Introduction to Composites
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Lecture – 09
Graphite Fibers

Hello, welcome to Introduction to Composites course. Today is the third of this particular week. Yesterday we had just started discussing about graphite fibers and I had mentioned that graphite fibers or graphite in general as a substance is layered, has a layered structure and by the very because of its very nature the structure is such that it has very high in plane modulus and out of plane modulus is not that high. The other thing about graphite is again based because of its structure is that it is very easy to break along its, between the planes. So, that is why graphite fibers also tend to be brittle in nature.

Now, what we will do is, we will look at different types of graphite fibers and also how are they produced. So, let us look at production process.

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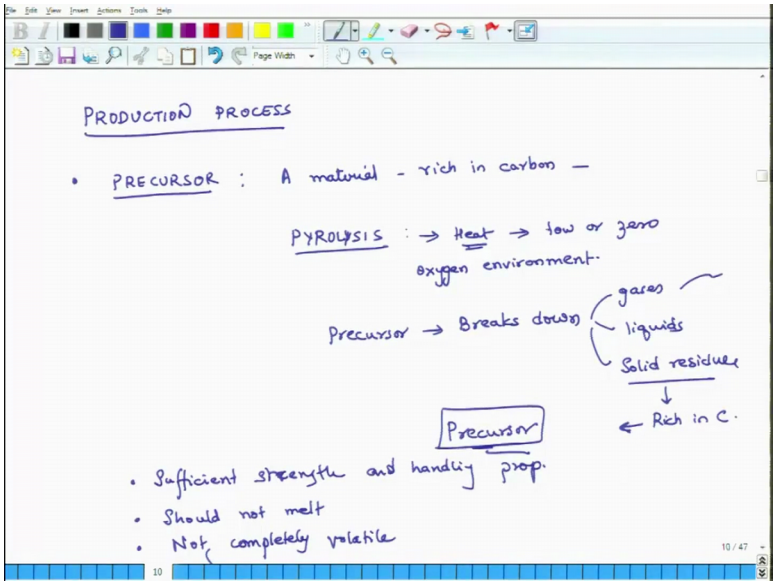

How are graphite fibers produced? So, to produce a graphite fiber you need some raw material, you need some raw material the raw material used for graphite fiber is called a precursor, precursor, that is the raw material. And what is; if we have to define what is precursor, it is a material which is rich in carbon because if you have to produce carbon fibers you need to lot of a carbon. So, it should be rich in carbon and this material when

it is subjected to heat somehow, we somehow from this material we removal other elements and we are left with only carbon. So, this is a material which is rich in carbon and the way you remove all other materials and just are left with carbon alone is through the process known as pyrolysis.

So, pyro is associated with the meaning of fire. So, essentially what you do is you heat this material in a special way because if you heats let us say wood in air it will just burnt. So, you have heat it in a special way so that you are only left with carbon and the thing does not burnt. So, in pyrolysis what happens? We apply heat and as a const in a special way and, so this is basically in a low or zero oxygen environment and at high temperature. So, this temperature is not small it is at a high temperature. And as a consequence of it the material precursor it breaks down, it breaks down into gases, some liquids and solid residue and this solid residue is rich in carbon, rich in carbon. So, this gases go out liquids are taken away and what you are left it is rich carbon based residue. And it is this material which is then use for further what you call production of graphite fibers. So, this is what gives you the precursor.

So, how do you get a precursor? You take a material which is rich in carbon, heated through pyrolysis and then you are left with the residue which is left with precursor. So, so this your precursor, and if it is a good precursor what should it have? It should have sufficient strength, sufficient strength and handling properties. So, why do we want, because at a basic level the fibers may not be very strong when you just make them there are ways to make them stronger. So, you should be able to handle them so that the while they are being strengthen they do not break it themselves. So, it should the precursor should has sufficient strength. It should not melt during production process, it should not be completely volatile should not be completely volatile because completely volatile than you may not end up with a lot of thing carbon.

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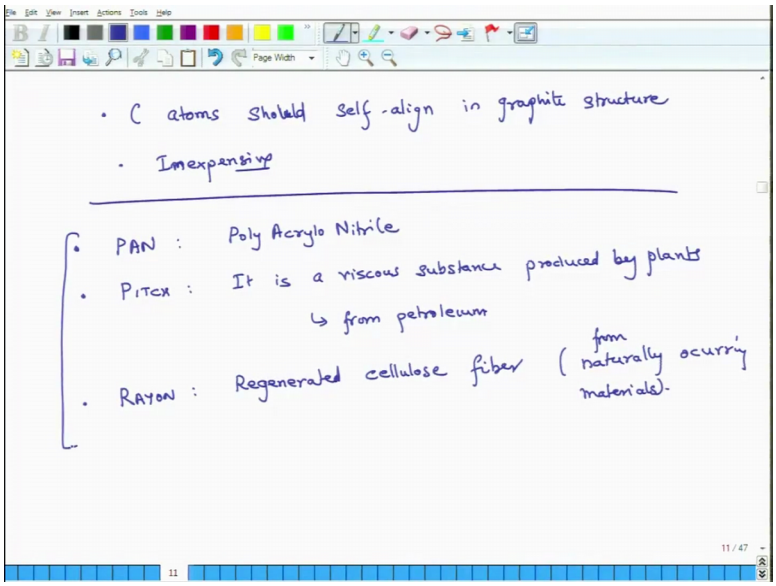

This is important also that carbon atoms should self align in graphite structure, in graphite structure and once the self align this enhances the mechanical properties and of course, it should be inexpensive. So, these are some of the important materials, important properties which are good precursor material should have.

Now, in general there are three important types of precursor materials used one is known as PAN now this is an abbreviation it is what is it? It is poly acrylo nitrile. So, that is why it is pan polyacrylonitrile actually its one word, but I just broken it up into three small pieces so that you know where is P A N coming from. So, this is one thing because very popular precursor material.

The other one is pitch what is it? It is viscous substance produced by plants or you can have artificial pitch synthetic pitch. So, you can also get it from petroleum. So, these PAN, pitch they are the raw materials for as there they used the figure should and the third important one is rayon.

Now, several of you may have heard of it, it is a fiber it is an organic fiber, and what it is made from? It is basically re generated cellulose fiber. What is cellulose? It is there in all plant cells the covering of those plant cells is made up of cellulose. So, its regenerated cellulose fiber and it is produced from naturally occurring materials. So, it is produced from naturally occurring materials, so PAN, pitch and rayon. Depending on your carbon come fiber comes from whether it is coming from PAN or whether it is coming from

pitch or whether it is coming from rayon it will have different material properties. So, there is no common property for all different graphite fibers because based on which type of fiber precursor is used the alignment between different carbon atoms is of a particular type and that defines the strength and modulus of the fiber.

So, what we will discuss maybe another for 5 7 minutes is how are graphite fibers produced from PAN.

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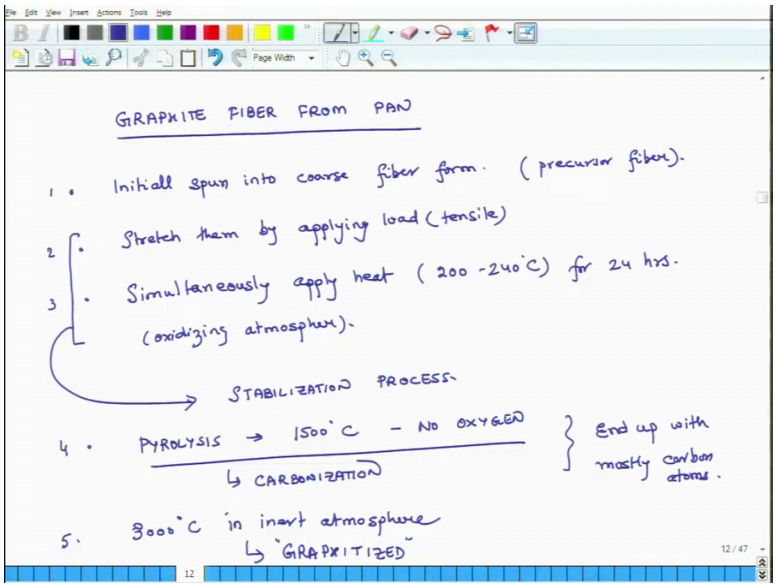

So, again the point is not to because experts into how these fibers are produced, but we should have some idea or how this production process there because if this understanding is there it will also help you arrive at good judgments that for your application which type of fiber you need to use.

So, the first thing is that you have this precursor material called PAN, it has a lot of carbon in it and it is initially spun into codes fiber for. So, it is not a very fine fiber some [FL] some coarse fiber. So, you spin it, it is a piece of plastic you spin it and you get some coarse fiber form. So, these are precursor fibers. Then you stretch them by applying load. What type of load? Tensile load which you have a fiber and you stretch it by applying some tensile load, and in that process the molecules of carbon they start aligning because of this external force and while you are stretching you also subject simultaneously, simultaneously apply heat how much heat 200 to 220 degree c for 24 hours.

So, you are applying some external force and you are applying heat and in this heated state things soften up and fibers get carbon atoms and molecules they get to align at elevated heat because things start flowing. So, you apply heat and as a consequence, and this is an oxidizing atmosphere, so whatever volatiles are there and things which will burn off easily they burn off, but carbon will not burn off easily because you have to heat it at a higher temperature beyond 250. So, this is an oxidizing atmosphere. So, oxygen is present.

So, this process, so this is 1, this is 2, this is 3, 2 and 3 they go together. This process is known as a stabilization process, this is known as a stabilization process. Overall structure starts getting stable. The fibers start getting stabled.

Fourth then these stabilized fibers are subjected to the process of pyrolysis. So, what happens in pyrolysis? You take these fibers subject tend through very high heat 1500 degree centigrade and at this temperature if there is oxygen everything is going to burn away, so no oxygen, no oxygen. So, as a consequence all the things and carbon can take very high heat carbon can as take very high heat. So, all other things which are volatiles nitrogen, hydrogen, oxygen, everything else in the system it gets out and what you are left with its more or less pure carbon. So, this process is called carbonization, carbonization. So, in this process you are left with end up with mostly carbon atoms.

Now, they are carbon atoms, but they may not be in graphite form because carbon can exist in different forms. So, they may not be in a graphite type of a structure, but now you are left with more or less carbon. And to put them in graphite form finally, you subject them to 3000 degree c in a atmosphere. And as a consequence you get graphite, so the carbon then gets transformed into graphite. So, this is called the carbon is graphite, graphitized, these fibers graphitized and graphite crystals develop in the fibers. So, at 1500 degrees it is just carbon and if you try to pull it, it will be very weak, it will break. But then you subject it to 3000 degree centigrade and at that cent things the heat drives the atoms in to graphite type of a structure because that kind of a structure is stable at 3000 degree other structures are not stable. So, it goes into that kind of a structure and you end up with graphite fibers.

So, this is using PAN, poly acrylo nitrile material. So, now, we have some idea how graphite fibers are produced. Next what we will look at is what are the, in a subjective sense difference is between different types of graphite fibers.

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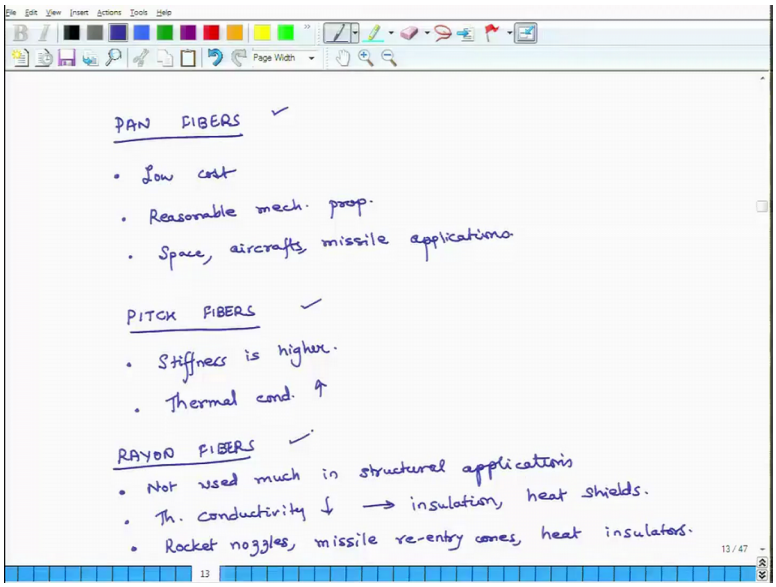

So, PAN fibers, this means graphite fibers produced from pan precursor low cost, but low cost as in not compared to metals or not compared to silica glass fiber within graphite fibers itself they are the least expensive because production of graphite fibers is very expensive you have to use so many steps, so much of heat is needed, all that is there.

Reasonable mechanical properties and actually we will see these properties and they have because of low cost and reasonable mechanical property is a very popular in space, aircrafts and missiles, applications.

Next look at pitch fibers or fibers graphite fibers produced from pitch. So, compared to pan their stiffness is higher, their thermal conductivity is also higher, thermal conductivity thermal, conductivity higher and as a consequence especially in space applications, if you have to transfer heat from one part to the other, on earth if this is hot and this part is cold this part is cold and suppose this is hot because of convection heat will flow because of here, but in space there is no air. So, if I have to transfer heat from very super hot part two some part which is cold I connect them with pitch fibers or I can connect them with a structure which has pitch fibers and pitch fibers have very high

thermal conductivity so that heat can be directed in the particular way. So, these are some two important points about pitch fibers. And then the last one is rayon, rayon fibers.

So, they are not used much in structural applications, not used much in structural applications. In contrast to other fibers their thermal conductivity is actually low and we will see that in comparative terms. So, here they are used as insulation and they are also used as heat shields. And this is important they have a lot of resistance to high heat they can bear a lot of high heat, so they are used in rocket nozzles, missile, re entry cones, heat insulators. So, this is PAN fiber, pitch fiber and rayon fiber.

So, finally, let us look at some of the important and general properties of these different types of graphite fibers.

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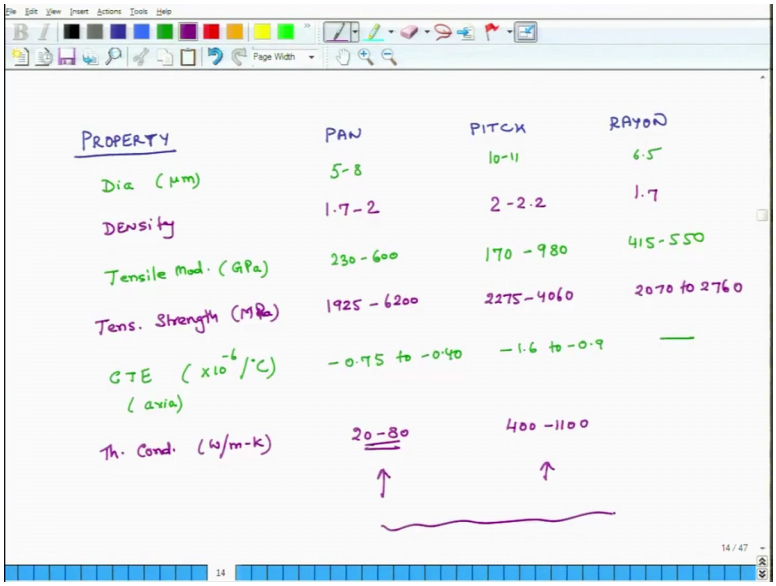

So, we will just develop a table first column will be property and three different fibers, three different types of graphite fibers. The first one is coming from PAN, second one from pitch, third one from rayon.

So, first thing is let us look at diameter and the units are micrometers. So, this is 5 to 8, 10 to 11 and this is somewhere in between 6.5. Let us look at density or a specific gravity, so this is 1.7 to 2, there is a lot of variation; pitch is heavier more dense 2 to 2.2 and this is 1.7. Tensile modulus, tensile modulus of the fiber so, what is this? It is in GPa, this is, there is a lot of variation 230 to 600 density this is specific gravity or you can say

grams per cc. So, lot of radiation. For pitch also there is a significant variation 170 to 980 and this is 415 to 550. Tensile strength and this is in mega pascals, this is 1925 to 6200, 2275 to 4060 and this is tighter 2070 to 2760. And then we will look at coefficient of thermal expansion, this is into 10 to the power of minus 6 per degree centigrade.

And this is important to remember graphite fibers have a negative coefficient of thermal expansion this is very important to remember, in the axial directions, in the axial direction. So, if you heat of a graphite fiber it will shrink in length, but it will become fatter it will shrink in length, but it will become fatter. So, what is the thermal expansion? Minus 0.75 to minus 0.40, pitch contracts even more so this is minus 1.6 to minus 0.9 and we do not have data on this and then here is the important thing thermal conductivity, watts per meter Kelvin and this is very important to understand.

So, to give you a comparison the thermal conductivity of steel is around 10. So, around 10, 7 by 8, 11 depends on which type of steel we are talking about. Of a PAN base graphite fiber it is 20 to 80, thermal conductivity of copper is 400 very pure copper copper or silver its way up there, for pitch based graphite fiber it is 400 to 1100. So, you take this fiber and you can use it as an insulator. You take this fiber and you can use it as a very efficient conductor of heat to transfer heat. So, you have significant difference in thermal conductivity properties.

So, this is important to understand and I hope this table gives you an overview of the different types of graphite fibers which are there and used very popularly in the market. In case you are using or you plan to use graphite fibers it is important to understand that it is not just all fibers of graphite are same, you have to make sure that which particular fiber you are interested in and whether it meets your needs or not.

So, with that we close the discussion for today, and tomorrow we will discuss some more types of fibers. And with that I am sure you will have a great weekend and great night and I look forward to see you tomorrow. Bye.