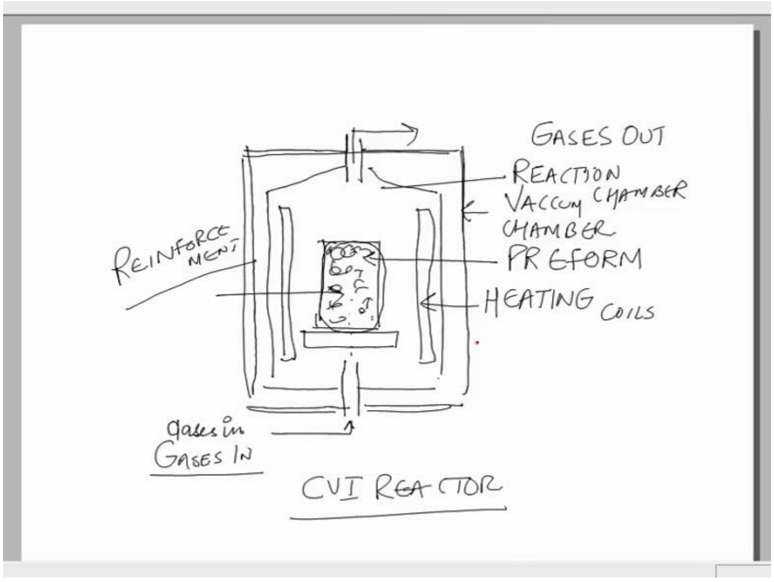

So, on your screen you can see. Now, I am going to draw one typical reactor and we will try to see this with the help of diagram, which is there in the presentation also, but let us first see how a reactor would look like this is a chamber, and then we have a passage for the gases to enter. So, the first important point in our case was the feed system and in feed system we have a passage for the gases to come in. So, again we can write. So, that it is clear the gases in. So, the gases will come in from this direction.

Then we have reaction, chamber where the actual reaction would take place. So, this is the chamber in which the reaction would take place and the second important part of this process is the effluent, the gases out. So, we have a passage from which the gases would come in and the passage from which the gases will come out. So, we have, to have, now have a perform.

Now, this is our perform so, through this preform we have to pass the gases. So, this particular we also have a porous plate here. So, on this particular preform is kept on a porous plate. So, we can see this is a preform which has a array or a network of fibers and which is porous in nature. So, when these gases will pass through this preform the gaseous reactants would react and at an elevated temperature, we can see that this is the reaction is taking place at an elevated temperature. So, we can see, we need to have the heating arrangement also. So, these are our, we can say heating coils. So, we have the heating coils also.

So, basically we have the in feed system we have a out system from which from where the effluents are coming and the actual reaction chamber. So, this particular dome type structure is called as the reaction chamber and this total is called as the, which we have already drawn this is called as the vacuum chamber. So, we have a vacuum chamber, we have a reaction chamber in which the actual reaction is taking place.

We have a fibrous preform through which we have to pass the gaseous reactants, we have a in feed system through which the gases are entering into the reaction chamber, we have a gases out system or the effluent system in which the gases or the effluents are going out of the reactor. So, this is the basic construction of the reactor we have a heating arrangement also. So, that the reaction takes place and the reaction products or the solid product reaction products are deposited on the fibrous preform which is porous in nature. So, this is basically, we can call it as a CVI reactor. So, this is a CVI reactor. So, on your screen you can see that the process is fairly simple to understand, but there has to be certain control variables which have to be maintained that for how long the gases should pass, what should be the constitution of the gases that are going inside the preform and what should be the network of the perform, how much porosity should be there in the preform and what type of porosity is acceptable when the ceramic matrix composite has been form.

There are large number of parameters which has to be governed, but we are not go into the details of those parameters, but we just need to understand the application of the CVI process for fabrication or processing of ceramic matrix composite and for that I think this particular diagram summarizes that how actually a CVI process takes place and how the ceramic matrix composite is made.

Basically, in this particular diagram, we can further see that this is now our reinforcement; because, we are talking about a composite. So, the reinforcement is the fibrous preform and the deposition that is taking place the solid material that is getting deposited in the porous spaces or on the top of the fibers which are the parts of the perform that is the matrix material. So, the matrix is been created or deposited on top of the preform or on top of the fibers which form a part of the preform. So, the matrix is coming from the gaseous reactants.

So, we have the gases in and gases out, the gases are passing or the gaseous reactants are passing through the preform and finally, we are getting a dense preform on which the matrix has been generated inside the preform. So, the matrix has been created now inside the preform and the diameters of the fibers have increased why they have increased because of the deposition of the solid reaction products.

So, basically we are now creating a composite material in case of polymer matrix composite, if you remember we are taking the reinforcement, we are taking the matrix and we are combining the 2 things together, but this in particular case, the difference is that we are generating the matrix and we are depositing the matrix on to a solid structure of or we can say not the solid but, a porous structure of the reinforcement so the reinforcement in the form of the preform which is placed inside the CVI reactor. So, the preform is porous in nature and in these pores only we are creating our matrix by the gaseous reactants. So, the difference why the polymer matrix composite process is…

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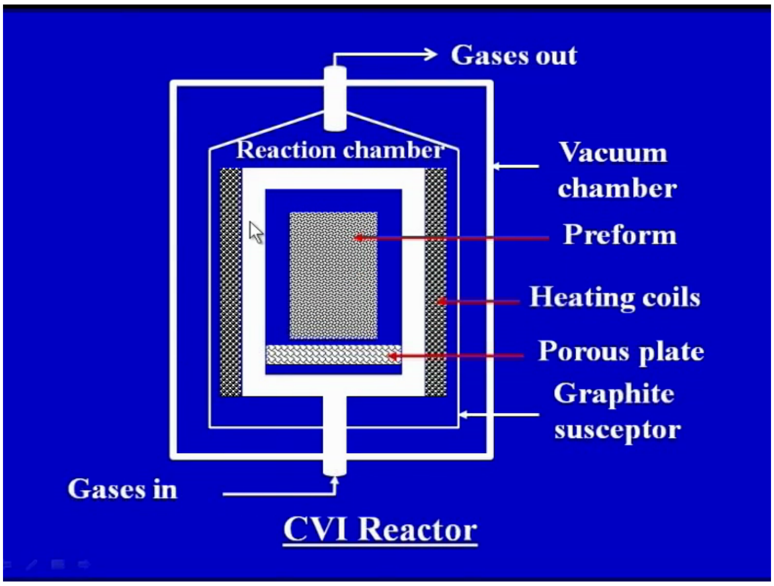

Now, let us see again we can see this diagram which has been incorporated into the slides, here you can see this is a better diagram I have tried to explain by drawing the diagram and here we can see this is again the same diagram which I have tried to explain we have the gases in we have the gases out.

So, we have the vapors in here and they are out from here then we have main important points are this is the preform this is the fibrous preform which is in our case. Is the reinforcement this is the vacuum chamber where the process is taking place under vacuum then we have heating coils these are the heating coils gray colored heating coils. So, this is we can say the basic construction details of the CVI reactor.

Now, we can see again once we can see what is the process of CVI reactor, we have the gases from where this gases are coming if you remember the previous diagram we are generating the gaseous reactants from the reactants, the reactants can be solid or liquid reactants and when the reaction takes place gaseous reactants are produced and gaseous reactants are taken into the carrier gas.

The carrier gas and the gaseous reactants are then they pass through a reactor and this particular reactant contains a heated preform. So, this is the again a diagram of the actual reactor, how the reactor works, here we can see the gases are coming, what is the source of this gas that we know in the previous diagram, we have seen in the gases are passing through the heated preform and the reactions is taking place inside the preform because, of the high temperature involved.

The solid material is been deposited on the preform or inside the preform on top of the various fibers which forms the preform and finally, the effluent gases are coming out from the effluent system. So, this is the total CVI picture that how a ceramic matrix composite can be made or can be processed using the CVI process. So, each process has got certain advantages and certain disadvantages. That we will try to understand that what are the various important points that have to be kept in mind; when we are processing a ceramic matrix composite using a CVI process.

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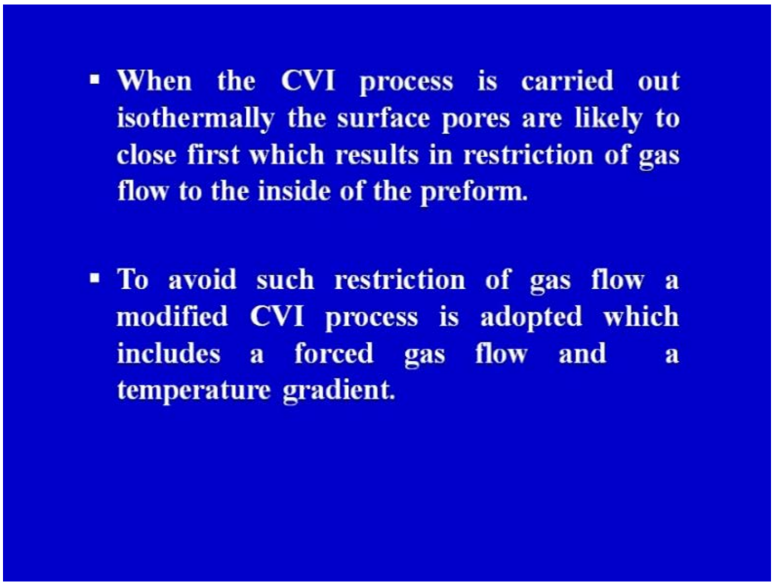

But, two important points you can see here when the CVI process is carried out isothermally the surface pores are likely to close first, which results in restriction of the gas flow to the inside of the preform. So, we have seen that preform has got a geometry now suppose it is a cuboids and in a cuboids we can see pores are filled because, it is porous in nature which we have seen.

The pores are filled at the surface and how the pores will be filled inside because, we have to increase the density the fibers in each and every section of the preform should be properly wetted or should be properly the material from the gaseous reactant should be deposited uniformly on all the fiber so.

Basically, if we see if we are depositing using a normal flow of the gas what is going to happen? As its clear from the very first point that on the surface the solid would be deposited because, it starts from the surface and inside the preform there would be no deposition of the solid material, which is not required why because, on the density would be higher or we can say or at the surface we will have more dense structure and towards the center of the core of the preform we will have very porous structure because, no depositing of the solid material has taken place at the center, why because, the core pores were closed at the periphery. So, that we do not want at the surface the pores were closed because, of the reaction products because, of the reaction taking place. The surface has closed down and which is not allowing the gases to infiltrate or pass through the bulk of the preform which is not desirable. So, what can be done?

So, let us first try to understand what is the problem that is arising; the problem that is arising is that, when the CVI process is carried out isothermally, the surface pores the pores on the surface of the preform are likely to close first. So, the deposition of the solid matrix would be starting from the surface. So, the pores at the surface would be closing first which results in the restriction of the flow of the gases inside the preform towards the center of the Perform.

The gases will not be able to reach and when the gases will not be able to reach at the center, the center would be remaining porous only. So that is not what is desirable because, we want to have a uniform distribution of the matrix inside the reinforcement. So, what can be done to avoid this? So, you can see on your screen the second point to avoid such restriction of the gas flow, a modified CVI process is adopted. So, we will modify the process. So, how it can be modified, which include includes a forced gas flow and the temperature gradient. So, two important process variables are taken into account.

That is, the gas flow is forced now, suppose in previous case the gas flow was not forced it was a natural flow only but, now we have a forced gas flow we are forcing the gas into the preform and second is that we are going to establish a temperature gradient. So, how these two things are going to help us in avoiding, the problem we can say which was there recorded in point number one. That the structure in the center are at the core of the preform.

The material is porous, only and the pores are closed at the surface which is restricting the flow of the gases towards the center of the preform that is our problem and now that problem can be overcome by the forced flow of the gas and establishing the temperature gradient. So, a new modified CVI process can be used to overcome this problem, which has been highlighted in point number one.

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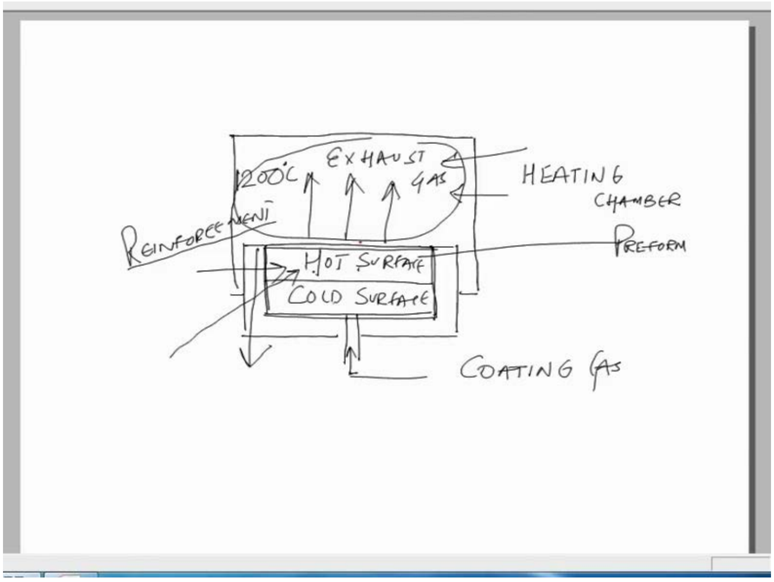

So, let us now try to see that what this process is. On your screen you can see I am going to draw a diagram which would illustrate this particular modified process. So, you can see again the basic mechanism would remain same we have to pass the gases through a porous perform. Now, this is what we can say chamber which can be called as a heating chamber. So, we have a heating chamber, in this we have placed our preform this is our total preform. So, we can say this is our preform. So, this can be divide this is divided because, of the reaction that is taking place.

We have a hot surface and a cold surface, why we are calling it hot and cold surface because, of the flow of the gases, that is taking place now this is our input. So, we are inputting our coating gas from here in this particular case, we can call it as a coating gas.

In previous case, we have just used the simple term that is the gases, in that was the feeding system. So, here this is the feeding system and the coating gas is going through the preform. So, this is our solid preform. So, solid preform means that through this we have to pass our gases and we have to deposit the solid reaction products inside the preform So that, the matrix is created. So, this can be we can say the reinforcement is already been kept. So, this is basically a reinforcement that is a preform.

So that, reinforce is already been kept and this is we can say the exhaust gases. So, again we see the principle is same, we have an inlet for the coating gas, the effluent gas or the exhaust gas are coming out of the perform, we have kept our preform inside the heated chamber and the heat is already there. So, because of this heat can be up to the tune of suppose 20 1200 degree centigrade. So, on your screen I have written 1200 hundred degree centigrade.

So, basically what is happening here we are forcing the gas inside? So, one important point is this is the modified CVI process from the point of view that we are forcing the gas inside. So, first one is it is not a natural flow of the gas, it is the forced flow of the coating gas through the preform. So, our preform is our reinforcement which is porous in nature and these particular pores we have to fill with the reaction product or the solid being deposited because, of the reaction taking place.

Now, the gaseous reactants which are been passed through the fibrous perform, we can see on this particular section it is heated. So, because of the heat the reaction would takes place at the top of the preform. So, the deposition would start from the top. So, we can see already we have written this is our hot surface, why this is hot because of this heating chamber. So, we have a heating chamber here. So, because of the heat the reaction would takes place first at the hot surface and this reaction will then travels towards the depth of the preform. So, the reaction would travel in this direction. So, the coating would take place first at the top that is the hot surface that we have already written and then finally, it will travel down. So, in the top portion the solid would be deposited first and then towards the bottom we will get the deposition of the matrix at a later stage.

So, basically when what is happening when the preform is in contact with the heating chamber, the temperature is higher and because of the reaction taking place the solid matrix material is being deposited at the surface or at the top of the preform and then the top portion is heated. The deposition is taking place and then slowly, the reaction would takes place towards the depth of a perform. Why because, the density is increasing at the top and the thermal conductivity we can say can be increasing. So, because, of the increase in the thermal conductivity. The total preform will get heated and when it will get heated the reaction would takes place and the total structure of the composite can be created. So, basically one or two points that needs to be kept in mind in this modified process is that now we are forcing the coating gas inside the perform, the effluent is coming out as it was coming out in the basic process and in this we have a heating chamber the preform or the surface of the preform which is contact with the heating chamber, at that particular surface the we can say the deposition of the matrix material will takes place earlier and then this deposition would be travelling from the top towards the bottom.

So, first in this particular case at the top we will have a hot surface and at the bottom we will have a cold surface because, it is away from the heating chamber, but with passage of time as and when the gas would be forced through the perform, the reaction would takes place towards the cold section of the preform also and finally, the cold section would also get the deposition, it will also get heated and the deposition of the reaction product would takes place at the cold section also.

And in totality when the process would be over the total preform would have the uniform structure although, that the deposition has taken place in stages, but the total composite that we have made out of this modified process would be having the uniformity in structure. So, these are the important points specifically in case of this modified CVI process in which we are forcing, the coating gas through the preform and we are heating chamber to create a thermal gradient in this particular case.

We will get a uniform distribution of the matrix material which was not possible in our pervious case, in which we have seen that the in case of isothermal reaction the cores at the pores at the surface would get closed first and the gases will not be able to reach towards the center of the perform, thus we will not get a uniform structure.

But, in case of this forced type of CVI process in which we are forcing the gas through perform, we will get a uniform structure the two important differences are the temperature gradient, that is been generated here because, of the heating chamber and the forced gas flow through the perform. Now, as I have already told that each process has got certain advantages and certain limitations. So, we will try to understand this particular process with the help of a neatly drawn diagram in the presentation and finally, we will move towards the advantages and the limitations of this process.

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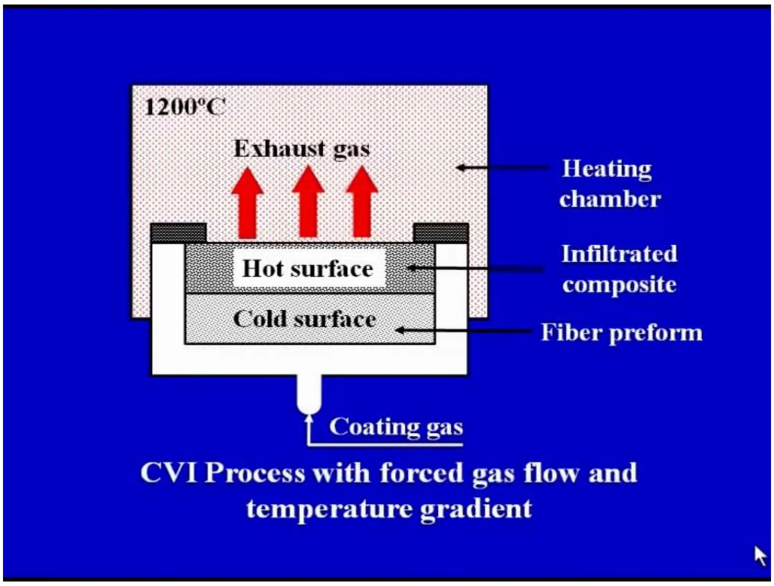

So, this is the diagram on your screen you can see, we have a heating chamber this is the heating chamber in totality 1200 degree centigrade, which is one of we can say range of temperature, it can range may be 1100 to 1400 . So, general temperature is mentioned that is 1200 degree centigrade depending upon the different types of composites, we may require to change the temperature. So, basically we have a heated chamber.

This is the coating gas, which is entering from here, this is the hot surface infiltrated composite and this is fibrous preform actually this total is the preform but, this is already been infiltrated and this cold has to be infiltrated. So, with the passage of time when the coating gas would be forced to flow through this perform, we will be able to infiltrate this particular fiber preform also and we will get the uniform structure of the total fiber preform. So, this is basically a modified process in which we have established the temperature gradient by providing this heating chamber and the coating gas has been forced through the preform.

So, let us see what are the advantages of this process first and foremost as we have a preform and the gases are been passed and the reaction product are solid is been deposited on the fibers and we are creating the matrix material and blending the matrix and the composite together matrix and the reinforcement together to get the composite material.

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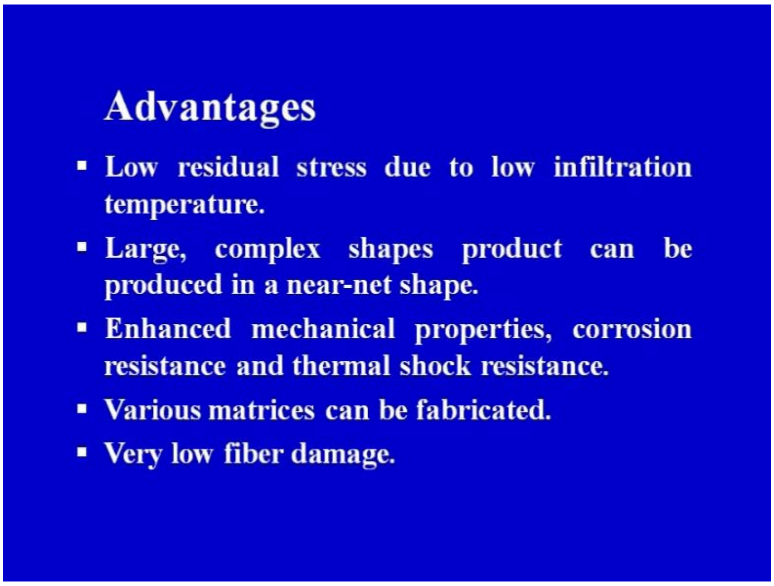

So, there are, Low residual stress due to Low infiltration temperature. So, the residual stress that is developed is lower in case of CVI process. Large, complex shapes product can be produced in near- net shape. So, whatever final shape we want we can make a preform of that particular shape and then we can pass the gaseous reactants, through that particular shape, the solid material would be deposited on the fibers and the finally, we will get a very complex shape. So, basically complex shapes can also be made.

If you see, in case of powder processing which we have already seen sometimes it is difficult to make complex shapes ceramic matrix composite, but in case of CVI yes, we can get large shapes also and we can get complex shapes also. So, the size and shape both are flexible in case of CVI process for ceramic matrix composites.

So, we get enhanced mechanical properties, corrosion resistance and thermal shock resistance, these are additional three properties that we get in CVI process the mechanical properties are good corrosion resistance is there and thermal shock resistance is also there.

Various matrices can be fabricated because; we are creating the matrix in this particular case. So, we can have different types of matrix materials and the fiber damage is also less because, in our previous lecture we have seen that in case of hot pressing or in our previous lecture, we have seen the process of powder processing of ceramic matrix composites, where we have seen that in some cases there are chances that the viscous or the fibers that we are using as a reinforcement material in a ceramic matrix may get damaged, but here in this particular case the chances of fiber damage are very less.

So, that is also another advantage because, the fibers are the main load bearing members and if they get damaged the mechanical properties that we are going to get would not be adequate. So, in this particular case because of the Low fiber damage we are getting the enhanced mechanical property which is also advantage, which is listed in point number 3. So, again just to revise, that what are the important advantages on your screen you can see low residual stress are developed large complex shapes can be fabricated by CVI process, mechanical properties are good thermal shock resistance is good fiber damage is very less and the different types of matrices can be used for getting the ceramic matrix composites.

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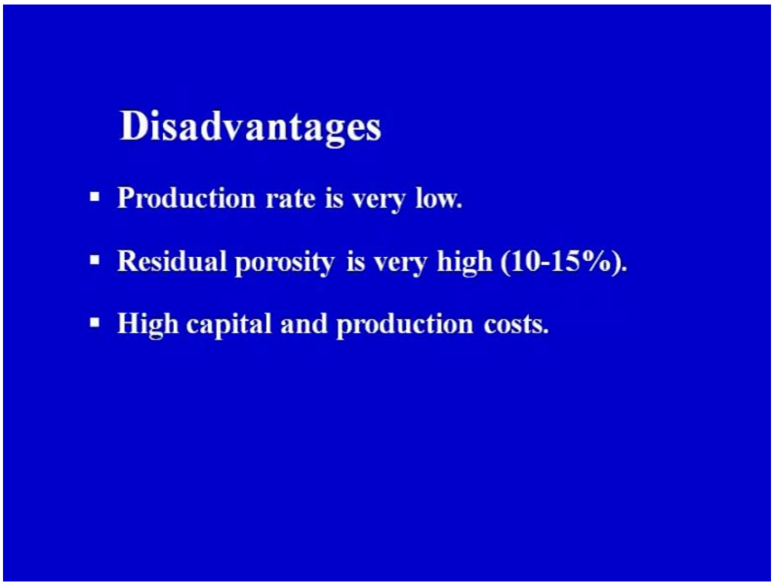

Now, what are the important disadvantages? So, disadvantages are that the production rate is low, in case of the normal flow of the gaseous reactants or the gases; we require lot of time for the deposition of the matrix to take place on the fibrous preform. So, this process is slow. So, the production rate is low residual porosity is high. So, 10 to 15 percent porosity usually is noted in case of ceramic matrix composites produced by this method, and then the capital and production costs are also high.

These are some of the disadvantages which are related to the CVI process, but apart from these disadvantages we although, apply this particular process for processing of ceramic matrix composites. So, basically we can see that, we have to combine the reinforcement and the matrix together and we can have a solid reinforcement, we can have in this particular case we have seen that the reinforcement is in the form of a preform and the gases are been used to create the matrix.

Whereas in our previous discussion, we have seen powder processing in which the reinforcement was also solid particles and the matrix was also solid particle and we were blending them together and then consolidating them to get a composite product.

So, in that particular case the reinforcement was solid, the matrix was also solid here, and we can see the reinforcement is solid. In this case of CVI process which is in the form of fibrous preform or substrates, but, the matrix is been created by the flow of the gases and then we will see in subsequent lectures that what are the other process in which the matrix can be in the form of a liquid.

So, we will see slurry impregnation or liquid infiltration techniques, in which the matrix the reinforcement would be certainly a solid material, but the matrix would be generated by the flow of the slurry or the liquid infiltration, so that we are going to cover. So, we can see that different mechanisms are used for combining the reinforcement and the matrix together in order to make a composite material.

And another important point to note is that the processing techniques, that we are discussing for ceramic matrix composites are different from those for which we have discussed for polymer matrix composites. So, we can see the importance of discussing these important topics.

So, with this we come to the end of today's discussion, that is CVI process for processing of ceramic matrix composites, just to revise what we have seen today, we have seen the various steeps involved in the processing of ceramic matrix composite with the help of CVI process. We have seen, what is the basic structure of the reactor which is used for passing the gases through the fibrous preform and finally, we have seen a modified CVI process in order to overcome one of the major limitations of the normal or the basic CVI process in which we have a forced flow of the gases through the preform and we established a temperature gradient, in order to improve the productivity or the efficiency of the CVI process specifically in case of ceramic matrix composites. In our next lecture, we would see certain other processes like, slurry impregnation and liquid infiltration which are used for the processing of ceramic matrix composites.

Thank you.