Manufacturing of Composites
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Lecture – 21
Fabrication of Ceramic Matrix Composites

Welcome to lecture number 21. So, in this lecture, we will more focus towards fabrication of ceramic matrix composite before getting into the different processes.

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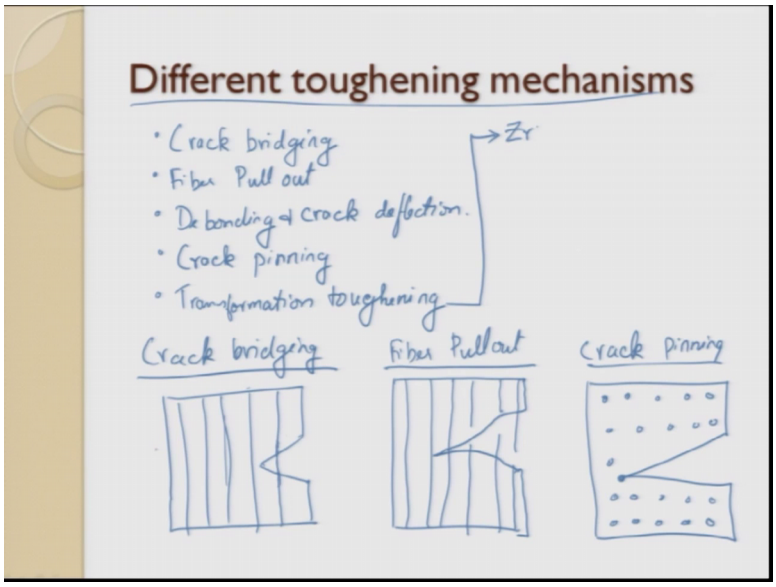

Let me once again reiterate the different toughening mechanisms which are playing a very predominant rule in ceramic matrix composite. So, as I told you in the last class, ceramic matrix composite is more focused towards enhancing the toughness and as well as enhancing their high temperature behavior; so, for this, we always go for ceramic matrix composite though the quantum wise polymeric matrix composite still dictates, but the amount of ceramics matrix composite which are getting fabricated for various applications in aerospace and automobile where high temperature is involved.

So, they have started moving towards ceramic matrix composite in ceramic matrix composite the important thing is the toughening mechanism. So, there are different types of toughening mechanism which we saw last class. So, let me write to you in detail. So, this is one is crack bridging this is one type of toughening mechanism the next mechanism is fiber pull out the third mechanism is going to be the de-bonding and crack

deflection next one is going to be crack pinning and the last one is going to be going to be transformation toughening. So, these are the 5 predominant toughening mechanisms which are involved in ceramic matrix composites. So, here because of the introduction of reinforcement particle these are the benefits which we get. So, when we try to talk about crack bridging yesterday we went through little bit.

So, I will just draw suppose if we have a ceramic matrix composite and these are the fibers which run along. So, fibers run along. So, here are the cracks which are getting bridged by the; or this reinforcing fiber tries to hold back these 2 parts together and this is called as crack bridging the next one is fiber pull out. So, fiber pull out is all where and which you have these fibers which are involved. So, here, if we are trying to have a crack which grows like this; so, here you see the fibers are getting pull out and then the toughening mechanism happen.

So, that the cracks do not go fast. So, you get the toughening mechanism. The next one which we have already seen is de-bonding and crack deflection I made several figures in the last class the SCM figured what we were discussing is on de-bonding and crack deflection crack pinning is the other one crack pinning is these are particulate types reinforcement. So, here are some particulates which tries to stop the crack which is further growing.

So, these things are called as crack pinning the recent one which people have been talking about is transformation toughening this happens predominantly by adding zirconia as a particulate in the ceramic matrix composite.

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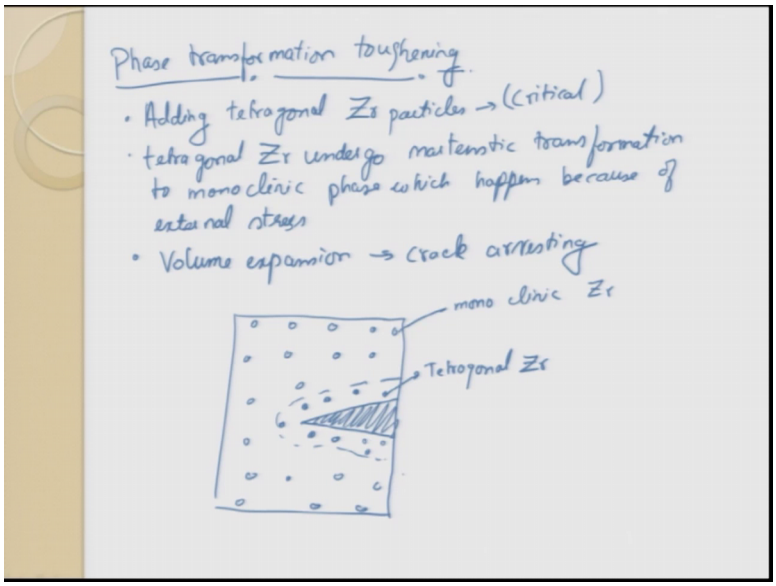

So, let us see that in detail. So, this is the phase transformation toughening this happens by adding tetragonal zirconium particles first point the next point is the tetragonal Zr gets transformed under goes martensitic transformation martensitic transformation to what to mono clinical phase this transformation which happens because of stress because of external stress whatever we apply this transformation happens and so, because of this transformation there is a volume expansion and this volume expansion leads to crack arresting.

So, here the particle size is critical so; that means, to say you are supposed the it does not happen in all zirconium size particles lesser than a critical size only this happens. So, if you look at the schematic diagram, this is the tetragonal zirconia getting changed in the volume and you can see these are the monolithic zirconia particles which are present in the ceramic matrix. These are mono clinic not monolithic monoclinic monoclinic zirconia; monoclinic zirconia. So, this is a transformation toughening mechanism this is a fifth transformation toughening mechanism all these mechanisms are used while building up the ceramic matrix composites.

So, this is very very important why are we going to ceramic matrix composites is only to enhance the fracture toughness behavior and then on high temperature bringing in some changes. So, these are the 2 necessary things which pushes as hard to go to ceramic matrix composite of course, ceramic matrix composites are very light as compared to

that of polymer matrix composite today the aero the complete turbine g turbines there all completely moving toward ceramic matrix composites.

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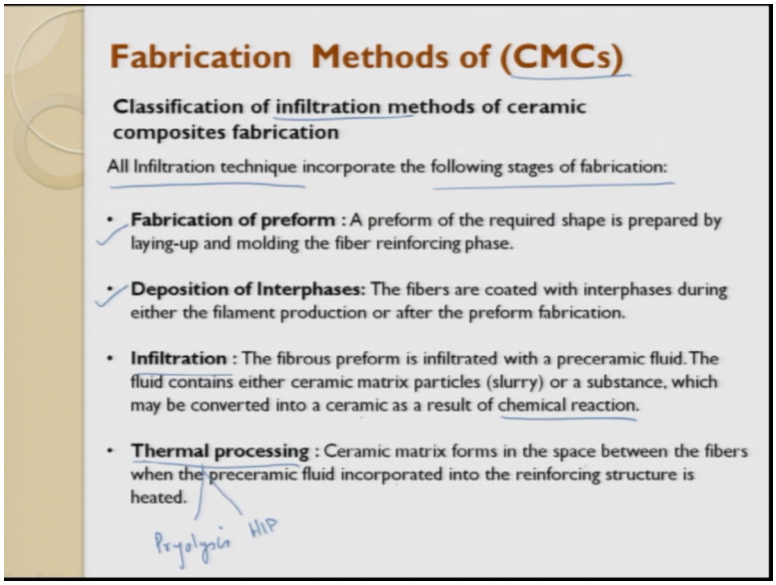

Now, let us go into the fabrication; fabrication of ceramic matrix composites. So, the classification of infiltration what is infiltration there is a free space you are trying to push some material inside. So, here what happens we make we try to take a ceramic powder then we try to compact that ceramic powder into some pre-form shape and then when we try to compact we make sure that we live enough of force through this force you can try to push in whatever material you want. For example, you can push in polymer you can push in metal whatever you want you can push it depends on the 4 size as well as what is the principle of capillary action you bring in there.

So, this is; what is a basic mechanism in ceramic matrix composites fabrication. So, the classification of infiltration method of ceramic matrix composites fabrication all the infiltration techniques incorporates the following stages of fabrication. So, one as I told you, we make a pre-form of whatever shape you want for example, let me take the aluminum metal matrix composite where and which on the top alone, they have the ceramic ceramic crown which is given for the piston further very high temperature applications we do. So, what we do we make the piston by casting process or high pressure die casting process then the top most potion were the crown where that it is going to be exposed to very high temperature. So, what we do is we try to make a pre-

form. So, this pre-form can be made out of powder or it can be made out of slightly longer fiber.

So, that is what is a pre-format a pre form is of required shape is prepared by laying and molding the fiber reinforced phase then what we do is we deposit the inter-phase which we discuss last time the fiber are coated with inter-phase during either the filament production or after the pre-form formation. So, what is this I told you about the capillary action to suck through this force? So, now, what you do is you can pressurize the other way round is you can also give it some coating such that it of its own tries to catalyze the processes.

So, that is deposition of interface, then third thing is infiltration; infiltration is a process which I was talking to you about the fibrous pre-form is in filtered with a pre ceramic fluid. So, if it does metal you take it to a liquid state ceramic if you want to take it to a liquid state what we do we try to mix the ceramic and the form of slurry in a slurry what we do if we try to mix it with a with a polymer substance plus we also try to mix it up with water or alcohol. So, what happened during infiltration process we try to push the infiltrate inside and the water can be evaporated and the polymer also can be burnt.

So, now what you get is ceramics slurry which was there; now all the burning goes up now the ceramic gets retained. So, now, that is a how you former a ceramic matrix composite. So, when the ceramic states that the ceramic can former reaction or it can exist on the stage generally for what happens is it forms a small reaction there to get a very good adhering in between the matrix and reinforcement the fluid containing either ceramic matrix particles that that is a slurry or any other substance is mixed which is then converted into ceramic as result of the chemical reaction and finally, what you get is still green. So, you want to increase the hardness. So, we always go for a thermal processing. So, the thermal processing is done the ceramic matrix forms in the space between the fiber when the pre ceramic fluid incorporated into the reinforcing structures heated.

So, once it is heated this ceramic returns there it forms a very good inter-phase and that is how you make a ceramic matrix composites. So, when I said thermal process majority of the thermal process when you do with polymer we always do pyrolysis reaction. So, pyrolysis reaction we do. So, convert the polymer into a required ceramic material. So,

we do that or we try to do it with very high temperature isostatic process hip and other thing where high temperature is applies. So, that we get the very good composites.

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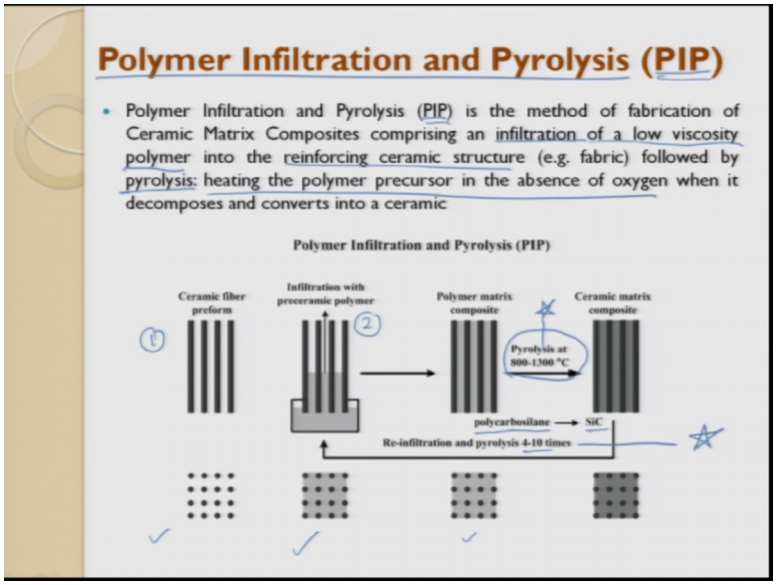

So, polymer infiltration and pyrolysis process which is otherwise called as PIP. PIP; this is a very very common process in ceramic matrix composites; so, the polymer infiltration and pyrolysis. So, here are the steps which are there whatever I have dealt earlier the same steps are followed step one a ceramic pre-form is formed step tow you see that you have a infiltration with pre ceramic polymer. So, then the polymer the polymer matrix composites is formed then what you do is you do pyrolysis; pyrolysis at 800 degrees to 1300 degrees you try to take a furnace and then try to take the temperature to that anything about 1000 degree Celsius it demands a special kind of furnace.

So, as and when you go higher and higher and higher the furnace becomes very expensive. So, anything about thousand the furnace cost goes high. So, 1300 degrees, you try to maintain and then what happens all the polymer whatever is there is converted into ceramic matrix composites whatever you get here need not be very perfect. So, what you do is you repeat this process 3 4 times n times. So, here I have said 4 to 10 times, if you want to have really a very good ceramic components ceramic matrix composite. So, people have done even hundred times to get a very good output. So, if you look at the plan view, you see the pre-form is there then infiltration polymer is done. So, then what happens is these polymer matrix composite. So, they are form and then these the burning

happens because of pyrolysis and what you get this. So, polycarbosilane is converted into SiC the polymer whatever was there. So, this process is called as pip. So, if you go back to the previous slide I said the deposition inter-phase and then interface.

So, the in deposition inter-phase is some coating which is given and infiltration it has to be a liquid which flows through. So, we always try to mix this ceramic or take a polymer and convert it into a ceramic by pyrolysis process. So, PIP is the method of fabrication of ceramic matrix composite comprising and infiltration of a low viscous polymer into the reinforcing ceramic structure which is a fabric followed by pyrolysis; pyrolysis is heating the polymer precursor in the absence of oxygen that is important if you do with any other gas you will not be able to land up with a ceramic matrix composite. So, pyrolysis means heating it in the absence of oxygen. So, what do we get we get a ceramic matrix composites.

So, this process is PIP process where in which polymer use you use. So, the polycarbosilane is covered into sic and please keep that in mind; this step is also very important if you do not repeat the re infiltration then.

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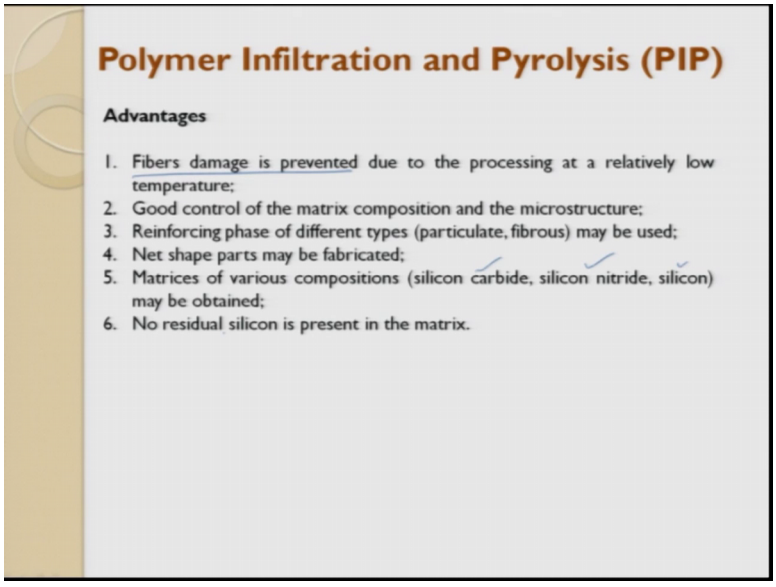

You will not be able to get the required output when you will have lot of force. So, what is the major advantage fiber; fiber damage is prevented due to the process at a relatively low temperature good control of the matrix composition and the microstructure can be got the reinforcing face of different types particulate and fibers may be used particulate

when I say means you make a green you put it in a die and try to make it then the net shaping is done. So, it is; it leads to near net shaping. So, people call this as a green manufacturing process where and which you get the output to the required shape dimensional and the strength properties in one shot the matrix of various composition is silicon carbide silicon nitride and silicon can be done by changing the polymer matrix depending upon your requirement no residual silicon is present in the matrix after conversion.

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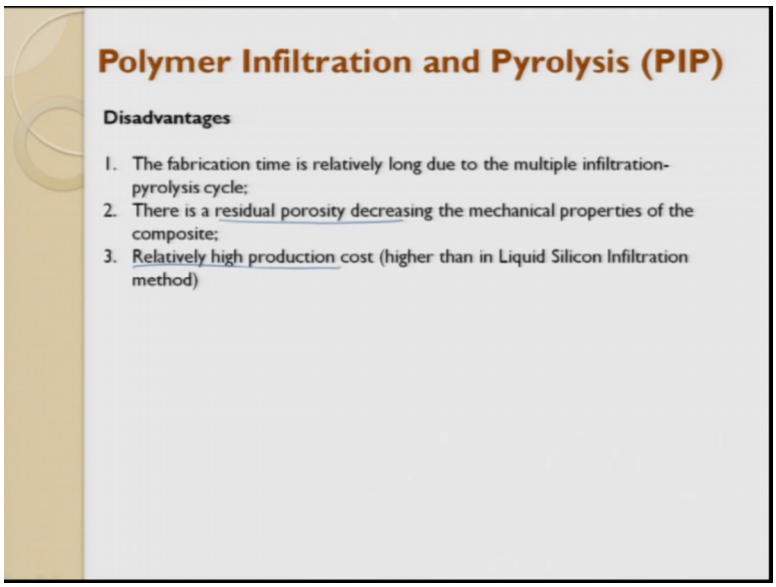

The disadvantages it is relatively time consuming process why because you have to do multiple re infiltration and the second thing is as we have already discussed non destructive testing of composites since we have multiple face it is also very difficult to find out whether we are getting hundred percent consolidation by this infiltration process are there is a residual porosity decreasing the mechanical property because if you are not pretty sure you stop the multiple in infiltration after six times or eight times. So, then you might lead to force this will lower mechanical properties and it is relatively expensive because pyrolysis furnaces are always expensive.

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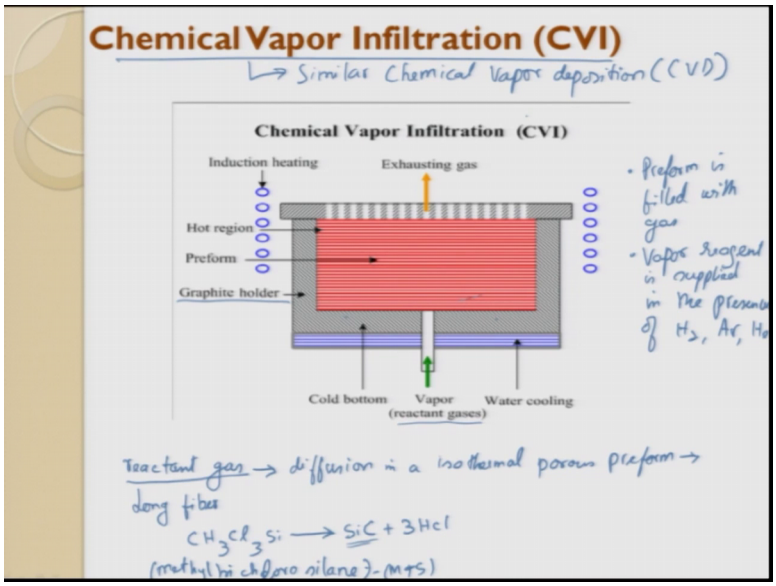

The next process of discussion is going to be chemical vapor deposition. So, in this process the ceramic matrix is composite is fabricated with reactant gas this gas what happens it undergoes a process of diffusion this diffusion in a ISO thermal porous reform.

So; that means, to say there is a heat and you can use here long fibers long fibers ceramic fibers can be used for making the deposition. So, here are reactant gas is used for example, we try to form C H 3 Cl3 Si which gives you silicon carbide plus 3 Hcl. So, here what happens this is used for making sic matrix. So, here as I said diffusion is involved. So, it is very similar to that of this process is similar to that of CVD chemical vapor deposition; this process is very similar to the that of chemical vapor deposition in which there is a gas reactant gas which gets deposited on to the substrate to give a coating in chemical vapor deposition here it is pushed into a pre-form ceramics whatever is there. So, this one I will write the name it is methyl tri chloro silane is the gas it reacts with a very high temperature and then it tries to form SiC; SiC is a very commonly used ceramic matrix for various applications. So, this is otherwise also called as MTS.

So, let me write down some of the steps here. So, the deposition the pre form is filled with gas. So, when I say gas this MTS will also sometimes we will also use some carrier gas. So, that with this will this will try to help in deposition of faster weight. So, the vapor reagent is generally supplied in the presence of H2 or argon gas or helium gas in

the presents these gases are allowed to deposit and then ceramics on this reaction it tries to form. So, this process is called as chemical vapor infiltration. So, this is the induction heating coil where the pre-form is heated then we have this is a hot region.

So, these are the pre-forms this is the hot region whatever is there. So, vapor reagent is pushed in from the bottom that is the MTS here. So, it is pushed in from the water. So, the bottom and then you have a cooling a cold bottom there. So, that the gas goes inside gets deposited and you form. So, here the temperatures are very high we always use a graphite crucible or graphite holder is used.

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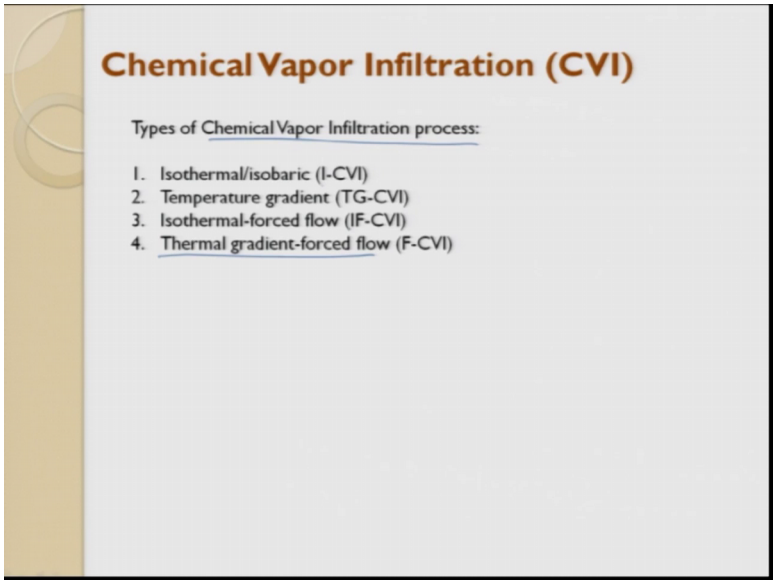

So, after the reaction the gas is allowed to exhaust and it goes into the atmosphere generally it is not in the pre atmosphere, but in into an exhaust. So, there are different types of chemical vapor infiltration process. So, one is called as isothermal or isobaric. So, isothermal constant temperature isobaric is also there constant pressure we can do it that is called as I-CVI you can also I have temperature gradient TGCVI; you can also have isothermal forced to flow IF-CVI. So, these are all variants of the process where and which it is used for used to make the ceramic matrix composite in a high quality output. So, the thermal gradient forced. So, if you see that it is all combination of the isothermal and thermal gradient isothermal forced flow. So, these are some of the different types of chemical vapor infiltration process which is used for making ceramic matrix composite.

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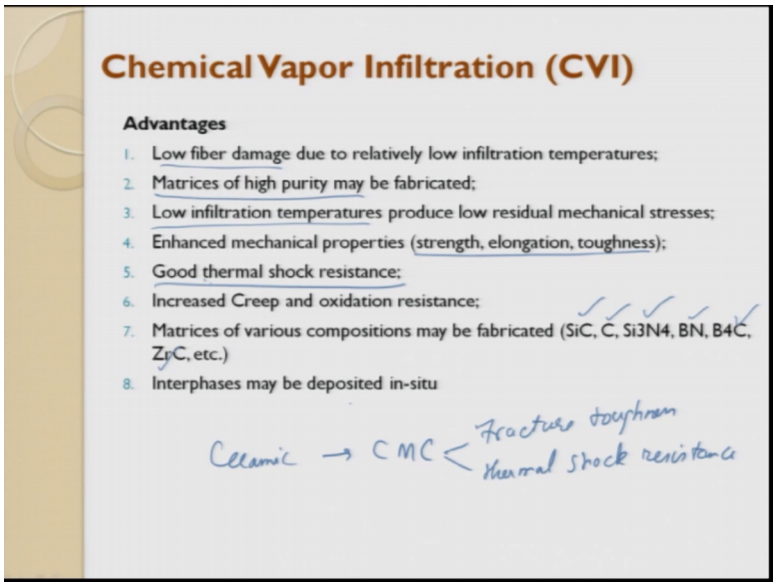

So, the advantages are the low fiber damage is due to low infiltration temperatures that is one and second thing since it is gas.

So, not much of the high pressure is applied there then the matrix of the high purity can be fabricated because it basically depends upon the gas reactant gas CVD process it is a reaction. So, here we use than MTS for making sic the low infiltration temperatures provides a low residual mechanical stresses which are there the enhancement in mechanical properties in terms of strength elongation toughness can be done a good thermal shock resistance is brought in. So, ceramic matrix composite is why is ceramic converted into CMC is because of 2 reasons one is fracture toughness and the other one is thermal shock resistance these 2 are the are a very very valid points which are trying to push ceramic to ceramic matrix composites.

So, in that case if you see CVI process gives you a very good thermal shock resistance then creep and oxidation resistance the matrix of various compositions can be fabricated sic we saw an example using MTS which gets the gas along with the reagent of hydrogen it gets into the pre-form forms SiC plus it releases Hcl also. So, you can have carbon you can have silicon nitride you can have boron nitride boron carbide and zirconium carbide as the matrix the inter-phases may be deposited in C2.

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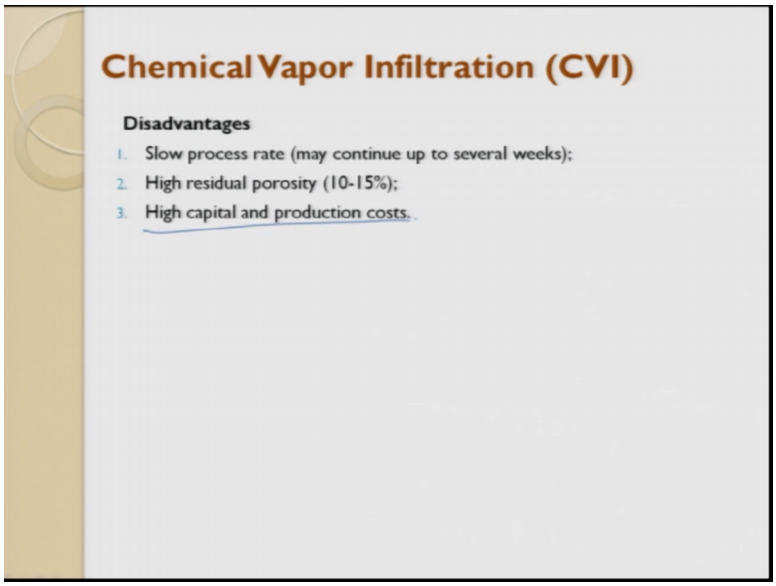

So, the disadvantages are this is a slow process the porosity even after all these things there is a porosity which is coming up 10 to 15 percent all the ceramic matrix composite fabrication process is highly capital intensive.

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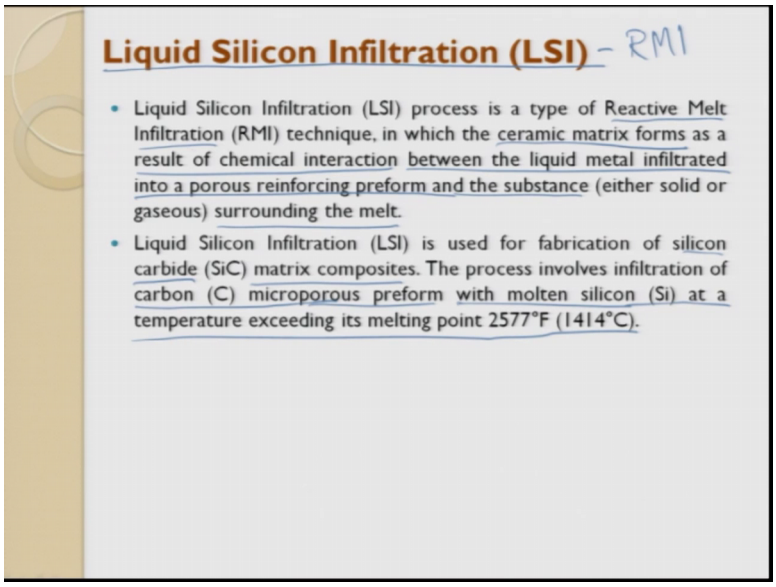

And the production cost is extremely high the next process of discussion is going to be liquid silicon infiltration process which is otherwise called as LSI liquid silicon infiltration process is a type of reactive melt infiltration RMI technique in which the

ceramic matrix form as a result of a chemical interaction between the liquid metal infiltrate into a porous reinforced pre-form and the substance surrounding the melt.

So, what you are trying to do is we are trying to take a we are already have a pre-form which is made out of ceramic and then we try to react with the pre-form with the matrix which is in liquid right and then it tries to form this composite ceramic matrix composite for example, in LSI infiltration is used in fabrication of sic matrix composite the process involves an infiltration of carbon micro porous pre-form into the with melt silicon at a temperature exceeding its melting point of 1414 degree Celsius.

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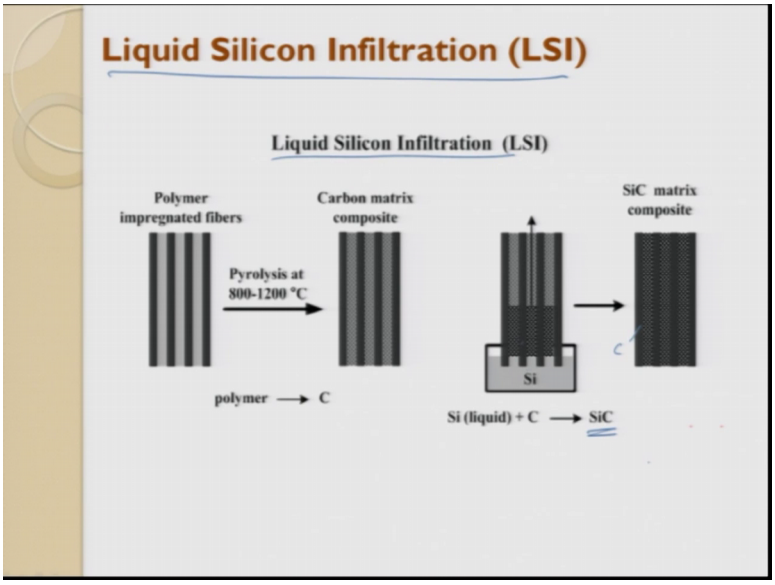

So, this is what it is. So, liquid silicon infiltration process polymer impregnated fiber I told you the common steps. So, that is there from there what happens it goes to pyrolysis it gets converted into a carbon. So, you form a carbon matrix composites right the next one is we try to put this carbon matrix composite inside liquid silicon and then through to capillary reaction this Si goes into this carbon matrix composite and forms SiC matrix.

So, this process is called as silicon liquid infiltration process and it is it is one of the classification of RMI. So, it is reactive melt infiltration it tries to react. So, now, the silicon whatever enter inside tries to react with the carbon and tries to form a silicon carbide matrix. So, this is used. So, the reinforcement fiber can be carbon also. So, it can be SiC dash C ceramic matrix composites and if you see all these fiber which are getting reinforced. So, the mechanisms which we discussed in the beginning of the lecture on

wearing types of mechanism fiber breakage fiber pulled out bridging of cracks all this things can happen in this ceramic matrix composites.

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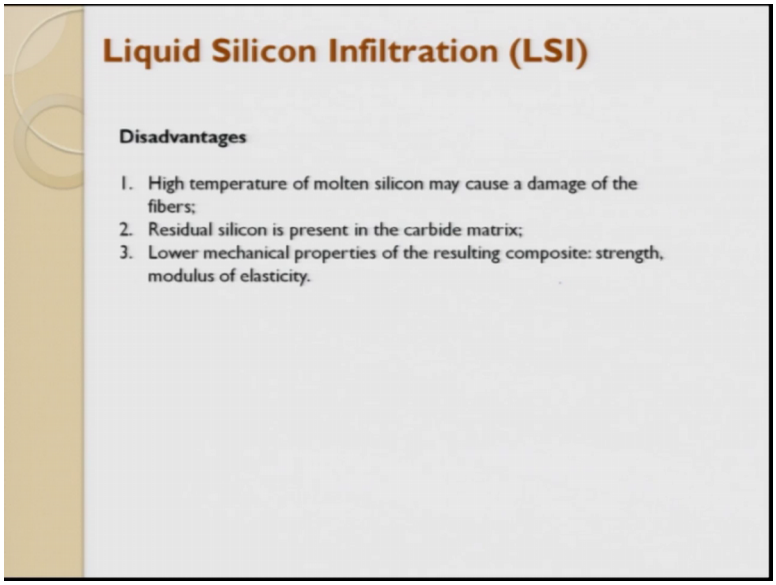

So, the advantages going to be this is low cost the production it needs a very short production time it has very low residual porosity because you first do the polymer matrix convert to pyrolysis and then that step also can be reiterate; for example, if you this step can be reiterate several times to get the packing of carbon in the in between the reinforcement.

So, thermal conductivity is very high electrical conductivity is done then it is also made to near net shape fabrication. So, the disadvantages are the high temperature molten silicon we are talking about a temperature of 1414 right. So, 1414; so, if you want have 1414 degree Celsius in a crucible. Now you have to see what should be the temperature of the crucible and next on top of it what should be the heating mechanism for this crucible. So, that you try to maintain a 1414 degree Celsius. It is really expensive and the technology is IP it is protected technology. So, the molten silicon is maintained at a temperature exceeding its melting point of 1414. So, the residual silicon is present in the carbide matrix that is one problem and it has a low mechanical property.

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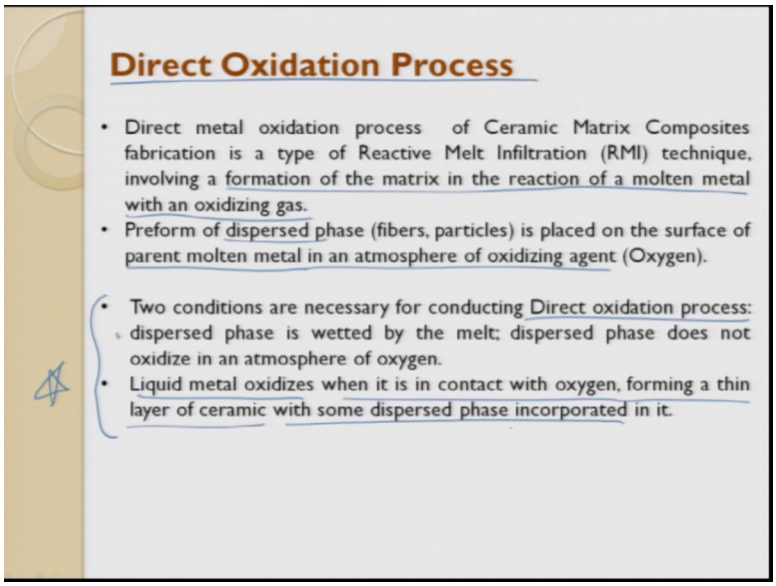

So, that it as compared to the others the next one process is called as direct oxidation process in direct oxidation process this is also one kind of RMI. So, here in which we involve of formation of the matrix in the reaction of a molten metal with an oxidizing gas that is why it is called as direct oxidation process. So, here RMI reactive metal infiltration is done. So, here the matrix which is getting which is which is pushed into the pre-form reacts of a molten metal reacts and then in the presence of oxygen it forms a ceramic matrix composite.

So, the pre form of the dispersed phase is placed on a surface of a parent and molten metal in an atmosphere where oxygen is reach. So, there are 2 conditions are necessary for conducting this direct oxidation process one is dispersed phase is wetted by the melt dispersed phase does not oxidize in an atmosphere of oxygen the dispersed phase; that means, to say the pre-form; pre-form must be wetted. So, that you bring in good inter-phase and the next thing is if it is oxidized then it will not allow the liquid metal to flow through.

So, the liquid metal oxidizers when it is in contact with the oxygen forming a thin layer of ceramic with some dispersed phase incorporated. So, these 2 conditions are again very very important. So, one the dispersed phase the ceramic should be wetted and then it should not react the liquid metal when coming in contact with the oxygen forms a thin

layer of ceramic with the silicon with the dispersed phase which brings in the ceramic matrix composites.

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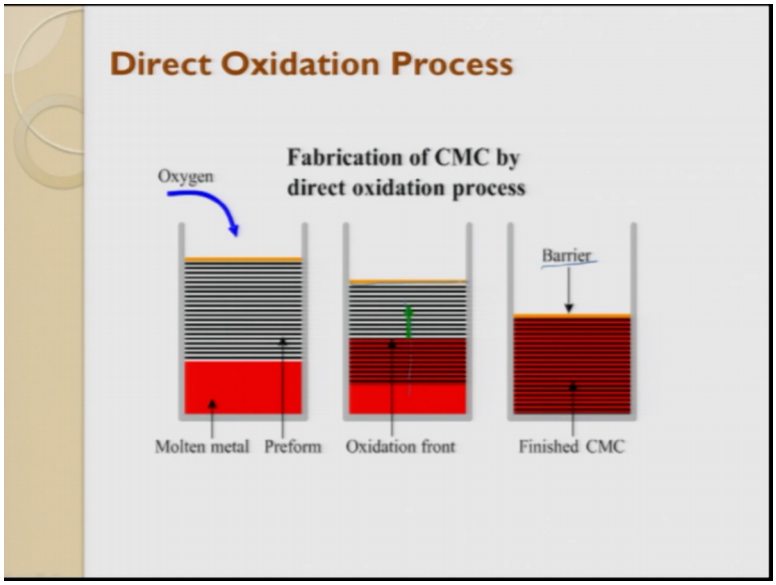

So, the figure is like this molten metal. So, here are the pre-form kept here is a molten metal. So, what we do is we try to pressure put oxygen on top right. So, then what happened the due to capillary action or due to force this metal slowly gets inside his mood by capillary action inside this pre-form and then in the oxygen which is there the it reacts with the oxygen and then it tries to form a ceramic matrix composites. So, this is the barrier. So, here is the oxygen which is reach. So, the 2 important points are is the dispersed phase is wetted by the melt right the dispersed phase is wetted by the melt disperse phase does not oxidize in the presence of oxygen next is the liquid metal oxidized when comes in contact with the oxygen forms a thin ceramic layer with some dispersed phase in incorporated into it.

So, this is a process for direct oxidation process. So, this is also part of r reactive melt infiltration RMI. So, if you see that RMI is direct oxidation processes is a RMI process and liquid silicone infiltration is also and RMI process.

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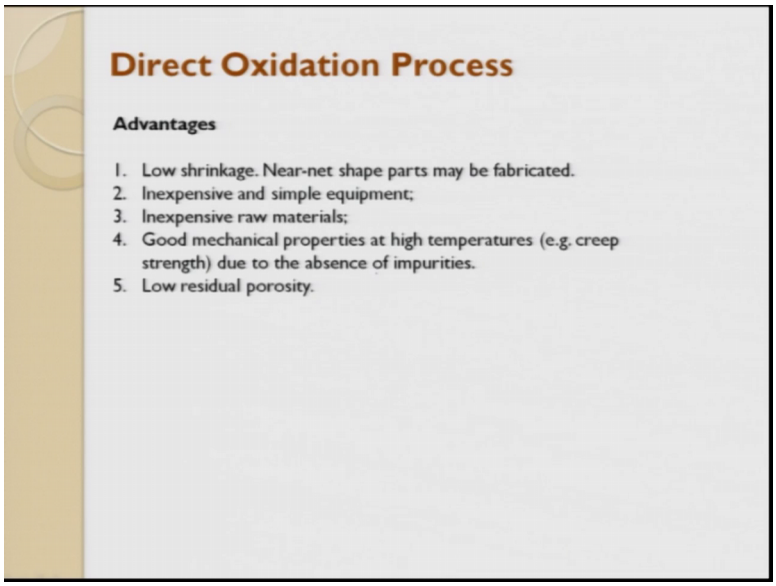

So, what are the advantage it has low shrinkage near net shape can be made, it is inexpensive because you do not need to have very high pressures and pushing and the raw material is also inexpensive, it has a good mechanical property at very high temperature in the presence and due to the absence of impurities.

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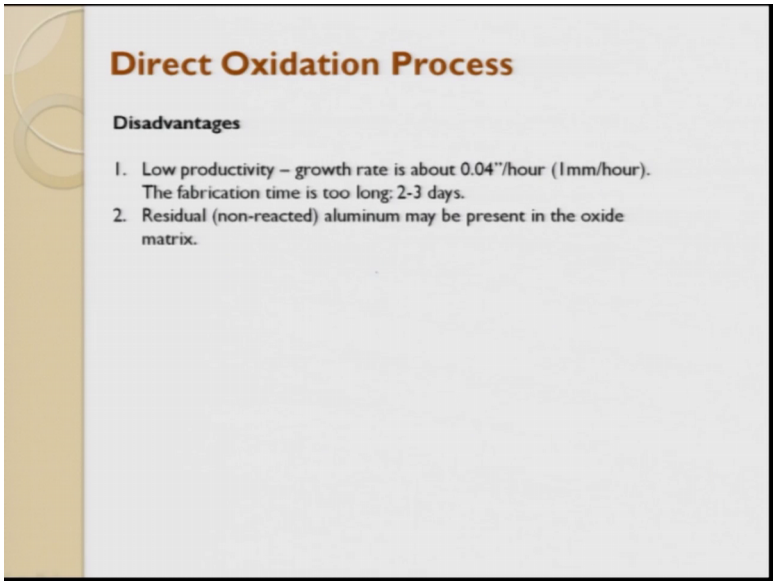

It is very good, it has very low residual and porosity in it the disadvantages are going to be it has low productivity and the residual aluminum may be present in the oxide which tries to react and form oxides and this will try to reduce.

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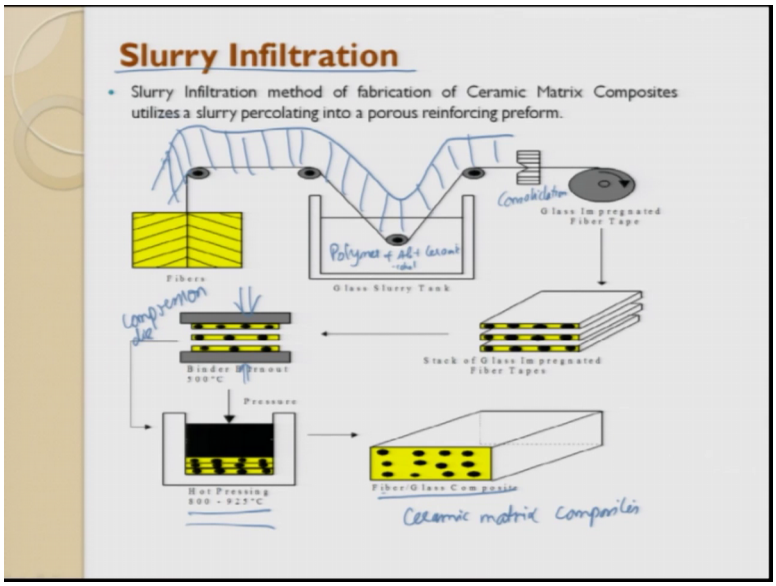

The mechanical properties the next process for fabrication is going to be slurry infiltration. So, what is slurry infiltration?

So, I here; what we do if we try to make this slurry which is pre coated and then on to a fiber. So, here is a fiber which passes through here is a slurry tank which has a mixture slurry tank which has a mixture of polymer which has alcohol plus it tries to mix with some ceramic. So, this is slurry. So, this slurry the fiber passes through the slurry and then the fiber gets dried up the slurry gets dried up and then it gets into a tape form. So, you here it is 1 D. So, you can also have 2 D; that means, to say a cloth along this direction you can have one more which goes like this. So, you can this is. So, this is something like a something like a mat all. So, you can have. So, this passes through and then it goes through the die. So, in this die what happens is consolidation happens consolidation means the slurry and the fiber they get properly wet and the excess slurry is removed and then what we do.

Is we try to make it into a tape this tape is now cut in depending upon the orientation like polymer matrix composite it is cut and then they are stacked on one above each other and then they are pressed in their pressed in at; in a compression in a compression die compression die it is pressed like a compression molding process it is press at 500 degree Celsius and all the binders are removed once it is all removed. So, then what do we do is

we try to take the pre-form put it in a hot press at 800 to 925 degrees C and then what happened; it tries.

Now whatever is that then this one whatever we get is a glass composite which we get and this is called as slurry infiltration method? So, through this what we get is we get a ceramic matrix composite; it is like your prepaid you can get the steps also their available in market. So, here you put according to the orientation and then you try to remove the binder first round and you can try to do why are you doing are 2 stages because if you can directly do it at a high hot press right, but the problem is if these binders are not removed and at hot press if it is getting removed it might stick on or it might create force.

So, that is why we do step by step removals. So, binder is removed in the first the gases can go away all the polymers can go away water can go away or whatever alcohol. So, alcohol not aluminum it is alcohol the alcohol can go up and then this ceramic is residue there and now you press it. So, all the small pores are removed.

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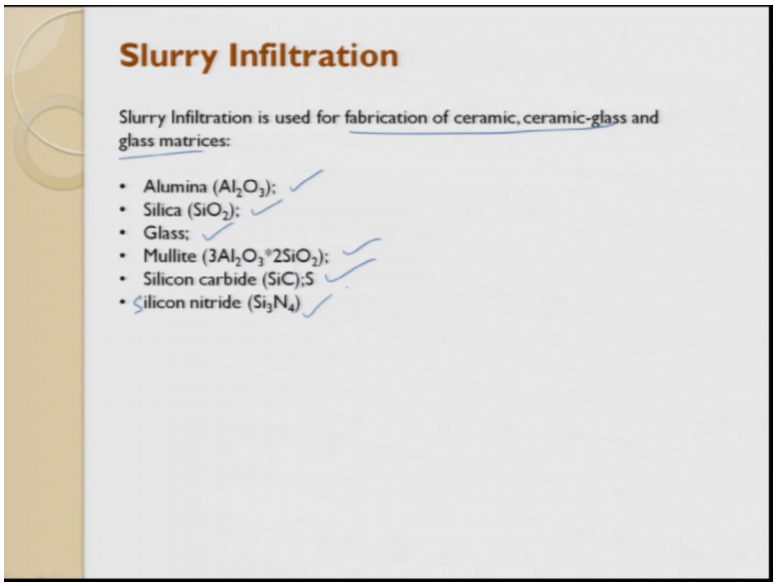

So, you get a clear composite ceramic matrix composite. So, this slurry infiltration can be the you can use these are the fabrics for fabrication of ceramic and ceramic glass and glass matrix alumina can be thought of silicon; siloca can be thought of glass mullite which is the form of a glass, then I SiC and then you can also have silicon nitride Si silicon nitride is also used in the in this slurry to; so that we can make the composites.

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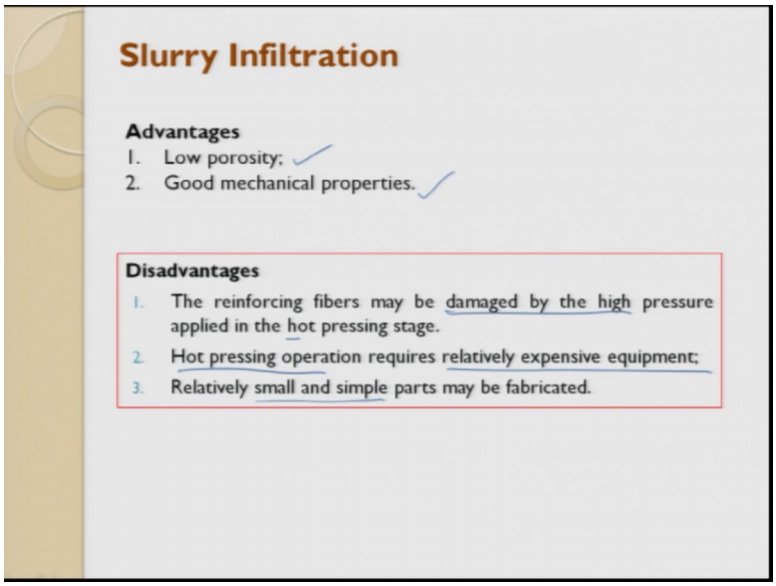

So, the slurry infiltration process it as an advantage of low porosity and it is has a good mechanical properties can be achieved because of this the disadvantages are the reinforcing fiber may be damaged because we are applying very high pressure and the 2 stages then the hot press generates relatively needs are relatively high cost equipment and they are used for making very simple and small parts using this process.

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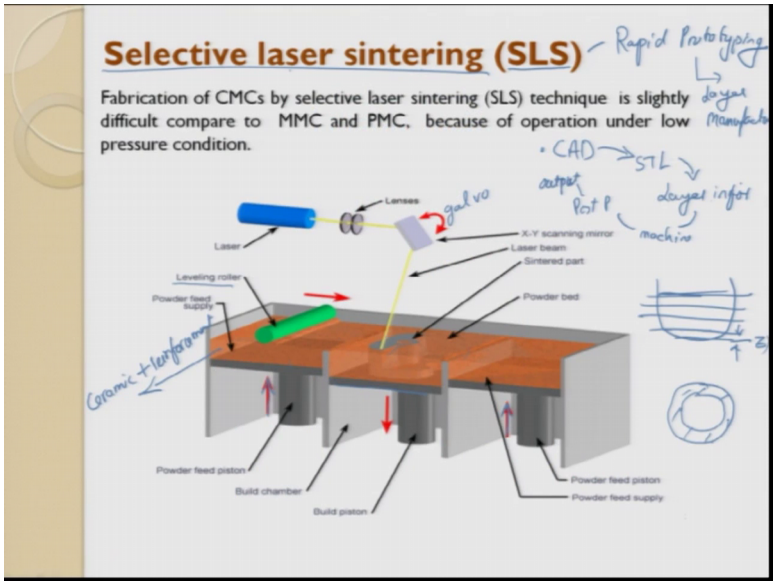

So, the other process which is called as selective laser sintering process this is part of rapid prototyping which is part of rapid prototyping technique. So, this is also used for

making ceramic matrix composite. So, here what do we do is we you can see here there are 2 powder feed units are there 2 powder feed units are there. So, in between what you have is a table. So, this is the table what you have. So, predominantly what we do is we try to take the ceramic powder and mix it with the reinforcing powder we do the reinforcing powder or what we do is we try to take the ceramic and try to coat the ceramic with for example, in a slurry form we tried to coat with the reinforcing and then we allow it to dry and keep the powder here. So, this is a powder supply if powder feed supply is done here and here it is also there. So, what happened is there whenever the; in rapid prototyping is always called as layer manufacturing layer manufacturing in layer manufacturing what we do is we try to build the product layer by layer by layer.

So, layer means it one layer. So, suppose you have a cup. So, this cup is made layer by layer it is built layer by layer by layer. So, this layer has a z has a thickness. So, this thickness will be the layer thickness here. So, every time when you try to sink that table by z the thickness. So, then what will happen the powder the powder feed supply unit this will advance by a certain height and then the powder will be moved from here to the center table that is done by a roller the roller is otherwise called as leveling roller; the leveling roller tries to move the powder which is a ceramic and reinforcing mixed powder into the center table.

So, now, in the center table what will happen is we will use a laser this is a laser which comes and the laser power depends upon the material. So, the laser hits on a Galvo stage. So, then that the information whatever was there one layer information is now transferred to the table and the laser hits at the table and sinters the shape whatever you have in one layer. For example, if this is a cup this is one layer, if you see the cross section; this will be something like this something like a ring.

So, now what has happened the laser will try to establish a boundary and then it will try to generate the thickness and then also try to have a inner boundary. So, with this one layer information is made. So, the laser is used to hit at the work piece and then at the table and then create a layer of information by this way you can also selectively use laser and follow a sintering process to get a ceramic matrix composite. So, selective laser sintering is the; is a new process which is coming to existence and people find lot of application here we directly; since we directly make it from a from a cad. So, in rough in selective laser sintering in rapid prototyping the steps involve on first we make a cad

model from a cad model we try to take an STL file; STL file to layer information layer information layer information to machine to post processing if anything is required and then we get the output.

So, since it follows this; so, any product which you want to make it into ceramic matrix composite. So, we draw the drawing we give the figure converted into some other STL and other formats and then bring that layer by layer information moment we have this layer by layer information then I have explain to you how does this work. So, layer by layer information a laser hits at one layer and tries to sinter selectively whichever places you wants to have a material, he just burnt that and tries to do a sintering process gets one layer of information. Now this is feed to a machine in this machine you have a laser to do it.

So, this process is used for making near net shape manufacturing. So, instead of this ceramic powder you can also use metal power you can also use polymer powder to get the required output. So, here if in case you want to generate a porous structure a pre-form can be fabricated through this process. So, that you can try to use any of the previously discussed process where in which you infiltrate a slurry or you infiltrate a polymer to get require ceramic matrix.

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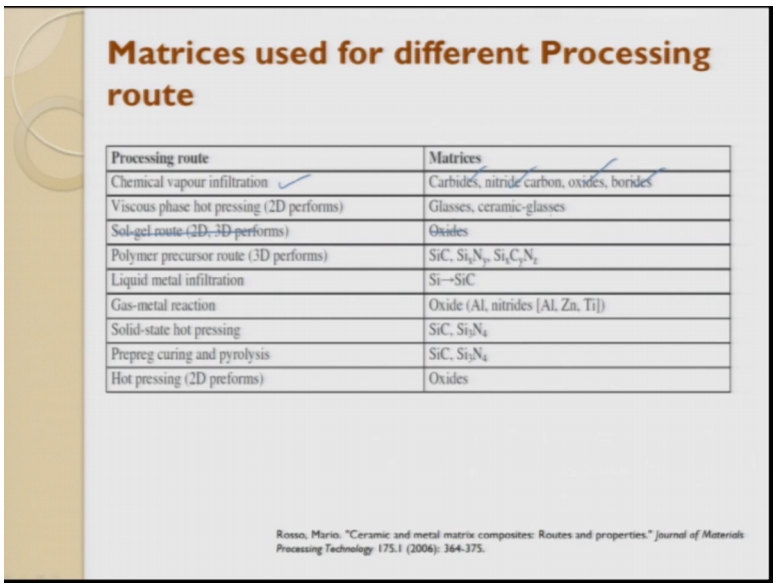

So, the matrix use for different processing route are for example, chemical vapor deposition CVI we use matrix of carbides nitrides nitro car carbon oxides and boride. So,

these are some of the matrices used. So, viscous 2 D form that is a hot pressing and other things we use glasses ceramics and glasses mix to use sol gel process we have not discussed. So, sol gel process we will avoid thus it is not very popular. So, sol gel process we use oxidies; so, then polymer precursor route which we have seen for SiC si. So, this is silicon nitride silicon carbon nitride this is what it is then liquid metal infiltration Si to sic then gas metal reaction this is nothing, but CVI which we have oxides then solid state hot pressing we can get SiC; Si silicon nitride prepreg curing and polymer pyrolysis process you can have sic and silicon nitride hot pressing we can have oxides.

So, these are the different processing routes and these are the different matrices which we can try to get the output sol gel route which is not very popular.

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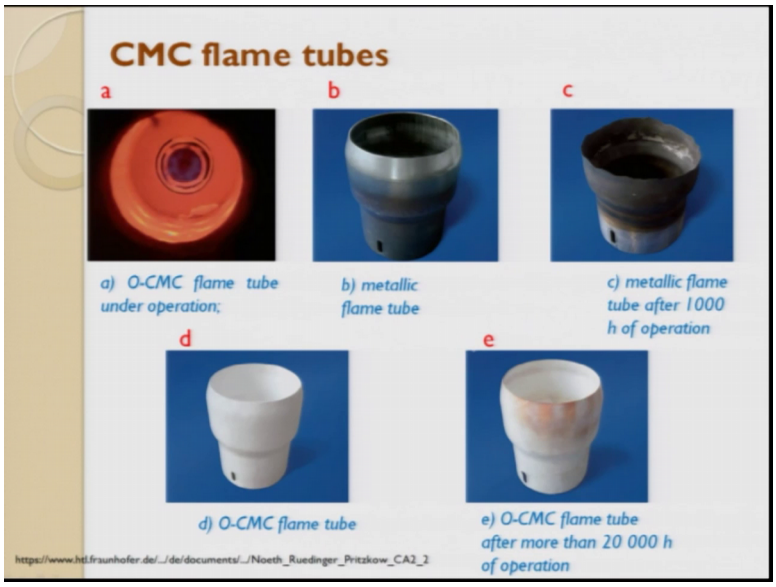

So, I am not covering it in this lecture. So, here are some of the ceramic matrix; matrix composite flame tubes which are made. So, you can see here this is oxygen ceramic matrix composite flame tube under operation. So, this is metallic flame tubes these are metallic flame tube after 1000 hours of operation metallic, right and this is oxygen ceramic matrix composite flame tube after to 20000 hours you can see this high temperature whatever was undergoing here we have used the same this is the processing under operation.

So, when you use metal what happens after 10,000 hours when you use ceramic after 20,000 are also we do not see any change in the shape. So, this is the beauty of ceramic matrix composites with this we will come to an end to ceramic matrix composite processing we will see in the next lecture about nano composite; how are polymer nano composites fabricated?

Thank you.