Processing of non metals

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Module - 6
Ceramic Matrix Composites: Processing
Lecture - 5
Ceramic Matrix Composites: Processing

A very warm welcome to all of you in this lecture on Ceramic Matrix Composites - Processing. As you are well aware that we are discussing in the module number six in our course on processing of non-metals. We have seen different types of materials and the processing techniques for different types of materials, which have non-metallic properties. Now, we are discussing an important aspect of material, which are basically use for high temperature applications that is ceramics, and ceramic matrix composites. So, the basic aspects of ceramics, we have already covered in a previous module and in this particular module our focus has been on ceramic matrix composite.

If you remember in the previous lectures, we have seen that what is the basic philosophy behind developing the ceramic matrix composites, because most of the applications are in met by the monolithic ceramics also. So, why do we need to rein force the monolithic ceramics with different types of reinforcement in ordered to get the ceramic matrix composites that we have already seen in our previous lectures, in this particular module only. We have also compared the metals and the ceramics that metals which important properties, they process and ceramics what are their specific properties, which make them applicable in certain applications. And then, we have seen that there are different types of toughening mechanisms in ceramic matrix composite. Our focus has been on the basic aspects or the fundamental aspects of ceramic matrix composites, and also we have seen mechanical properties of the ceramic matrix composites.

So, as our focus is on the processing aspects in this particular course that is processing of non-metals. We have seen some of the important processing techniques, which are used for processing of ceramic matrix component. We have seen the powder processing technique, and in the previous lecture we have seen an important technique which are used in which a vapors or the gaseous reactants are used to process the matrix material and a preform is used as the reinforcement and the process was called as CVI process

that is chemical vapor infiltration. So, CVI process the details we have seen that how the process actually takes place, where the preform is kept what is the basic construction detail of the reactor that we have seen in that lecture. And also we have seen a modified CVI process in which the gaseous reactant are forced through the preform and a temperature gradient is establish and the preform basically has a top layer and bottom layer. Basically the total preform can be divide into hypothetically into two zones; one is a heated zone which is closed to the heating chamber and then there is a cold zone which is away from the heating chamber.

And we have seen that the reaction or the deposition of the solid matrix takes place near to the heating chamber, and then this particular deposition travels from top to the bottom. Why, because a thermal conductivity increases of the preform and the porosity decreases? The porosity decreases it means that the deposition is taking place in the vacant spaces all around the reinforcement. So, basically we have seen that there is a modified CVI process, which is used for processing of ceramic matrix composites; in which, we have a forced flow of the gaseous reactants and a temperature gradient is establish. Two important points to note in the contexts of the preform is the thermal conductivity of the perform and the temperature gradient in the preform, as well as the change in the porosity of the preform, so that was the end of our previous lecture of CVI.

And today we are going to see certain other processing techniques which are used for processing of ceramic matrix composites. So basically the idea of giving this introduction was that in case of ceramic matrix composite; our main aim is to combine the two thinks together. Now what are these two thinks or these two constituents that make up the ceramic matrix composites that we have already seen in previous lectures, but sometimes there is a audience which is new and in only interested in certain important lecture only. So, basically to give you a overview of a ceramic matrix composite, we can classify a composite material on the basis of the matrix and we can have a polymer matrix composite we can have a metal matrix composite and we can have a ceramic matrix composite. At this particular module, we focused on ceramic matrix composite. So, from the name itself, we can see that the matrix material here is a ceramic material.

So, basically we have a matrix which is a ceramic, and we have a reinforcement which can be any type of a fiber. So, it can also be made up of ceramics fiber, the reinforcement

can also be a ceramic, the matrix can also be a ceramic and we will get a composite of a reinforcement and the matrix which in this particular case would be a ceramic matrix composite. So, in CVI process, we have seen in previous lecture that how the reinforcement and the matrix are combined together to get a composite material specifically the ceramic matrix composite material.

And today, we will see few important techniques like slurry impregnation and liquid infiltration. Two important process is we are we are going to study today with the help of diagrams will try to understand that how the two thinks the matrix and the reinforcement are combined together to get a composite materials. So our focus today would be the liquid infiltration and the slurry impregnation. If you remember, we have seen two important techniques in our previous lectures - that is powder processing and the chemical vapor infiltration. So, in both the process is you see, the reinforcement was in the solid form only; in powder process in the reinforcement was solid powder; in case of CVI, the reinforcement was in the form of a fibrous preform or a substrate.

But today, we will see that the reinforcement in today's case would also be a solid, but the matrix would be infiltrated which means that it would be in a liquid form and that is the difference between the process is that we are going to see today, and the process is which we have already covered in our previous lectures that is the CVI process and the powder processing. So, in powder processing, the reinforcement and the matrix both were solid; they were powders. In CVI process, the reinforcement was solid in the form of preform and the gaseous reactor would pass through the preform and the solid matrix was deposited because of the reaction taking place. As a reaction for what it was deposited on the fibers we have also seen that how the diameter of the fiber increases were the when the gaseous reactants pass through the preform.

And in today's lecture, our focus is on the infiltration of the liquids of the matrix would be in the form of a liquid and this matrix would go and fill the preform. And finally, we will get a composite material; in which we have the reinforcement and the matrix. The matrix is in this case infiltrating into the fiber preform. So, we will see two important process is today one is a slurry impregnation, and another one is a liquid infiltration as I have already told in the beginning of today's lecture.

So, with this particular introduction, let us now start our discussion on the processing aspects of ceramic matrix composite. So, the first process is on your screen that is slurry impregnation. So, we have seen that we can combine the matrix and the reinforcement together to get a composite material. So, in today's lecture, we will try to first understand the basic aspects of slurry impregnation and then we will try to understand the basic process that how the process takes place, and how a composite is got or a composite is fabricated or a composite is processed. Now let us see the fundamental aspects of slurry impregnation technique for processing of ceramic matrix composites.

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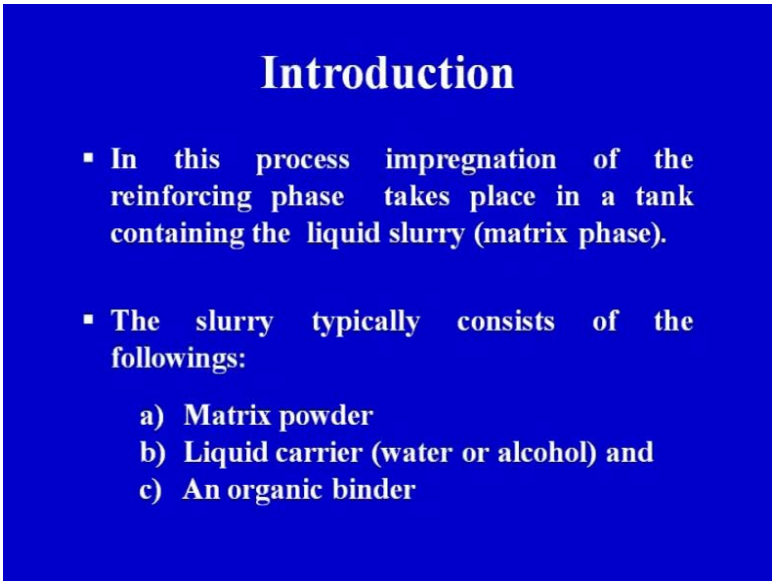

So, on your screen, we see the introduction of slurry impregnation. In this process, impregnation of the reinforcing phase takes place in a tank containing the liquid slurry. So basically, two important words in this sentence you can see reinforcement and the matrix; these two thinks we have to combine together to get a composite material. So, in this process, the impregnation of the reinforcing phase, so the reinforcing phase in this particular case would also be a solid; it can be a layer of solid wires or it can be a network of solid wires which would be impregnated through a liquid. So, a slurry containing the matrix is there in a tank, and this particular network of fiber or the area of fiber pass through the slurry tank and gets impregnated. So, the matrix would be deposited all around the fibers. So, in first important point in this process, impregnation of reinforcing phase and I have taken the example of the fibers. So, reinforcing phase can be fibers. So, fibers takes places in tank containing the liquid slurry. So, there is a tank

which contains the slurry. What are the constituents of the slurry that we are going to see now and this slurry contains the matrix phase. So, reinforcement is coming and in the resin that is getting dip and it is taking a matrix phase from the liquid slurry that is present in the resin tank.

So, basically the slurry typically consists of the following. So, we can see it can be a matrix the three important ingredients of the slurry would be matrix powder, liquid carrier, and an organic binder. So, the most important part or the most important ingredient is the part number A that is matrix powder. So, basically, we have to combine the reinforcing phase with the matrix powder and then we have to generate a composite material, but the other two thinks that to the liquid carrier and an organic binder or also required and they have got specific purposes. So, basically, there are three important thinks in the liquid slurry, and these are the matrix powder, the liquid carrier and an organic bound binder which would later on be removed during the process. So, binder and carrier would be removed and only the matrix powder and reinforcing phase would be combined together to get a ceramic matrix composite.

If you remember in one of our previous modules on polymer matrix composite, we have seen a process which was called as resin transfer molding, and we have seen a process which is called as filament winding. So, in filament winding, if you see if you remember the fibers are coming and they are getting impregnated in the resin tank. So, the polymer is kept in the resin tank and the fibers are coming from the fibers pool and they are getting wet or impregnated in the resin tank. So, in this filament winding process we are this process in case of ceramic matrix composites is quite similar to the filament winding process that we have seen. And the second process that I have told in the very beginning today that is the liquid infiltration is quite similar to the other process I have just named for polymer matrix compose that is the resin transfer molding. So, basic mechanism is to combine the resin and the reinforcement together.

So, basically today's two process is that we are going to discuss that is process number one that we are seen is slurry impregnation; process number two that we are going to study today is liquid in filtration. So, process number one in today's class that is slurry impregnation is quite similar to the filament winding process; in which the fibers are coming and getting wet inside the resin tank. And the process number two that is liquid infiltration that we are going to study in the subsequent slide is similar to the resin

transfer molding. So, basically the mechanism in all the process is that we are using for processing of non-metals is same specifically when we talk about the composite materials, because in composites our main aim is to combine the reinforcing and the matrix phase together and the basic methodology can be same, the materials can be different. So, it is important to understand that what are the important tools and technique which are used for combining the two phase together.

So, here we can see that we have a reinforcing phase which we are impregnating with the liquid slurry. The slurry is contained inner tank and when this will get impregnated we will have a matrix powder all around the reinforcing phase and there are subsequent others steps which have to be followed in ordered to get a ceramic matrix composite. But at this point, it was important because there can be a confusion that the same think is happening in case of polymer matrix composites also in filament winding. So, we should try to distinguish the two thinks together, although the process mechanism is same, but there is a difference in the types of material then the type of processing conditions that are subjected to when the process is taking place.

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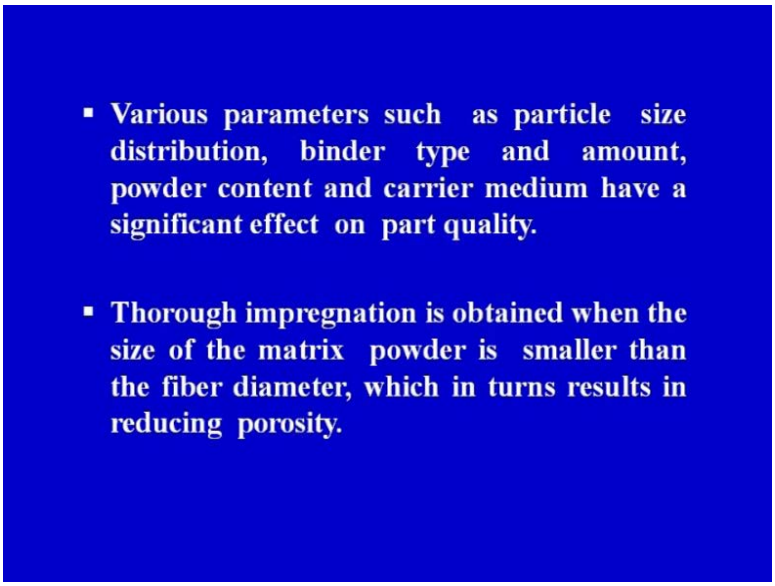

Various parameters as I have already told are different in the processes that use for the polymer composites and the processes that are used for ceramic matrix composite. So, the various parameters such as the particle size distribution, because the matrix powder is present inside the slurry. So, what is the size the distribution of the size, there can be

some particles which can be larger in size, there can be some particles which are smaller in size. So, the particle size distribution is one parameter. Binder type and amount, as we have seen that they are three important ingredients in the slurry so, the binder type and amount is also important. What should be the type of the binder, what should be the amount of binder in slurry. Then the powder content, the amount of powder that we have to put inside the slurry is also important. Carrier medium, the carrier medium that we are using in the slurry that is also important. All this have an effect on the part quality. Part quality basically is the ceramic matrix composite part that we are producing that is the quality of part that we are producing using the slurry impregnations process through the quality of that part depends upon all this parameters.

Now, let me just revise because there are two thinks that we combining together. So, there is not much that we are controlling on the reinforcing side because the reinforcement is coming and it is getting impregnated inside the slurry. So, the slurry is an important part that we are we can manipulate and what do important thinks can be manipulate it, what do important thinks can be controlled that is given in part number one. That we can control the particle size distribution, we can control the binder type and amount we can control the powder content and we can control the carrier medium. So, all these things, we can control and when we can control all these things we can control the quality of the part that we are manufacturing.

So, it is important depending upon the specific requirements for which we are making the ceramic matrix composites, we have to choose all these important points very very carefully. So, all this important operating conditions have to be chosen very carefully or the operating variables have to be chosen very carefully. So, thorough impregnation is obtained, so this is one important guideline that is thorough impregnation is obtained when the size of the matrix. So, size of the matrix because the matrix in this case is in the form of the powder. So, the size of the matrix is the size of the matrix powder. So, the thorough impregnation is obtained, when the size of the matrix powder is smaller than the fiber diameter. So, this has been established as one of the important points and is available in the literature which in turn results in reducing porosity. So, the important point to note here is that the size of the matrix powder should be smaller than the fiber diameter. So, this is important and this result in reducing the porosity.

Basically, we want in certain cases we required the porosity in CMC products, but in many cases we may not be requiring the porosity and we want to control the porosity, we want to have a very dense product. So, therefore, some times when we have to control the porosity, we can very easily follow this guideline. So, I am again reading the guidelines for you that guideline is that thorough impregnation is obtained when the size of the matrix powder is smaller than the fiber diameter. So, we in this case the reinforcement that we are using is in the form of fibers, and this results in reducing the porosity. So, this is a specific case in which a reinforcement is in the form of the long fibers and the size of the particle or the matrix powder should be smaller than the diameter of the fiber. So, this is important guideline which as to be kept in mind.

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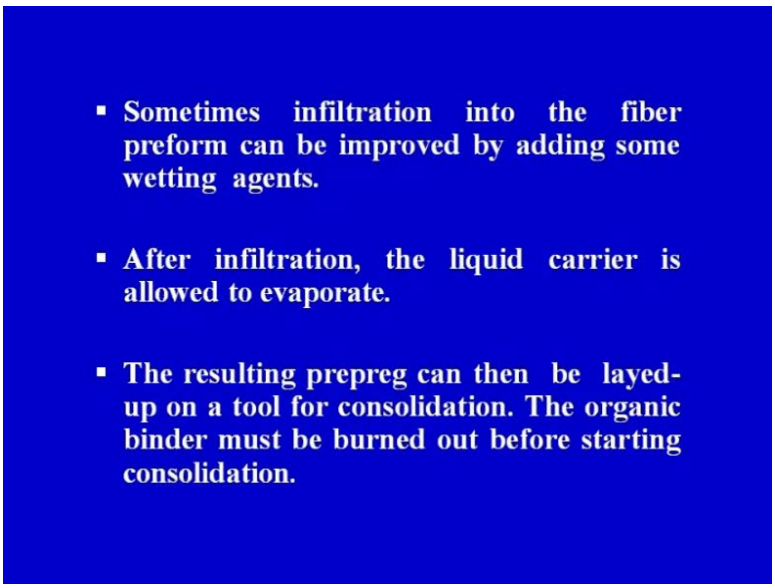

Next important point that is infiltration into the fiber preform can be improved by adding some wetting agents. So, in many cases, certain wetting agents may be used, so that the infiltration or the impregnation is better. So, in this particular case, we can use different types of wetting agents. After infiltration the liquid carrier is allowed to evaporate. So, as I have already told there is a carrier, there is a binder and there is a matrix powder. So, matrix powder finally, has to form the matrix phase in the ceramic matrix composite. So, the matrix powder is one think that will remain; the other two thinks that is a carrier medium and the binder as to go during the process.

So, in this particular points - second point on your screen, the liquid carrier is a allowed to evaporate. So, the carrier will be later on when the we can say we have already passed the reinforcement through the liquid slurry and we have been able to get our prepreg or the preform, we would allow the carrier to evaporate. The resulting prepreg that I have already told, the resulting prepreg can then be layered up on to a tool for consolidation. So, depending upon the final shape that we want we will design tool and on that tool we will us this prepreg that we have got. Now what is a prepreg basically?

Because this is a new term that is coming in this particular module; otherwise prepreging we have already seen in our lecture in polymer matrix composes in that particular module we have seen what is prepreging. So, prepreging as already been discussed, but since, it is coming in this particular lecture prepreg basically is now a combination of the fibrous reinforcement and the slurry which as been carried by the fibrous reinforcement. So, the two thinks have combined together, the fibers and the liquid slurry. The slurry and the fibers when they have been combine together, they have solidified, it is called a prepreg. Now this particular prepreg would be further used for making the ceramic matrix composite products. So, important point is that we should understand what is a prepreg.

So, the resulting prepreg can then be layed up; layed up means we can stack up one layer on top of another layer, and another one top of another layer and one top of another depending upon the thickness that we want for the ceramic matrix composite product, we will lay up adequate number of layers of prepregs. And we will design a tool depending upon the final shape of the product that we want. The organic binder must be burnt out before starting the consolidation. So, the second point is clear that the liquid carrier as already evaporated, the binder also must be we can say removed. So, the binder must be burned out before starting the consolidation process. So, only now after the burning out of the binder, the thinks that would remain would be the matrix powder and the reinforcing fiber. So, we have a matrix powder and the reinforcing fiber and these we will consolidate and we will get our final product.

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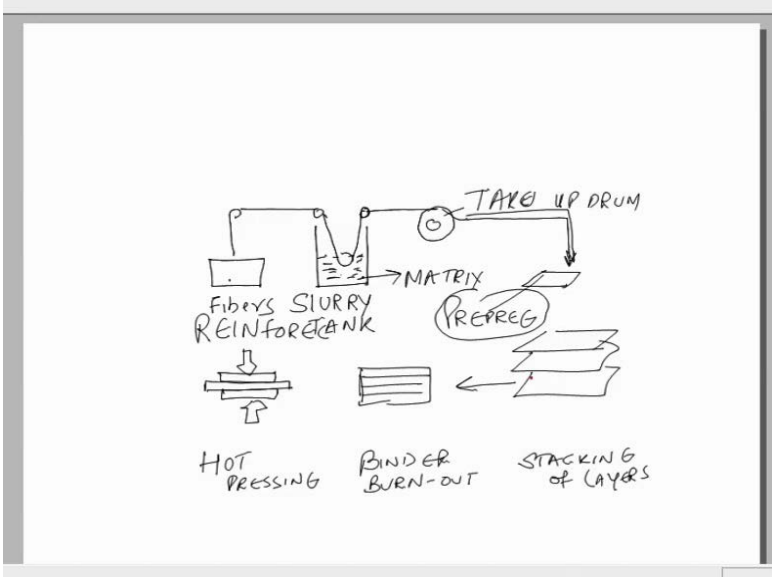

So, now let us try to understand this particular phenomenon, this particular process with the help of a very simple diagram. So on your screen, you can see, this is we can say the fibers. The fibers are coming, this is not an individual fiber, this is we can say a bundle of fibers or network of fiber or a layer of fiber that is coming. Now this is our slurry tank. So, we already know that what is there in the slurry tank, there is a matrix powder a binder and the carrier medium. So, this our slurry tank, we can say it is filled up to this point, this is a slurry tank. And from the slurry tank now this impregnated fiber network is coming and we get a layer and this layer we can call as the prepreg.

So, what is basically a prepreg? A prepreg basically is a combination of reinforcement. So, this is fibers, we have written. This is acting as a reinforcement, and this particular we can say a slurry is acting as a matrix. So, we have a reinforcement in the form of fibers, we have a matrix in the form of slurry, and when these fibers get impregnated through the slurry tank, and they take up we can take a we can use a take up drum this can be called as a take up drum. So, we have a take up drum. So, this will prepreg will get wound over the take up drum.

So, basically the process is very very simple. We have a net, we we can have a layer of fibers that is coming. These layer of fibers can be made up of any material, the fibers can be of any material depending up on the type of the composite that these can be ceramic fibers also. So, these fibers are coming, the fibers are getting impregnated in the slurry

tank; and after getting impregnated, they are taken up by the take up drum. From the take up drum, we take them and we make a different layer. So, we have got one prepreg layer; we can stack up different layers together. And we can consolidate them, we can take different layers and then we can consolidate them layer by layer into we can say a composite material.

So, basically when we can solve, we can make a different layers together, and finally we can apply the pressure. This is suppose our composite material, and when we apply the pressure on this part will be able to generate a composite material. So, this particular process is called hot pressing. And at this stage, we have the binder burn out which I have already told. And this we can say, this is the stacking of layers and this is a individual prepreg that we have already seen, this is a prepreg.

So, again let us see what is the process like. In this, we have fibers, which act as a reinforcing phase. The fibers move and they are impregnated by the slurry, which is kept in the slurry tank. The ingredients of the slurry all of us know now. After getting impregnated the fibers and the matrix, it is it forms a prepreg, and it is taken up by the take up drum. From the take up drum, we take out the prepreg and we cut it into the desired size - that is a length and the breadth. So, desired size is cut are the tapes are made of desired size and once the desired size tapes are made they are stacked up depending up on the final thickness of the product. And once they are stacked up the binder burn out takes place the binder as to be removed. And finally, the hot pressing is done to consolidate the ceramic matrix composite product. So, this is the simple process of slurry impregnation for making the ceramic matrix composite.

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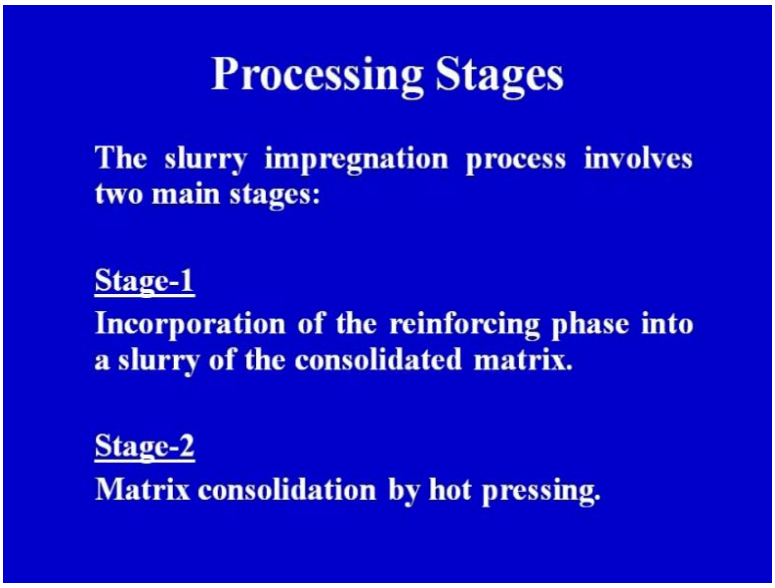

So, let us see a diagram for this particular process. So, before going to the diagram, let us see that what are the important processing stages. So, slurry impregnation process involves two main stages is as we have seen in the diagram. Stage one - the incorporation of the reinforcing phase into a slurry of the consolidated matrix. So, basically we have to combine the two thinks together that is the reinforcing phase and the matrix phase. So, in the initial two three steps when the fibers are coming and getting impregnated in the slurry tank. And then this combination of reinforcing phase and the slurry are taken by the take up roll and a prepreg is formed - that is of stage one in which the incorporation of the upon reinforcing phase into the slurry of consolidated matrix is taking place.

And after that when we are cutting the prepreg depending upon the final dimensions of our product, we are stacking up the different layer and finally, the hot pressing is done that falls under the stage two - that is the matrix consolidation by hot pressing. So, we are cutting the prepreg stacking up the different layer of the prepreg together and finally, doing the hot pressing, so that is the stage two.

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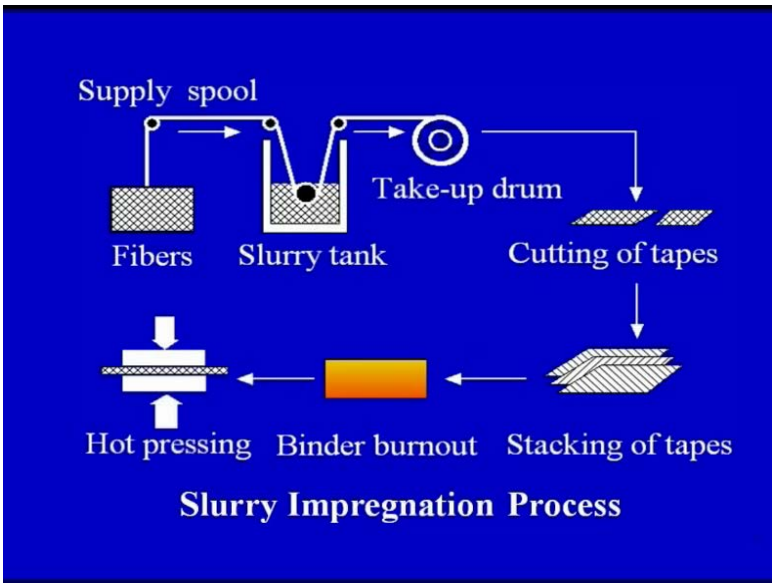

Now, let us again see which are this stage one and stage two with the help of the diagram. On your screen, you can see this diagram, already I have drawn, just a revision of the slurry impregnation process. These are the fibers, this is the supply spool through which the fibers are coming, this is a slurry tank, which contains the matrix powder the binder as well as the carrier medium, so we have a slurry tank. Through this slurry tank, prepregs are formed which are taken up by the take up drum or the take up roll. So, here we have form the prepregs and this prepregs are now taken and the cutting of the tapes takes place, different tapes are cut depending upon the desired thickness of the final product. And finally, stacking of that tapes takes place, different layers are stacked up together. Finally, the binder burnout, the binder is removed and the last process is the hot pressing, this is the composite that we are forming that that is the hot pressing of the composite layers.

So, basically we are now farming a ceramic matrix composite. So, here we are having the fibers and the matrix powder, it has been combined together to make a composite material. So, this is a, we can say important process for processing of ceramic matrix composite materials. So, each process we will have certain limitation and certain advantages. So, now we will try to see that what are the important advantages and limitations of the slurry impregnation process. By now, we have understood that what are the basic process details of the slurry impregnation process, what is the reinforcing phase, what is the matrix phase, how the matrix phase is incorporated with the

reinforcing phase, what are the important step that are that have to be followed in order to make a ceramic matrix composites by the slurry impregnation process all that we already seen.

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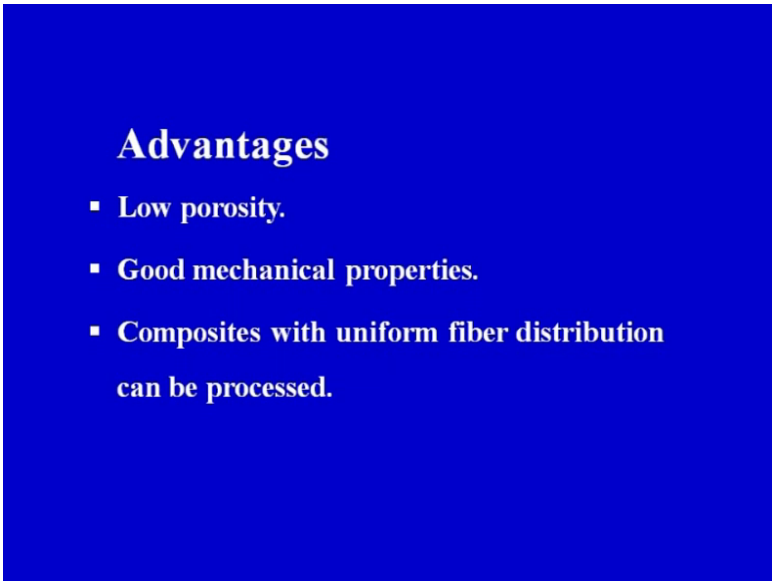

Now, let us see that what are the important advantages and limitations. So, on your screen, you can see the advantages of the process. First is in these particular case, we will get low porosity. So, in other cases that we have already seen the processes which we have already discuss that is the first process that we have seen was the powder processing, the second process was CVI process. So, in those cases, in certain cases, we get high values of porosity, but in this particular case because of the pressing and because of the solid reinforcement or the fibers reinforcement, we are getting low porosity. Because continues fibers can be used as reinforcing agents in this particular process which was not possible in some of the earlier process like powder processing one of the important points was that we can use a discontinuous type of reinforcement. Whereas in case of slurry impregnation, we can use continuous type of reinforcement or continuous fiber reinforcement that is one of the reasons that we get low porosity in case of ceramic metals composites formed by the slurry impregnation process.

Then the mechanical properties would be good why because already we have discuss that we are using continuous fiber reinforcement and when have continuous fibers in the reinforcement, the mechanical properties would be better as compared to the

discontinuously reinforced matrix material. Third important advantage is the composites with uniform fiber distribution can be processed, because a continuous well arranged network of fibers is being used as the reinforcement, therefore the uniform fiber distribution can be processed. If we use the discontinuous fibers as the reinforcement in many cases we may not be able to get the uniform distribution of the fibers which may in many cases lead to failure of the components. So, in this particular case, since continuous fibers we are using, therefore the uniform fiber distribution is one of the advantages that we can achieve.

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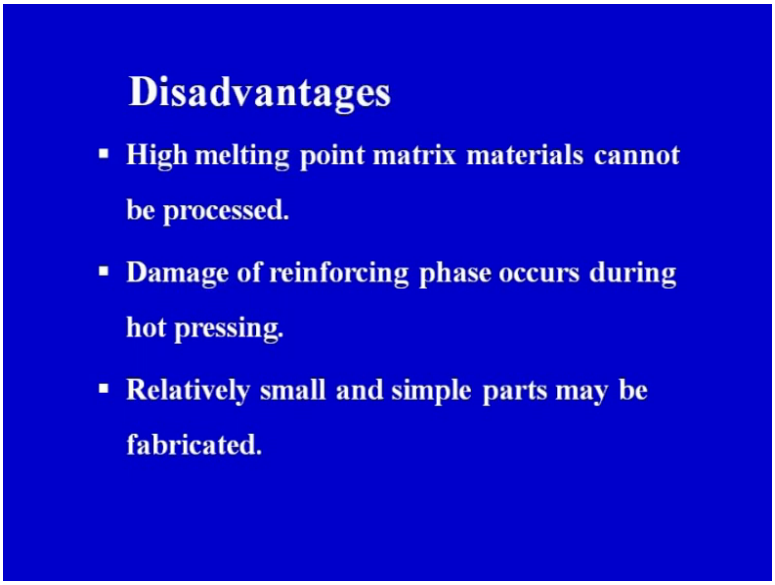

Now, let us see what can be the disadvantages of the process. One of the major disadvantages on your screen you can see high melting point matrix materials cannot be processed. Because you can see the matrix in this case is in the slurry. So, we need to increase the temperature to a higher level in order to formulate that slurry also. So, the high melting point matrix material cannot be processed - that is one disadvantage. Damage of reinforcing phase occurs during hot pressing when we are applying the pressure, if you remember in the previous slide we have seen that the carrier is have already evaporated, the binder has been burned out. And now we are pressing the ceramic powder that is the matrix powder and the reinforcing phase together in the hot pressing stage. So, where are chances that the damage of the reinforcing phase may take place during the hot pressing or in other words in the example that we have taken the damage of the fibers may take place because we have taken the example of the fibers has

the reinforcing phase. So, the damage of the fibers may take place during the hot pressing.

Next point on your screen is the relatively small and simple parts can be fabricated. So, you can see the last stage of the processing techniques is the hot pressing, and hot pressing in order to get a uniform pressure we can we need to design the products or design the parts which are made by slurry impregnation process which are simpler in nature. So, if parts are very very complex, or the parts are a very large size then the pressure requirements would also increase for large size parts. So, relatively small and simple parts can be fabricated using this particular process. So, basically we can see that there are many advantages on the process, but there are certain limitations also which have to be overcome in order to make this process more versatile and more applicable specifically in case of ceramic matrix composites.

So, till now let us see what we have covered we have just taken a introduction of today's lecture. Then we have see one of the important processing techniques, which is used for ceramic matrix composites that is slurry impregnation. And in slurry impregnation, we have try to understand the fundamental aspects, we have seen that what is a slurry, what are the important constituents of the slurry. And then with the help of the diagram, we have try to understand the process details that how the process actually takes place, I have drawn a diagram and that we have seen and that what are the important stages of the process of slurry impregnation. Now, we will see the second process that is liquid in filtration. And try to understand that what are the process details in liquid in filtration. As I have already told if you remember in today's lecture itself that liquid in filtration is quite similar to the resin transfer molding process that is use for processing of polymer matrix composite. So, the basic principle is seen, but the materials that we are processing is different.

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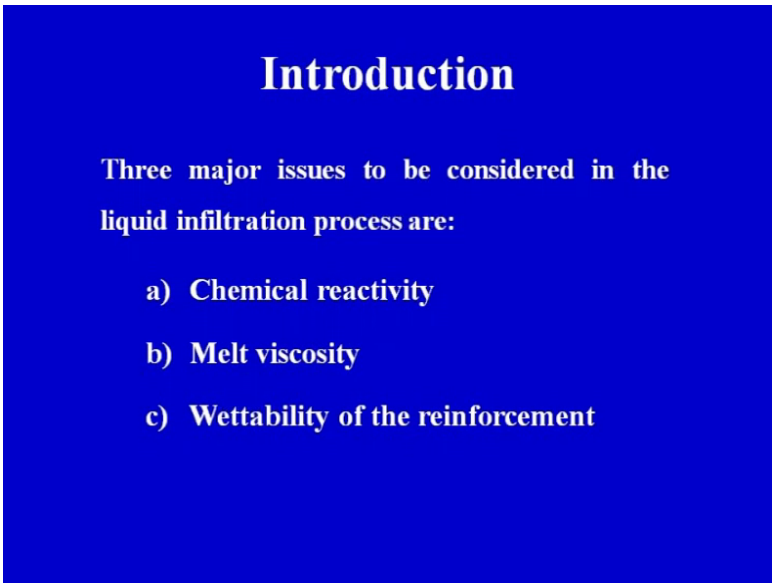

Let us now try to see the process of liquid infiltration. So, in liquid infiltration, we will try to understand it with the help of a diagram, but the major issues that are involved in liquid infiltration are first one is the chemical reactivity. We will try to understand this what do we mean by chemical reactivity, but let me first outline all the important points. Second is the melt viscosity and last is the wettability of the reinforcement. If you remember in the slurry impregnation process, we have seen that sometimes wetting agents are also added in order to improve the interfacial properties of the reinforcement and the matrix.

So, basically important point to note here is issues involved in liquid infiltration process, now let us address these issues one by one. So, the first issues is of the chemical reactivity. So the chemical reactivity means as we will see that this is done at a elevated temperature, the process temperature is higher or a process is done at an elevated temperature. So at that particular temperature, there are chances that the reinforcing phase and the matrix phase may react and there can be some unnecessary reaction that may takes place which may not result into the proper bonding of the reinforcement and the matrix and may lead to the failure of the product made by this particular process. So, one important point is the chemical reactivity between the reinforcing phase and the matrix phase at the elevated temperature.

Second point is the melt viscosity. So, we will see the melt viscosity of the ceramics is quite high as compare to that for that of metals, and therefore, it may so happen that the ceramic infiltrate may not be able to properly make a matrix inside the fibers preform or the ceramic preform. So, in this particular case also, we will have a preform and the liquid matrix would try to impregnate or would be force to impregnate the preform, but because of a very high melt viscosity, there are chance that the problem may arise.

And the last point of the wet ability of the reinforcement. In many cases, the infiltrant may not be able to properly wet the reinforcement. When the infiltrant is not able to wet the reinforcement, the bonding between the reinforcing phase and matrix may not be proper, and may lead to the failure of the product at the interface of the reinforcement and the matrix. So, these are the three important points that have to be taken into account that is the chemical reactivity between the two phases, melt viscosity of the infiltrant, and the wetability of the reinforcement that certain times we may be require to add certain wetting agents also in order to improve the wetability of the reinforcement.

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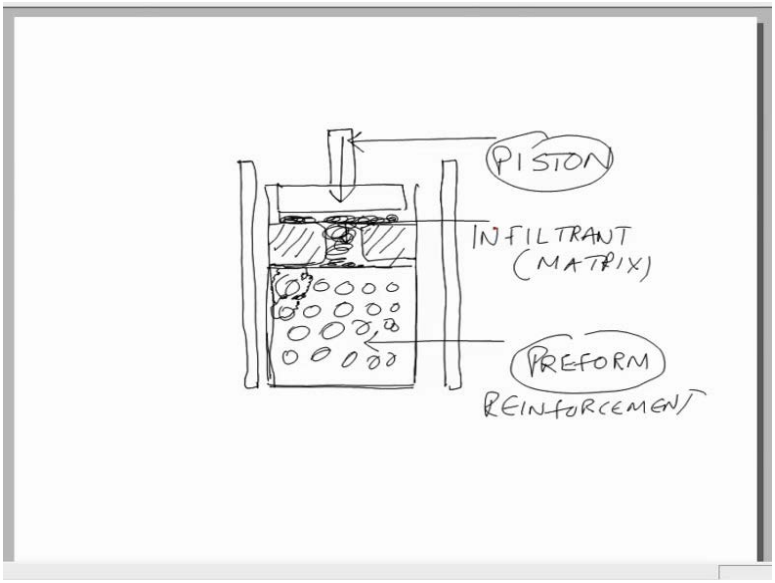

Now, let us try to understand this particular process with the help of a simple diagram. The process is very simple. On your screen, you can see, there are heating coils which are used to generate the heat. This is one heating coil then we have another heating coil; these are a two heating coils and inside we have kept a preform. This is a preform, we have the heating coils and then we have a infiltrant. This is the passage through which

the infiltrant will come. Now, we have to applied the pressure also, so that infiltrant flows into the preform now that purpose we have a piston. So, this piston will apply the pressure. So, we have a closed chamber in which the reaction is taking place and here we have this is our the thing I am drawing here is our liquid infiltrant. So, this is a liquid in filtrant these are two guides we can say. So, the liquid in filtrate when a pressure is applied on the piston the liquid infiltrant would be pressed and it would go and this is our we can say preform of fibers or raw network of fibers. And in this particular network, the we can say the infiltrant will come, let me write this our infiltrant, the infiltrant will come and it will fill the gaps inside the we can say on our screen, you can see it will fill the gap all around the fibers and it will we can say form a matrix space.

So, basically what is happening, we have infiltrant which is here liquid and then we have reinforcement which is in the form of a network of fibers. And when the pressure is applied, this infiltants infiltrates into the preform and in this particular preform it occupies the species which are there between the fibers and forms the matrix space. So, basically in all the processes that we are using for making of polymer composites or ceramic composites or any form of a composites material, our major aim is to combined the reinforcement and the fibers together. So, here the reinforcement is in the form of preform which is kept on yours you can see the reinforcement this is the reinforcement and the matrix is the infiltrant. So, we have a reinforcement, the matrix in the liquid form, it is pressed from with the help of the piston. The piston presses the infiltrant into the preform and it occupies the vacant spaces inside the preform and excess the matrix space. So, this is any simple process, but it has also got certain advantages and disadvantages that we are going to see now.

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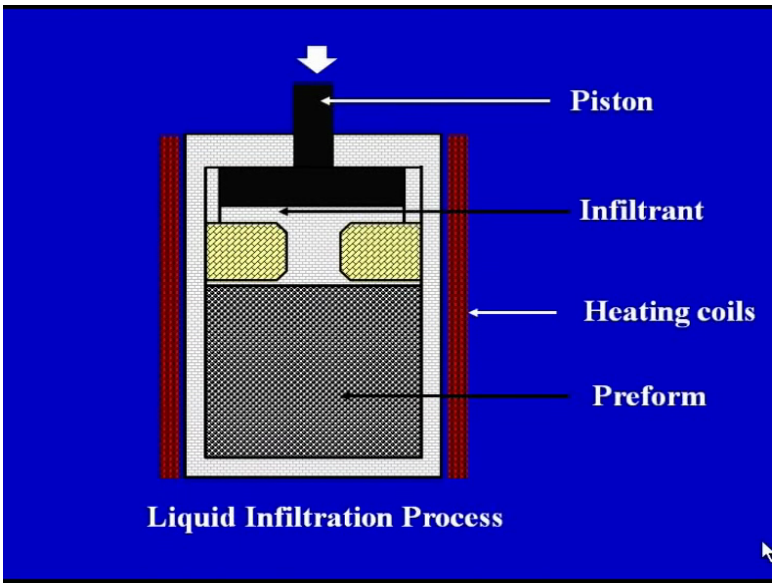

Let us first try to understand this with the help of a diagram. On your screen, you can see a very simple diagram. As I have already drawn we have a piston, a pressure is a applied on the piston this is a infiltrant with the help of this arrow it has been showed - infiltrant now. This infiltrant when the pressure would be applied on the piston this infiltrant would travel and fill the preform. So, preform is basically a network or a array of fibers which has been made together depending upon the design of the final product and this particular process is called the liquid infiltration process. So, the process is purely simple and here we have the two red columns indicate the heating coils, the process take place at elevated temperature.

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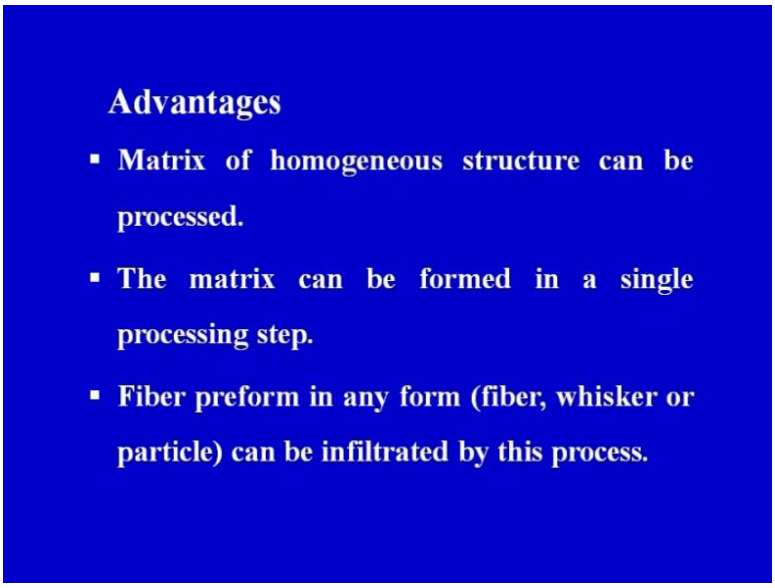

Now, let us try to understand that what are the advantages of liquid in filtration process. So, major advantages is the matrix of homogeneous structure can be processed. So, if we are seen in the previous process that the matrix powder was combined with the carrier medium, it was combined with the binder, but in this particular case some matrix of homogeneous structure can be processed. The matrix can be formed in a single processing step. In previous example or in previous process, we have seen that is slurry impregnation, there are number of steps involved, but in this particular case the matrix can be formed in a single processing step.

Another advantage is the fiber preform in any form here we can use a preform in the form of fiber, whisker or particle can be infiltrated by this process. Whereas in our previous process that we have covered today that is slurry impregnation, we have seen that continuous fiber reinforcement is used, but here the fiber preform can be in the form of fibers, short long whiskers or particles and that can be infiltrated through the matrix material.

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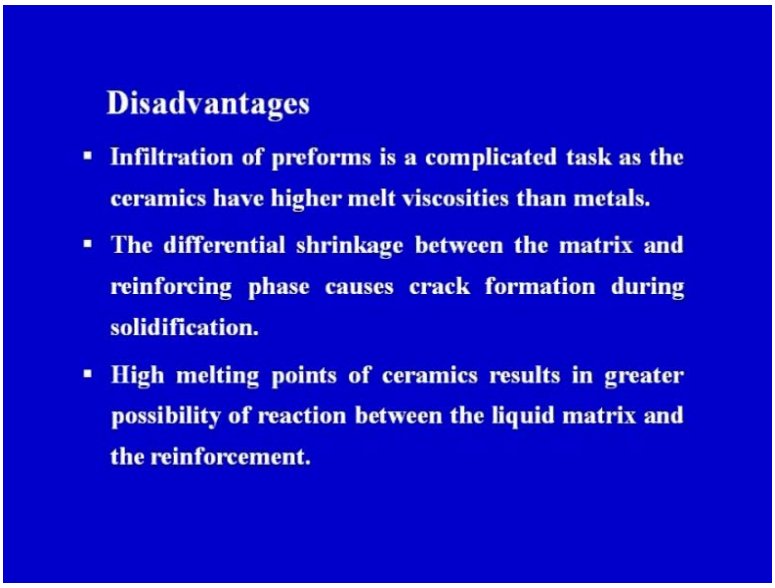

Now, what are the disadvantages? The disadvantages are the infiltration of preform is a complicated task as a ceramics have high melt viscosities than metal. Already I have told in the introductory slide to this particular process that chemical reactivity, melt viscosity these are important issues that have to be looked into. So, that is important point one of the disadvantage that the melt viscosity of ceramics have are higher as compare to that for metal. So, the infiltration of preform is sometime complicated. The differential shrinkage between the matrix and the reinforcing phase causes crack propagation during solidification. So, the shrinkage would be different, there are two phase is now and you have seen in the diagram there are heating coils. So, the process is taking place at an elevated temperature and when the shrinkage would take place between the matrix and the reinforcing phase, there are chances at the cracks may be formed and important points is to properly optimize the process. So, that the crack formation is nullified or minimized.

Last point on your screen, you can see, high melting point of ceramics results in greater possibility of reaction between the liquid matrix and the reinforcement which was also an important point in the very first slide that is the introductory slide for this particular process that is the reaction chemical reactivity. So, the high melting points of ceramics we can see the reinforcing phase is a we can see a preform, the preform is made up of fibers, but basically the matrix is a ceramic matrix and it is in the liquid state. So, we can say the very high temperature is require to melt the ceramic material. So, the high

melting point of the ceramic that is the matrix material, basically we combining the two things together the matrix and the reinforcement.

The reinforcement has been kept in the form of the preform. So, we are not melting the reinforcement, but we are basically melting the matrix. So, the matrix is the ceramic matrix. So, when we are melting a ceramic all of us know that ceramics have high melting point. So, the high melting point of the ceramics result in greater possibility of reaction between the liquid matrix and the reinforcement, so that reactions sometimes may not be advantages and may have may act as a disadvantage in the processing of ceramic matrix composite. So, basically we have seen that the process details are purely simple, but there are many control parameters that have to be kept in mind and the process has to be controlled properly. So, that we are able to fabricate a good quality ceramic matrix composite product using the processes that we are covering today. Both the process is the process details or the process mechanism are not very complicated, but there are important parameters that have to be controlled in order to make these processes applicable for a specific set of ceramic matrix composite materials.

So, with this, we come to the end of today's discussion on processing of ceramic matrix composites. Just to have a overview of what we are cover today, we have seen the introduction of what has already been covered in this particular module, this particular module focuses on processing ceramics of matrix composites. In our previous discussion what we have discuss that was revised, then we have seen two important processes that is the slurry impregnation and the liquid infiltration. So, we have try to understand with the help of the diagram that how the process take place, and we have try to highlight that what are the important advantages and limitations of both the processes. In our last lecture in this particular module, our focus would be to understand or discuss some more processes which are use for processing of ceramic matrix composites, and we would and the module with discussion on the post processing aspects of the ceramic matrix composites.

Thank you.