Processing of non metals

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Module - 6
Ceramic Matrix Composite: Processing
Lecture - 6
Ceramic Matrix Composites: Post Processing

Good morning to all of you, today we are going to discuss the post processing aspects of ceramic matrix composites. But before we start our discussion on the post processing aspects of ceramic matrix composites, let us first see that what we have already covered in this particular module, because this is the last discussion or last lecture in this particular module on ceramic matrix composites. So, in this particular module, our focus was primarily to discuss the details about the ceramic matrix composite with the focus on the processing aspects of ceramic matrix composite.

So, in the very beginning, we have seen that what is the difference between the ceramics and the ceramic matrix composites, why do we need to reinforce the ceramics, what are the disadvantages of the ceramics, which can be overcome the reinforcing with the reinforcement phase. Then we have seen that what are the various types of toughening mechanisms that are prevalent in case of ceramic matrix composite, and then we focused our discussion on the processing aspects of ceramic matrix composites. So, basically, whenever the word composite comes into picture all of us know that there are two macro constituents that combine together to make a composite material. So, these two macro constituents are the reinforcement and the matrix.

So, we have to somehow combine the two things together that is the reinforcement and matrix to make a composite material. We have already seen in the previous module that how the polymer matrix composites can be made, and we have seen the processing aspects of polymer matrix composites with the help of number of processes such as resin transfer molding, filament winding, pultrusion and a number of other processes. Similarly, in case of ceramic matrix composites also we have seen a number of processes till date. If you remember in our previous lectures, we have seen the powder processing method for processing of ceramic matrix composites then we have seen chemical vapour infiltration, we have seen slurry impregnation, liquid infiltration. And today we our focus would be on the directed metal oxidation process, and finally, we will see the post processing aspects of ceramic matrix composites.

So, basically if we see the processes, the processes that we have already covered in ceramic matrix composites, the reinforcement phase is mostly or may be in all the cases has been in the solid form only. Starting from the powder processing, we have seen the powders of the reinforcement and the matrix are combined together, they are blended together, and finally pressure and temperature may be used to make a composite product. In case of CVI also we have used a preform and then the infiltration or the impregnation of the vapors, a gaseous reactants into the preform. And then a liquid infiltration also we have seen that we have a fibrous or a network of fibers forming a pre form in which the liquid infiltrates. So, in most of the cases, we have seen that the reinforcement is in the solid form and the matrix is somehow generated into the preform or created inside the perform, so that we get a complete structure which is a composite structure in which we have a reinforcement phase and we have a matrix phase. So, basically the focus is on combining the two things together, and in our discussion on ceramic matrix composites also we have seen that the reinforcement and matrix have been combined together in a number of ways like powder processing, chemical vapor infiltration, slurry impregnation, liquid infiltration and there can be other process also, but these are the important processes that we have discussed.

So, today our discuss primarily would be on two processes just the basic fundamentals of the processes that how the process actually take place, and finally, we will conclude this particular module with a discussion on the post processing aspects of ceramic matrix composites. So, with this introduction, let us now start our discussion on the basic aspects or the basic fundamentals of the directed metal oxidation process. We will first see the salient points in the form of introduction to the process and then we would try to understand the process with the help of a diagram. And finally, we will see that what are the salient advantages and disadvantages of the process along with the application of the process.

So, let start our discussion for directed metal oxidation. So, directed metal oxidation, basically, we can see that a three words are there directed, method and oxidation. So, directed means, so that in a particular direction the reaction would take place; the reaction would be for a metal, because the metal word coming in the name, and oxidation means the type of the reaction would be the oxidation reaction. For example, the aluminum may combine with Al to form aluminum oxide. So, directed metal oxidation means the direction of the reaction the metal would be there and it would react and it would oxidize to create a reaction product.

So, this is the basic fundamental definition of the process that is directed, metal and oxidation. So, we should we can now have an idea that what is to be going to be there in the process that there is going to be a reaction that would take place and the products of the reaction would be used either as a reinforcement or as the matrix. But as the history goes, as we have seen in the previous processes that we have already discussed, the matrix is being created or being generated or being formed inside the fibrous preform. So, the reinforcement in most of the cases is already in place, but the matrix has been we can say in a very simple terms grown into the preform to make a composite material. So, in this case also, our focus would be on creating matrix only and the reinforcement would be in the form of preform only which would be created before the reaction taking place. So, we would be seeing that what are the various steps involved in the directed metal oxidation.

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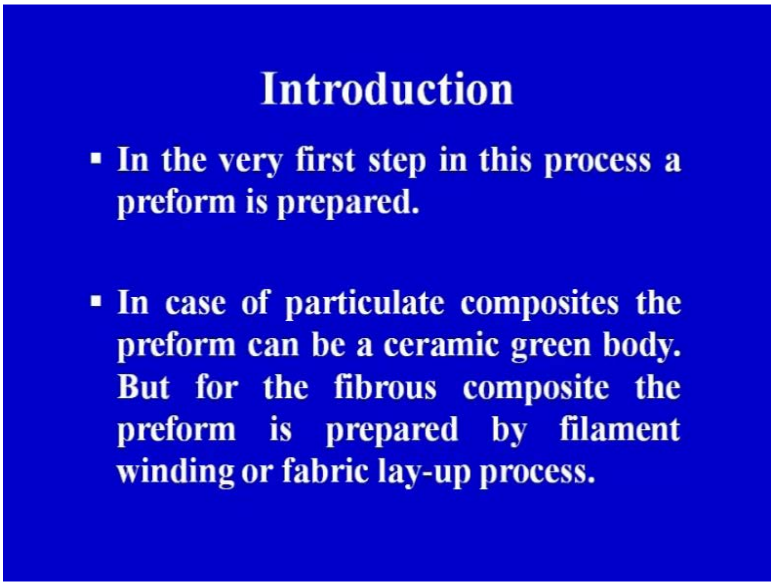

Let us see the introduction of the process; in this, we will see the various steps involved in the process. So, in the very first step a preform is prepared. As we have seen in the other processes for processing of ceramic matrix composite a preform is a prime prerequisite for making a composite material. So, the pre form is created in most of the cases, we have seen the preform is made up of fibers; sometimes particles can be use for making a preform or whiskers can also be used. So, the preform is basically the reinforcement that is going into the matrix or that is being combined with the matrix to make a composite material. So first and foremost, we have to generate a network of fibers, it can be continuous fibers or discontinuous fiber or whiskers which can be used as a reinforcing material inside the ceramic matrix.

So, first and foremost job is to create a preform that is first and foremost job is to bring the reinforcement into the picture. And finally, we will make bring the matrix also into the picture, the reinforcement and the matrix would combined together to make a composite material, and more specifically a ceramic matrix composite material, because this particular module is focusing on the ceramic matrix composites. So, therefore, matrix that would be generated would be a ceramic matrix, the fibers also in many cases would ceramic, therefore, we get ceramic ceramic composite material. In which the reinforcement is also a ceramic material and the matrix also a ceramic material.

So, the very first step in case of directed metal oxidation is to create a preform. So, in the very first step, the perform is prepared. How is prepared that we will see with the help of a diagram. In case of particulate composites, the perform can be a ceramic green body. Ceramic green body means there can be because the particles are there in the form of reinforcement, green body means there would be other additives also. So, it would be a green body means, it would have a structure, it would have a form in which the ceramic particles will also be there and would be bind it together with other additives. So, it is also important to note, because if the reinforcement is particulate the green body or the perform would be different. And if it is a continuous fiber reinforce the we can say perform would be of different shape and form. So, basically we can see this particular point clarifies that the particulate reinforcement can also be used in directed metal oxidation.

So, in case of a particulate composite, the perform can be in the form of a ceramic green body. But for the fibrous composites in which very we may be having a continuous fiber the perform is prepared by filament winding or fabric lay-up process. So, this is emphasizing the creation of a perform or this particular point is highlighting the creation of fabrication of processing of a preform before a processing a ceramic matrix composite. So, when we are preparing a perform, there are two three important points that have to be taken into account. First and foremost, we have to see the reinforcement the form in which the reinforcement is being used. If it is in the form of the particles then we have to prepare a ceramic green body; if it is formed in the form of a long fibrous, then we can use the filament winding process or the fabric lay-up process. So, we can have a continuous preform we can have a particulate type of reinforcement in the form of a ceramic green body. So, first and foremost focus is on the creation of a preform, because in all of the processes that we have seen for composite materials the focus has been on two important aspects and these aspects are the reinforcement and the matrix.

So, right now in this particular slide our focus is on the reinforcement part of the composite material, because here we are seeing that how the reinforcement has to be prepared for being blended into a matrix material. So, we can see that the preform is prepared in the form of a particles also or in the form of a continuous fiber reinforcement which can be made with the help of two processes; the continuous fibers can be filament wound or they can be made using the fabric lay-up process. So, this is a first important slide related to the reinforcement aspect in the directed metal oxidation and then slowly we will move towards the matrix aspect in case of the directed metal oxidation.

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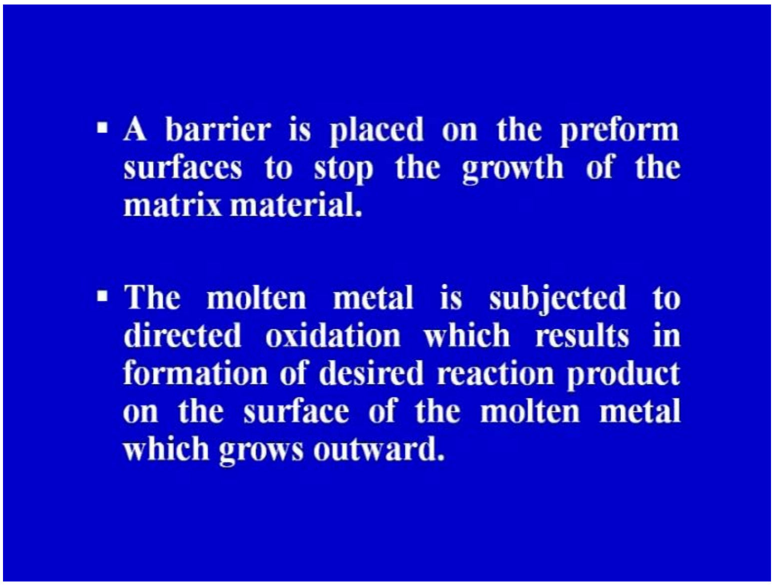

So, on your screen, you can see a barrier is placed on the preform surfaces to stop the growth of the matrix material. So, here also we have prepared a preform and in this particular preform, the matrix would grow. And how the matrix would grow that we would be seen with the help of a diagram, but there would be a covering or a barrier that would be placed on top of the preform, so that to restrict the growth of the matrix material. So, I am again reading the point on your screen to make it even more clear that a barrier is placed on the preform, the preform we have already generated in the form of a ceramic green body or in the form of a continuous fibers preform with the help of a filament winding or fabric layup process. So, the filament this preform is already ready with us now we are growing the matrix inside the preform and for that a barrier is placed on top of the preform why a barrier is place. So, that the matrix can grow up to a particular level only.

Before going to the next point, let us first revise this particular point because this is also important a barrier has to be placed on top of the preform. So, barrier is placed on the preform surfaces to stop the growth of the matrix material. So, next point is the molten metal is subjected to directed oxidation. So, as I have told in the very beginning in the start of the lecture itself that the name of the process is directed metal oxidation. So, here we can see, the molten metal the metal part is coming into picture. We have already prepared a preform, now the metal part is coming into picture, the molten metal is subjected to directed oxidation. So, the other two words are also coming into picture that is the directed and the oxidation. So, the name of the process directed metal oxidation. So, that molten metal is subjected to directed oxidation, which results in formation of desired reaction product on the surface of the molten metal which grows outward.

So, we will try to understand this, we will have a preform and below that we will have the molten metal which would be subjected to the directed oxidation, and the products or the reaction products that would be formed on the surface of the molten metal would be allowed to grow outward. So, when they will grow outward, they will enter into the preform and will form the matrix on the surface of the reinforcement. The reinforcements can be in the form of fibers or the particle and we will get a composite material. So, we have a preform, we have a molten metal, and it is subjected to directed oxidation the reaction products that are forming on the molten metal would be allowed to develop or move outward and they will form the reinforce, they will formed the matrix inside the preform. So, preform is already acting as the reinforcement, we have to generate the matrix, the matrix is being generated by the directed metal oxidation that is the basic fundamental of the process.

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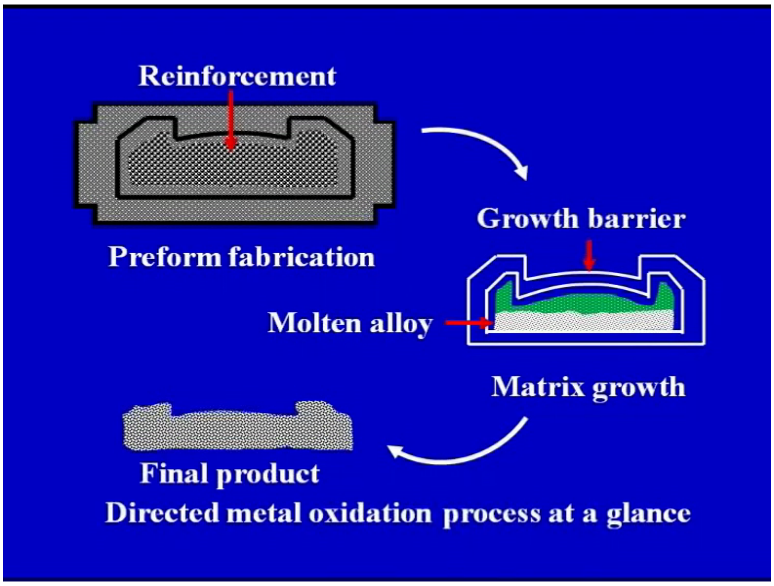

Now, let us see some other points related to the process and we will try to understand these points with the help of a diagram. On your screen, you can see, first and foremost is the preform fabrication. As we have seen in the previous slide, we have to make a preform; this is the preform. We can see this is the preform. Now the next point is the growth barrier; this can be the the white line x as the growth barrier. We have a molten metal which is subjected to the directed oxidation and the reaction products will form the matrix material. So, this is the molten metal, the matrix growth is taking place, matrix growth takes place in this direction from the bottom. The matrix will grow into the preform, and finally when the whole preform becomes tense with the growth of the matrix inside the preform, we get a final product that is a ceramic matrix composite.

So, again we can understand the process. This is a directed metal oxidation process, very basic steps are given here. This is a reinforcement in the form of a preform. As we have already seen the preform can have a particulate reinforcement or it can have a continuous fiber reinforcement in the form of a different layers of fabrics or we can make it by a filament winding process. So, we have we can have continuous fiber reinforcement or we can have particulate reinforcement; if it is a particulate reinforcement, we will make a ceramic green body which would be acting as a preform. So, basically a preform is ready then we make a growth barrier on top of the preform, so that we can control the growth of the matrix inside the preform at growth barrier is put on top of the preform. And once the growth barrier is put, the molten metal is oxidize or directed oxidation takes place of the molten metal, and the products that are formed are acting as the matrix material for the preform. So, we will get a composite material in which we have a matrix also and the reinforcement also; the reinforcement is in the form of a preform and the matrix is being grown because of the directed metal oxidation. So, this is a very simple summary or very simple representation of the process.

Again on your screen, you can just have a look preform fabrication matrix growth, and finally the final product. Matrix growth is the most important part of the whole process or the heart of the process, because here only we are combining the two things together. As I have already discuss in the very beginning of today's lecture, when we started this lecture I have just introduced the we can say concept of composite once again. Because there may be a audience which is only interested in this particular lecture that a composite is basically a combination of a reinforcement and a matrix phase and in combination they give the properties which are not attainable with any of the individual constituents. So, basically in all the processes, which are use for processing of composites, we have to blend or we have to combined the two phases that is the reinforcement and the matrix phase together.

In this particular case of directed metal oxidation, this is the reinforcement and the matrix is being grown because of the reaction that is the directed metal oxidation. So, this is the important phase where we have the reinforcement in the form of a preform and the matrix is growing inside the perform at to make tense composite product. So, basically the growth of the matrix phase is an important point and here we have to control the process properly, so that we get a good quality composite product, otherwise there would be some kind of defects or some kind of problem areas that have to be addressed at later stages. So, that we will discuss in the subsequent slide that what are various disadvantages or the limitations of the process, but yes this process has been found to the suitable for fabricating ceramic matrix composite materials.

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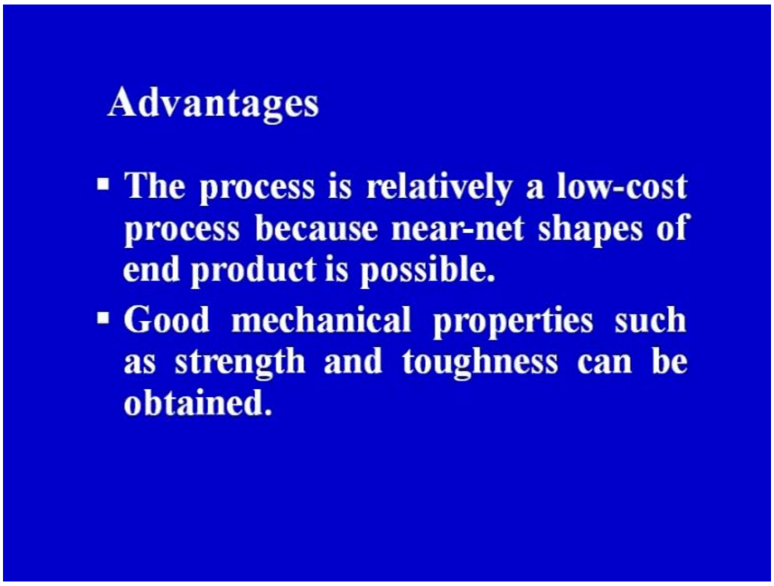

Now, let us come to the advantages of the process. So, we can see there are certain advantages. The process is relatively a low-cost process because near-net shapes of end product is possible. Now let us see there are two-three important points in this particular advantage first important point is that it is a low cost process. So, we have seen some of the other processes for ceramic matrix composites or for processing of ceramic matrix composite which are high cost intensive processes. Because that kind of or the mechanism involved is a high cost mechanism or it involve sophisticated instrumentation, but in this particular case the no sophisticated instrumentation is required therefore, this is the simple low cost process.

So, the process is relatively a low cost process that is one important. And why it is low cost, there can be other point one is that the instrumentation or the infrastructure required for this process is not very costly as I have already highlighted. The second point, why it is low cost is because it can be use for near-net shapes of the end product. Now what do we mean by the near net? Near net means the exact shape of the final product; near net means the net shape near to the net shape product we can make by this process. So, basically it is a near-net manufacturing or near-net processing technique; why, because in this we are creating the preform as the first step of the process. If you remember the steps involved in this process, we have seen the very first step involved is the fabrication of the preform. So, the preform we can make in the shape of the final product or the end product that is desired.

So, as per the design requirements, we have a shape of the product; and the preform we can create according to the shape of the product, and once the shape of the product has been made then we can grow the matrix inside that shape and directly get the final product. Which is not possible in the some of the other processes which are use for processing of ceramic matrix composite. So, therefore, this process can be use to make near-net products, and therefore, the additional processes or the post processing techniques may not be required in terms of machining or rolling or giving it a shape at a later stage after forming a bulk of the material, sometimes we trim it, remove the material and form it to give a desired shape. All those secondary processing or post processing processes are eliminated, when we are able to generate a near-net product and this particular process has the advantage of producing a near net product. So, therefore, this is low cost process and least expensive in terms of producing the products, because it is able to generate the near-net product. And secondary processing or post processing of composites need not be done if the product has been produced by the directed metal oxidation process.

Now, the second advantage is that good mechanical properties such as strength and toughness can be obtained. We will see that from where the toughness is coming into picture, because the toughness is related to is one of the important parameters in case of the ceramics. So, we need certain amount of toughness in case of ceramic product and specifically in ceramic matrix composite product. So, how the toughness is coming into picture that we will see, so but one important point to note here is that we get good mechanical properties in case of directed metal oxidation process for processing of ceramic matrix composites.

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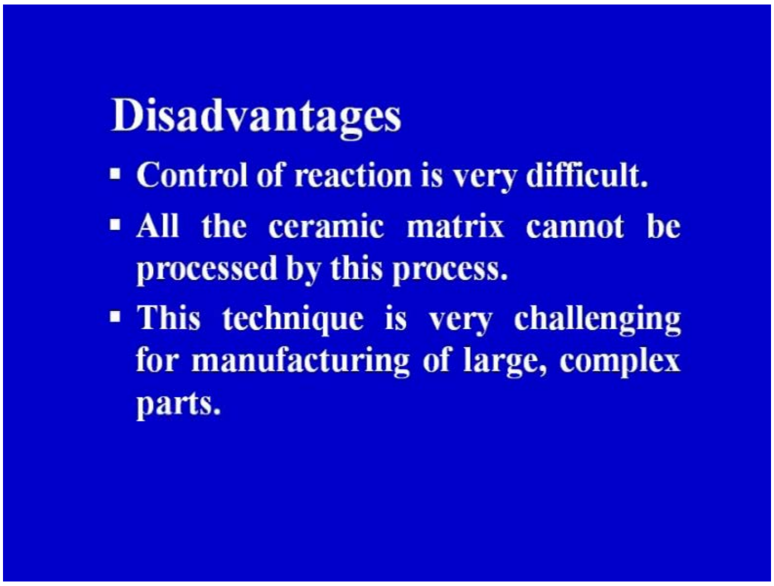

Now, what are the disadvantages of this process? There are silent disadvantages, some important disadvantages also. Control of the reaction is very difficult as the name of the process suggest directed metal oxidation. So, here the reaction is taking place or the oxidation of the metal is taking place at a elevated temperature. So, the control of reaction is very difficult that is one important disadvantage, because the reaction is acting as we can say one of the important sources or is the important source for the formation of the matrix inside the preform. And if we are not able to control the reaction properly the formation of the matrix inside the preform or the growth of the matrix inside the preform would not be optimal or would not would not be as per the desired requirements or as per the desired specifications. And therefore, the final composite product that we will get may not have the properties for which it has been processed or designed. Therefore the control of the reaction is very very important; and if we are able to control the reaction properly, we will be able to get a very dense composite product a very a composite product which has very good mechanical properties which has got good toughness and can be use for a variety of engineering application.

So, the important point as I have already told that there are basically three steps involved in the process. First step is the formation of the preform, and second step is the growth of the matrix inside the preform, and the second step is the most important step in the process, because here we have to control the process in the most optimal manner; otherwise we will not get the product according to our requirement. So, the important point to control is the reaction, because reaction is the we can say backbone of the formation of the matrix inside the reinforcing preform or the reinforcement in the form of the preform. So, the growth of the matrix is important and that growth of matrix depends upon the reaction and if the reaction is not controlled properly we may not get a very good composite product. So, again and again the emphasis is on the growth of the matrix inside the fibrous preform. So, this is important point to control the reaction properly.

Second important disadvantage is that all the ceramic matrix cannot be processed by this process. So, different types of ceramic matrix cannot be processed, maybe we can have a selected matrix materials that can be processed by this process. The technique is very challenging for manufacturing in large complex parts. So, if we have a small part, we can grow the matrix in a particular direction inside the fibrous reinforce, but if we have very large parts sometimes we may not be able to have a uniform distribution of the matrix material inside the preform and the quality of the product that we get may not be that good. So, the technique is challenging it is it cannot be said that it is impossible, but it is challenging there are different types of operating variables that need to be controlled if the size of the product is large. So, this particular technique is very challenging for processing of large complex parts. So, one is large another is complex. So, if the geometry of the preform is very very complicated in that case also sometimes we may not be able to grow the matrix properly inside the preform. So, in those cases also, we may not get uniform density of the product or we may not get the uniform properties all around the bulk of the product.

So, basically, there are challenges also, disadvantages also related to the directed metal oxidation process. Just to highlight the challenges because or the highlight the disadvantages because this is the important from the application point of view, because when we are making a product and there are few challenges or disadvantages those have to be over come in order to make a product of very high quality. So, one is the to control the reaction properly that is the directed metal oxidation; second is that all the materials cannot be processed by this process. And last one that this technique having a challenge if the shape of the product is very very complex and is a size of the product or the ceramic matrix composite product is very very large. So, these are important points to be taken care of these are the important limitations of directed metal oxidation process.

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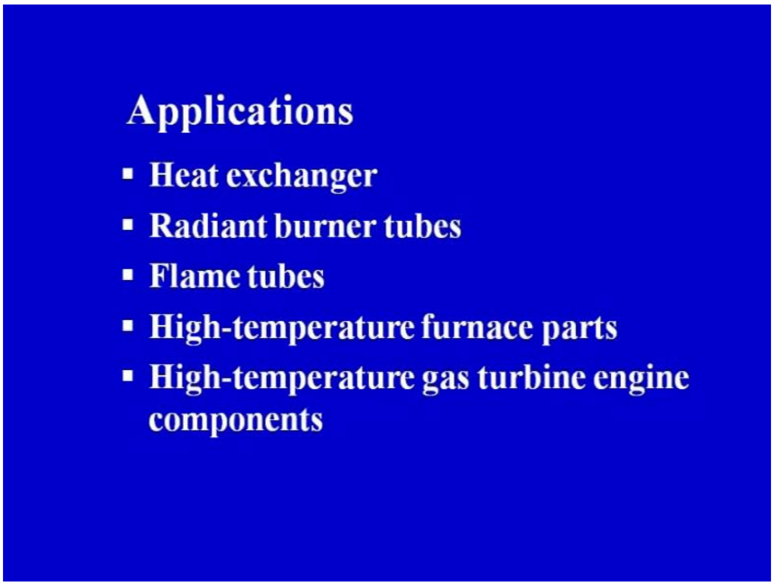

Now, let us come to the applications of this process. The applications are we can see let us let me first read all the applications. This can use for making heat exchangers, radiant burner tubes, flame tubes, high temperature furnace parts, high temperature gas turbine engine components. So, basically, you can see a most of the applications in rather I should say all of the applications are related to high temperature applications. Heat exchanger where the temperature would be very high; radiant burner tubes wherever the burner word comes the temperature is are to be high; flame tubes - flame automatically the temperature is high; high temperature furnace parts, high temperature gas turbine engine component, so this particular slide emphasizes the application of the ceramic matrix composites.

In other process is also that we have seen like powder processing chemical vapor infiltration slurry impregnation and liquid infiltration, all these processes make the parts of the ceramic matrix composite part and all these parts are useful for high temperature applications. That is one of the we can say important application areas for components made by ceramic parts or ceramic composite products. So, basically we can see on this particular slide, the important emphasis or highlight of putting this slide in this presentation is that whatever parts or whatever applications we are suggesting for the composite products made by within the ceramic matrix or the ceramic matrix composite products would certainly find application in high temperature applications or elevated temperature application.

So, whatever product is designed, it has to be designed keeping in mind the final requirement or the final application of that particular product. And most of the products of ceramic matrix composites are finding applications in high temperature regions. So, basically, we can say that whatever processes we have covered are focusing on the high temperature applications only. And therefore, the processes have to be understood with the manner that the product that would be made by these processes would be subjected to elevated temperature. And therefore, the process induced properties should be such that they are able to withstand the high temperature applications, because during the processing also some properties would get change; their would be interface that would be developing between matrix and the reinforcement.

What should be the strength of the interfacial bond between in the matrix and the reinforcement, what are the type of the stress is being develop during the processing which would later on act as we can say failure for under the different types of application. So, processing induced properties are important to understand when the product would be used for specific applications. But our focus primarily in this particularly module is to understand the fundamental aspects that how the raw materials that is the ceramic matrices and the reinforcement are combined together to make a composite product. So, we have been able to discus number of processes.

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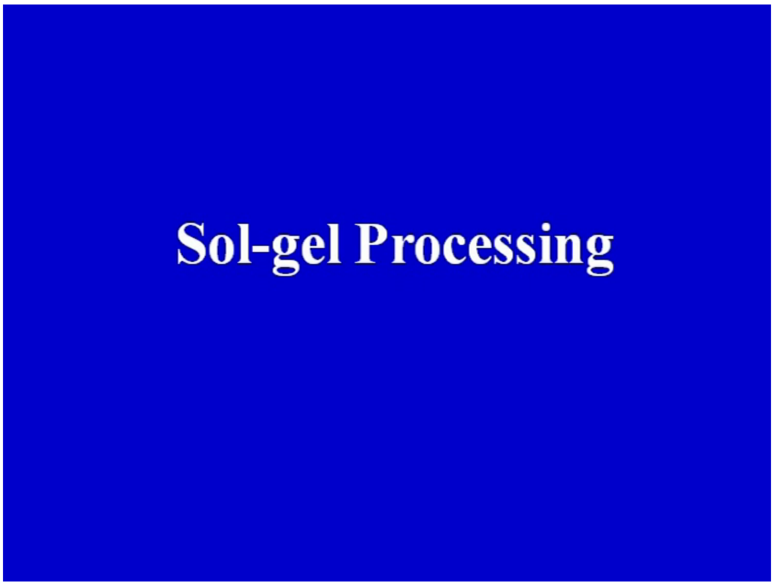

Now we will see the last process for processing of ceramic matrix composites that is the sol-gel processing. We will just see the fundamental of this process or the basic process mechanism, and move on to the last part of this module that is the post processing of ceramic matrix composites. So, let us now quickly see the basic mechanism of the sol-gel processing technique. In this particular technique, very fine particle size or very fine particles are used as the we can say the matrix material. We can have a preform and in that preform we will impregnate or we will infiltrate the matrix material which would finally, under the we can say temperature would form a final or a regular matrix and we will get a composite product. So firstly, from the sol, we will get a gel, and the gel would finally take the shape of the matrix where on solidification.

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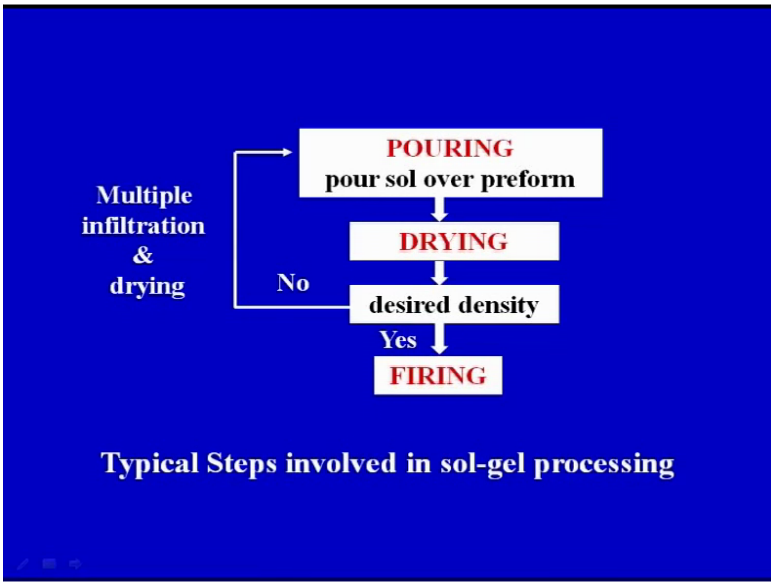

So, let us see with the help of the diagram. Typical steps involved in the sol-gel processing; very simply we have been able to represent. First is the pouring that is the pour the sol over the preform; drying desired density if it has been achieved if it has been achieved then we will go for the next step that is firing; if it has not been achieved, multiple infiltration and drying. So, basically this is process is quite similar to the liquid infiltration process that we have already discussed in our previous lectures in this module only that is module six on ceramic matrix composite.

So, in liquid infiltration process also, we are infiltrating a slurry or a liquid into the preform. The preform is the reinforcement and the liquid that we are infiltrating into the preform acts as the matrix material. And this process is similar to the resin transfer molding process that we have already discussed in the previous module on the processing polymer of matrix composite. So, in this process also, the pouring over the sol, pouring of the sol over the preform that is the first step, and then the drying; drying takes place and finally, if the desired density as been got we will stop and final go finally, go for the next step. And if the desired density has not been got then the multiple infiltrations would be done. So, this is a sol-gel process; the gel would finally solidify to get give us the matrix inside the preform.

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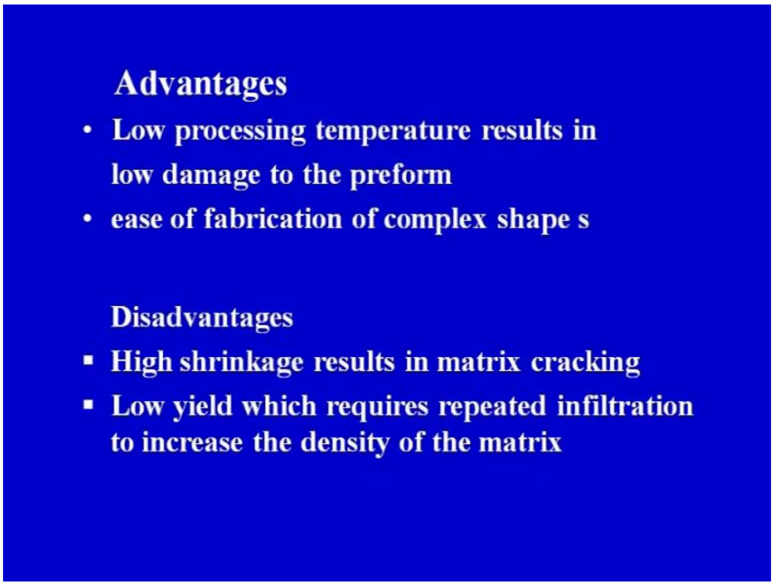

Now, what are the advantages of this process - sol-gel, because I have already told we are not discussing this processing in detail because it it is quite similar in principle to the liquid infiltration process. Where the preform is there, and liquid infiltrate is there, we have understood it with the help of diagram. There is a piston the piston presses the liquid infiltrate the infiltrant goes and fills the open species inside the preform and forms the matrices. Here also if you see the steps involved in the process the major mechanism or the basic mechanism is same, but there are process details which are different in case of sol gel. Because I have told the particle size is very very small in case of sol gel process, and there are other process details, which are different, but the basic mechanism is similar.

So, what are the advantages of this process low processing temperature results in low damage to the preform. So, preform if we dose a complete network of fibers. So, if high temperatures are their, there can be damage that may take place to the preform, but in this particular case low processing temperatures are involved, therefore minimal damage to the preform takes place. Next is a ease of fabrication of complex shapes. So, this particular process can also be use for processing of complex shapes. As we have seen in our previous process today that is directed metal oxidation, we can give a direct shape or a near net shape to the preform and then grow the matrix into the preform to get a final product. So, it limits the post processing of the final product that as been form.

So, in summary, we can say any product which as been made by the directed metal oxidation would require minimum post processing processes, because it is made to a near net shape. Here also in case of sol-gel processing, there are two major advantages advantage number one is the processing temperatures are low, and therefore, the damage two the preform is also is low. And which is very very important, because in the slide that we have seen relate related to the applications of ceramic matrix composite product if you remember we have seen most of the applications are high temperature application.

And their that I have told that the processing related properties should not affect the performance of the ceramic matrix composite product in service. Which means this important point is related to that sentence which I have emphasized again and again, because if the fibers would get damage or the reinforcement would get would get damaged during the processing then when this product with damaged preform or damaged reinforcement would be used in actual application there is hot to be a deterioration in the performance of the product. So, therefore, in this particular process that is sol-gel process in the temperatures involved are less, and therefore, less damage to the preform takes place, and finally, the final product that we will get would be of good quality, and it would be able to perform its desired functions reliably over a period of time. And if we induce or if process related we can say defects are there, or process related deterioration of the properties takes place during the processing then the product that we will get may not be able to perform its desired function reliably at a later stage or over a period of time. Therefore, we have two process the materials in such a way, so that their able to perform there function properly.

So, we have to minimize the damage to the constituents during the processing. And then another advantage is that this particular process can be used for complex parts. Then there are certain disadvantages also which have to be taken care of that is high shrinkage results in matrix cracking. This is also related to the performances of the product at a later stage. If matrix cracking takes place the product may not be of good quality; why, matrix cracking is taking place because of the high shrinkage that takes place during this process. So, this is a one a particular disadvantage high shrinkage leading to the matrix cracking.

Next is low yield which is requires repeated infiltration to increase the density of the matrix as we have seen in the three are four steps which were their in the process that if we are not able to generate the adequate density then we have to do multiple infiltrations and therefore, this process is a slow process. So, the low yield which requires repeated infiltration or multiple infiltration in ordered to increase the density of the matrix. And if we are not able to make a dense matrix the final product may not of the desired mechanical properties. So, therefore, in many cases multiple infiltrations may be required in in ordered to generate a matrix of adequate density. So, these are some of the important disadvantages related to the sol-gel processing technique of ceramic matrix composites.

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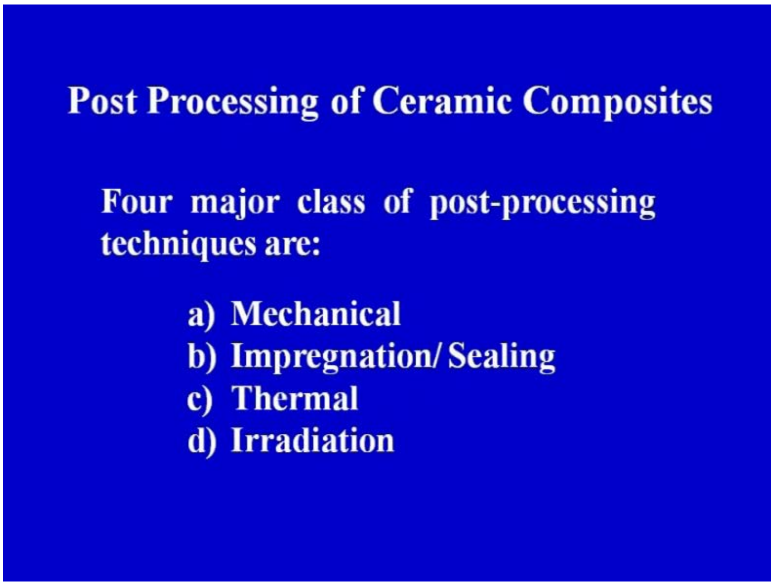

Now, coming on to the major topic for today's lectures that is the post processing of ceramic composites. So, four major class of post processing techniques are there. Let me name all the four; first one is the mechanical; second one as impregnation or scaling; third on is thermal, fourth one is irradiation. So, before going to the examples of these post processing technique, let us first focus on the need of the post processing when we have already processed the composite part. If you see by now we have discussed at least four or five different processing techniques for ceramic matrix composites. To name them, we have seen powder processing, we have seen CVI process, we have seen slurry impregnation process, we have seen liquid infiltration process, we have seen directed metal oxidations and the sol-gel processing. So, all these techniques would give us a ceramic matrix composite product.

Once we have got that product in ordered to make it suitable for a specific engineering application, we may require to do some post processing on that product which has been made by any of the processes which I have just outlined. So, post processing is to give a specific edge to that product for a specific application, but in many cases in we have to go for post processing. But in some of the cases, as we have seen in case of the directed metal oxidation, we get a preform of the desired shape in which the matrix grows and a near-net products is made. So, when the near-net product has been made, which reduces the application of post processing on that product, because already we are getting a near-net product. But in that case also, if there is a specific application for which a product has been made by the directed metal oxidation process, we may still go for some of or any of these processes which are there on your screen. So, in case of directed metal oxidation product also or the product of or the ceramic matrix composite which has been made by the directed metal oxidation process in that case also we may sometimes go for post processing depending upon the final requirements of the product for for which the product has been designed. So, now we will see one by one that what are the various types of post processing techniques which are used for ceramic matrix composites.

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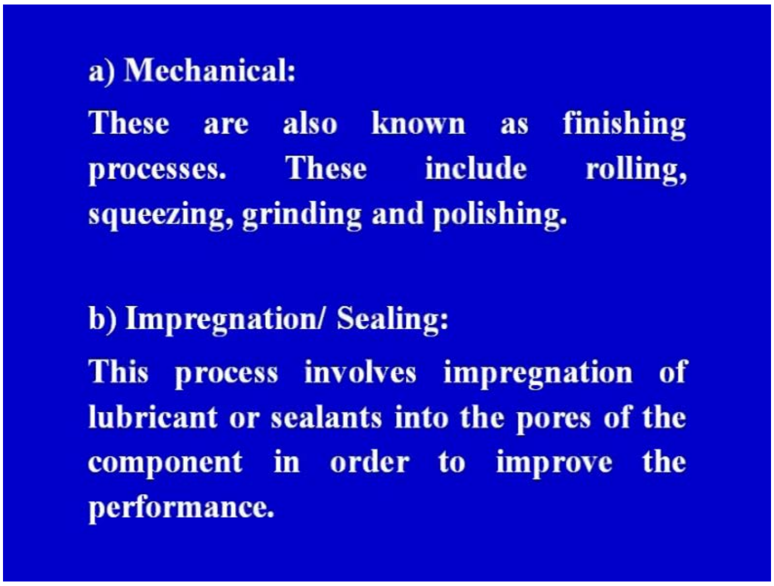

Mechanical - These are also known as finishing processes; these includes rolling, squeezing, grinding and polishing. So, once a ceramic matrix composite product has been made, in order to give it a suitable finish, in order to give it a sometime a required shape, we may go for mechanical type of post processing. So, the some of the examples of the processes that fall under the mechanical type of post processing are squeezing, grinding, polishing and rolling. So, these are four type of processes that fall under the mechanical post processing technique for ceramic matrix composite.

Next one is the impregnation and sealing. This process involves impregnation of lubricants or sealants into the pores of the component in order to improve their performance. So, this is second type of the post processing technique that is impregnation or sealing. In this particular case, all of us know that ceramic matrix composites have certain degree of porosity, and in those pores in many cases, we may like to impregnate the lubricants or the sealants in order to improve the performance of the ceramic matrix composite product. So, first important post processing technique is the mechanical post processing in which we are finishing the final product which has been made by any of the processing techniques for ceramic matrix composite, and sometimes we may do rolling or squeezing also, and finally, grinding and polishing in order to improve the surface finish. So, mechanical post processing can be done. Then impregnation and sealing are the other post processing techniques, which are used example has already been given. The pore can be filled or impregnated with oils or sealants or lubricants in order to improve the performance of the product.

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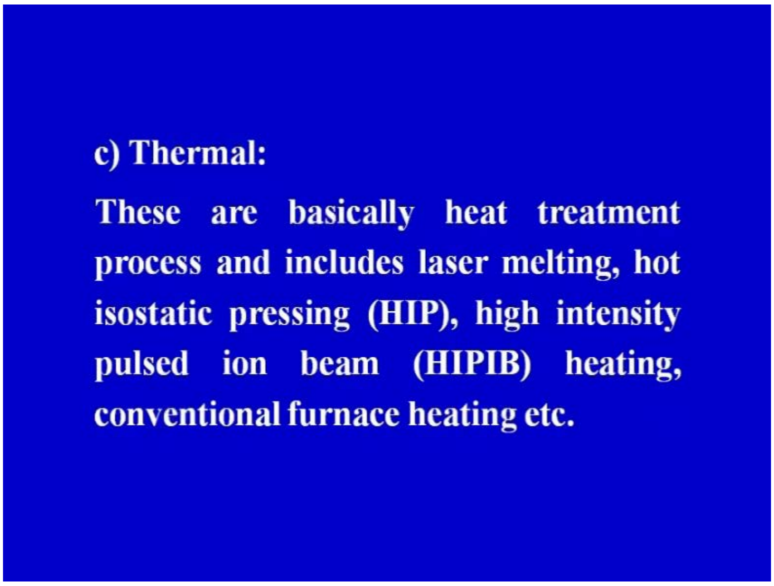

Then we can see the other type of processes like the thermal processes of post processing. These are basically heat treatment processes and includes laser melting, hot isostatic pressing, high intensity pulsed ion beam processing or heating conventional furnace heating. So, sometimes, we may require to heat the ceramic matrix composite product in order to achieve certain important characteristics or properties which are required for application of this particular product in certain specific domain. So, we have seen there are till now three types of post processing techniques - that is first one is mechanical second one is impregnation or sealing third one is thermal. So, thermal also may be required depending upon the specific application. As we have seen the applications of the ceramic matrix composite product in today's lecture, all the applications were related to the high temperature applications.

So, therefore, the thermal post processing of the ceramic matrix composite product become imperative or becomes necessary in order to subject them to a specific working environment. So, thermal post processing is also important. The examples of thermal post processing are given on your screen, you can see it may involve heat treatment, it may heat treatment processes such as laser melting, hot isostatic processing. So, they are basically heat treatment process and includes laser melting, hot isostatic processing then we can have conventional furnace heating and high intensity pulsed ion beam heating. So, basically we are heating the CMC product to get certain desired properties, so that it is applicable for a certain application spectrum.

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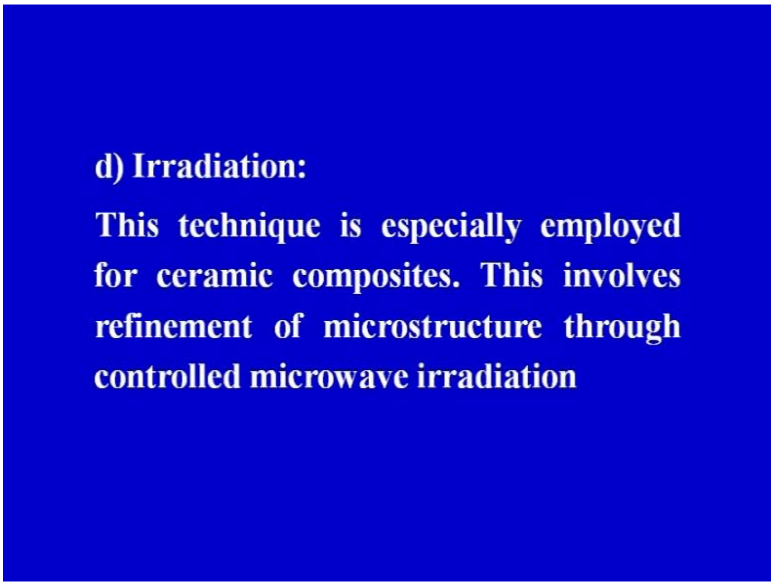

So, finally, we come to the last post processing technique that is irradiation. This technique is especially employed for ceramic composites. This involves refinement of microstructure through the controlled microwave irradiation. So, microwave also is a source of heat. So, in case of microwave irradiation, we are able to improve the properties or the microstructure of many ceramic composite products. So, irradiation is an important technique and which is specifically applied to the ceramic matrix composite products in order to improve certain characteristics of the ceramic matrix composites.

So, with this, we come to the end of our module six. In our final module, that is module number seven our focus would be on the secondary processing techniques for varies types of non metallic materials in which we may see the machining of polymer matrix composite, joining of polymer matrix composites, and in many cases some post processing techniques related to the ceramic products also. So, today we are ending our discussion in module six on the post processing of ceramic matrix composite products and finally, we will start our discussion in module seven with the secondary processing techniques for different types of materials.

So, in today's lecture we have seen the two important techniques for processing of ceramic matrix composite that is the directed metal oxidation and the sol gel processing. But very few fundamental aspects of sol gel processing only we have seen, and also we have seen four important post processing treatments that are given to the ceramic matrix composite products in order to give them certain specific characteristics and properties to make them applicable in certain defined application areas. So, with this we come to the end of module number six; module number six has focused on, the ceramic matrix composites. We have focused on the mechanical properties of the ceramic matrix composite, the fundamental aspects of the ceramic matrix composite, and finally, the processing aspects of the ceramic matrix composite. And we have seen different processes which are used for processing of ceramic matrix composite. And in today's lecture, we have seen some important post processing treatments that are given to the ceramic matrix composite in order to improve their application spectrum.

Thank you.