Processing of non metals

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Module - 6
Ceramic Matrix Composite: Processing
Lecture - 3
Powder Processing: Ceramic Matrix Composites

A warm welcome to all of you in this lecture three on Processing of Ceramic Matrix Composites. As you are well aware in our lecture one and lecture two, we have discussed or outlined the basic aspects of ceramics and ceramic matrix composites. Our focus has been to revise the fundamental aspects of ceramics and then try to outline the differences between the ceramics and the ceramic matrix composite. If you remember, we have seen that how ceramics compared with the metals, and also we have seen that how the ceramics compared with the ceramic matrix composites. It has been noted that ceramic matrix composites provide properties, which are not attainable with the monolithic ceramics.

We have seen on that of addition of reinforcement in the ceramic matrix composite a host or lot of properties are improved, one or two to name fracture toughness and percentage elongation to rupture. So, there are few properties or few mechanical properties which improve on adding the reinforcement in the ceramic matrix composites. We have seen the mechanical properties of the ceramic matrix composites; although we have not discussed in much detail, but it was highlighted that what are the important mechanical properties of ceramic matrix composites, which should be taken into account when we are advocating the use of ceramic matrix composite for certain applications.

If you remember that we have seen take we should take care of the tensile and the compressive behaviour of the CMCs, we should take into account the fracture toughness, the fatigue resistance. Creep is an important property of the ceramic matrix composites which should be taken into account. And finally, we have seen the r curve behaviour of the ceramic matrix composites should be highlighted, when we are going to use this particular components or products this particular material for a particular component or a product. We have also seen that on incorporation of the fibres into the ceramic matrix certainly some properties are going to improve, and this incorporation is going to affect

the fracture toughness and then there are certain toughening mechanism that are their or come into the picture on the addition of the fibrous reinforcement.

Now what are the different types of toughening mechanism that also we have seen. If you remember in lecture two, we have seen that the there is crack in feeding as one of the toughening mechanism; then there is a deflection of the crack or the fibre or the whisker pull out. So there are different types of toughening mechanism that come into picture when the ceramics matrix is reinforced with the fibrous reinforcement. So, we ended our lecture two in this particular module of ceramic matrix composite with the toughening mechanisms. So, already we have taken two lectures or we have discussed two important aspects of ceramic matrix composite that is the fundamentals what is the need to develop a ceramic matrix composites from a ceramic matrix, and the mechanical properties of the ceramic matrix composite.

As our focus primarily is on the processing aspect of non-metals. So, from now on we would be discussing the various techniques which are used for for processing of ceramic matrix composite. As the title of the today's lecture go that is the powder processing. So, we will see that how the powders of the various constituents of the composites would be combined together, or what are the steps involved in combining the matrix and the reinforcement which is available in the form of powder, and how we can make a product by combining the matrix and the reinforcing fibres. The reinforcement can be in terms of we can say particulates also particles can also be there, whiskers can be there, and we will see what precautions we should take when we are using the fibres as the reinforcing agent or the reinforcing phase.

So, in today's lecture, our first focus would be to highlight the various types of processing techniques or processing approaches which are used for ceramic matrix composite, and then we will see that what are the important challenges for processing of ceramic matrix composites. And finally, we will see the basic technique of powder processing. In our subsequent lectures, our focus would be on other processing techniques of ceramic matrix composite such as chemical vapour in filtration or impregnation and certain other techniques such as soul gel process. So, let us starts with our discussion with the introduction, which I have already given.

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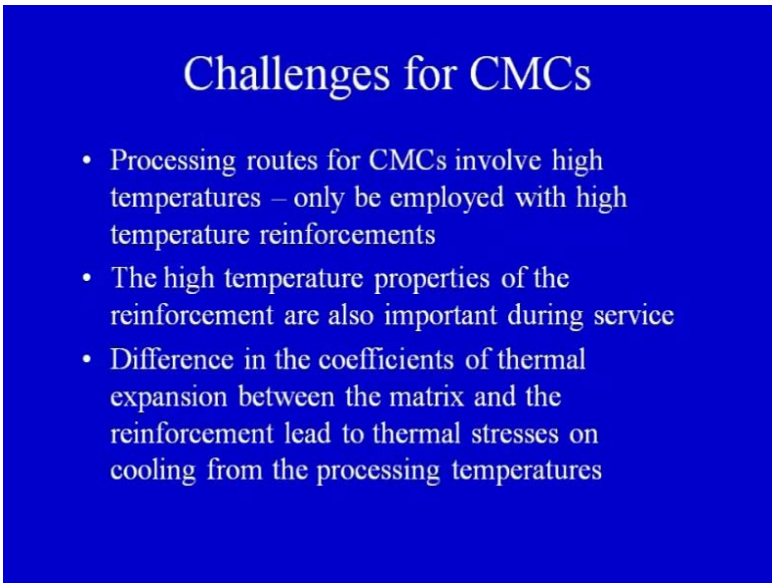

First and foremost I want to address an important point that is the challenges for CMCs. So, the challenges for CMCs basically are a hindrance to the widespread application of ceramic matrix composite. Now, what are the challenges? Point by point, we would try to address this important issue. First important point on your screen, I will read it for you; processing routes for ceramic matrix composite involves high temperatures. So, the techniques that we are going to use in certain techniques we would be doing sintering or other techniques, other high temperature, other types of high temperature would be required to fabricate the CMC product. So, the processing routes for CMCs involves high temperature, so whatever techniques we will see involved in one form or the other at one stage or the another stage or at one phase or at another phase high temperatures would be involved.

So, the first and foremost point is the processing routes for CMCs involved high temperature. So, only it can be employed with high temperature reinforcement. So, as you know, we have already been discussing the concept of the composite material, but for the audience who are only viewing this particular lecture, let me again revise that what is the basic concept of composites. In a composite, we have a matrix and a reinforcement, so there are two micro constituents which are combined together to make a composite material. So, in case of ceramic matrix composite, our matrix is made up of ceramic material, and all of us know that ceramic has high temperature applications. So, it is used for high temperature applications. So, important point is the matrix can bear the

high temperatures of processing, but the reinforcement that we are adding in the matrix should also have this high temperature resistant property that is it should be able to bear the high temperatures of processing.

So, if the matrix can bear the high temperature of processing, the reinforcement can also bear the high temperature of processing, we can combine the matrix and the reinforcement together at elevated temperature and can get a final product which is the ceramic matrix composite. But suppose we are using any metals as or in any metal fibres as a reinforcement material, so it will have a intermediate temperature, whereas the ceramic matrix can bear a very high temperature. So, the matrix can bear a high temperature, but the reinforcement cannot bear a high temperature and therefore, the processing will become difficult. So, one of the important challenge for processing of ceramics matrix composite is that both the constituents which are going into the composite should have high temperature capability. So, the first point has been addressed that is the processing routes for CMCs involved high temperature.

So, all the processes that we are going to see or that we are going or discuss in this particular module will involve high temperature at one stage or the other which has already been highlighted. So, the processing techniques can only be employed for those constituents which can bear the high temperature. So, all of us know ceramics can bear, but the reinforcement also should have this capability to bear the high temperature and then only the reinforcement and the matrix can be combined together to make a composite, and the composite in quotient in today's lecture is the ceramics matrix composite.

So, the second issue - the high temperature properties of the reinforcement are also important during service. Why this is important, because if you remember, we have seen that ceramics are often used for high temperature applications. Similarly, the ceramic matrix composite are also designed and developed for high temperature applications. So, no doubt the ceramics or matrix can bear the high temperature in service, but the reinforcement should also be able to bear the high temperature in service. So, if the reinforcement is not able to bear that high temperature, the product which has been made out of ceramic matrix composite will fail, so that is an important issue which limits the application of certain ceramic matrix composites, because the reinforcement is not able to bear the high temperature in service.

Third important point from the processing point of view is the difference in the coefficient of thermal expansion between the matrix and the reinforcement. So, this is true in case of polymer matrix composite also where we use the reinforcement in terms of fibres such as the carbon fibre, the glass fibre or the aramid fibre. So, the matrix is a polymer, either it can be a thermo set or be a thermo plastic; the reinforcement is the fibre and there is the difference between the properties of the matrix and reinforcement. Similarly, in case of ceramic matrix composite also, there is a difference between the properties of the matrix and the reinforcement, and one of the important properties is the coefficient of thermal extension. So, there is a difference between the coefficient and the thermal extension between the matrix and the reinforcement. And this difference may lead to the thermal stresses when the thermal stress would develop on cooling from the processing temperature.

So, as we have already seen in the point number one that the processing temperature in most of the processes that are used for processing of ceramic matrix composite are extremely high or on the higher side. So, from those processing temperatures, when the ceramic matrix composite will come to the room temperature, thermal stress would be developed in the composite on account of the difference between the coefficient of thermal expansion of the matrix and the reinforcement. So, therefore, this important point has also to be taken care of when we are processing the ceramic matrix composite. So, there are issues and challenges involved in processing of ceramic matrix composite and because of these issues and challenges, we are not seen many applications of the ceramic matrix composite, although there are applications. But as compared to the other counterpart that is the polymer matrix composites and the metal matrix composites the application spectrum of the ceramic matrix composite is limited.

So, these are some of the challenges which engineer should keep in mind, when he is going to process the ceramic matrix composite with one or the other route. Although we are going to discuss number of processing routes for ceramic matrix composites in our subsequent lectures, and today we are going to focus on the powder processing techniques for processing of ceramic matrix composites. So, let us now see that what are the important techniques, which are used or the important approaches that are used for processing of ceramic matrix composites.

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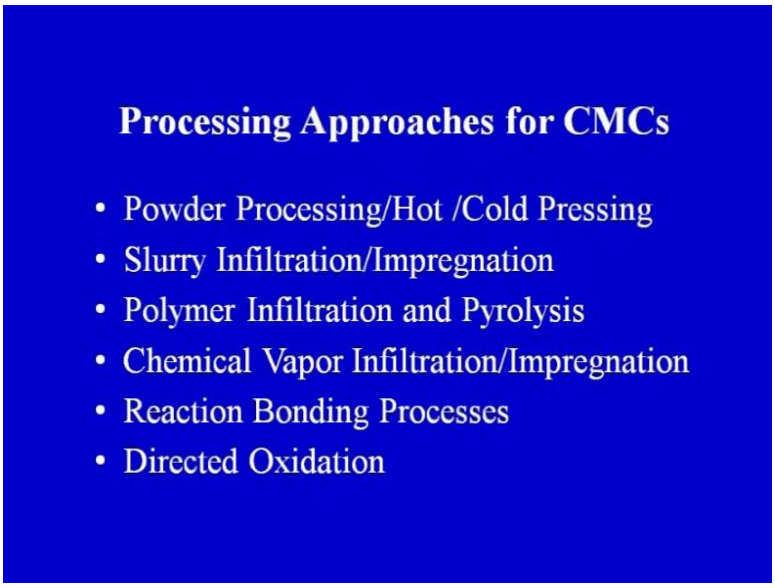

On your screen, you can see processing approaches for ceramic matrix composite. The first approaches is the powder processing; in which, we do the hot or cold pressing of the ceramic powders mix with reinforcement. So, we can do consolidation of the green fabricated, we can say raw martial which has been fabricated by the addition of the reinforcement and the matrix material. So, we will see in detail with the help of a flow chart that what are the various steps involved in powder processing. So, one of the processing approach for processing of ceramic matrix composites is the powder processing it can be hot and cold, it involve hot and cold pressing. Next technique on your screen is the slurry infiltration and impregnation that is also an important technique which is used for processing of ceramic matrix composites, and we will see in our sub sequent lectures the process details of this technique. Polymer infiltration and pyrolysis is an another technique, which is used which is developed. Chemical vapour infiltration or impregnation which I have already told in today's lecture that there are number of techniques which are used and the chemical vapour infiltration which is we can say subset of c v d that is chemical vapour deposition process. So, from there we have got this chemical vapour infiltration process which is specifically used in case of ceramic matrix composite then there can be reaction bonding processes, and finally the directed oxidation.

So, there are number of techniques which have been well developed or are in the stage of development into commercialization which have been used for processing of ceramic

matrix composite. So, we will try to see that what are the various process details and what are the various application areas of these processes in our subsequent lectures. But once a ceramic matrix composite product has been made by any of these processes, it has to be post processed, because in many cases, we require our product to perform a certain functions. It has to have a particular surface finish, it has to have a particular functionality; sometimes, we may be requiring to finish or to we can say glaze the product; sometimes, we may requires to machine the product which has been made by the ceramic matrix composite. So, these are the processes which will gives us a product that is the ceramic matrix composite. But finally, we have to do some post processing on this particular product for certain specific applications. So, why post processing is required that we are going to see in the subsequent slide.

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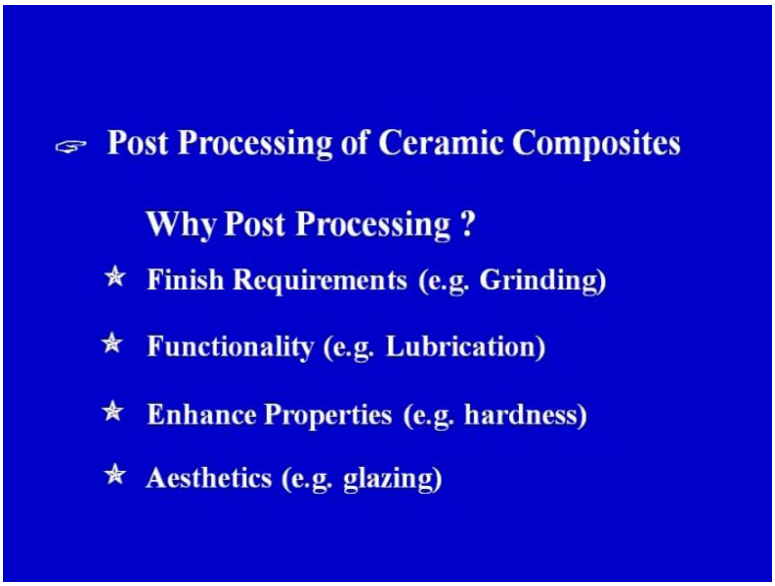

So, on your screen, you can see there are few points for post processing or in favour of post processing. So previous slide, we have seen that what are the important techniques, which are used for processing of ceramic composite or ceramic matrix composite. Now we will see the post processing of ceramic matrix composite, this point I have already highlighted in the fundamental aspect in lecture number one in ceramic matrix composite. In which, we have seen that why or what is the need of development of ceramic matrix composite, and we have seen that where the ceramic matrix composite fall in the broader picture of the composites family. There also we have seen that what are the major type of processing techniques and what are the post processing

requirements of the ceramic composite.

So, again I am highlighting the important point, because today we are going to start the discussion regarding the processing techniques of ceramic matrix composite. So, on your screen, you can see that why post processing of ceramics composites is required. So, there are four important points which are which necessitates the post processing of ceramics composites. First and foremost is the finish requirement and in finish we can undergo or we can undertake the process of grinding. So, sometimes in certain application, we require a very high surface finish of the product. So, for finishing, grinding is one of the most commonly used process. So, first and foremost post processing is in terms of finishing.

Second post processing is in terms of functionality; sometimes this ceramics all of us know that they are porous in nature. So that important we can say property of porosity is sometimes utilized for making suppose self lubricating bearing in which the oil or the lubricating oil would be pre impregnated in the bearing and then the bearing will be used oil would be coming out from the force of the bearing. So may be sometimes the functionality such as the lubricating has to be incorporated in the ceramic product or the ceramic matrix composite product and for that particular application we may be requiring some post processing like dipping it in a oil for a specific period of time. So, that the oil by capillary reaction or by any other action seeps into the force and it stored in the force and when in use it comes out for the purpose of the lubrication.

So, the functionality of the ceramic matrix composite has to be improve, and therefore, post processing becomes inevitable. Also sometimes to enhance the properties also post processing is required such as we require a very high hardness on the outer shell. So, for that sometimes of post processing treatment may be required to improve the hardness on the outer periphery of the CMC or the ceramic matrix composite products. So for that also sometimes certain processes or operations will be done after making the CMC product and the final result would be that would be getting enhanced hardness or increased hardness at the outer shell or the outer periphery of the CMC product.

And finally, which is the most important buzz word or catch word is the aesthetics that is the product should be pleasing to the eye. And the CMC product that we are making by any of the processes which we have seen in the previous slide, whatever product we get

we sometimes would require to make it more we can say pleasing to the eye or to be making it more presentable. And for that sometimes one of the operations can be glazing or there can be other operations which can be done in order to improve the looks of the CMC product.

So, we have seen till now that how what are the different types of processes which can be used for fabrication or processing of ceramic matrix composite product. And also we have seen that once the product is ready, we need to do some post processing on ceramics composites or on account of the finished goods requirements or to enhance the functionality of the product or to enhance the properties such as hardness. And finally, to make it pleasing to the eye or to improve the aesthetic aspect of the ceramics matrix composite product. So, processing is also important and the post processing is equally important to improve or increase the applications spectrum of the ceramics matrix composite product so that is important.

Now, we will see that what are all the challenges. Now it is easier said that done we have already seen in slide number one today that there are challenges for processing of ceramic composite. We have seen the high temperature applications, the temperature at which the reinforcement can sustain or it can retain its properties is equally important. Matrix no doubt, it has the capability to bear high temperature, but the reinforcement that we are putting in the ceramic matrix to make a ceramic matrix composite should also have the similar types of properties at elevated temperature then only the product would be able to serve the purpose. So, there are challenges and there can be certain other challenges which may be taken into account when we are talking about the processing aspects of ceramic matrix composites.

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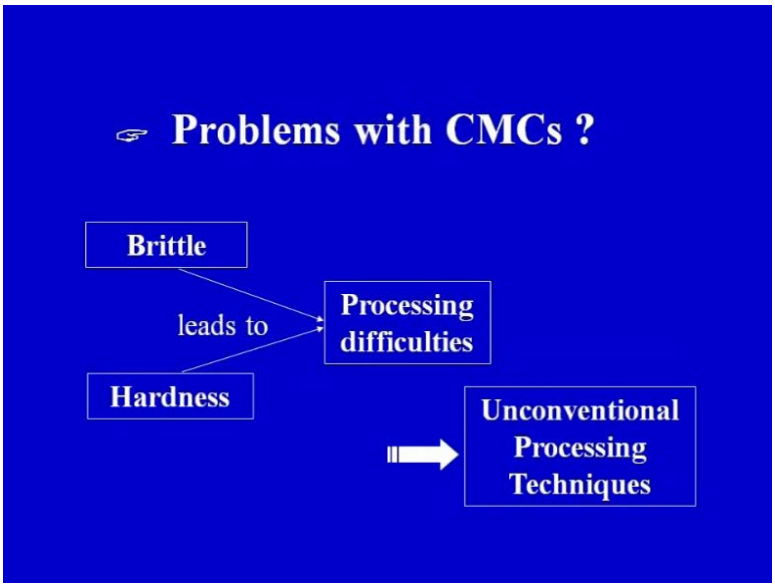

So, we can also seen that there are certain other problems like ceramics are brittle in nature. They have very high hardness and this leads to the processing difficulties. So, one important processing difficulty was the difference in the properties of the reinforcement and the matrix one of the important point we have seen is the difference in the coefficient of thermal expansion which may lead to thermal stress is being developed during the processing. So, difference in the properties of the matrix and the constituents, then the brittle nature of the ceramic matrix as well as the high hardness of the ceramic matrix often lead to certain processing difficulties. And therefore, the conventional methods of converting the raw material into the final product are not advisable for processing of ceramic matrix composites. And therefore, different types of approaches are developed or are in the process of development for fabrication of products made by the ceramic matrix composite.

And on your screen, you can see the problem area is associated with the fabrication of CMC product has lead to the development of unconventional processing techniques. So, we are going away from the conventional technique towards the unconventional techniques for processing of ceramic matrix composite. So, once again to revise what are the major challenges in fabrication of ceramic matrix composite. Major challenges are the difference in the properties of the matrix and the reinforcement the brittle nature of the ceramic matrix are very high hardness of the matrix and the reinforcement. So, these are all the important challenges which have to be taken into account when we discuss the

processing techniques for ceramic matrix composite.

Now when we come on to the basic techniques of fabrication of ceramic matrix composite products, so let us see the introductory part of powder processing. It is a fairly simple method, but there are many challenges involved in the powder processing that we would be covering in the subsequent slides. So, we will see that what is the process, what are the various steps involved in the processes. And finally, we will see what are the limitations or the challenges which have to be taken into account when we are going to make a product by the powder processing techniques for ceramic matrix composite.

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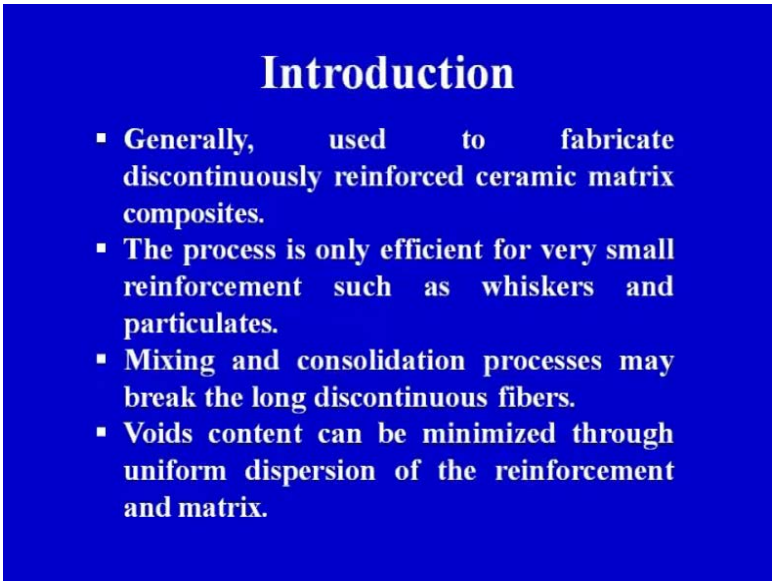

Let us see the basics of the powder process this is generally used to fabricate discontinuously reinforced ceramic matrix composite. So, if you remember, we have seen in case of ceramic matrix composite, the matrix is the ceramic matrix and the reinforcement can have three sub categories that is based on the shape of the reinforcement, based on the orientation of the reinforcement. And finally, based on the chemical nature of the reinforcement, there can be three sub categories of the reinforcement, and according to the shape of the reinforcement we can have particles in the reinforcement. We can have shot fibre in the reinforcement, we can have long wire continues fibre as well as we can have whiskers in the reinforcement.

So, this particular process that is the powder processing is generally used to fabricate discontinuously reinforced ceramic matrix composite. Discontinuously reinforced means

in this particular technique, we will not be using long fibres as the reinforcing phase or the reinforcement agent. We would be using small fibres or whiskers or the particles in the reinforcement phase or the reinforcing material would be short fibres whiskers or particles. Long fibres will not be used this is one important aspect which should be taken into account.

Second the process in only efficient for very small reinforcement such as whiskers and particulates which I have already explained in point number one, that this particular technique is specifically suitable for shot reinforcement. The shot reinforcements or the small reinforcement such as the whiskers and the particulates, even for the whiskers and particulates there are certain issues which it have to be addressed which we would have been covering when we have covering see what are all the challenges for processing by powder processing technique.

We will see what are all the issues and the challenges involved in the powder processing technique. Next stage is mixing and consolidation processes may break the long discontinuous fibres even in discontinuous fibres, also we will not go for fairly long fibres, although we are not using the continuous fibres we are using discontinuous short fibres only. But the length of the fibres is also important. If the length is considerably long or long fibres are there then this process of mixing and consolidation may break the fibres or the whiskers. So, therefore, we should limit the length of the fibres that we are putting in the ceramic matrix as the reinforcement.

Next point voids content can be minimized through uniform dispersion of the reinforcement and the matrix. So, there are the chances of agglomerations of the reinforcement sometimes some bundles of reinforcement or the bundles of fibres may formed within the bulk of the matrix. So, that has to be avoided because we want a uniform distribution of the reinforcement in the ceramic matrix then only we will able to get the properties or excellent mechanical properties.

If we have the concentration of the reinforcement at a particular location, so it will act as a inclusion and when this particular CMC product would be loaded, there are chances that because of that stress concentration at certain locations though product may fail. So, the prime object of the mechanical engineering or the engineer who is involved in the processing of ceramic matrix composite is that he has to ensure the uniform distribution

of the reinforcement in the ceramic matrix.

Again I am emphasising the last point on your screen that is the void content can be minimized. We do not want any voids certain times we adequately requires the porosity, sometimes the porosity may be required, although it may be required in certain cases. But in many cases, it may not be required, also the depending upon the applications if we want to avoid voids contents can be minimized with uniform distribution of reinforcement and the matrix. So, when we are mixing the reinforcement and matrix we should ensure a uniform dispersion and then only we would be able to achieve the mechanical properties.

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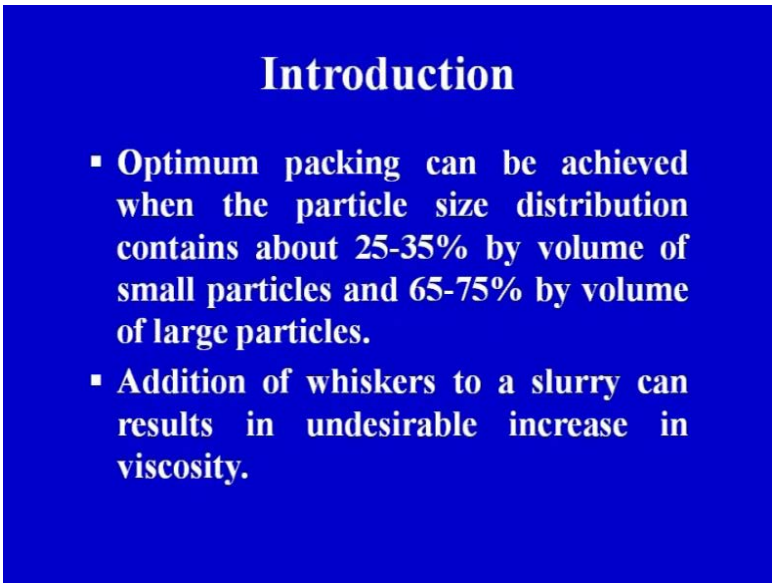

Moving forward from the last point on your screen, you can see optimum packing can be achieved now we want a optimum packing we want a dense product. So, optimum packing can be achieved when the particles size distribution contains 25 to 35 percent by volume of small particles and 65 to 75 percent volume of large particles. Now let us taken an example when we are mixing the reinforcement with the ceramic matrix, if all the reinforcing particles are of same size, suppose we take an excreted scale we take that all the reinforced particles are like tennis balls. So, all the balls are of same size, we will not get optimum packing, but if we have the distribution in the particles size we have a particle size distribution that few particles are of small size.

There are other particles which are of medium size, and there are few particles of large

size we can expect a optimum packing. So, which means which tennis ball we can have few table tennis balls also and we can have few marbles also. So, when we pack the tennis balls the table tennis balls and marbles together we can expect the optimum packing of the particles. So, this particular points highlights because in our previous slide we have seen that we want a uniform dispersion of the ceramic matrix particles and the reinforcing particles. So, the optimum packing is the our desirable characteristic can be achieved, when the particles size distribution contains a well distributed particle size that is some particles may be 25 to 30 percent by volume or small in size 65 to 75 percent particles are large particles. We will get a optimum packing of the particles and we will get a purely dense products.

Addition of whiskers to a slurry can results in undesirable increase in the viscosity which is another point which has to be taken into account. So, the viscosity of the slurry has to be maintained. So, that is another issue which has to be taken up when we are processing the composite product. So, there are few points which has to be taken into account, and if all these things are taken into account at a initial stage of the processing. And all the important characteristic or the important requirements are optimized we would be able to get a very good quality ceramic matrix composite product.

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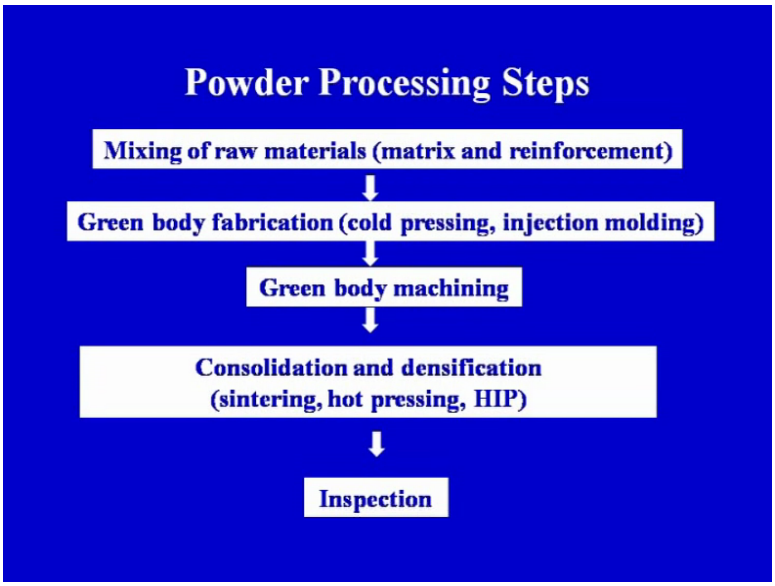

So, now let us see the process details of the powder processing. What are the important steps involved in powder processing. On your screen, you can see, these are the basic

and the fundamental aspects. There can be few additional steps also which may be present or which may be required to get certain specific requirements or certain specific feature in the final product. Because whatever final ceramic matrix composite we want to form, it may be designed for certain specific applications and there would certain design requirements which have to be met at the processing stage only, but the fundamental steps would remain same and our focus is to understand this fundamental aspects only.

So, let us see what are the fundamental aspects of the powder processing to first and foremost, we have to undertake the mixing of raw materials. Now what are the raw materials that are going into the final product? There are two, one is the matrix and another is the reinforcement. So, matrix in this case would certainly be a ceramic matrix the reinforcement can be any other types. So, we have a ceramic matrix and the reinforcement. Reinforcement has to be in form of as we have already seen that we are not going to use long fibres used in case of powder processing. So, we are going to have reinforcement and in the form of short whiskers or very small particles. So, mixing of the raw materials that is the ceramic matrix and the reinforcement together. So, we can get this powder by different processes like ball milling can be one of the processes for getting the uniform distribution of the particles. So, we can get the powders from boll milling, but once we have got the ceramic powder as well as the reinforcement we will mix the two things together.

So, the first important step is the mixing of the raw material. So, once they have been mixed together we have to avoid the accumulation or the aggregation of one particular or the reinforcement phase, because it has a tendency to form bundles or to form the agglomerate that has to be ensure that the reinforcement is uniformly spread in the matrix. So, that is one important point to be taken care of in the very first step of powder processing technique. So, first step is to ensure a uniform mixing of the raw material.

Second is the green body fabrication and it can be achieved by cold pressing or injection moulding. Green body means that it is the initial step as we see in case of costing say green sand mold. So, similar analogical green body fabrication can be binders also which are added to the process during the mixing, we can drawn here also the green body fabrication, there can be binders also which are added during the mixing of the the raw material. So, these binders will give a particular shape to the product. So, here we will do the green body fabrication it can be done by cold pressing without any temperature or by

the injection molding the other processes also which can be used for green body fabrication. So, we mix the raw materials, and we have ensure the uniform mixing of the reinforcement or the uniform distribution of the reinforcement in the ceramic matrix. Next stage is the green body fabrication; two processes are there. On the screen can be other processes also which can be used for the formation of the green body then we give a particular shape to the green body by machining or certain times. We may not require machining within a mold, also we can try to give a shape to the green body once the green body has been fabricated. We know the fabricated shape, but our shape that we want to know, finally, we want to do the consolidation and the densification.

So, we want a dense CMC product and for that we need to do the consolidation, how it is done. It can be done by sintering; sintering can be done at an elevated with the help of pressure or without the pressure. In many cases, it has been seen in the formation or powder processing of monolithic ceramics that sintering can be done without the application of pressure. But in many cases with the applications or with the incorporation of the reinforcement certain times the sintering without pressure becomes difficult.

Again I am going to tell this important aspect that in monolithic ceramics, when we are forming the ceramics products sintering can be done without the application of pressure. But when the reinforcement is added into the ceramics matrix, we are going to make a ceramic matrix composite in which we have the reinforcement in terms of whiskers or small fibres or small particles. In that case, sometimes the sintering to achieved sintering process without the application of pressure is difficult, but it is not unachievable, but it can be done with under certain specific requirements and in many cases the pressure would be required. So, pressure can be applied as the other two processes, you can see the other applications in this particular step of consolidation and densification the hot pressing can be done or the hot isostatic pressing can be done.

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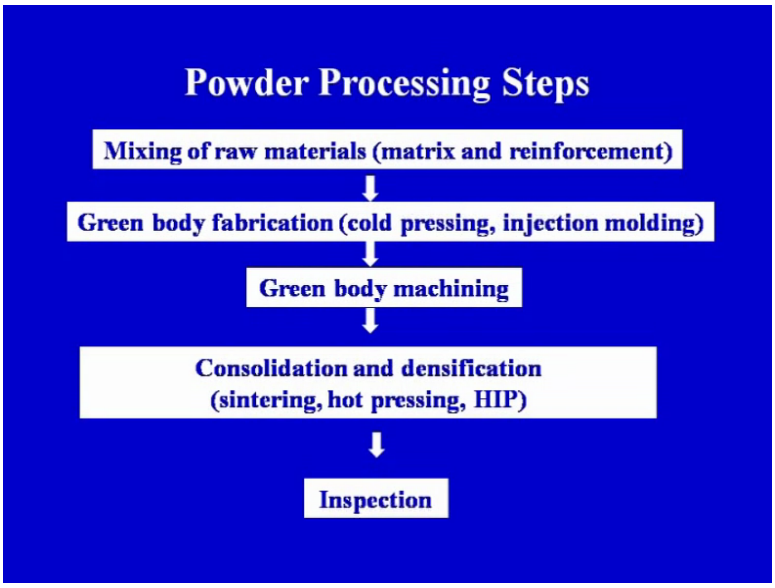

In hot pressing, we apply pressure also, and in hot isostatic pressing again the pressure is applied. But this hot pressing and hot isostatic presssing, when we are applying the pressure on the ceramic matrix and the reinforcement or on the green body, it has got its own challenges. Because in hot pressing also there are challenges, and we need to have a press for that we need to have a press of very high tonnage. And in case of hot isostatic pressing, it is expensive process. So, if we want to make a products which are to be sold in non structural applications or which are not for very high-end applications and if the products are to be sold in consumer market. And cost is an important factor criteria, because we will not like to have a expensive equipment for the formation of CMC. So hot isostatic pressing one of the challenges there can be other challenges also is that it is the expensive process.

So, hot isostatic pressing is a difficult or not a difficult, but expensive process; and hot pressing, we require a high tonnage. So, both hot pressing and isostatic pressing has got its own limitations. And finally, the inspection has to be carried out. So, we have to have a adequate consolidation, adequate density and sometimes we may requiring porosity in our final product. So that has to be chaired by different techniques for the products which has been formed is porous or not what is the degree of porosity in the final product. So, the basic steps involved are without going into the details of the various steps, I would just like to revise that what are the various steps involved in the powder processing.

First step is mixing of the raw materials. In this particular stage, we have to ensure the uniform dispersion of the reinforcement and the matrix that is the ceramic and the reinforcing agents. Second is the green body fabrication that is giving shape or forming the ceramic matrix composite product that forming can be achieved by cold pressing or injection molding. Next is certain time machining may be required or may not be required; and finally, the consolidation and the densification which in case of ceramic matrix composite may require pressure also. So, we may go for hot pressing or we may go for hot isostatic pressing, but both hot pressing and hot isostatic pressing have got their own challenges, but certainly if we will use this processes we can get the adequate amount of consolidation and densification. And finally, once the product is ready the last stage is the inspection of the formed product.

So, these are the basic steps involved in the powder processing of ceramic matrix composite product, but there are many challenges involved. So, we will try to highlight that what are all the challenges because looking at the steps involved, it seems is that it is a very simple process at which we can achieve a good quality product ceramic matrix composites can easily be got or easily be fabricated. But there are challenges, but one by one we will try to address these challenges.

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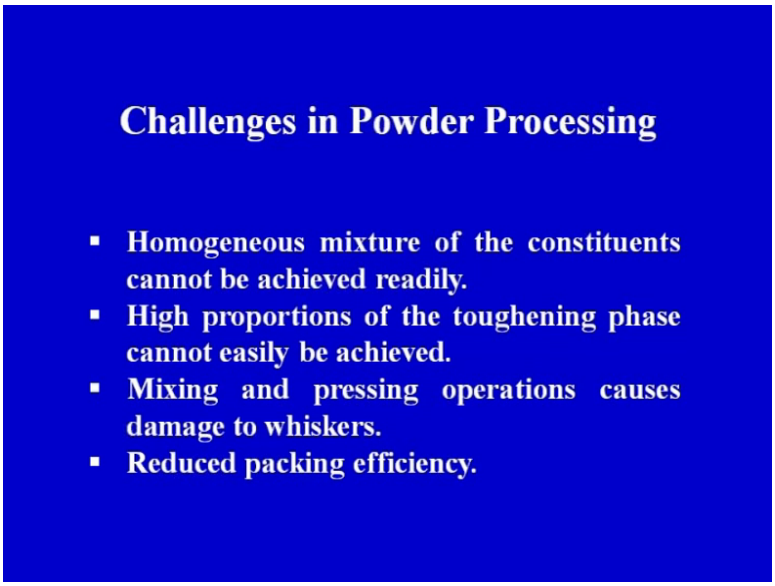

Now, what are the challenges involved in powder processing. First important challenge is the homogeneous mixture of the constituents cannot be achieved readily. So, the first

step also I have told may be two or three times that we have to ensure a homogeneous mixture or uniform dispersion of the matrix and the reinforcement. So, it is sometime difficult to achieve, why, because the reinforcement has the tendency to form agglomerate and the agglomeration big issue or the big problem; sometimes fibre bundles are also noted, so that has to be we have to minimize that effect. So, we have to avoid this agglomerates and fibre bundles during the mixing stage. So, first important challenge is the we have to ensure the homogeneous mixture of the constituents.

Second high proportions of the toughening phase cannot easily be achieved. So, the volume fraction or the we can say the bi volume or the toughening phase. What is the toughening phase? Toughening phase is the reinforcement. So, it is difficult to achieve a very high proportions of the reinforcement in the ceramic matrix composite, so that is also an issue. Next challenge mixing and pressing operations causes damage to the whiskers. In specific case where the reinforcement is done in form of whiskers, it has been noted that the mixing and pressing operations time causes damage to the whiskers. So, when the whiskers are damaged or reinforcement is damaged, it would certainly affect the mechanical properties of the product which has been achieved or which has been processed with the whiskers as the reinforcement. So, the whiskers reinforced ceramic matrix product may certain times have certain we can say deteriorated mechanical properties, because of this particular processing difficulties that is the damage to the whiskers which has taken place during the processing. Next is the reduced packing efficiency that is the another challenge that is that the packing efficiency sometimes is less when we are processing the product by powder processing technique.

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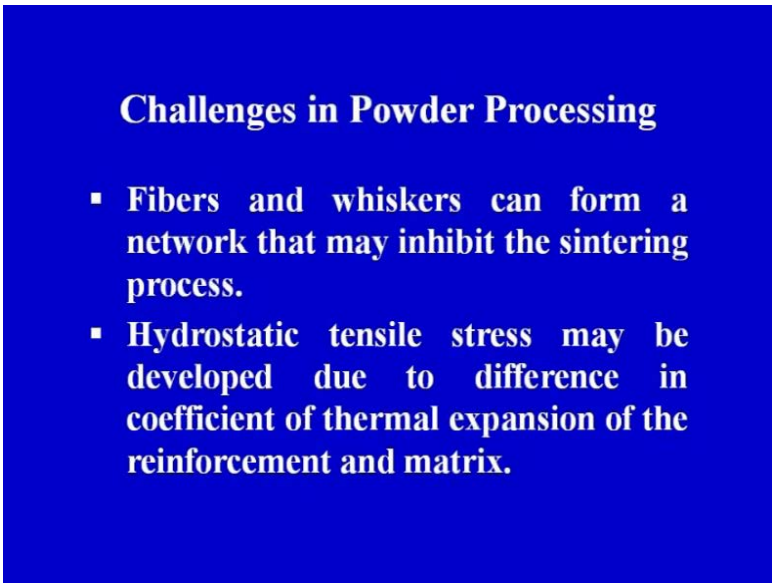

The other challenges in powder processing are fibres and whiskers can form a network that may inhibit the sintering process, so that is another challenge which we have already seen that agglomeration or fibre bundles formed during the process of mixing, so that has to be avoided. And if this bundles formed or network of the fibres and whiskers are formed, the sintering process become difficult. So, if the sintering is not done properly, we will not get proper consolidation and densification, and because of not improper densification and the consolidation the product that we are getting may not be able to achieve the target or the designed requirements for which it has been fabricated.

The next stage is the next challenge is the hydrostatic tensile stress may be developed due to difference in the coefficient of the thermal expansion of the reinforcement and the matrix. So, that we have already seen that because of the difference in the very beginning in today's lecture in the very first slide we have seen that there is a difference in the properties of the reinforcement and the matrix, and these difference may lead to certain type of stresses that are developed during the processing. So, in this particular point as one of the challenges, it is seen that the tensile stress is developed due to the difference in the coefficient of the thermal expansion of the reinforcement and the matrix. And which may later on the when we are going to use this product for a particular application, these particular stresses may lead to the failure of the product. So, these type of stress have to be avoided. So, the important point to note is that we have to take care of the difference in the properties of the reinforcement and the matrix. So, we have seen that

although the process of powder processing seems very simple, but there are many challenges in the processes which have to be taken care of in order to make a good quality product by powder processing.

So with this, we come to the end of this lecture number three in module six of our course on Processing of Non-Metals. In module six, our focus is on processing of ceramic matrix composite product, and we have already seen the fundamental of the ceramic matrix composites, and today we have seen one of the important techniques of making ceramic matrix composites that is the powder processing. We have seen the basic steps involved in the powder processing and the important challenges that are present in the powder processing techniques. With this, we come to the end today's lecture, and next lecture we would be focussing on certain other techniques of processing of ceramic matrix composites.

Thank you.