Testing of Functional and Technical Textiles
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Lecture – 10
Testing of Fibre Reinforced Composite Materials

So, hello everyone we are discussing the course Testing of Functional and Technical Textiles. So, till now what we have discussed is the part first part which is Testing of Functional Textiles; where you have dealt with the low stress mechanical characteristics of functional textiles. Also the transmission characteristics like; air transmission moisture transmission and heat transmission.

Now, we will enter the next phase of the course that is; the testing of technical textiles. As I have mentioned earlier that we will discuss various types of technical textiles their testing methods. To start with we will first discuss the testing methods of fiber reinforced composite material. There are different types of composite materials, but in this class we will concentrate mainly on fiber reinforced composite material. So, first let us try to understand what is composite.

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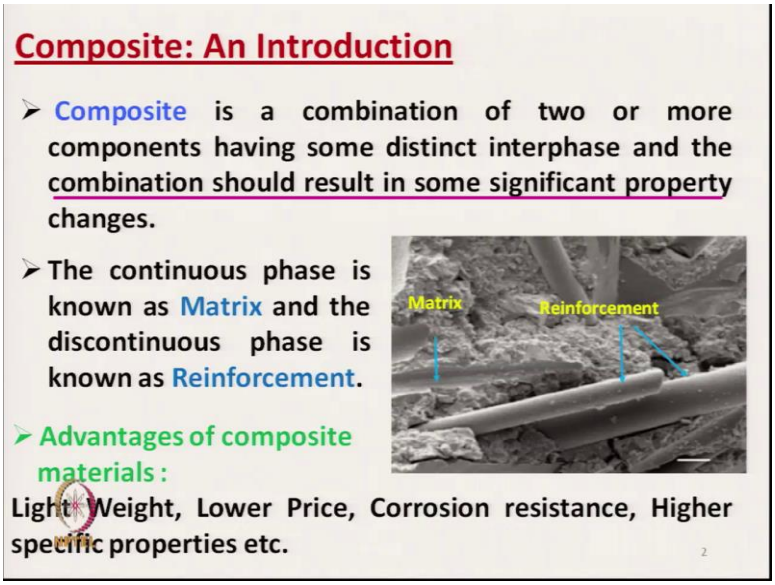

So, composite is a combination of two or more components having some distinct interface and the combination should result some significant property change. So, there must be some significant improvement in properties. So, that is why we prepare

composite the composite has got three distinct components. One is matrix component, second one is reinforcing component and third is that distinct interface. So, combination should result significant improvement in characteristics of material.

So, this picture shows composite material it is inner structure of composite material where this is showing the matrix which is continuous phase. And other part this is reinforcement it is reinforcing fibers which is termed as discontinuous phase. So, the continuous phase is known as matrix and the discontinuous phase is known as reinforcement in our case here we will discuss the reinforcement material mainly the fiber. So, fibrous material like filament staple fiber in loose form may be in yarn form or in the form of fabric.

So, why do you need composite? So, composite is prepared to get some special material characteristics like the weight of the material should be light. So, there are many applications where we need lighter and stronger material like aviation industry. Its price should be lower as far as the similar characteristics is concerned, it should be corrosion resistant higher specific properties. So, higher specific strength should be there it should be lighter. So, all these characteristics are required in composite material. So, let us now see how the composite materials are classified.

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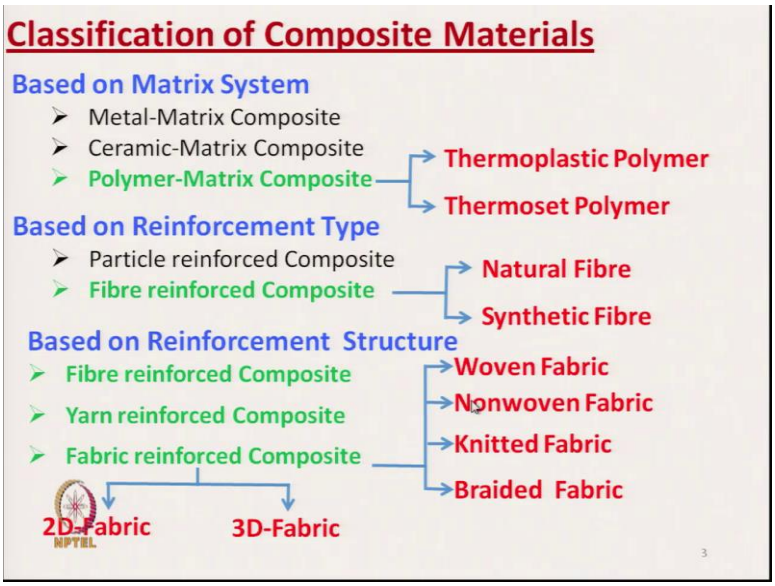

So, composite materials are classified based on matrix system based on reinforcement type and based on reinforcement structure, first based on matrix system. So, the matrix

which is used in composite are basically of three types; first is metal matrix composite, next is ceramic matrix composite and third one is polymer matrix composite. In our discussion we will concentrate on evaluation of polymer matrix composite materials.

And polymer matrix composite if we sub divide we can subdivide into two components. The first is the thermoplastic polymer and next is the thermoset polymer. And we will discuss details about the test methods of thermoset polymer and thermoplastic polymers. And reinforcement types are of basically two types one is particle type reinforcement and next is the fiber type reinforcement. And fiber reinforcement is of two type one is natural fiber reinforced composite.

And next is that synthetic fiber reinforced composite based on reinforcement structure these are sub divided into three broad categories first one is that the fiber reinforced composite, where we directly use loose fiber and mix with the matrix material to get the fiber reinforced composite. And next is that yarn reinforced composite yarn may be twisted yarn may be filament yarn different type of yarns maybe staple yarn. So, yarn reinforced composite and third one is that fiber fabric reinforced composite.

So, fabric reinforced composite we can divide in two categories one is based on the type of dimension that is two dimension fabric or three dimension fabric. So, based on this dimension we can have different types of composite materials and also we can divide the fabric reinforced composite based on type of fabric we use. So, first is woven fabric reinforced composite, then non woven fabric reinforced composite, third is knitted fabric reinforced composite and fourth one is braided fabric reinforced composite.

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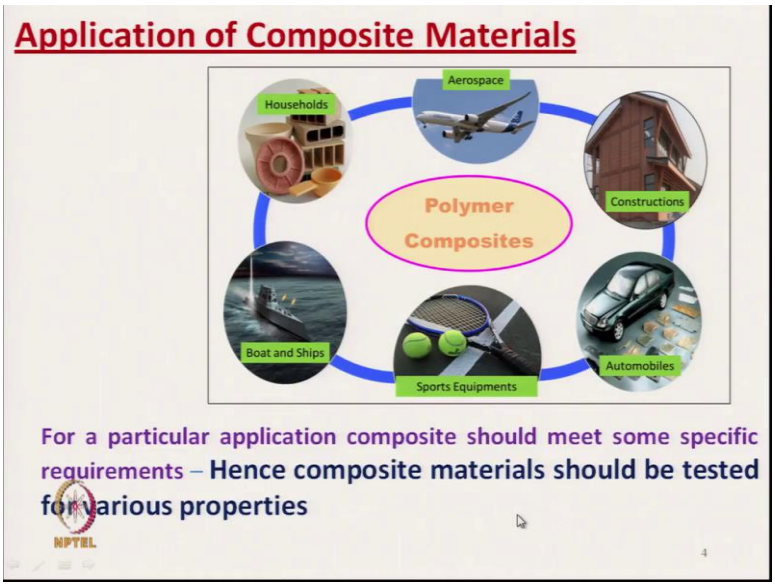

So, there are various applications. So, broadly the major areas applications are it is aerospace industry in that polymer composites that is fiber reinforced polymer composites are mainly used in this application areas. So, in aerospace industry we use the polymer composite like or carbon fiber reinforced composites which is very high strength and lighter in weight.

In construction industry we use polymer composites, in automobile industries automobile parts automobile that car body part there are various applications are there. In sports equipment like tennis racket or there are various applications we can use the polymer composite material.

And boat and ship body we can use to make them lighter and household items we can use composite material. So, apart from this there are many other applications for a particular application composite should meet some specific requirement. Hence composite material should be tested for various properties. So, for airspace we need a very specific different properties than the composites which are used for household application. So, the test methods should be different for airspace industry and for household industries. So, there are different test methods available we will discuss one by one.

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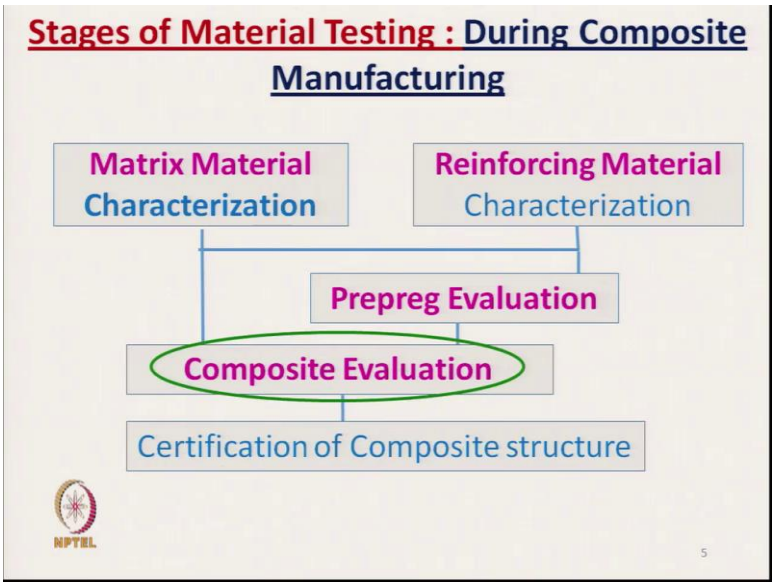

So, there are the stages of material testing during composite manufacturing. So, depending on the application area, the test severity changes. So, for testing of composite we must first test the matrix material then the reinforcing material characterization is required. So, matrix and reinforcing material characterization are important to get a required quality of composite. After that we may test the prepreg evaluation and then composite evaluation is important. After composite evaluation certification of composite structure is given ok.

So, this certification is issued only after the composite evaluation is over and it actually is, it is the characteristics is more than the required characteristics. So, matrix material reinforcement material and prepreg evaluation and composite evaluation we will discuss all this test methods one by one. First we will discuss matrix material characterization.

So, as we have mentioned that matrix materials are of two types one is thermoset matrix another is thermoplastic matrix. Their test methods are most of the test methods are same, but few test methods are different specifically for thermoset matrix and few specific tests are required for thermoplastic matrix.

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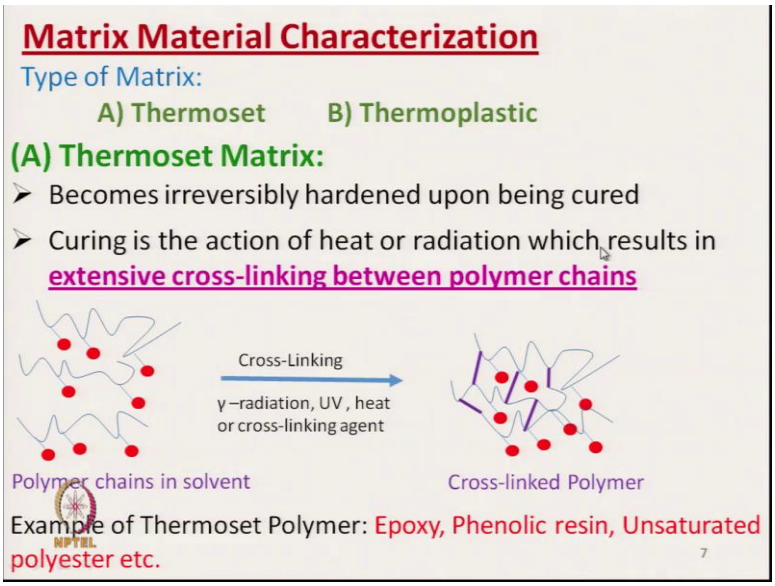

So, there are two types of matrix material polymer matrix material one is thermoset matrix another is thermoplastic matrix. First we will discuss the test methods related to thermoset matrix. So, what is thermoset matrix? It becomes irreversibly hardened during being cured. So, after cured after curing the thermoset matrix becomes hardened and this hardening is irreversible we cannot get back to the original component ok. So, after curing this matrix become hardened. So, curing is the action of heat or radiation which results in extensive cross linking between the polymer chain.

So, during heating application of heating or radiation like UV radiation, gamma radiation or simply heating so cross linking takes place. So, this diagram shows the polymer chain in a solvent. So, these are the polymer chains and once they are cross linked by applying heat or radiation. This polymer chains are cross linked and form the thermoset matrix. And this thermoset matrix it is hardened and this cannot come back to original position ok. So, the examples of thermoset polymer is epoxy resin, phenolic resin, unsaturated polyester etcetera. So, these are the very commonly used thermoset matrix material.

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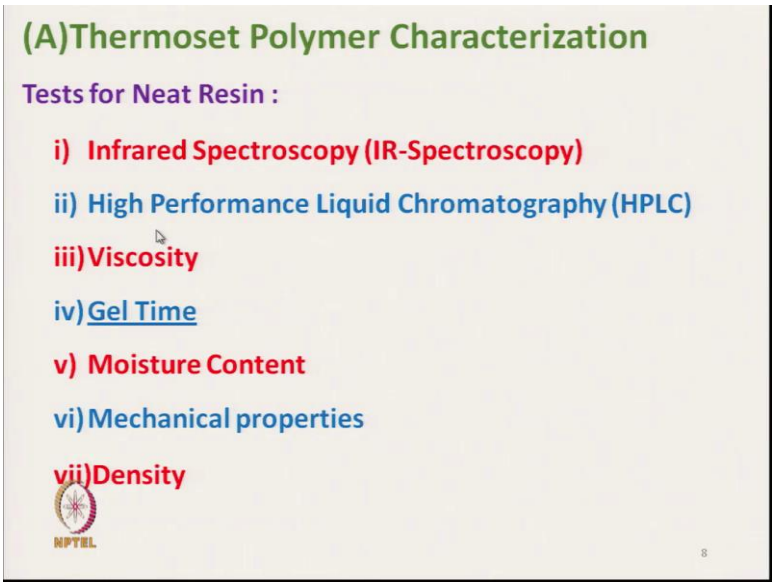

Now there are different types of test methods available for the thermoset matrix. The advantage of thermoset matrix is that at room temperature or lower temperature the viscosity of thermoset matrix is very low. So, proper penetration inside the fibrous structure takes space. So, the chances of void content is less in the matrix. So, the net resin of thermoplastic resin the test methods are first is that infrared spectroscopy IR spectroscopy.

Next is that HPLC that is high performance liquid chromatography. Viscosity, viscosity is extremely important characteristics for matrix material. If the material is highly viscous then penetration of matrix inside the fibrous structure will be poor. Next method is gel time characteristics gel time measurement is there which indicates the solidification time ok.

Moisture content which is important characteristics mechanical properties are important that is the strength properties density. So, these are the characteristics which are important both for thermoset resin and also for thermoplastic resin. And this gel time which is underlined this characteristics is only for thermoset resin ok. Now first let us start with IR spectroscopy.

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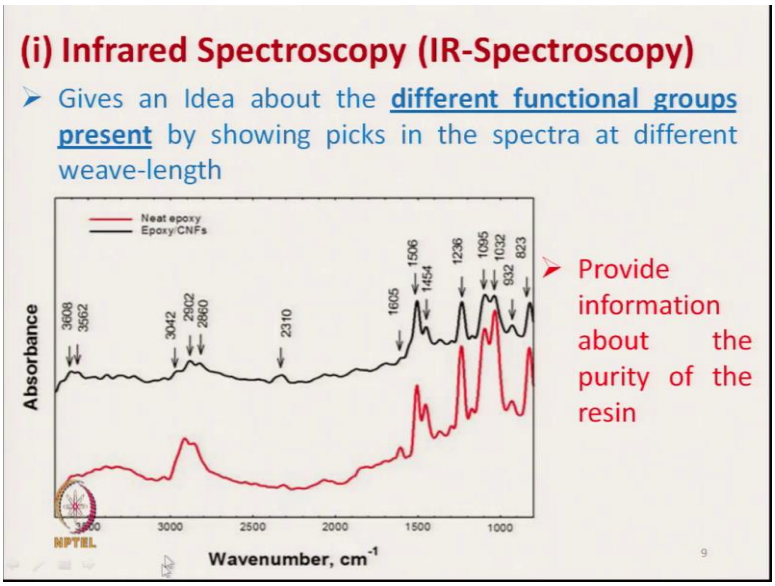

So, what is IR spectroscopy? It gives an idea about the different functional groups present by showing the peaks in the spectra at different wavelength. So, in x axis it is a different wavelength and the spectra at different wavelength and y axis it shows the absorbance. So, for different functional groups present in the material it shows by the peaks these are the different peaks.

And in the red curve it is showing the net epoxy material. And the black line shows the epoxy material with carbon nano fiber. So, this is the; these are the peaks available provided information this actually peaks this provide information about the purity of the resin. If the resin is not pure it will show multiple peaks.

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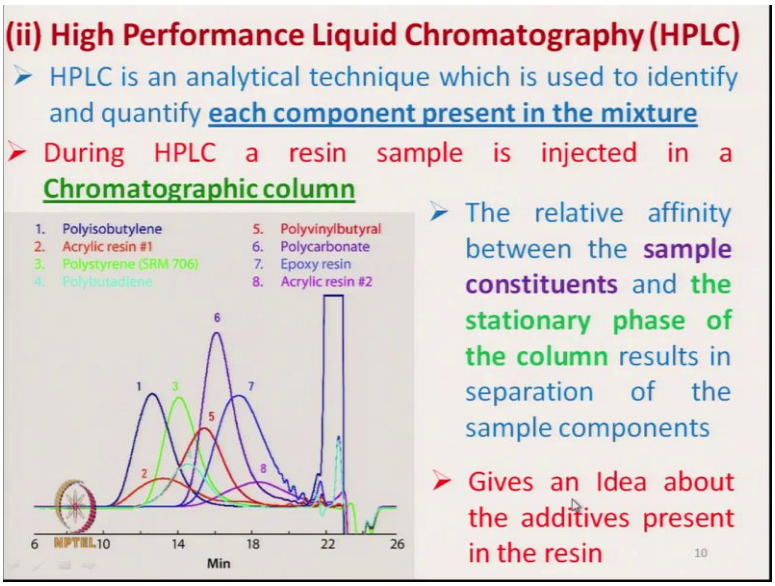

Next is that HPLC; High Performance Liquid Chromatography. So, what is this; HPLC is an analytical technique which is used to identify and quantify each component present in the mixture. So, the matrix material may be of mixture of different components ok. And this will show, this will quantify each components ok. During HPLC a resin sample is injected in a chromatographic column there will be a chromatographic column. And resin sample will be injected.

The relative affinity between the sample constituent and the stationary phase of the column there will be stationary phase of the column. And depending on the relative affinity of the sample which results in separation of the sample components. So, sample components will get separated and we can calculate the quantity of the component present. So, it gives an idea about the additives present in the resin. So, there may be different additives present in the resin at that we can quantify how much additives are added in the resin.

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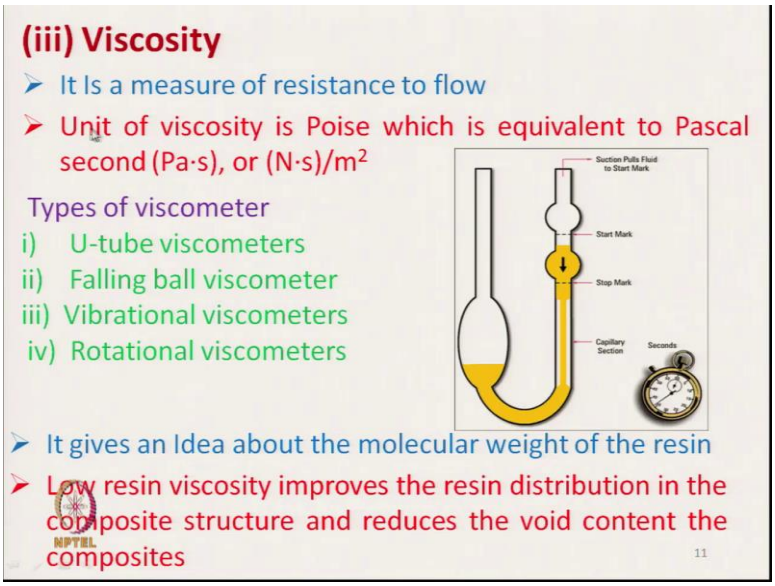

Next is the viscosity; which is extremely important characteristics of any matrix material. So, as I have mentioned at low temperature the thermoset matrix has got advantage of very low viscosity. Low viscosity means the flow through the pores of the fiber penetration of matrix material will be easy. On the other hand the thermoplastic matrix in normal temperature they are solid like polypropylene. To reduce the viscosity we have to increase the temperature.

And the viscosity of thermoplastic matrix are relatively high. So, we must measure the viscosity of matrix material. So, it is a measure of resistance to flow. So, if the viscosity is high the flow will be slower ok. Unit of viscosity is poise as we know which is equivalent to (Pa·s), or $(N \cdot s)/m^2$. There are different types of measurement techniques very commonly used measurement techniques in laboratory is U-tube viscometer.

So, this U-tube viscometer is normally used for thermoset resins. Other methods are falling ball viscometer then vibrational viscometer and rotational viscometer. And the diagram it shows the U-tube viscometer. Here this U-tube on the right side the fluid the resin material which is actually it is been lifted to start point, this is the start point by suction there will be manual suction arrangement. So, this fluid this resin will be sucked to the initial point then it will be released. And the tip of this fluid column will gradually drop depending on the viscosity of the fluid. And as soon as the tip point reaches the end mark this is the start mark this is the end markf we can note down the time.

So, higher the viscosity higher will be the time required for fall. It gives an idea about the molecular weight of the resin. So, higher molecular weight will have higher viscosity low resin viscosity improves the resin distribution in composite structure and reduce the void content in the composite has I have already mentioned.

So, low viscosity will result very smooth flow of matrix material within the structure will and will result the lower void content. On the other hand if we have a matrix material with very high viscosity in that case we need very high pressure to penetrate this resin within the structure. And that some time will result the void generation inside the composite which in turn reduce the strength and other characteristics of composite.

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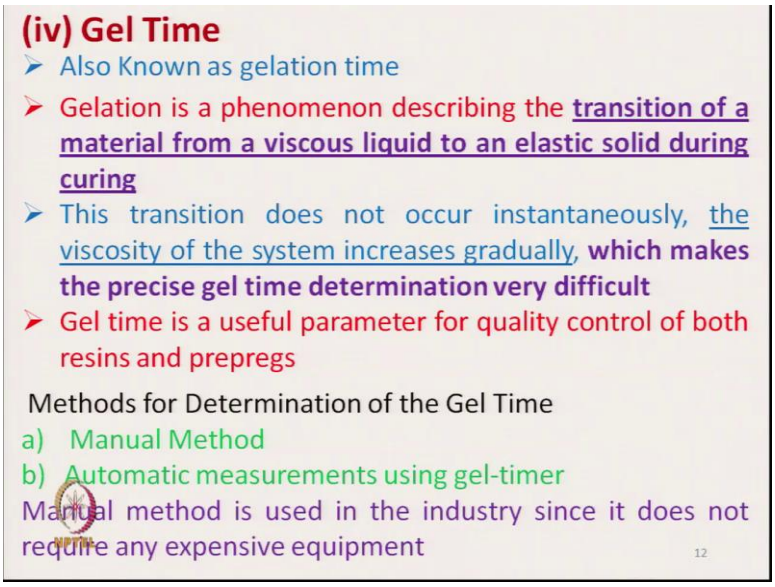

Next characteristics is gel time. Gel time is normally used for the thermoset matrix it also known as gelation time. Gelation is a phenomena describing the transition of a material from viscous liquid to an elastic solid during curing. So, during curing it forms a elastic solid material. And that time required from viscous liquid to elastic solid it is actually measured. This transition does not occur instantaneously only takes time the viscosity of the system increases gradually which makes the precise gel time determination it is very difficult ok.

So, that it is very difficult to measure the gel time precisely because it is difficult as this is taking place gradually. It is not at a certain point so precise measurement. So, we have to do repeated test manually. So, gel time is a useful parameter for quality control of both

resin and prepregs. So, you must know the gelation time. So, that we can come to know the by what time the curing should take place. So, method of determination of the gel time is one is the manual method. And second one is automatic measurement using gel timer.

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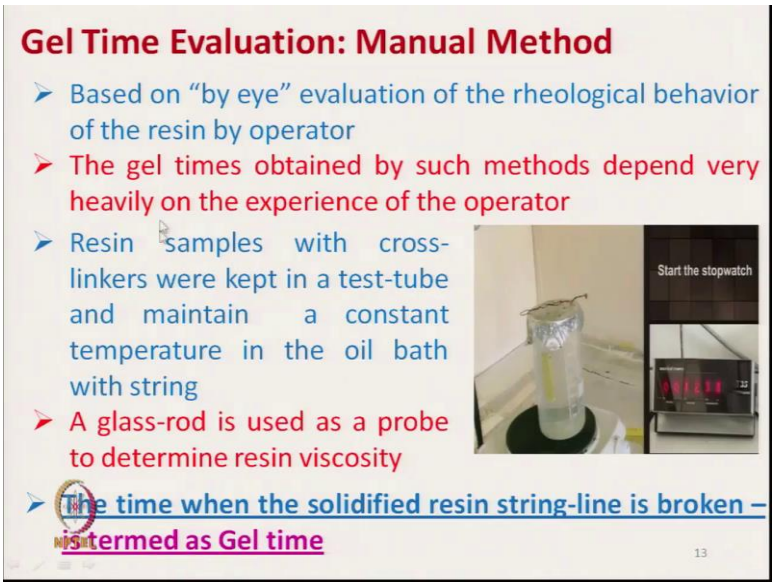

So, manual method is that manual method is used in the industry because it is a simple one and since it does not require any expensive equipment. So, manually industry follows this method. So, it is a based on by eye evaluation of the rheological behavior of the resin by operator. So, operator actually evaluate manually he can see the rheological behavior. The gel time obtained by such method depend very heavily on the experience of the operator. So, the measurement it is basically depends on the operators experience ok.

The resin sample with cross linkers were kept in a test tube, this is a test tube. And maintain a constant temperature in the oil bath with stirring. So, they start stirring and the temperature is maintained at constant in the oil bath. So, and the stirring is done by the glass rod. A glass rod is used as a probe to determine the resin viscosity. So, it is stirred with the glass rod and viscosity as viscosity increases there will be the resin string formation.

And the time when the solidified resin string line is broken it is known as the gel time. So, before that the when the solidification is not completed the string line will not be

broken because it will be flexible. But as soon as the solidification is completed the string line will be broken and that time is recorded as gel time. Next important characteristics is the moisture content.

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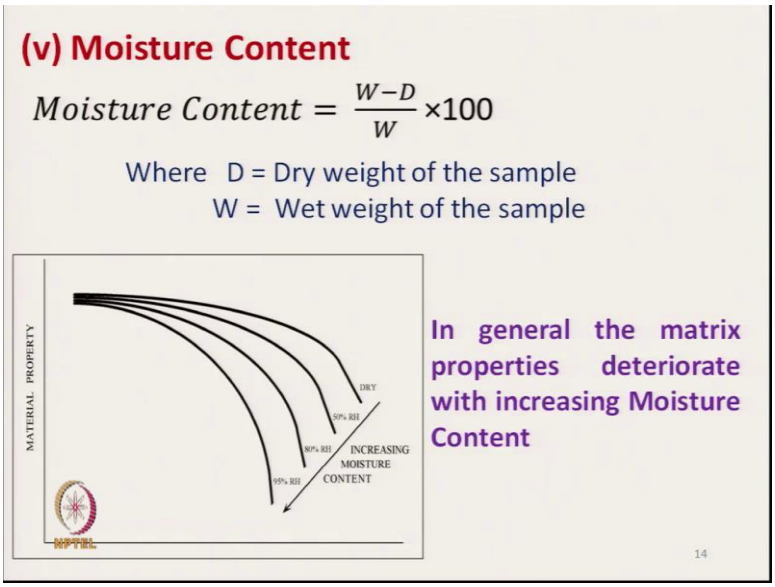

So, we must know the moisture content of matrix material because this moisture content affect the characteristics of matrix. So, this picture we can see that as the moisture content increases this is the dry 50 % relative humidity and this is the 95 % relative humidity, as the relative humidity increases, so, increase in moisture content is there. So, drop in characteristics is there. So, it is a; there is a sharp drop in the material property.

So, material property in general it reduces. So, moisture content, is measured by measuring the dry weight of the sample and wet weight of the sample. First we take the normal weight that is wet weight of the sample then we dry the material to remove the excess water inside it. And the difference that is

$$Moisture\ Content = \frac{W-D}{W} \times 100$$

Where D = Dry weight of the sample

W = Wet weight of the sample

In general the matrix properties deteriorates with the increase in moisture content.

So, we must actually do something so that the matrix does not absorb moisture either we can use some matrix material which is not absorbing moisture or we can use some treatments. There are different treatments to make the hydrophobic hydrophilic matrix to hydrophobic matrix ok so, that those points I will also mention after discussing the thermo set matrix characterization.

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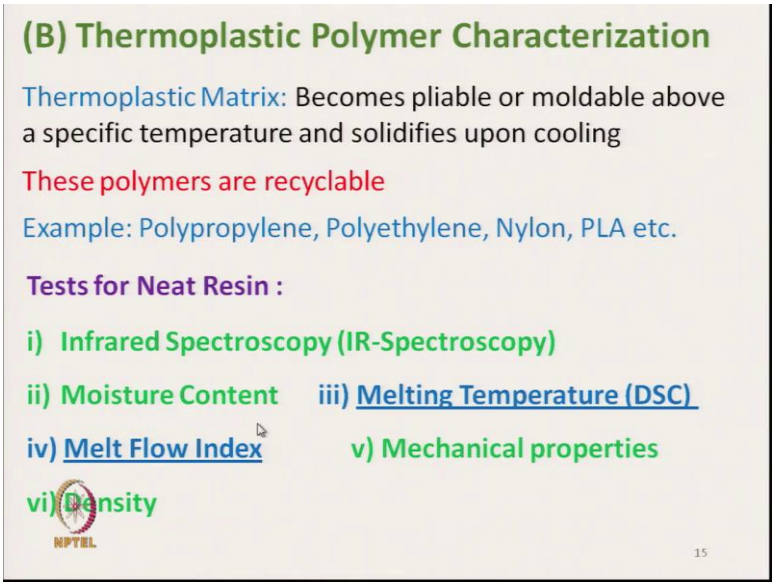

Now, we will discuss the properties of thermoplastic polymer characterization that is the thermoplastic matrix materials. So, what is thermoplastic matrix? Thermoplastic matrix becomes pliable or moldable above specific temperature and solidifies upon cooling. So, as we have seen in thermoset matrix, it does not get actually pliable or moldable once it has become solid. But thermoplastic matrix is reversible in nature. After being solidified upon cooling again if we reheat we can make it actually pliable.

So; that means, the thermoplastic matrix we can reuse repeatedly. That is this polymers are recyclable. The examples are polypropylene matrix polyethylene nylon PLA these are the polymers which are thermoplastic in nature. So, the tests are here IR spectroscopy

as we have discussed earlier, moisture content, melting temperature, which is used by DSC.

So, melting temperature is used for thermoplastic polymer which is not required for thermoset polymer and melt flow index. Then mechanical properties and density they are also common for thermoset matrix. So, in thermoplastic matrix characterization we will discuss here the melting temperature measurement and the melt flow index. So, melting temperature melting point is actually measured by DSC method the differential scanning calorimetry.

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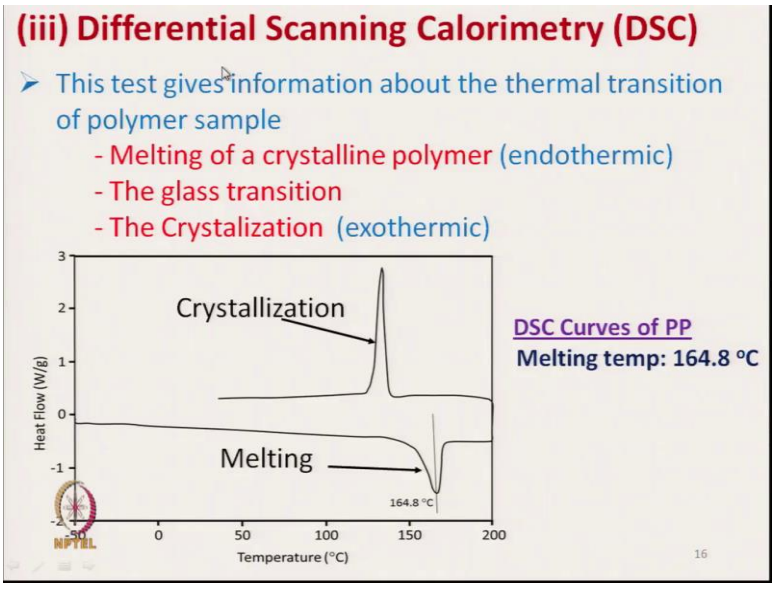

So, this test gives information about the thermal transition of polymer sample. So, thermal transition means here at certain point it will actually absorb heat or it will release heat. So, the during the melting during melting it will it is a endothermic reaction. That is the heat it will take the heat melting ok. And during crystallization which is exothermic so it will release heat. And also you can measure the glass transition temperature.

So, from this DSC curve here this is this typical curve it is for the polypropylene. Here we can see the endothermic point is at **164.8 ºC** which shows the melting point of polypropylene or for this particular polypropylene is **164.8 ºC**. So, this DSC method can also be used to understand to know the mixture. Whether there is any mixture or not the polymer there is any mixture there or not that we can quantify.

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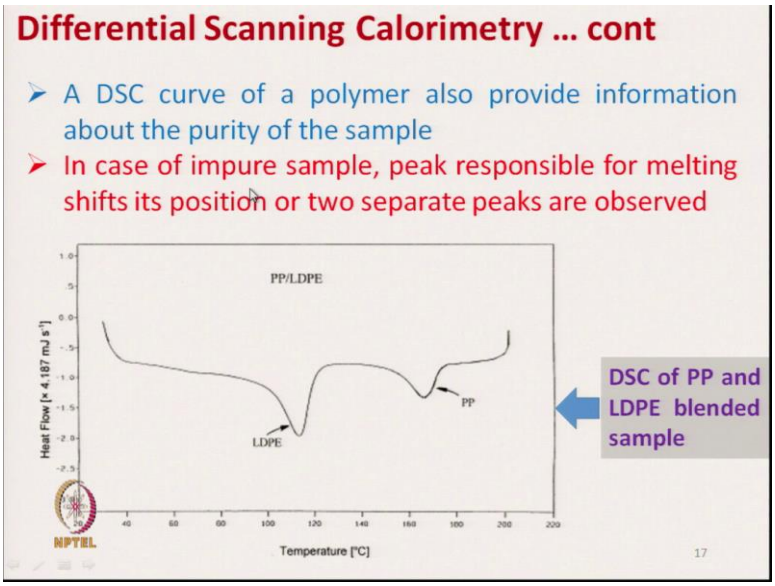

So, DSC curve of polymer, also provide information about the purity of the sample. So, this curve there is a polypropylene it is a blend of polypropylene and low density polyethylene blended sample ok. So, as this is blended, so polypropylene will have certain melting point here, this point. And LDPE will have another melting point here. So, this two different peaks are showing that this polymer, is actually mixture of polypropylene and LDPE. So, in case of impure sample peaks responsible for melting shifts it is position or two separate peaks are observed ok.

Either the peaks may gets shifted in case of impure polypropylene or impure polymer or it can show of two or more different peaks. From there we can come to know the whether the polymer is pure or impure. Next is that melt flow index, what is that? It is basically it shows that at certain temperature. What is the flow characteristics which is extremely important for thermoplastic polymer composite material fibrous material.

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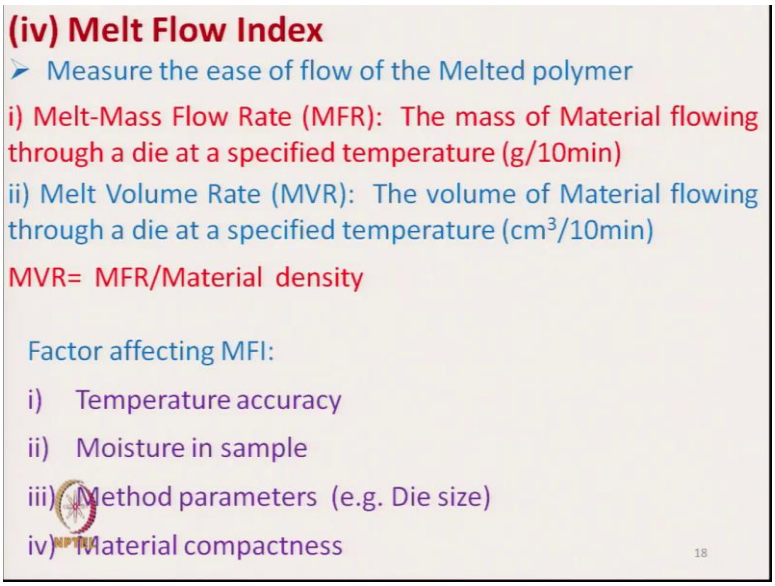

So, if the melt flow index, the flow characteristics is better it is a good in a particular temperature. Then the composite will be better characteristics will be better. It measures the ease of flow of the melted polymer. So, how easily the polymer melt flows inside the structure. Melt mass flow rate the MFR it is called MFR. The mass of material flowing through a die of specific dimension at a specified temperature.

So, the die specification may be different. So, for a specific die size the amount of material molten material flows per unit time so, in general it is expressed in g/10 minute. So, for 10 minute time the molten polymer how much quantity it is flowing through a die that is measured ok. And another characteristics which is called melt volume rate MVR ok. What is that melt volume rate, the volume of material flowing through a die at a specified temperature that is in cm^3/10 minutes. And the relationship is that MVR we can calculate if we know the MFR and material density.

MVR= MFR/Material density

And the factors which affect the melt flow index or temperature accuracy. Like when we heat the material at a particular temperature. So, if the temperature accuracy is not maintained properly with sudden change suppose, sudden increase in temperature even 1 degree increase in temperature, melt flow index will change. So, that temperature should

be maintained perfectly, otherwise we will get wrong result. Moisture in the sample the method parameter like die size. So, as I have mentioned the die size will control the quantity of material flown per unit time and material compactness also.

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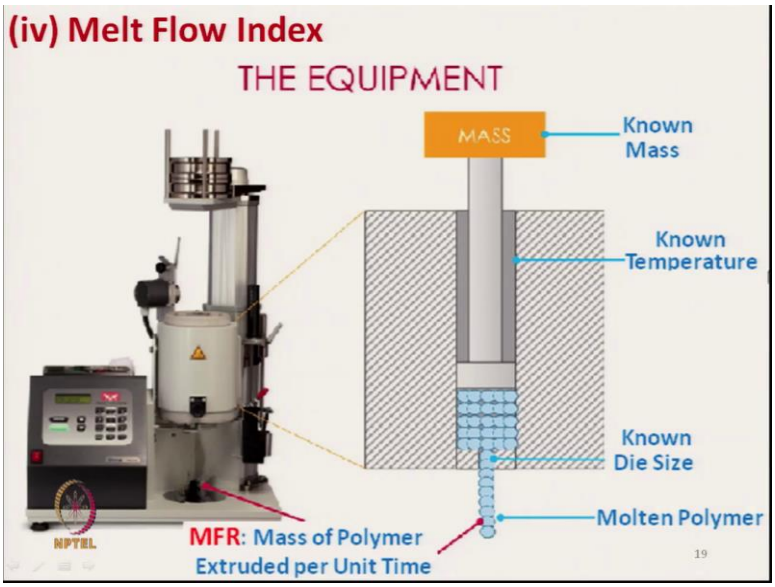

So, this is the equipment where the molten polymer is actually of known mass is placed here. And temperature is maintained we know the temperature at what temperature we have to keep the material this molten polymer and the die is kept here at the bottom and when the polymer molten polymer is flown through the die the quantity required quantity per unit time it is measured the mass of polymer extruded per unit time it is measured and that shows the melt flow index.

So, if we change the temperature or if we change the die size the mass flow index, the melt flow index will change. So, matrix material characterization we have discussed. So, we have discussed now the thermoplastic matrix. Also I have discussed thermoset matrix. Now we will start the measurement technique for reinforcing material. So, reinforcing material characterization we will discuss.

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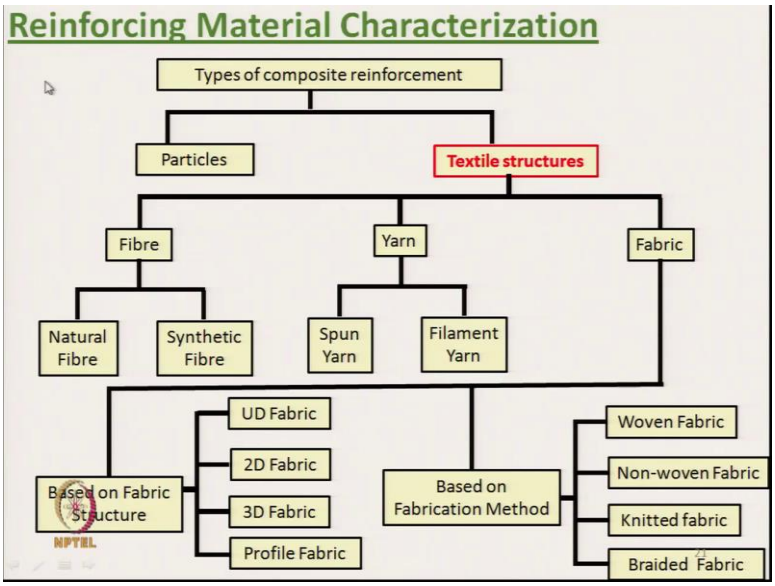

So, these are the reinforcing material. First is that particles which we will not discuss because we will be discussing the textile structure. So, textile structure these are of basically three types; one is fiber, yarn and fabric. Fiber natural fiber and synthetic fiber, yarn spun yarn or filament yarn and fabrics are first is that based on the fabric structure Unidirectional fabric 2D dimensional fabric 3D dimensional fabric and profile fabric.

So, we can actually develop different profile structure of fabric. And based on the fabrication method woven fabric non woven fabric knitted fabric and braided fabric. So, these are the characteristics of the textile structure. So, which affect the characteristics of quality of the composite material. So, we must know the characteristics of reinforcing material.

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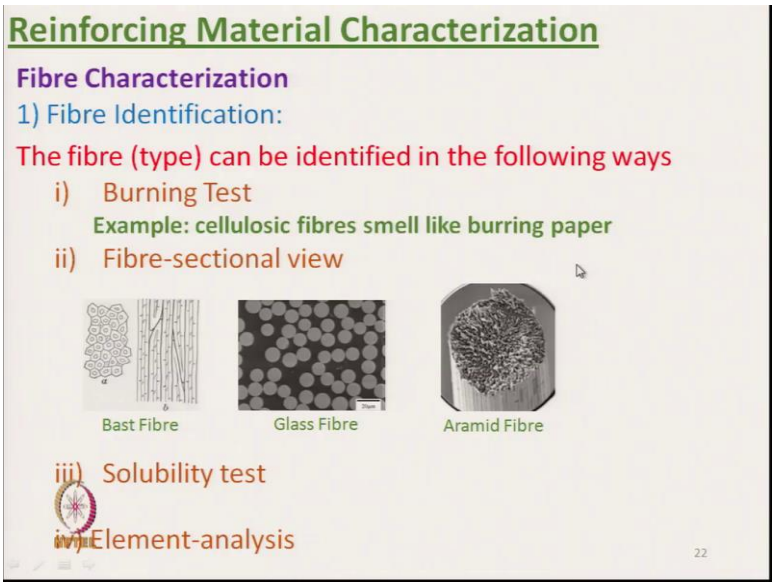

First the fiber characteristics. So, fiber characteristics starts with the identification of fiber. First we have to identify what is the fiber which fiber is being used in a composite material. So, that fiber identification is very important. So, before we start proceeding for composite manufacturing we must know which fiber is being used. So, the fiber can be identified in different ways first is that burning test ok. Burning test is very commonly used for example, cellulosic fiber smell like burning paper when it is burned.

Then fiber cross sectional view is another technique of fiber identification. Next is very commonly used it is called solubility test we can do solubility test to identify the fiber. There are different ways of test of solubility this details we are not going to discuss here and element analysis. So, what is the chemical composition of fiber that analysis also we can do to identify the type of fiber.

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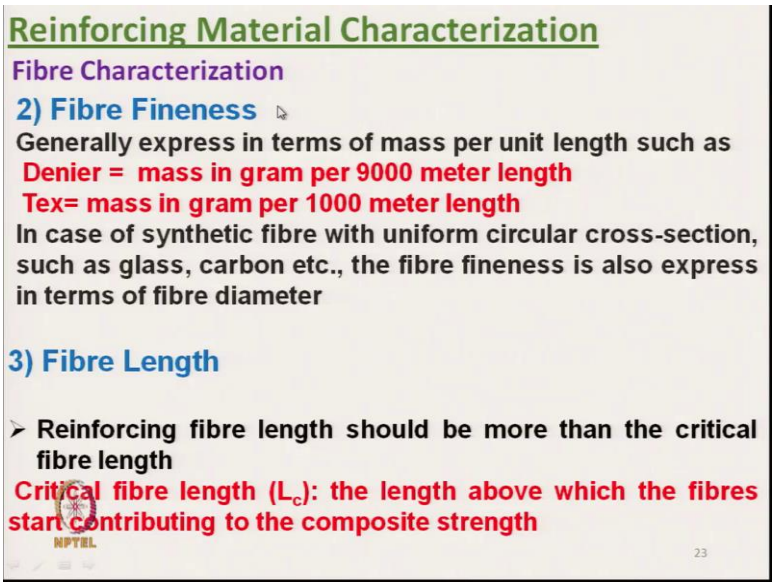

Next is that fiber fineness or diameter of fiber. So, in general for other material engineering material where the diameter or thickness of material are uniform in those case we can directly use the diameter of fiber. But most of the textile material the diameters are not uniform, even the cross sections are not uniform. In these cases generally the term mass per unit length that is the linear density is measured. So, in textile fiber the term denier or Tex are used, what is denier? Denier is mass in gram per 9000 meter of length of filament ok. And Tex is mass in gram per 1000 meter length of filament.

So, in case of synthetic fiber with uniform cross section like glass fiber or carbon fiber. The fiber fineness can be expressed in terms of diameter or micron. Fiber length measurement it is very important characteristics for reinforcing material. The reinforcing fiber length should be more than the critical length of the fiber that is very important. So, we can calculate the critical length of a fiber. And accordingly we can decide the length of the fiber. The critical length is the length above which the fibers start contributing to the composite strength.

So that means; if the critical length is actually the fiber length is less than the critical length. In that case the reinforcing material, that is the fiber will not actually contribute to the strength of the composite ok. So, that is why we must use a length which is longer

than the critical length and critical length can be calculated theoretically and accordingly we should use fiber length which is longer than the critical length.

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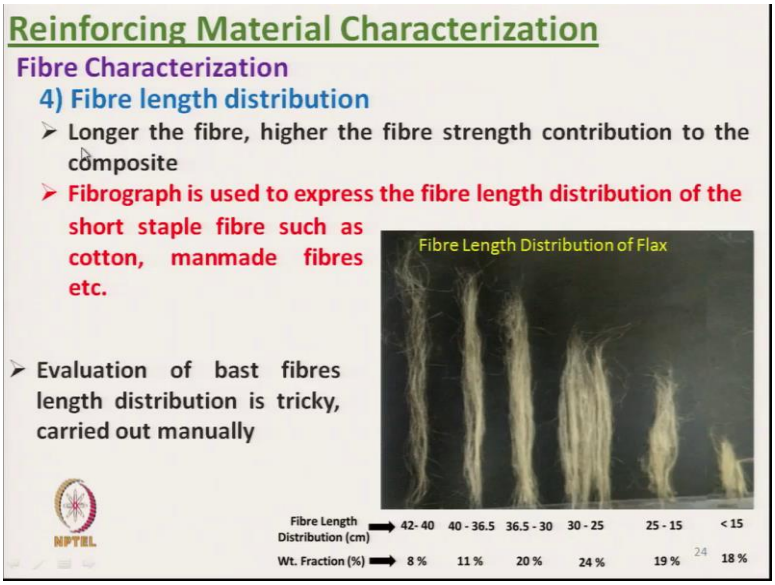

Now, the fiber length distribution is also an important characteristics, longer the fiber higher the fiber length contribution to the composite. And for cotton we can use fibrograph which actually measures the fiber length distribution ok, of the short fiber. In addition to cotton we can also use the manmade fibers. But as far as bast fibers are concern like jute fiber or flax ok.

This fibers, the length measurement is tricky ok. We have to actually carry out the length measurement purely manual manually. Otherwise we cannot use the fibrograph or any mechanized technique.

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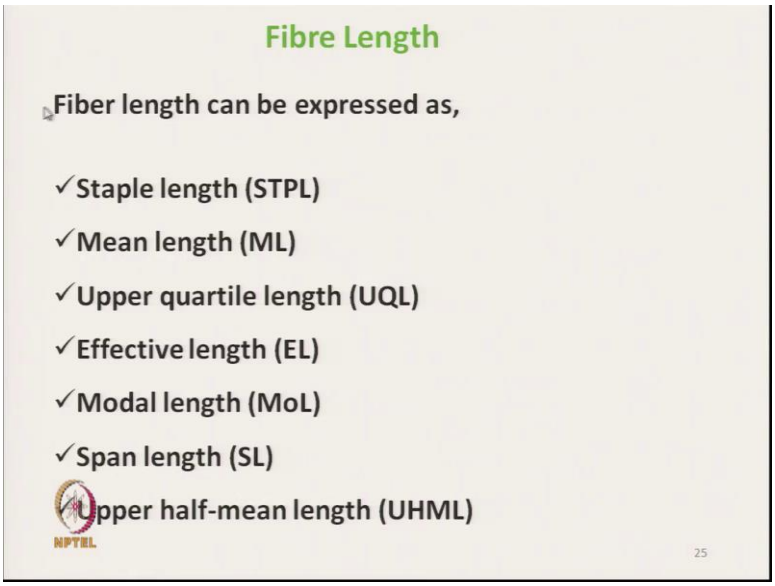

Now, the fiber length it can be expressed in terms of staple length. Staple length means it is not continuous fiber it is a short fiber staple length. Then mean length, upper half mean length, upper quartile length, effective length, modal length. Modal length is that length where the most of the fibers are showing that length that is a mode of the fiber length which is called modal length. Span length upper half mean length. So, these are the different length characteristics where fiber length can be expressed. At this point we are not going to discuss all this parameters because you all must have learnt in undergraduate evaluation of textile material or textile testing subject.

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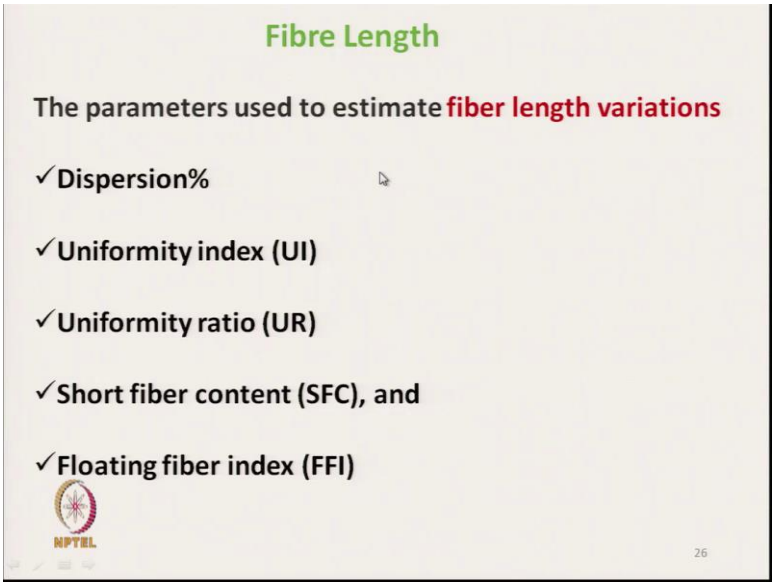

And the parameters used to estimate fiber length distribution or fiber length variation; these are dispersion percent, uniformity index, uniformity ratio, short fiber content and the floating fiber index. So, these are the different characteristics which shows the dispersion characteristics of fiber. Again all these terms you can actually learn in other course which is a textile testing course or evaluation of textile material course.

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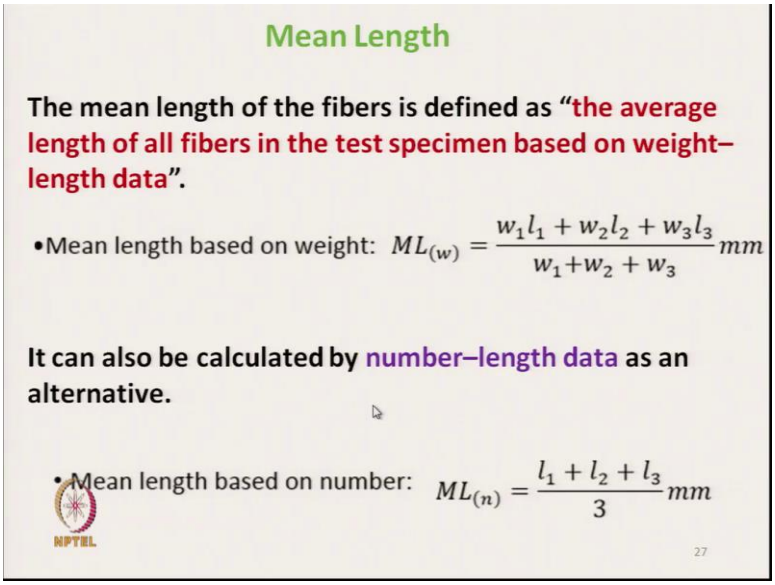

And what is mean length? The mean length of fiber is defined as the average length of all fiber in the test specimen based on weight length data. So, weight length data this is the weight length data. So, the total mass of fiber w 1 with the length of length l 1 l 2 length w 2 is the mass l 3 length w 3 is the mass and so on. And divided by total mass this is the mean length based on weight. So, we can have mean length based on number also. So, this is the number length data. So, l 1 l 2 l 3 and divided by 3. So, based on number.

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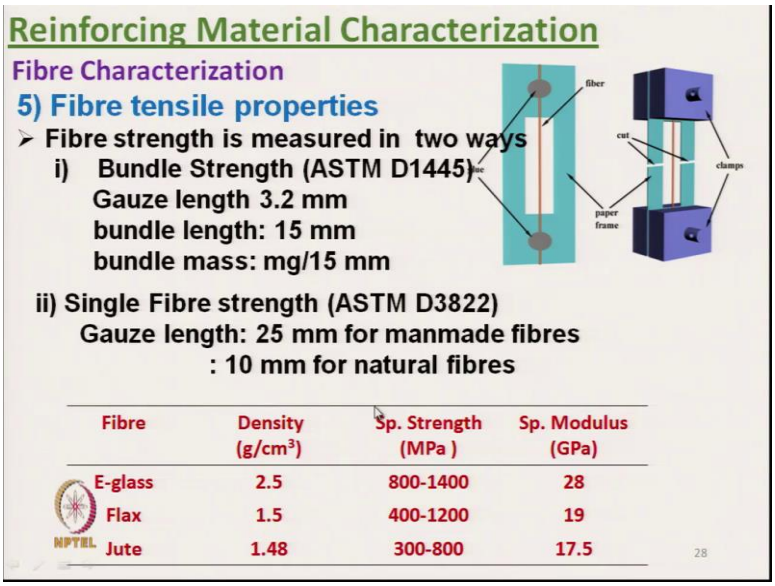

So, another characteristics which is fiber tensile property which is extremely important for composite because fibers are used as reinforcing material. So, reinforcing material must have very high strength. So, fiber strength is measured in two ways; one is bundle strength that is by ASTM D1445 where gauze length is kept 3.2 millimeter. And bundle length is 15 millimeter. This is this is the actual bundle length, but the gauze length is 3.2 millimeter and bundle mass is milligram per 15 millimeter. So, total bundle mass is actual is measured.

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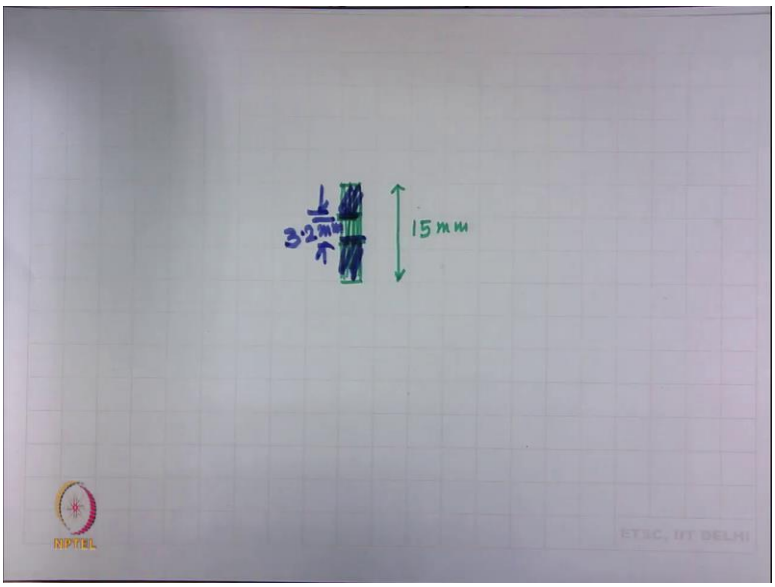

So, this is the way which goes. This is the fiber bundle this length is 15 millimeter. And once we are gripping these are the grips this is the jaw and here it is a jaw and this length this is gauze length which is 3.2 millimeter. So, bundle strength test is done in this fashion. And in addition to the bundle strength we can also perform the single fiber strength test. And the gauze length here it is 25 mm for manmade fiber and 10 mm for natural fiber ok.

This is the fiber where and here these are the it is a fixed here and it is with a fixed on a frame and these are gripped by the tensile tester. And then this frame is cut at the sign and where only fibers are exposed. And then we can get the fiber strength test this is this paper frame and paper frame along with the fiber is placed on the tensile tester. After that these two sides are cut and these are the clamps. And then we can test the fiber single fiber strength ok.

And these are the typical characteristics of fiber strength like fibers are E glass, flax and jute. The density of E-glass is 2.5 g/cc, 1.5 for flax, 1.48 for jute and strength typically for E glass 800 to 1400 MPa. And for flax it is around 400 to 1200 MPa, jute it is 300 to 800 MPa and specific modulus for glass is much higher than the flax and jute fibers and another characteristics of reinforcing material which is moisture content.

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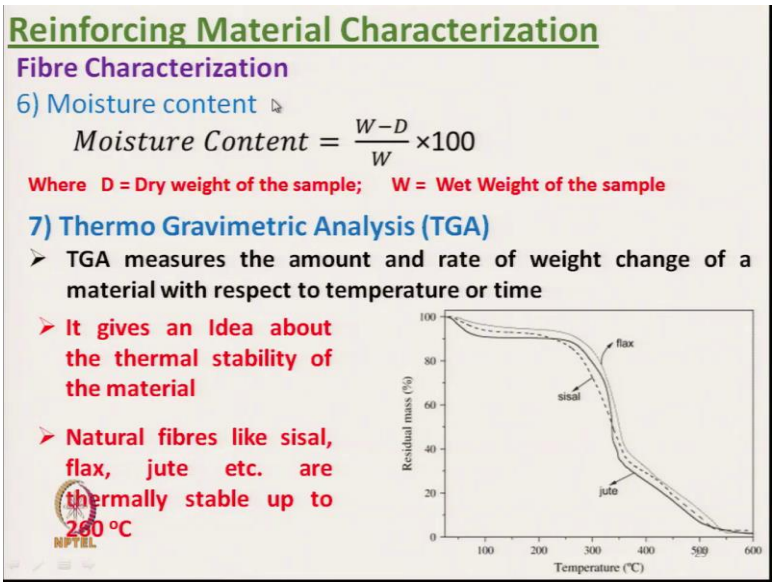

So, moisture content we can measure by measuring the dry weight of the sample and wet weight of the sample. So, we take the material and we first condition the material at

standard temperature and humidity. And after that we take the W, which is wet weight of the material.

And then we dry the material, it is a bone drying ok. Which remove all the moisture present in the structure and we get dry weight

$$Moisture\ Content = \frac{W-D}{W} \times 100$$

Another test method for reinforcing material which is thermo gravimetric analysis this is very important property, where it shows the change of mass change of weight during heating ok. TGA measures the amount and rate of weight change of material with respect to temperature or time.

So, in x axis this is showing the temperature and in y axis the residual mass. So, once the material is heated at high temperature, at very high temperature the material lose it is weight due to internal structural change, internal decomposition. So, that will show with this curve. It gives an idea about the thermal stability of the material, if the material is not stable; that means, it will lose its weight. The residual mass will be less and natural fiber like sisal, flax, jute etcetera are thermally stable at least upto 250 to 260^0C. So, these are the three different fibers natural fibers and initially the residual mass is 100 %.

And it maintains almost 100 percent or close to 100 percent at least upto 260^0C. And after that it starts it is not stable anymore beyond that temperature it starts decomposition. And then the residual mass drops gradually it is steeply there will be drop ok. So, that shows the TGA testing ok. So, we can come to know with this curve that how much stable the material is up to what temperature. We will stop here will continue with this discussion in next class till then.

Thank you.