Manufacturing of Composites

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Lecture – 18
Processing of Metal Matrix Composites

Friends, let us move to lecture number 18, where we are going to discuss about processing of metal matrix composite. Last class, what we went through was what is metal matrix composite, what are the different types of metal matrices, what are the different types of reinforcement. What are the different types of forms of reinforcement, this is what we saw basically, in the matrix we saw that, it is aluminium. It is titanium, it can be copper, it can be magnesium, if you want to have a very high temperature application.

You can have cobalt, then you can also have cobalt, nickel, alloy mixed for those applications and as for as reinforcement is concerned. We had particulate reinforcement, wicker reinforcement, short fiber reinforcement and continues fiber reinforcement. So, today what we will do is we will go through some of the processes, which are commonly used for making metal matrix composites.

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So, we will see introduction followed by introduction. We will see different processing methods. Then, here we would see some of the liquid state processing of metal matrix composites. So, it is stir casting, is a process infiltration is a process in infiltration, you can use gas pressure, you can use squeeze casting, you can use pressure die processing of metal matrix composite in processing of metal matrix composite. You have many different techniques.

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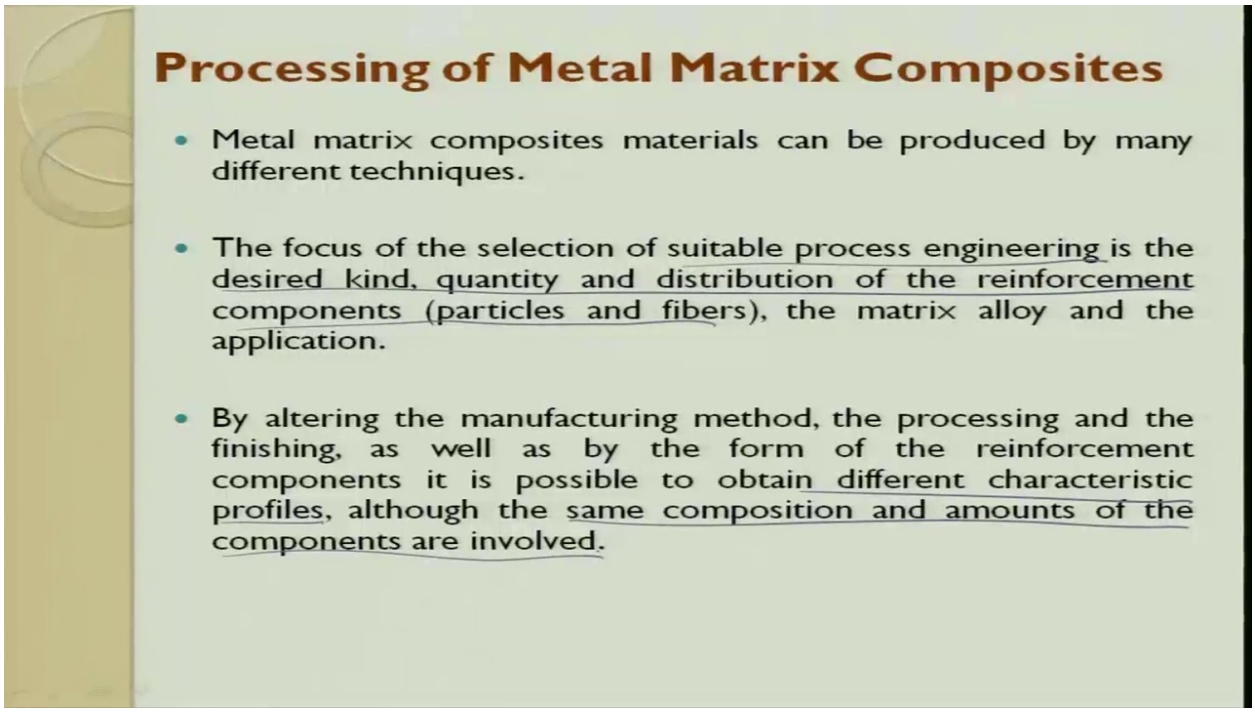

So, what you have to do, you have a suitable process is engineer, such that you have a desired kind quality and the distribution of reinforcement components in terms of particles and fiber, but altering the manufacturing methods the processing and the finishing and the finishing as well as by the form of the reinforcement component. It is possible to obtain different characteristics profile, all though the same composition and amount of the components are involved. So, by just playing with the process parameters you can even try to change the mechanical properties for your requirements. So, the processing methods can be classified into liquid state, In Situ process liquid status. You start the matrix in a liquid form and then you try to make a composite that is what is called as liquid state.

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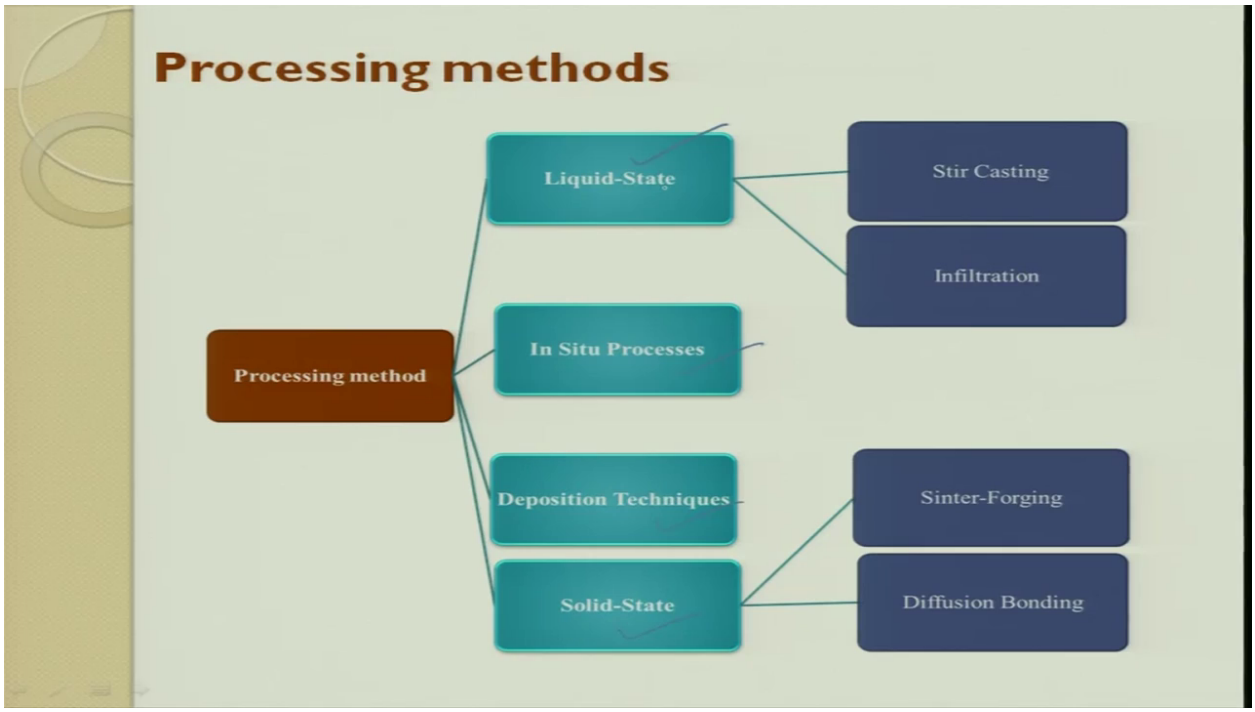

So, the vice versa you can also have a solid state; you can have something called as deposition technique. You can also have something called as In Situ technique. In Situ technique are basically, I take A plus B, I just put A plus B and then maintain a constant, I maintain some pressure or some temperature A and B reacts and In Situ, it form a composites.

So, those thing are called as In Situ processes, liquid state, the metal whatever is there is converted into a liquid metal or a alloy is there it gets converted into an liquid alloy. Then this liquid alloy is poured in the composite, in the ceramic net or the ceramic is added to the liquid state of the metal and then finally, we try to cast it, to get a require product out. So, those processes are called as liquid state process, what is. So, solid state process, I try to take a metal for a simple example like, I try to take a metal foil, I take 10 metal foil layers and in between the 2 foil layers. I try to keep some reinforcement.

So, this reinforcement can be a metal reinforcement or it can be a carbon fiber reinforcement or even a glass fiber reinforcement. So, when I say carbon fiber glass fiber in solid state. I can even keep a continues fiber, I can also keep a mat and then I stack them all in the required orientation, whatever I need and then I apply pressure and temperature. So, the metal melts and defuses into the reinforcement, such that you can try to get the required output. So, this is you have sintering for forging there and you also

have something called as diffusion bonding in liquid state fabrication, the liquid state fabrication.

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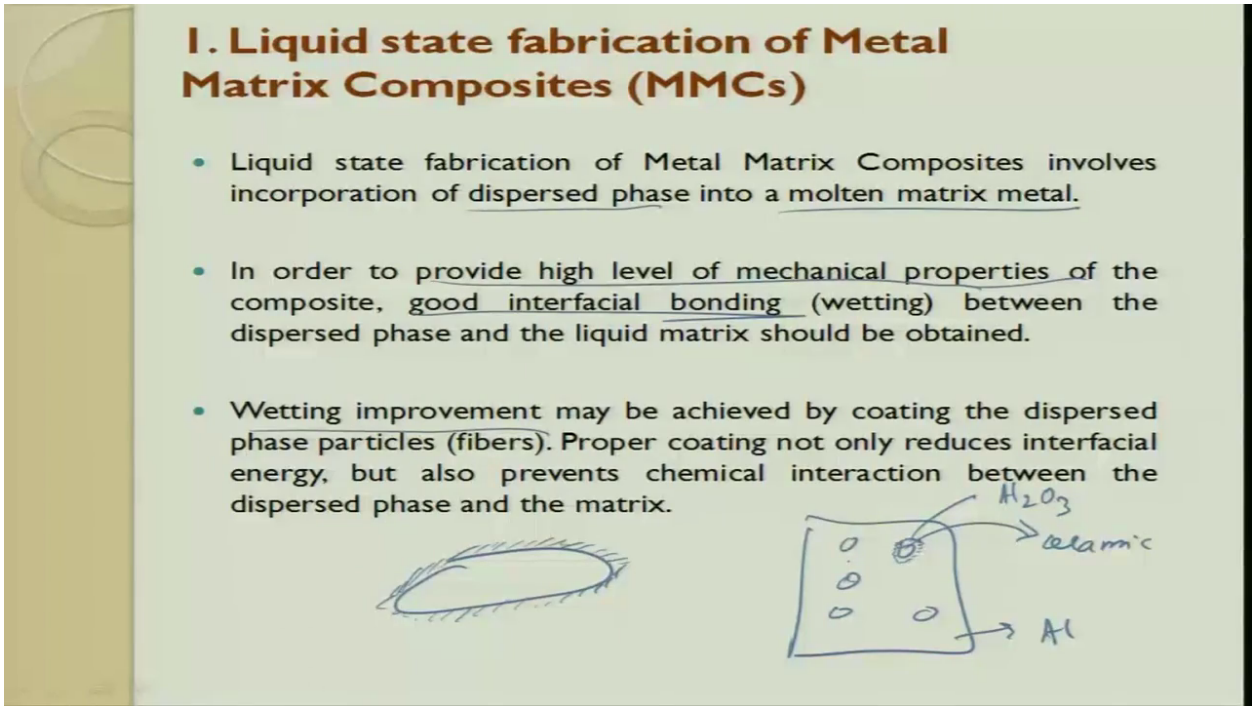

What happens is we take that, we try to take a molten metal and then dispersed a phase into a molten metal. It is like, you have a liquid molten liquid, it, let us take water and then you have this Sodi a Nacl. You just throw Nacl into water. So, here in this case Nacl dissolves, but assume that, it does not dissolve. So, what happens it gets mixed into the water and assume that you just put it inside a freezer, you freezer it.

So, when you freezer it, all this dispersed particles stay, wherever they are and the matrix get frozen and then you try to get the composite. So, in order to provide very high level mechanical properties, the good interface bonding is very important. So, people look that is why people look into what is the surface energy of the ceramic particle or what is the basic nature of the matrix can, these two fellows gel with each other and the if it gels properly than that of proper interface, if there is a week interface what happens is suppose, you have and you have a week interface, these interfaces, these has ceramic material. So, this interface will just drop out fall out because, there is not much of proper bonding with this fellow, with the matrix. So, there, when it falls out it, it creates dense. So, this is why, we always talk about good interfacial bound in metal matrix composite.

So, between the dispersed phase and the liquid matrix, it is to be obtained the wetting property; the wetting property can be improved. So, it is. So, suppose, you decide I wanted to take aluminium and I wanted to take this as alumina, but alumina and aluminium does not gel properly, assume it, does not gel properly, but still what is the way out, the only way out left to you is between this alumina and the aluminium.

So, you try to coat one more layer, with this layer which can try to help in locking of these particles, in the base matrix. So, wettability improvement can be achieved by coating that dispersed phase particle. It can be a fiber, it can be of particulate water or it can be a whisker. So, it tries to coat them and after coating, you try to disperse them. So, when I try to do it, there is a good interface strain, which is happening. So, a proper coating not only reduces the interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. So, that you can get a required output

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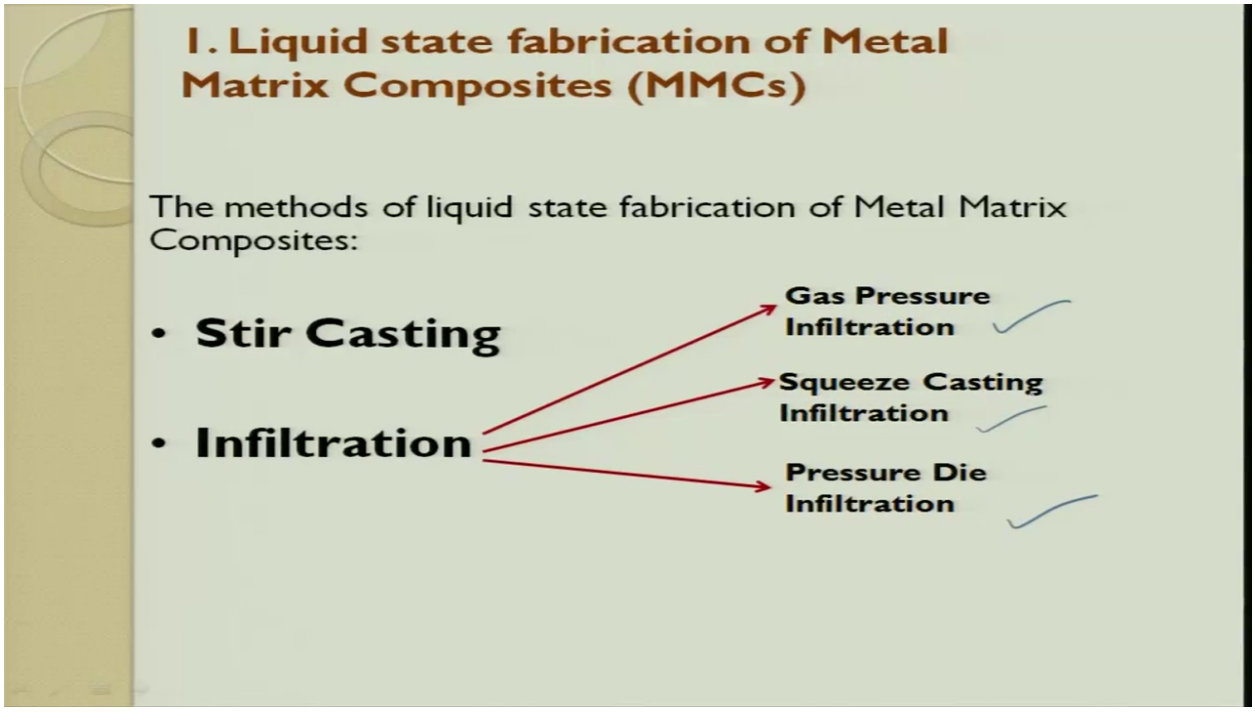

So, stir casting and infiltration, in infiltration you can have gas pressure, infiltration you can have pressure die, infiltration you can also have something called as squeeze casting infiltration. We will see them all, this process one by one. First is stir casting process.

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Stir Casting

- Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring.
- Stir Casting is the simplest and the most cost effective method of liquid state fabrication.

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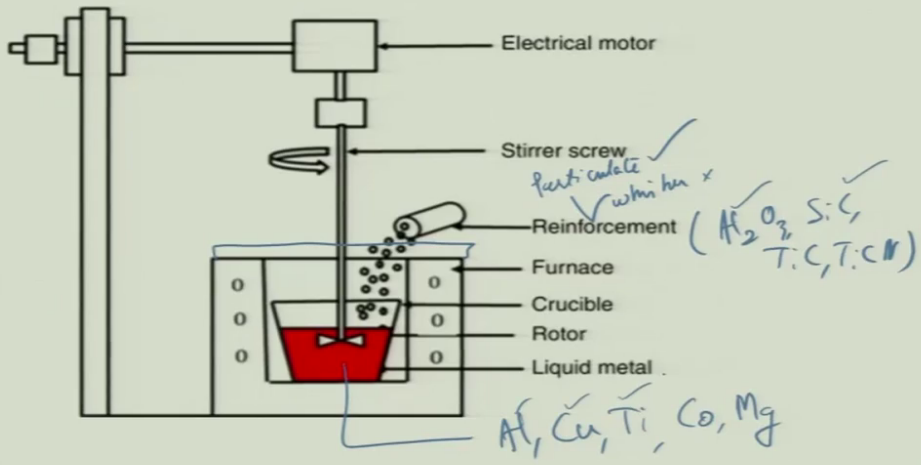
Stir Casting

Schematic diagram of Stir casting technique



So, in stir casting process, this is the basic process and majority of the researchers who work in metal matrix composites, for various applications, they tried to use the stir casting process, if you wanted, develop a setup. It is very economical. So, all you have to do is, you have to have a bucket or it is called as a crucible. So, this crucible is filled with a metal alloy, whichever you want to take. This can be aluminium, this can be copper,

this can be titanium, this can be whatever cobalt, this can be mg, whatever you want. So, it tries to mix it, you try to first heat it to a higher temperature and then what you do is, you try to, if you want, you can also try to maintain the atmosphere, heating is done.

So, the alloys get melted. So, once it is melted, what you do? You use a stirrer and then, this stirrer is used for stirring and uniformly distribute in the heat amongst the metal. So, it does a convention to this, tries to distributed the heat. So, that uniform melting as happen all along, at a certain viscosity, which you have already done. Some experiments, for you have figure out, which is the right viscosity, you tried to disperser reinforcement in to the metal. So, here it can be alumina, it can be SiC, it can be T i C, it can be TiCN, whatever it is. So, it is not necessary, you should use only one reinforcement, you can also use a combination of two three reinforcement mixed.

So, this is mixed and the reinforcement is dispersed. Now, inside the molten metal and even after dispersing, then the stirrer still keep continuing. So, the stirrer basic function is first to maintain uniform heat in the molten state and then, when there is a disbursement of ceramic happening, this these disperse particles should be uniformly distributed such that it gets very high mechanical properties. So, this process is called as stir casting process and after this stir casting, if you want you allow it to solidify, if you want, you take this mixed one and pour it inside a mold or insider a die to get a required output. It can also be used, it can also be poured and then, it can be used for injection molding also, metal injection molding also, I can be done. So, that you tried to get the required product out.

So, here the starting material pre dominantly will be only 2, one is particulates or the other one is whisker, but whisker is always a challenge. So, we always choose particulate and then try to disperse it. So, here depending upon the crucible size, you can have 1 kilo yield or 1 liter yield, you can have 10, you can have 100, depending upon the crucible. When the crucible goes larger and larger the heats application also should be taken care. So, this heat, the heater also should rating will increase, if you want, you maintain at vacuum or you can do it at free atmosphere. So, here copper also, people do it aluminium, they use it very exhaustively, cooper they use it. Some people have also use titanium magnesium, has some difficulty in processing through this root.

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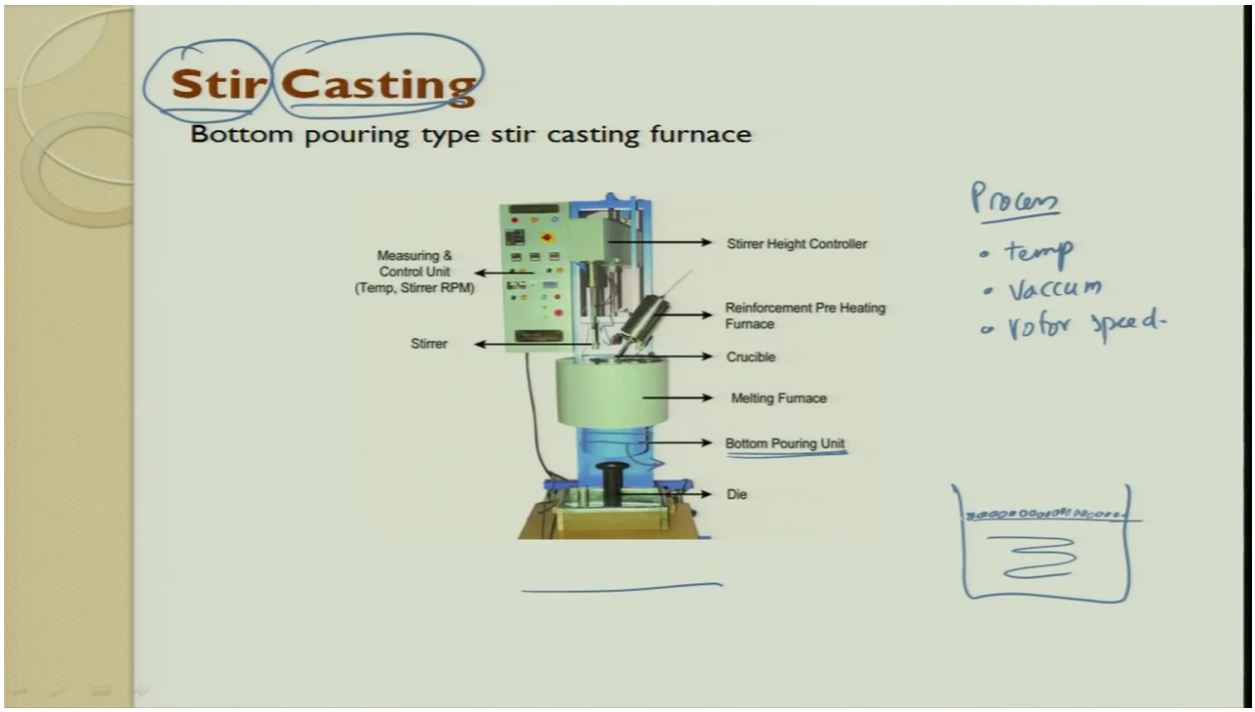

So, people do not use it. So, this is a typical setup, which is commercially available. So, these are the, and what are the process parameter, is one, is temperature, suppose you have a vacuum. So, you have to maintain vacuum, then you have to have a rotary speed very important. So, this rotary speed is used and then this is trying to disperse. The particles, you can see that, you can reinforcement separately or you allow the reinforcement to pass through, this stirrer and it can be done. So, this is a controlled process and you get the required output.

So, here once every, this is done on the top. There is something called as bottom pouring. So, here, what happens, this bottom pouring suppose, if there is a lied, this lied is opened out and everything is collected at the bottom into a vessel and then it is used for casting processing. So, that is why it is called as stirrer casting. You are stirring it and then finally, you casting it to get the required output, stirrer casting is characterized by the following features. The content of the disperse phase is limited. So, here you cannot go more than 30 percent volume, fraction should keep that in mind.

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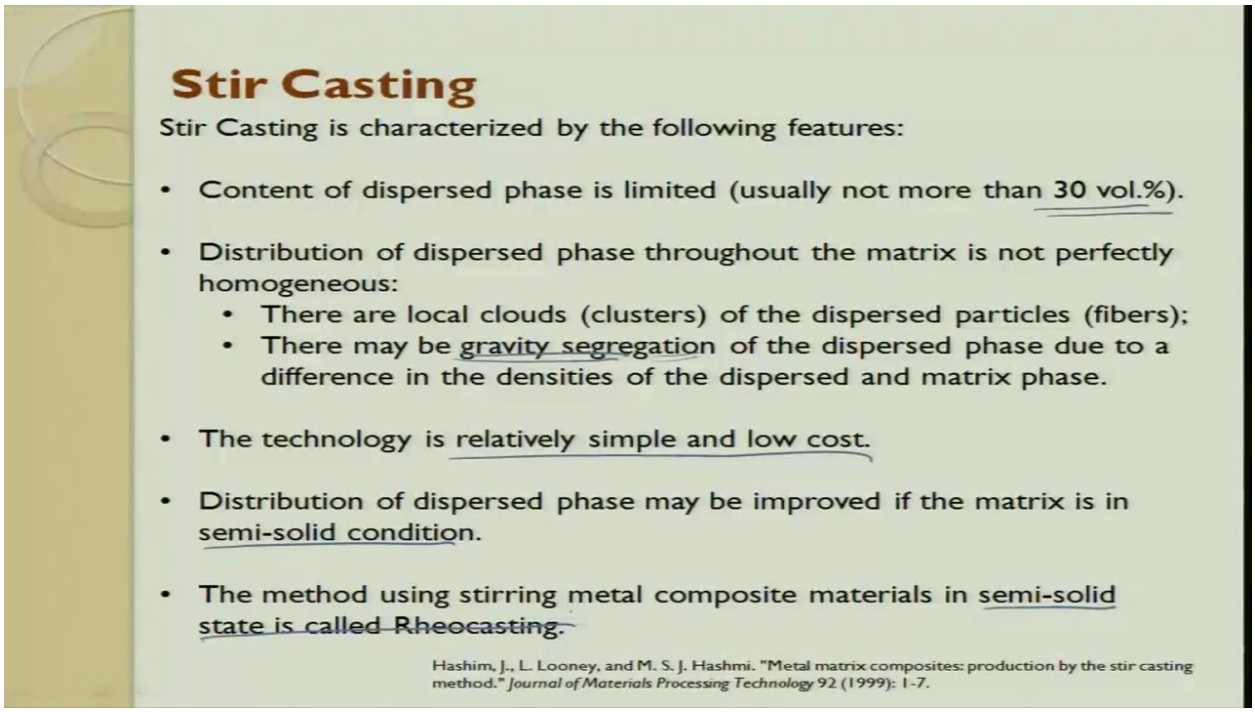

So, why is that very important? Suppose, you want make really a light weight composite, metal matrix composite. You keep adding more and more and more disperse. A ceramic particles will be dispersed it, moment you disperse it becomes lighter and lighter and lighter. So, if you have more amount of volume fraction of ceramic materials, then there is a problem of agglomeration. So, in order to have a proper distribution, the maximum best to possible is 30 volume fraction; however, this can be enhanced up to 60 percent by do by taking proper care and doing necessary modifications, in the set up. You can definitely get it done. So, the next one is the, distribution of the disperse phase throughout the metal matrix composite is not perfectly homogeneous.

So, in order to have that, what we do is we try to always functionalized the particle, the next thing is the ceramics, are always light in weight. The metal, if it has a higher density, then there is a problem of gravity, which come and this ceramic particles do not get mixed at the bottom. They always stay at the top. So, there may be a gravity segregation of the dispersion, because of the density difference. This is very important. So, you might get a metal matrix composite, liquid might be there, ceramic might on the top of it. So, if you look at it, ceramics will be the liquid, will be here and all the ceramic particles will be placed here, if there is density difference, it will be there and when you try to pour the first few set, all the ceramic particles get inside and afterwards, you get whatever you get filled up in the die, is only in the metal. So, this a very serious issue,

you have to keep this in mind and try to sort it out. The technology is relatively simple, because of that, it is very less expensive. The distribution of dispersion phase maybe improved, if the matrix is in a semi solid condition. So, that is why people call it as meshy state or reo casting.

So, today this stir casting methods are the method using for stir casting in the semi solid state, is also called as reo casting. So, rather than taking it to a liquid spastically, what you are trying to do; you have a solid, you convert it into liquid and then, try to freeze it and get back the solid rather than doing it. I try to take a solid, bring it to a meshy state. So, I apply lesser energy, but the viscosity is there. So, I have to make sure that viscosity plays an important role for dispersion. Keep that in mind and then add the ceramic particle and quickly space. So, by doing this, you are trying to reduce that time. You are also trying to reduce energy, which is used, but there are implications, which you have to make sure.

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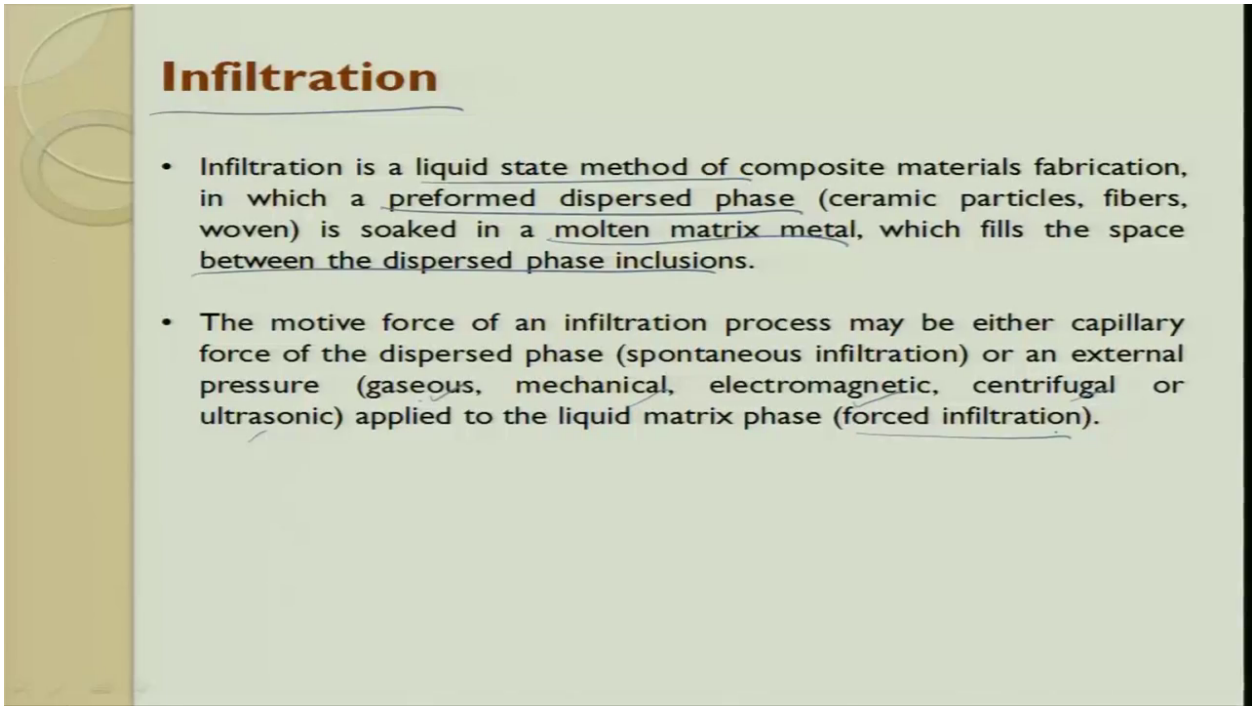

The next one is infiltration. Infiltration by the English meaning itself, it's says that you are trying to push somebody inside between the holes. So, here the somebody which is pushed inside is a liquid. So, how can you push liquid inside, either by a positive pressure or by a negative pressure.

So, the infiltration is a liquid state metal state method of composite fabrication, in which a pre form dispersed phase is soaked, in a molten metal matrix with which fills the space between the dispersion phase inclusions. The motivation force of infiltration process, maybe either capillary, a force of dispersion phase or an external pressure, which that is what I told you. It can be gaseous, it can be mechanical, it can be electromagnetic, it can be centrifugal or it can be ultrasonic. The liquid phase is forced inside infiltration. So, if it is by capillary vacuum, it is called a spontaneous infiltration.

If it is pushed intentionally, it is called as forced infiltration. So, now, quickly what all should come to your mind, whatever is the dispersed phase. Now, I cannot have just particles there. So, it has these particles, should be in some form. So, when it is some form, it has to be stiff enough for the metal to get infused. So, these are some of the difficulties.

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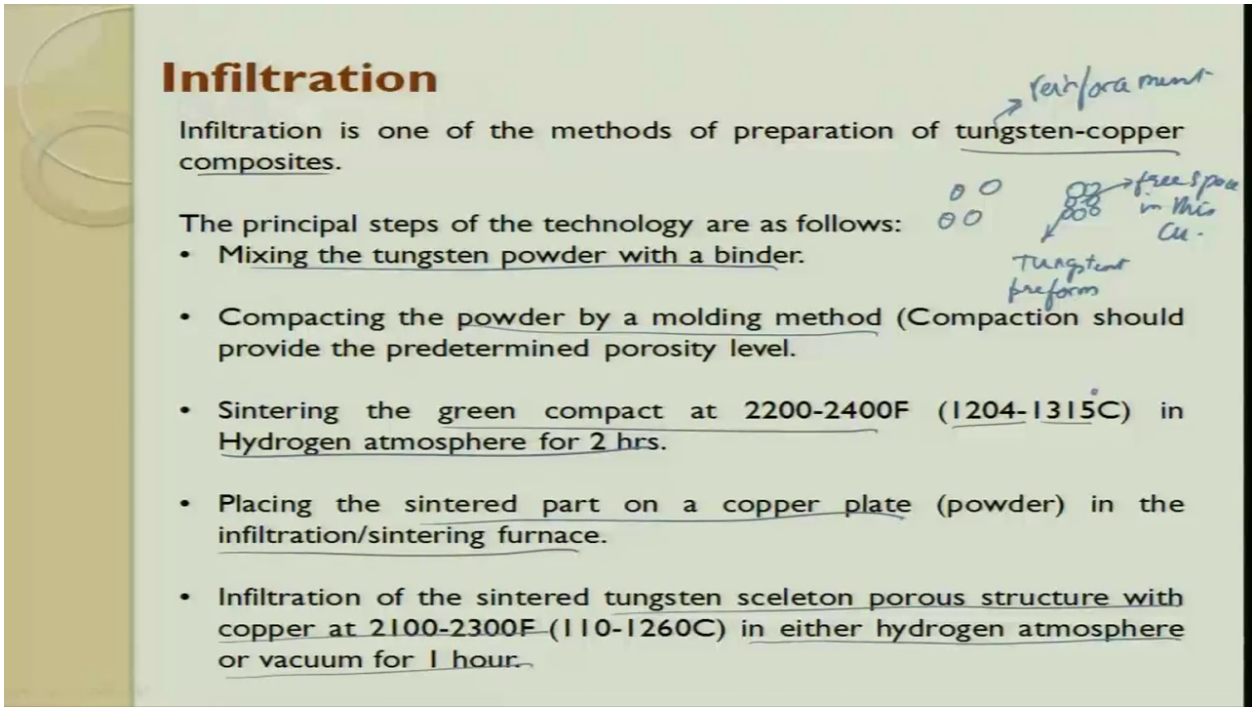

So, the infiltration is one of the method for preparing tungsten, copper. Composites is one of the methods, I said, there are many methods and any metal matrix composite can be produced by any process, but you always look at the best output in terms of energy, in terms of performance, then you choose it. So, here infiltration, the mixing of tung titanium powder, with a binder, then it is, then compacting of the power by molding

method, then you sinter that green compact to such a high degree and 1,200 to 1,300 degree Celsius. It is degrees Celsius, in a hydrogen atmosphere.

So, that you do not have any reaction getting formed place, the sintered part of the carbon plates, in the infiltration or in a sintering furnace, the infiltration of the sintered tungsten porous structure with copper, at this temperature. In either hydrogen or in vacuum for 1 hour, what happens is the copper gets infused inside the tungsten or the tungsten particles try to give the, this is a reinforcement. So, finally, how does it look like? So, you have a particles, these particles are bound and then, this is a free space.

So, in this copper comes. So, this is an infiltration method, where and which copper is infuse inside the tungsten, tungsten it is a pre form.

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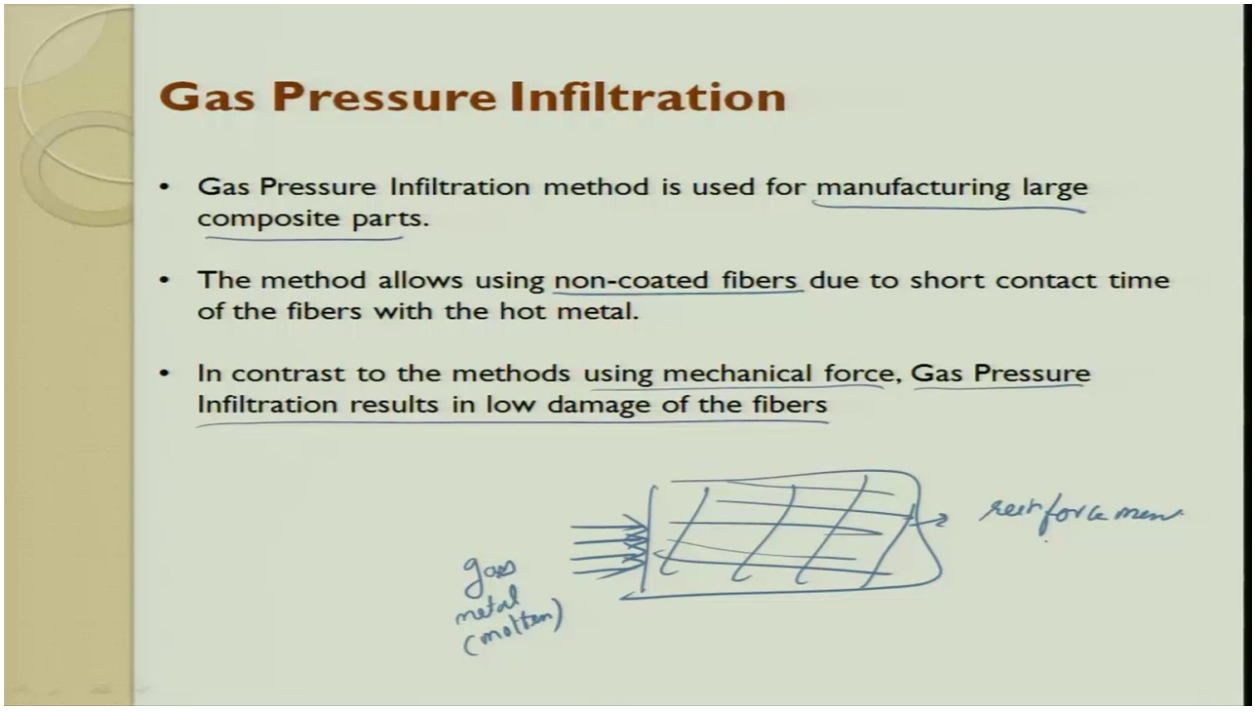

So, gas pressure infiltration, the gas pressure infiltration method is used for making very large composite parts of made out of metal matrix composite. The method allows using non coated fiber due to short contact time of the fiber with the hot metal in contrast to this method, using mechanical force. Gas pressure infiltration results in lower damage, to the pressure basically, what happens is you have reinforcement preform, which is nothing, but the reinforcement, if you try to push this fellow push, this fellow with gas

and what are you pushing, you are trying to pushing, a push, a metal and this is in the molten form.

So, then what happens the preform, whatever is does not get damage, the metal gets reinforced and then tries to produce an output.

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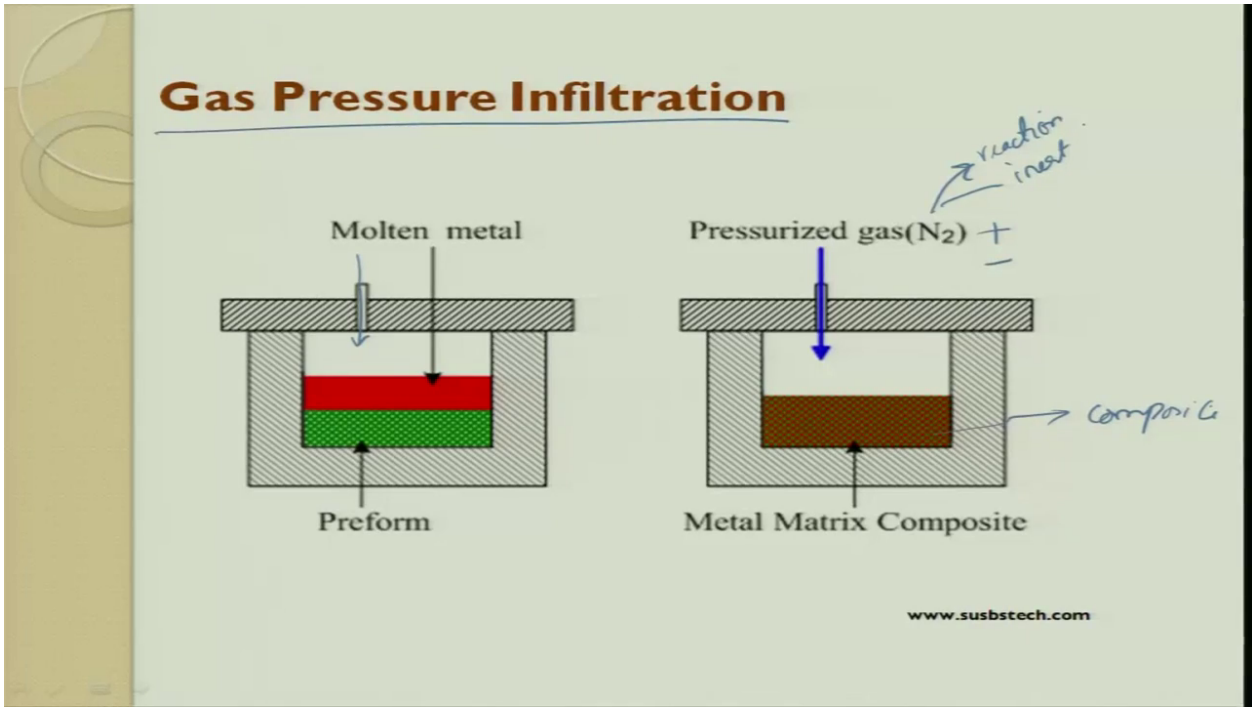

So, this is the gas infiltration, which is by pressure. So, what we do is, we have a container, we have metal, we have a pre form whatever is there and now, what we do is, we apply pressure through this. When we apply pressure through this, the liquid whatever is present there tries to get infused in to the preform and try to make a composite. So, this is a composite, you can use it positive pressure. You can use a negative pressure and here, this gas plays a very important role, you can also have this gas. Can you, can also choose this gas to have reactions. You can also have a inert gas. So, that you do not have any reactions to happen.

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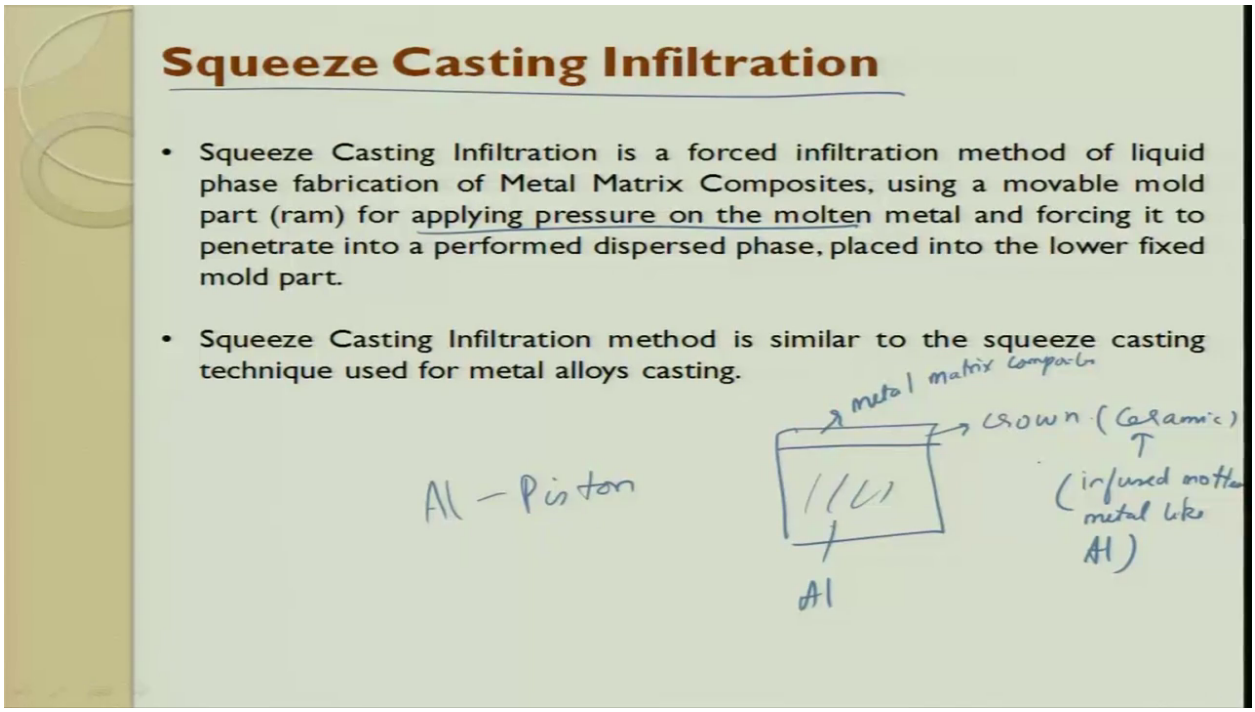

The last one in the infiltration process discussion is going to be squeeze casting. Squeeze casting is, you squeeze, you apply force. So, here it was not apply, it was force apply to gas pressure right, but here what we are trying to do is, we are trying to squeeze, we are trying to pressurized, we are trying to inject metal in a very high pressure. So, squeeze casting infiltration is a process, where in, is a force infiltration method, where in which the liquid phase is moved is pushed by applying pressure. By applying, this pressure, this pressure tries to be exerted on the metal and this tries to infused and then try to produce an output, a sample example is the piston aluminium pistons. So, in the piston, you have a crown. So, this is a crown.

So, here what we do is we try to reinforce with ceramic particles and this ceramic particles are infused with molten metal like aluminium. So, here this is alloy. This is a metal matrix alloy, metal matrix not metal matrix alloy. Metal matrix composite and it is only at the top. So, that you try to get. So, here it gives you wear resistance it also gives you the thermal wear resistance - it also gives you the thermal wear resistance; that means, to say when (Refer Time: 22:23) the nothing get a eroded on the surface, because there is a ceramic, also protecting the metal. So, squeeze casting infiltration is similar to that of a squeeze casting other techniques used in the metal matrix alloy castings.

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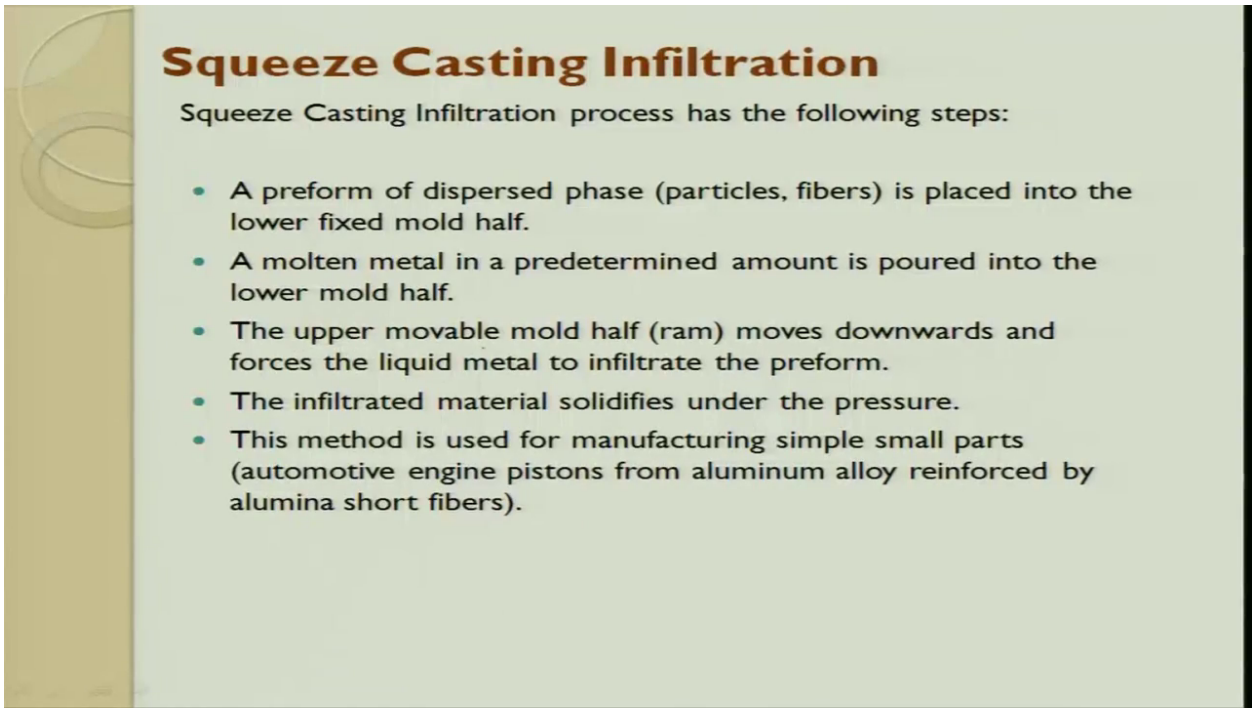

So, here the process of pre form of a dispersed phase. It can be a particle, it can be a fiber, is placed inside a mold, it is placed inside a mold and then what we do the molten metal is in a pre determine amount is pour into the mold, the up then what we do is. So, we try to use. So, you can see the figure here.

So, first what we do is we put a pre form. We tried to put the liquid metal on the top and then we try to use a ram, a press, we used here press.

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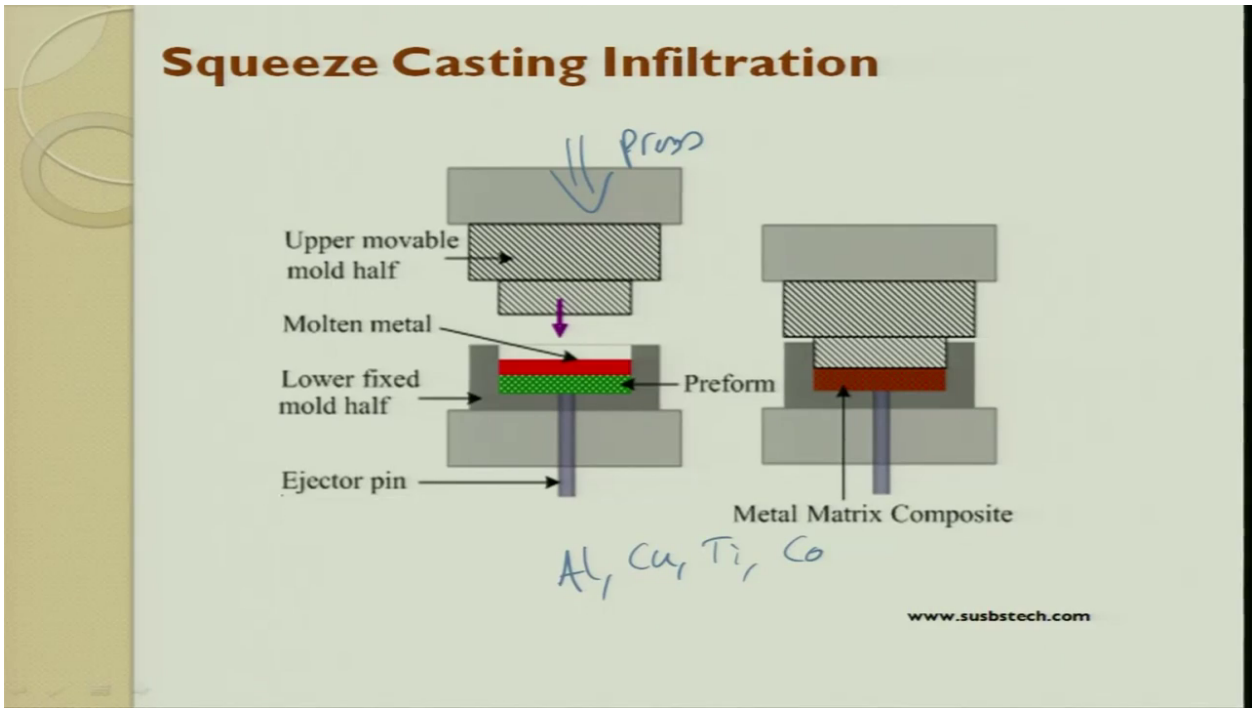

So, this press, what it does is it tries to heated the metals and then this metal is now pushed into the space, whatever is there in the reinforcement and thus we get metal matrix composite. So, here it is called as squeeze casting infiltration, the first one what we saw was, it was gas pressure infiltration. Here, it is mechanical squeeze cast infiltration.

So, here you can use aluminium, you can use copper, you can use titanium, you can use cobalt, whatever you want and apart from this you have, you can also use many other things. Today, people are started using a rare earth metals also getting mixed and here the important aspect is an injecting pin, the injecting pin is use to release, the composite after the composite is fabricated. So, till it was, it was squeeze casting, then it is pressure die casting.

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Pressure Die Infiltration

- Pressure Die Infiltration is a forced infiltration method of liquid phase fabrication of MMC, using a Die casting technology.
- When a preformed dispersed phase (particles, fibers) is placed into a die (mold) which is then filled with a molten metal entering the die through a sprue and penetrating into the preform under the pressure of a movable piston (plunger).

So, in pressure die casting, the pressure die infiltration is a forced infiltration method of a liquid phase fabrication of metal matrix composite in the die casting technology where the, when the pre form is dispersed phase is placed into a die, which is filled with a molten material enters the die through a sprue and then gets. So, this is the way we do it.

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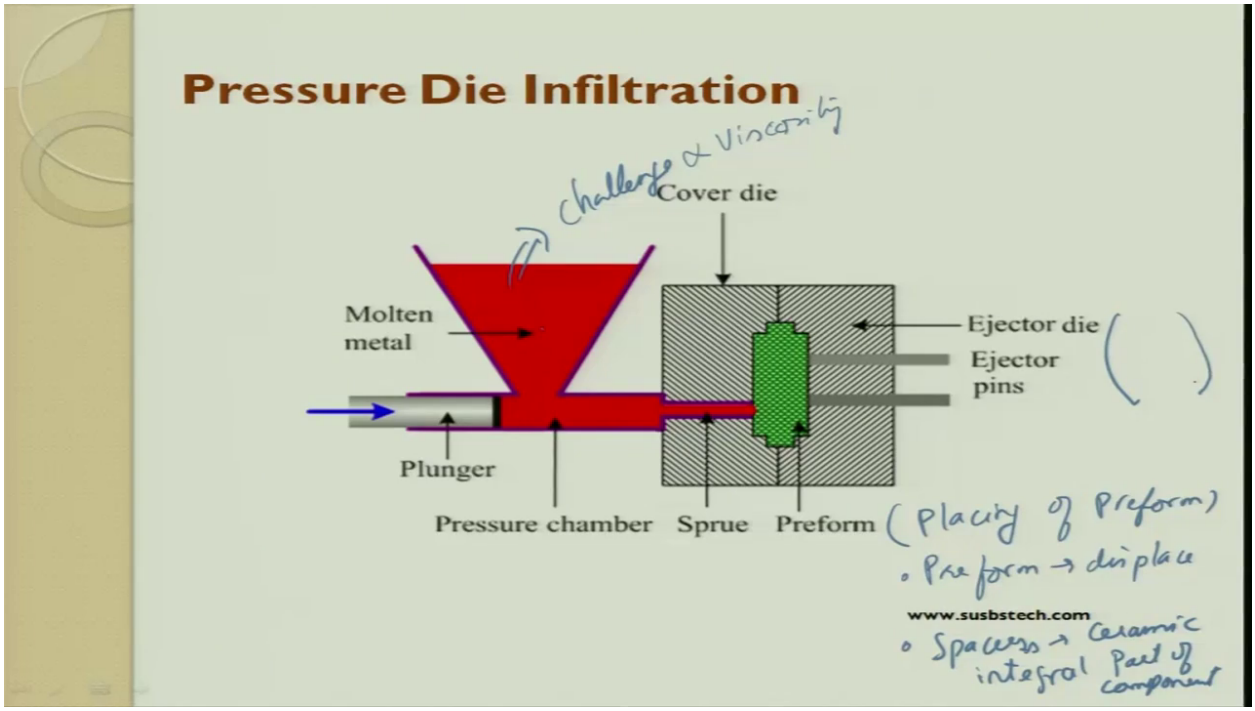

So, here is a molten metal, the challenge. This is a challenge, it is not. So, easy pictorially, it looks very easy. This is a big challenge you try to take a liquid metal, try to maintain the temperature of the liquid metal, why is it important. So, that this is your, have the challenges directly viscosity measurement, viscosity what measurement, viscosity maintain. So, this has to be in a form, such that is in a liquid form and this liquid form is used to the plunger, is used to pressurize. It goes through a sprue and then here is a preform placing, the pre form is also a challenge placement of preform, why; because of this very high pressure the preform gets displayed moment it gets displayed, we will not have a quality product.

So, what people have started doing is they are trying to add like in casting, they are also trying to add some pressures and these pressures are again ceramic material and they are becoming later integral part of the component. So, moment they have made as a integral part of the component. So, then this also stays there for rest of it is life. So, we have to choose a proper pressures. So, that we maintain it. So, these are injecting pins for removing the component freely as an when it is made.

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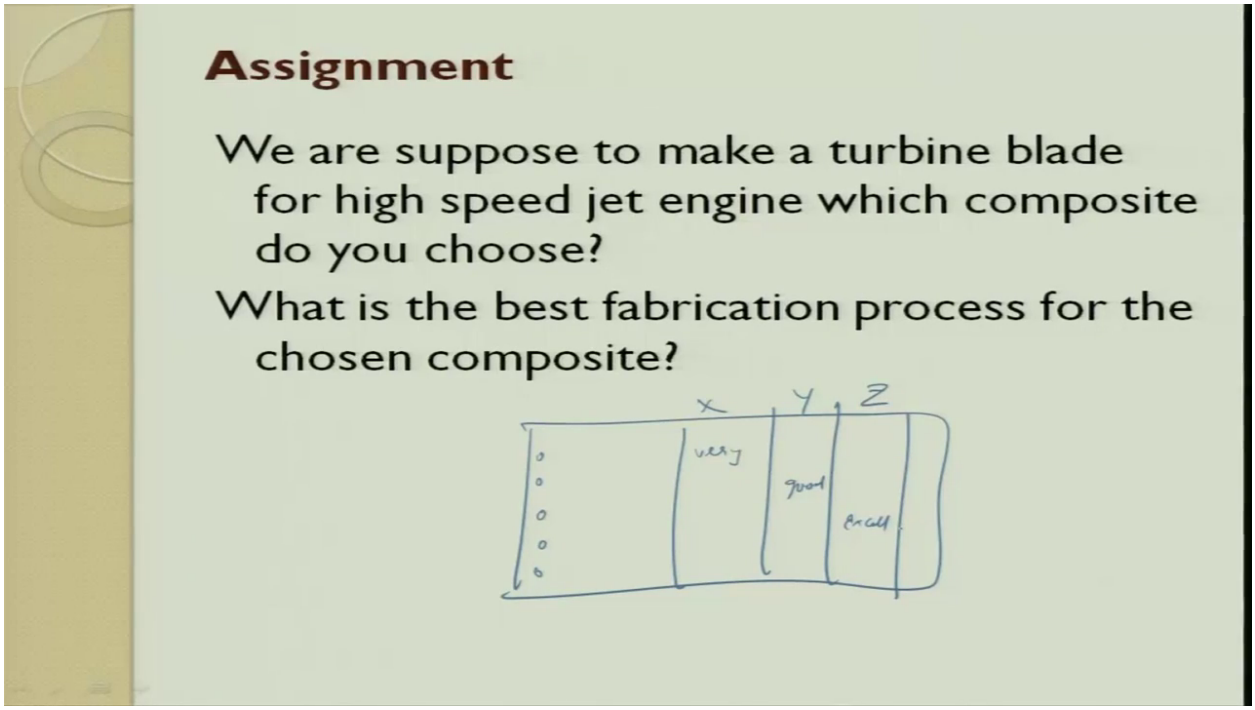

So, with this we come to a conclusion. So, what we covered today was, we just looked into only one type of one set of liquid, liquid state fabrication process of metal matrix

composite. In the next lecture, we will see other processes also the most simplest one which is used is stir casting process, the form, the application point of view, from quality point of view, performance point of view.

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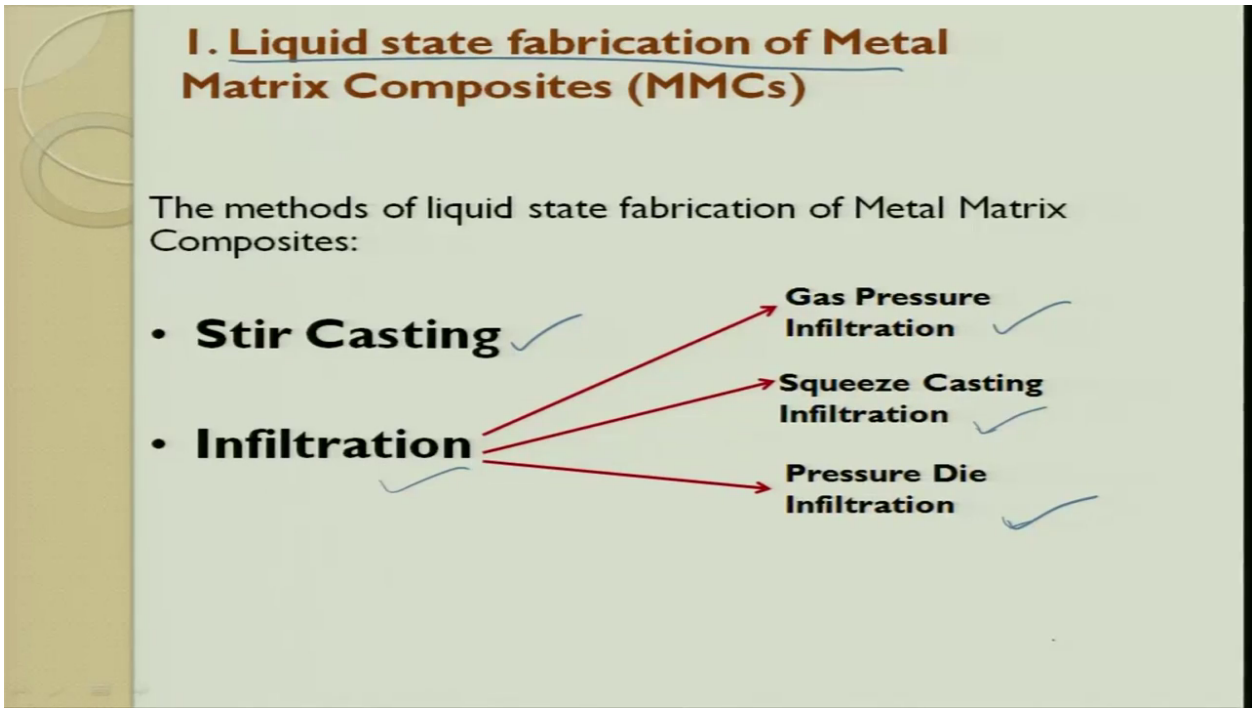

We always go for infiltration technique. This infiltration technique can be done by gas it can be done by squeeze; it can be done by pressure.

So, in gas what we do is, we just apply a gas pressure on top of it and we make sure that wherever there is a space in the pre form of ceramics, this gets defused. Then we also, what is diffusion; diffusion always happens, when there is a concentration difference. So, there is a diffusion happing. So, then squeeze is, what we do is, we try to apply pressure, mechanical force and then we try to squeeze it, when in pressure die, the pressures are phenomenally high, which is used to inject a metal into the preform, such that we get the good quality output. So, pressure die casting aluminium pistons are made out of pressure die casting, squeeze casting, they are used for making very large area of parts and that there has to be a pre form. So, with this, we come to an end of this lecture.

So, we were, would an assignment, which is again a self study for you is now, if somebody approaches you that he wants to make a turbine blade for a high speed jet engine, which metal matrix composite will you choose and what is the fabrication

process will you suggest for making such blades. So, when you try to say the second question answer, try to write it in a tabular form, try to compare with process x, process y, process z and then try to say these are the salient points for each process. I said very good, good, excellent, whatever it is. So, please try to make it in a table form and compare and then conclude, which is the best fabrication process, do you suggest for making this turbine blades, for high speed jet engine.

Thank you very much.