Testing of Functional & Technical Textiles

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Lecture – 11
Testing of Fibre Reinforced Composite Materials (Contd…)

Hello everyone, we will continue with the discussion on measurement of reinforcing material characteristic. So, in last class, we have discussed few characteristics, and we are discussing thermo gravimetric analysis - TGA analysis.

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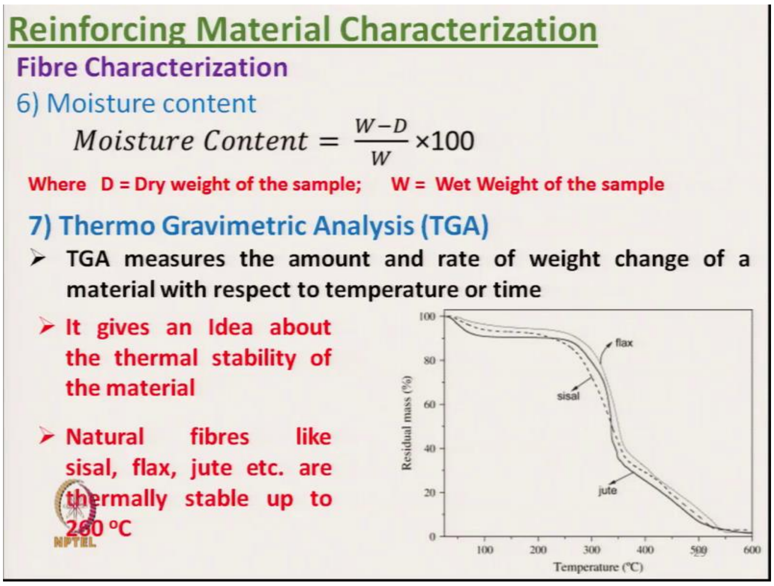

And TGA measures the amount and rate of mass change of a material with respect to temperature or time. And this curve shows that the residual mass that is change of mass in case of flax, jute, sisal occurs around a temperature around 260^{0}C, so that means, the materials are stable up to 260 ^{0}C.

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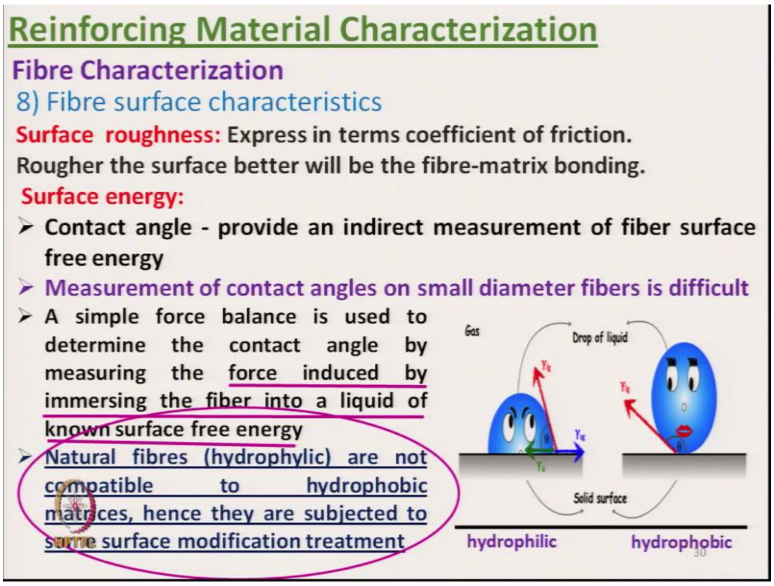

Next characteristics is that surface characteristics of fibre that can be expressed, one is that surface roughness. Surface roughness of fibres are extremely important for composite manufacturing, because it express the coefficient of friction. The rougher the surface better will be the fibre matrix bonding at least physical bonding will be there, the keying effect ok. The surface energy can be measured by contact angle which provide an indirect measure of fibre surface free energy, that means, the measurement of contact angle on small diameter fibre which is difficult to measure ok. And a simple force balance is used to determine the contact angle by measuring the force induced by immersing the fibre into a liquid of known surface free energy.

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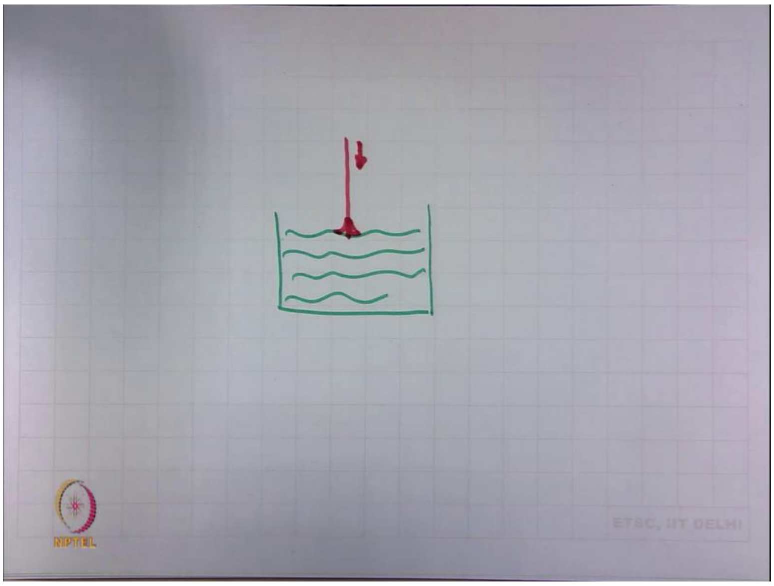

Like this is measured the surface energy or contact angle is measured by this method. There is a liquid; liquid of known surface free energy. And once the fibre is dipped and it will actually try to the liquid will try to rise and it will form a contact angle, and that will have some downward force. The liquid contact with the fibre, will start pulling the fibre downward and that force is measured.

So, this, this will actually indirectly give the indication of contact angle. The force induced by immersing the fibre end into a liquid of known free surface energy. The natural fibres like hydrophilic fibres are not compatible to hydrophobic matrices. So, hydrophilic fibres, they have problem with the hydrophobic matrices, hence they are subjected to some surface modification, so that they can be made hydrophobic; otherwise they are not compatible. And majority of the thermoplastic composites are hydrophobic in nature that is the matrix materials. So, surface modification of natural fibres are can be done using different techniques.

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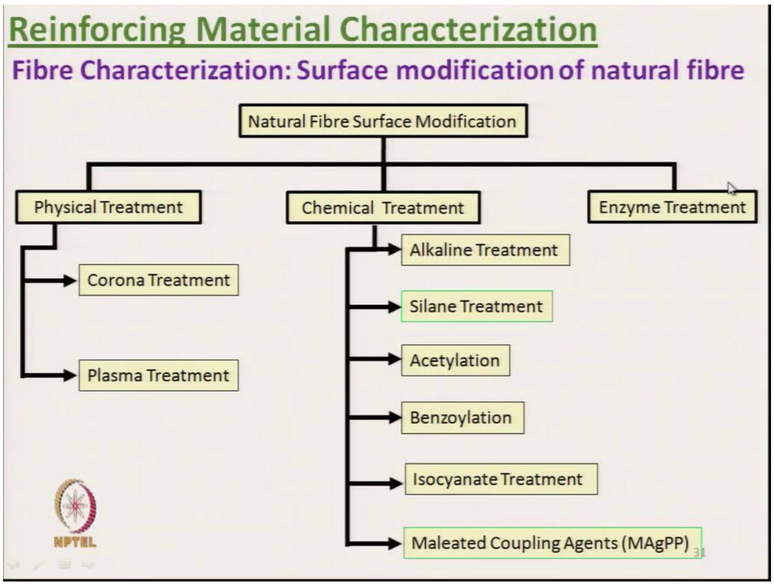

Natural fibres in general they are hydrophilic in nature. So, these surface modifications are done by physical treatment, by natural fibre surface modification or by enzymatic treatment. The physical treatment is done by corona treatment or plasma treatment, there are other treatments available. So, typically corona and plasma treatment, they modify the surface. And chemical treatment is that that by alkaline treatment, silane treatment, silane material treatment, acetylation, benzoylation, isocyanate treatment, and MAgPP maleated coupling agent. So, MAgPP is extensively used to modify the surface characteristics of natural fibre. I will give examples of treatment with MAgPP, and how the MAgPP treated natural fibre like flax results improvement in composite characteristics.

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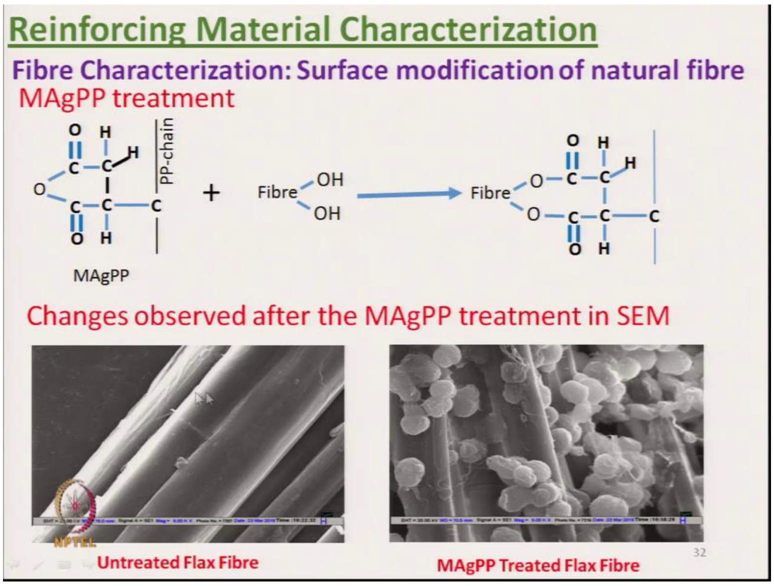

So, this is fibre, cellulosic fibre with OH group present in it. And here it is a MAgPP molecule. So, the surface treatment is done here. So, the change these are observed after MAgPP treatment in SEM. So, this is the untreated fibre. And once it is treated, there is a bond formation, and the MAgPP the molecules are visible. And this makes the flax fibre which is initially hydrophilic. And after MAgPP treatment the flax fibre has got very good cohesion with the matrix material. Initially the it was not that compatible that natural flax was not that compatible with the matrix material. And after treatment this was compatible.

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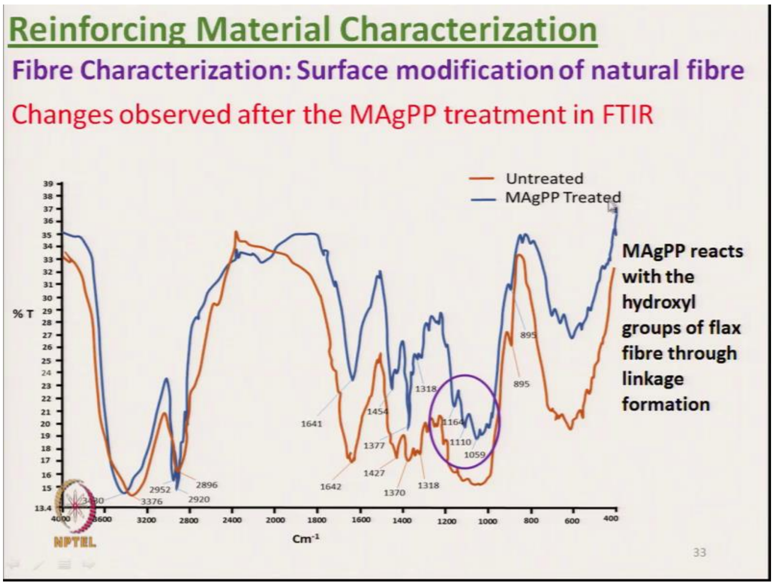

Now, the changes observed after the MAgPP treatment in FTIR is that we can see here this is the yellow graphs lines are untreated material ok, and this blue one is treated with MAgPP. So, MAgPP reacts with hydroxyl group through the linkage formation. So, it changes. So, in x-axis it is a basically frequency, it shows the frequency. Here the it is the IR-ray is being actually pass through and proportion it is absorbed. So, y-axis it is shown. So, accordingly there is a change, its distinct change is observed once the flax is treated with MAgPP.

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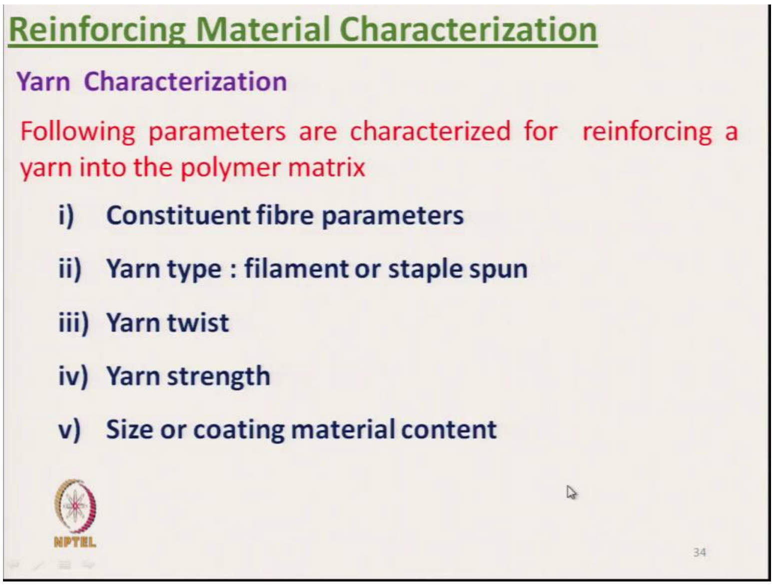

After fibre characterization, there are yarn characterization. So, there are different methods of measurement yarn properties. The following parameters are characterized for reinforcing a yarn into polymer matrix. So, first is that constituent fibre parameters. So, in a yarn what are the different fibre parameters present, so whether the yarn is staple fibre right or the filament fibre. Then you should know the twist of yarn. So, yarn twist actually affect the composite characteristics significantly.

Then yarn strength, strength of yarn directly affect the strength of composite material, and size or coating material content. So, what is the coating material content that also is important. After yarn, next is that fabric characteristics. So, yarn and fabric characteristics are basically we are not discussing here in detail, because testing of yarn and testing of fabrics one can learn from other course that is evaluation of textile material which is undergraduate level course, so that is why we are not discussing here.

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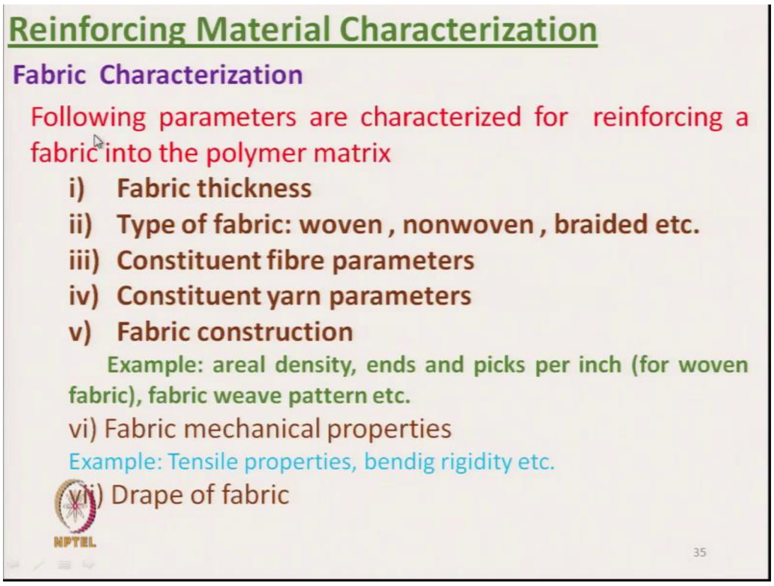

The reinforcing material as fabric, where the important characteristics are measurement of fabric thickness type of fabric, whether a fabric is woven, nonwoven or braided that we must know what are the constituent fibres present in the yarn or fabric and constituent fibre parameters, what are the test parameters, what are the strength, diameter of fibres present that directly affect the fabric characteristics and also the composite characteristics constituent yarn parameters and then fabric construction parameters. So, if it is woven fabric, what is the structure, what is the ends per inch, picks per inch, what is the other characteristics, what is that structure of fabric. Whether it is a plain woven fabric or twill fabric or unidirectional fabric, all these characteristics all these constructional parameters of fabrics are important.

So, the constructional parameters are the areal density, ends and picks per inch for woven, fabric fabric weave pattern. So, these are the different parameters. Then fabric mechanical properties like tensile properties, bending rigidity, these are also important for manufacturing the composite material and drape characteristics drape of fabric. So, after this evaluation of matrix material and reinforcing material, so we will now start the testing of composite material. So, before going to discuss the composite material testing, we must first understand the failure mechanisms of composites.

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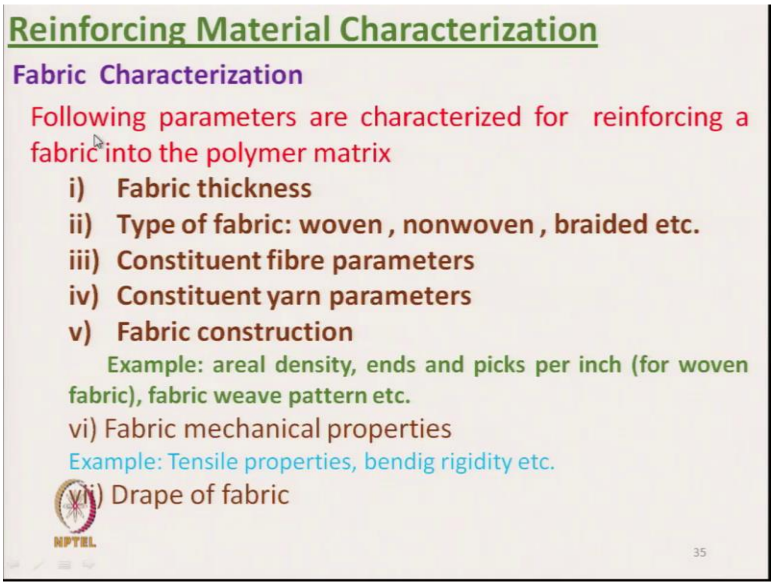

So, during its life or composite is subjected to different force ok, different forces, which deform the composite. It can with stand some forces and some damage, its structure. So, amount of force or direction or type of force that either deform or the damage the structure or in some case it can withstand. We must clearly understand the type of force or type of damage following incidents are observed when a fibre reinforced polymer composites fails.

What are these? These are matrix cracking matrix may crack, fibre pull out may be there, fibre may actually come out from the matrix, fibre bridging may takes place, fibre matrix de-bonding may be there that is that the bonding between fibre and matrix may be broken that means, fibre may get separated from the matrix material, and fibre itself may get rupture.

And nature of damages can be of different type these are in-plane damage~~,~~ that means, once the material is actually stressed there will be in-plane damage. Then micro buckling, once the materials are actually composite is compressed, there will be micro buckling in the reinforcing material as well as composite material will take place. Then delamination, so composite materials are normally consists of different layers, once these are suppose ~~it is a~~ it is a composite material. Once it is compressed, so there is a delamination is taking place. So, this is delamination. Then buckling delamination, that this is actually a type of buckling delamination. So, first let us try to understand all these terms.

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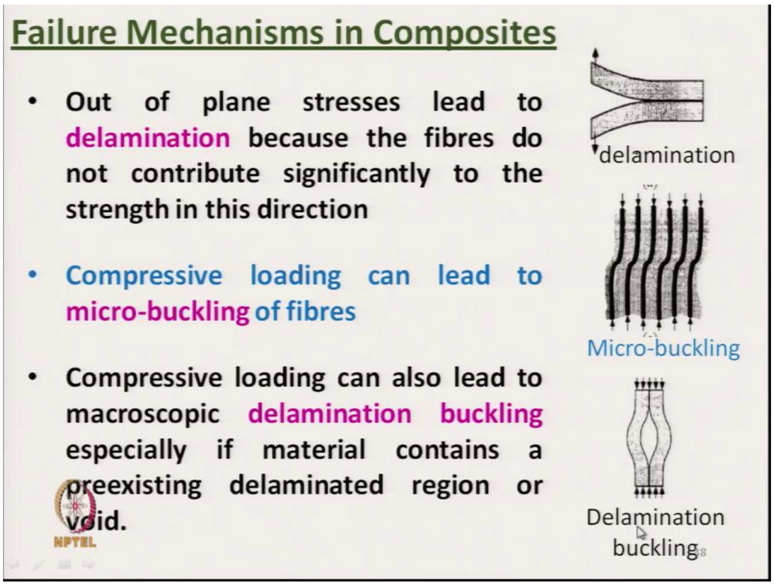

Out of plane stress leads to delamination because the fibres do not contribute significantly to the strength in this direction. Now, this is the picture. Now, let us see.

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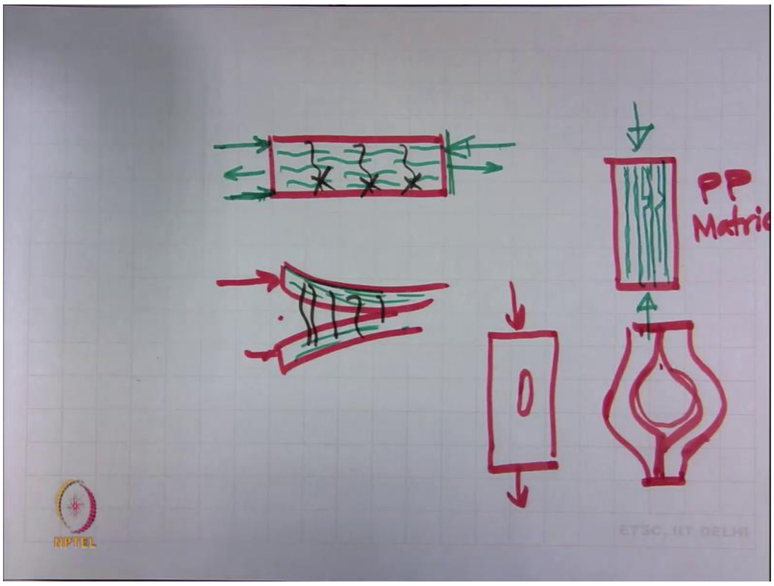

Suppose, this is a composite material, and fibres are aligned in this direction. And what is in-plane force, this is the in-plane. Here we are talking about out of plane stress. So, out of plane stress is that suppose it is fixed here, and one force is in this direction ok, another force is in this direction and another force from this direction.

And as there is no fibre in vertical direction~~.~~ s~~S~~o, this composite will get easily delaminated, because it is out of plane force. This will get delaminated like this. It is delaminated due to the force. And the fibres are along this axis. As there is no fibre in vertical direction, so there will be chance of delamination due to this out of plane force out of plane deformation. So, this type of delamination, if you want to prevent~~,~~ we can use the three-dimensional, 3D structure of the reinforcing material. So, if the fibre orientation was vertical as well as the horizontal direction, in that case this type of delamination we can eliminate.

Next method of failure is that this mechanism is that compressive loading can lead to micro-buckling of fibre. Micro buckling takes place like suppose this is a composite say polypropylene matrix, and here we have fibre say, glass fibre, glass fibres are there. And once the force is applied to compress, this polypropylene will get compressed, but the fibre in the lengthwise what will happen, there will be micro-buckling. And this is actually this will result the declaration in characteristics. So, this is the micro buckling and this actual results failure of composite material.

Third is that compressive loading can also lead to macroscopic delamination buckling especially if the material contains preexisting delamination region or void. Suppose, a composite material it contains a void here. Once the load is applied this from this void or some delamination, then what it will create it will create natural delamination, ~~yeah,~~ there will be compressive delamination this side it is a delamination void.

So, so the compressive loading can also lead to macroscopic delamination buckling especially if the material contains a preexisting delaminated regions or void. So, in the center in the inside the structure, there was certain void. And due to this force application compressive force application, there is a delamination buckling of the compressive material. So, these are the very common ways of failure, these are the mechanisms.

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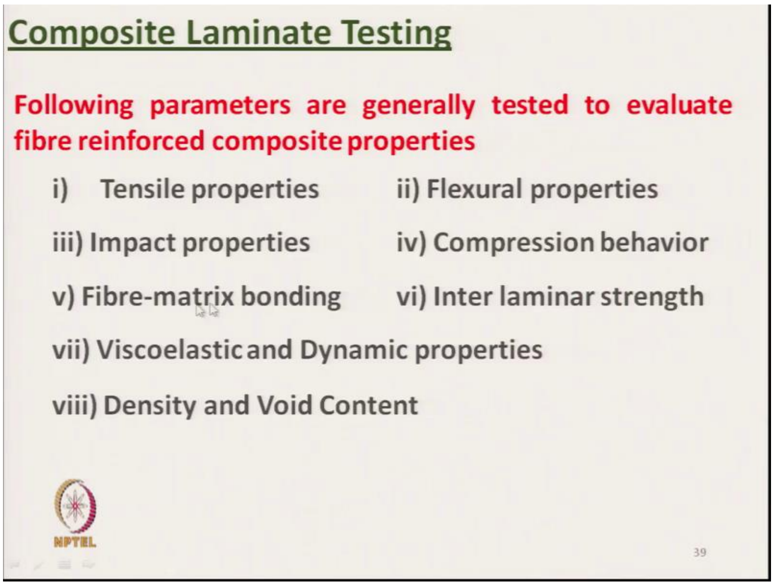

Now, we will discuss that the test methods of composite laminates. So, following parameters are generally tested to evaluate fibre reinforced composite properties. One is tensile properties. Then flexural properties tensile properties means the tensile load is applied and we can get the tensile strength or tensile modulus. Flexural properties are the when the materials are bent the bending characteristics, then its impact properties, then compressional properties.

Fibre-matrix bonding characteristics; it is extremely important; otherwise the composite will fail easily because the reinforcing material which is fibre will not carry the load if the bond strength is less. So, you must know the bond strength. So, we will discuss the measurement techniques of fibre-matrix bonding properties. Inter laminar strength characteristics, viscoelastic and dynamic properties those we will discuss. Density and void content of composite, because void content is a measure property which actually shows the final performance of the composite. A composite with higher void content will perform poorly, first we will start with the tensile characteristics.

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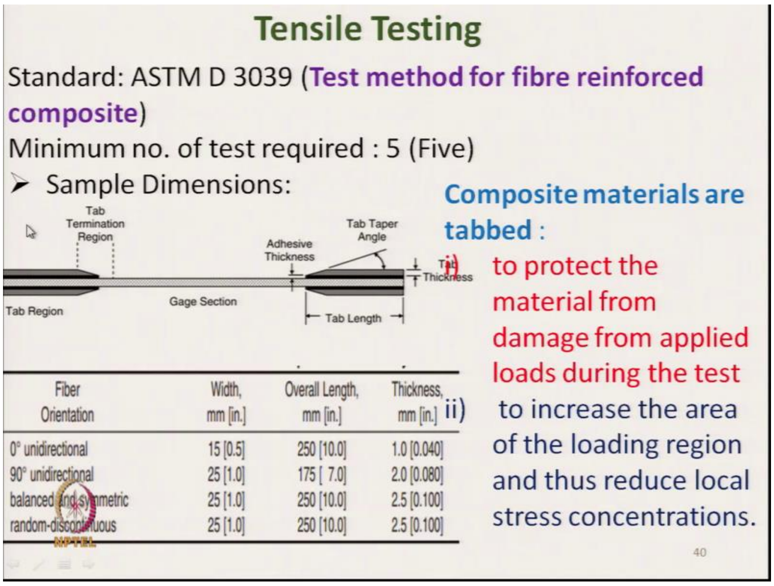

So, tensile testing its done as per ASTM D 3039 method. There are different other methods also, but as per this ASTM D 3039 test method, it is specifically for fibre reinforced composite. Here recommended tests are minimum 5 test per sample. And the most important part is that the composing material is tested after making a tab material ok. This is the tab region we have to create this composite materials are tabbed for basically for two reasons. First is to protect the composite material from damage from applied load during the test, because once it is gripped, the composite material may get damaged, so which will show the deterioration in test result.

To prevent the composite material during gripping to prevent it from damage say so this tab materials are used to prevent the damage during testing, and also to increase the area of loading region thus reduces locals stress concentration. So, once the tab material is created, the composite material is tabbed, it will increase the area of loading region. The tab has got some specific dimensions ok. And the dimensions are its called tab angle that is a tab taper angle, this is the tab taper angle ok, tab length ok. And tab is created on the composite material just there will with the help of some adhesive material.

So, first on the composite material there will be some adhesive material added with certain thickness, and then we have tab material with some thickness. And so tab thickness is another characteristics, and then tab termination region. So, tab termination full tab region, and then tab termination region, so between that there will some tab angle ok. And in between two tabs, there will be gauge length. So, gauge length is that the length between two tabs and which is being tested. So, these dimensions are different for different fibre orientation.

So, fibre orientation if the fibres are unidirectional that is orientation angle is 0, then the width of the specimen is 15 mm. And the overall length of the material is 250 mm that is overall length including the tab length, and the thickness is recommended as 1 mm. So, if the orientation of fibres are 0 degree, but for other direction orientation we need to have thicker composite specimen, wider specimen and the overall length is shorter.

So, once the fibre orientations are 90 degree, the width of the specimen becomes 25 mm, and overall length is 175 mm, and thickness is becomes 2 mm. Accordingly these are some specifications available; depending on the fibre orientation, we have to change the specimen dimension.

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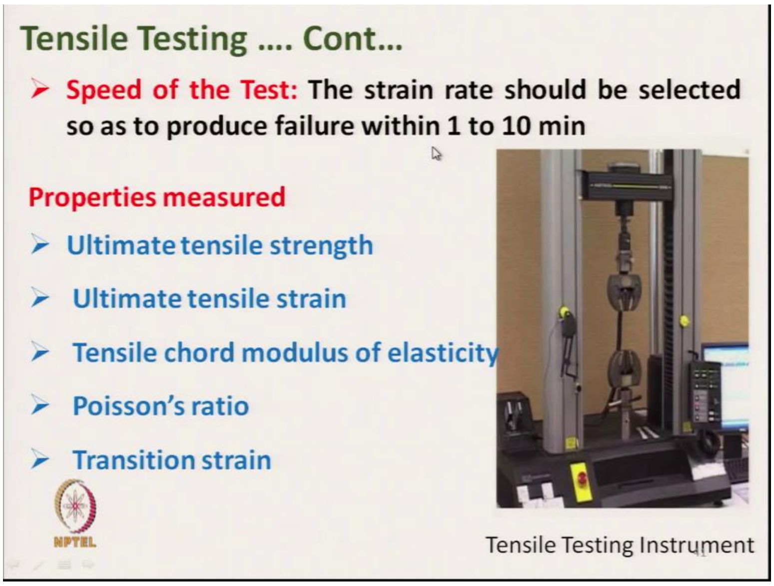

And the speed of the test is maintained, and such that the failure should takes place within 1 to 10 minute of the specimen ok. So, the strain rate should be selected, we can change the strain rate, so that as to produce failure within 1 to 10 minute. So, if you know the breaking strength, so we can select the strain rate accordingly. The properties which is measured which are measured in this tensile testing are ultimate tensile strength, ultimate tensile strain, tensile chord modulus of elasticity, Poisson's ratio and transition strain. There will be one transition point, we can calculate the transition strain or transition stress.

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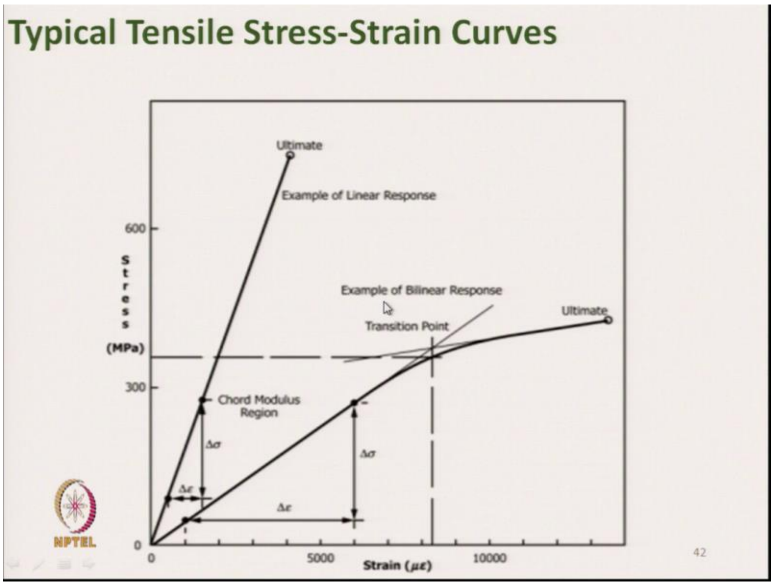

Now, this is the typical curve ok, where in x-axis it shows the strain; and in y-axis it showing the stress in MPa. This is one curve for a particular composite, where this point, it is a ultimate stress, ultimate point. This is the ultimate strain from there you can calculate an ultimate stress we can calculate. And this is showing the linear response of the composite. Before it bent, it reaches the ultimate point ok.

And for say thermo set matrix with say glass fibre reinforcement, we can get this type of curve, but there are other types also. This is showing one transition point, where at this point, this is transition point. So, from here we can calculate the transition stress and transition strain. And here this is the ultimate stress. So, this phenomena is known as bilinear response. This is unilinear response, the linear response and this is bilinear response.

And chord modulus which is nothing but the modulus of material measured from any two points of straight region, straight line region. We take any two points, so that is called chord modulus. We can actually measure we can measure we can take two points and join this two lines two points with a line and then from there we can calculate the modulus. Now, we will discuss the different modes of failure, and how to actually identify, how to express this different mode of failures composite material.

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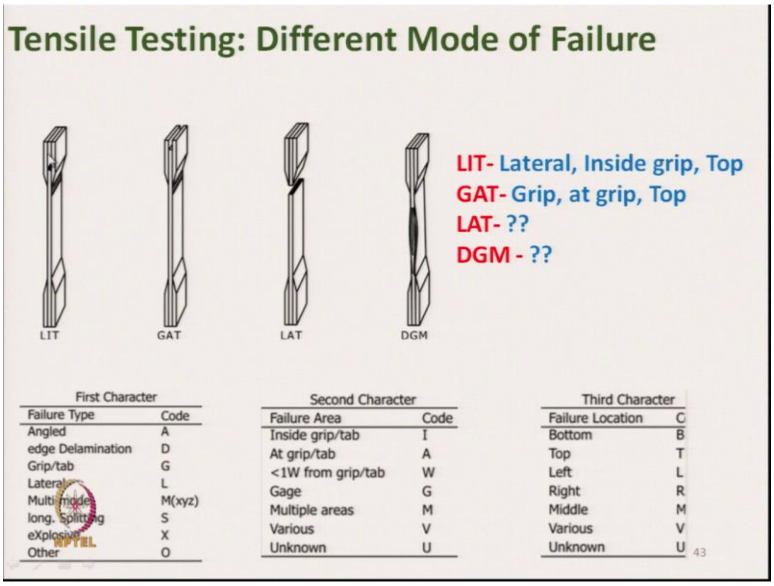

So, this is showing the composite specimen with tab portion. And ~~this~~ these modes are expressed with the three letters ok; tensile failures are expressed with three letters. The first character which is one single letter character, which is showing the failure type, it is a type of failure. Second character which shows the area of failure area which at which area the failure takes place~~.~~ a~~A~~nd third character is the location of the failure.

So, location is shown by the third character. So, if we know these three characters without looking at the composite, we can make out the type of failure. Like first character which is showing the failure type these are like angled is expressed with the code A. Code D shows the edge delamination; code G that failure type is at grip or tab that is due to grip or tab; L is lateral; M is multimode that is more than one mode like x, y, z different mode mixture. S is that long splitting if the failure type is splitting long splitting time type in that case we can use as S. X is the explosive, suddenly it is broken that is a explosive. O is all other type ok.

Similarly the second character which is failure area it what area the failure took place; like whether it is a within the grip or within this, this gage zone that area it is specified. Like I means in side grip or tab any failure which occurs inside grip or tab there the middle character will be I. Similarly, A, if it is at grip or at tab, so if it is at the point of tab or grip, the middle character will be A ok. W is the~~ the~~ less than one of width from the grip, that means, less than width of the material that the there is a length from the grip or tab that is called W that the ~~the~~ length where the failure occurred that length is less than the width of the specimen.

G is the at gage ok, this is the at gage there is a failure. So, gage means between the tab portion between the tab. Multiple area M, if it is multiple area then the middle character will be M. V is various, and U unknown. So, if the failure characteristics or failure area is unknown, then we can use U. And various means at different zones, so for different sample it is a randomly taking place, then it is a V.

Similarly, the third character is failure location. It will specifically locate the failure zone that is at bottom B, at if it is at top it will be T. So, here the failure took place at top. So, that is why it is T. So, it has at top at top that is why it was T. L, if it is at left side ok. R, it is right side; M if it is middle. So, here, here it took place at the middle~~.~~ V various and U unknown. So, these are the ways to express the mode of failure.

So, if we know L I T, so the tensile test the tensile modulus ultimate tensile strength all this things are important for composite as a material, but the mode of failure is also important, because the composites are used for structural material ok. So, LIT means lateral, lateral, inside the grip and at the top that is the LIT. GAT, it is at the grip at grip and at ~~at~~ grip and at top ok. LAT, what will be LAT, L is lateral, A is at grip, and T is at top. So, similarly, DGM, we can always actually expressed the mode of failure. So, we for any failure we can express this failure mode by these three letter, three character.

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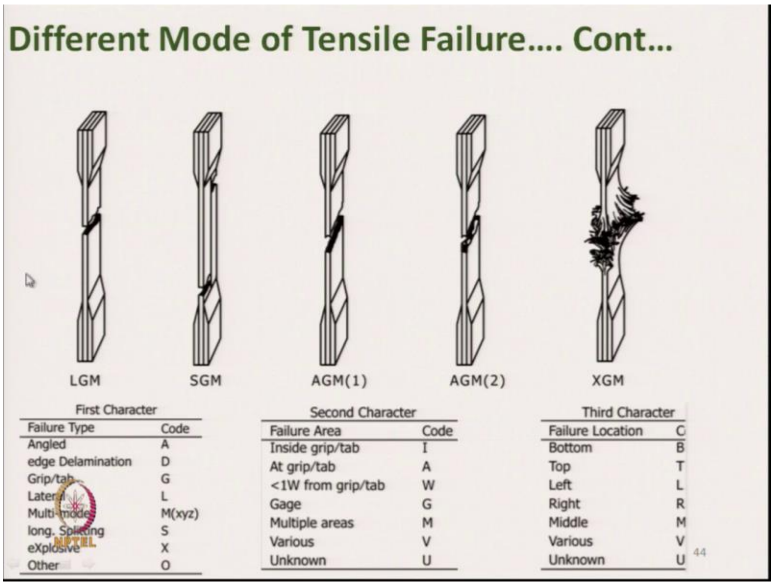

If we see this mode of failure, let us see couple of this XGM. What is X, X is explosive. It has broken suddenly just is like suddenly it is blasted. So, this is the explosive type of breakage. G, what is G, G is that gage that between these two tabs. And M, what is M? M is at middle at middle. So, AGM what is A – angled, there must be some angled so failure type angled. G at gage; and M it is at middle. So, we can clearly distinguish the type of failure. So, in addition to the value, it is addition to the numerical value of tensile characteristics the mode of failure is also important ok.

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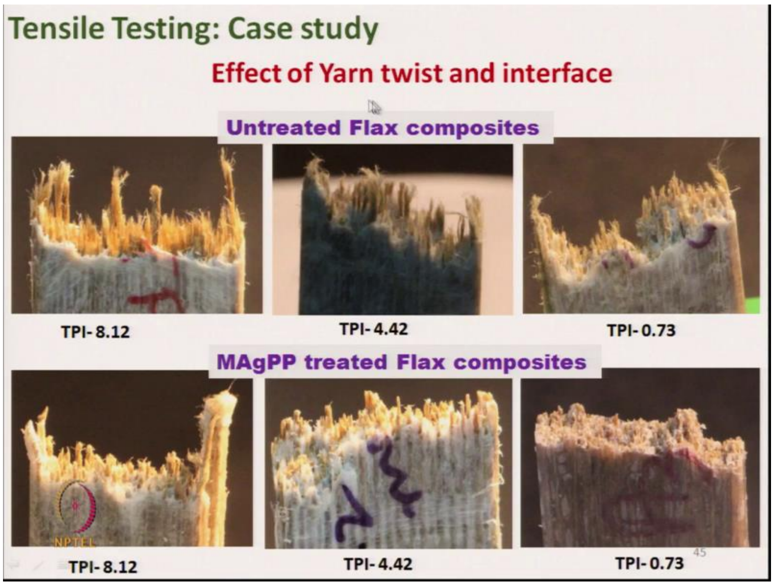

Now, few experimental data, the effect of yarn twist and interface. So, we have made some interface with MAgPP treatment on flax fibre. So, untreated flax fibre composite, after tensile breakage, these are the photographs. And here we have studied the effect of twist and interface. So, if we see the left side this picture, it is untreated flax composite with the with high twist 8.12 twist per inch. And twist is gradually , reduced and right side it is a TPI is 0.73.

And these three pictures on top are untreated flax. And here at the bottom these are flax treated with MAgPP ok. And the matrix materials are polypropylene. So, here we can see at the right bottom corner, it is a lowest twist with MAgPP treatment, where the fibre slippages are not there ok, because the twist was less. So, matrix penetration was proper inside the structure, and also as MAgPP treatment was there on the flax, there was proper cohesion, so which shows the improvement in characteristics of composite material as far as tensile characteristics are concerned.

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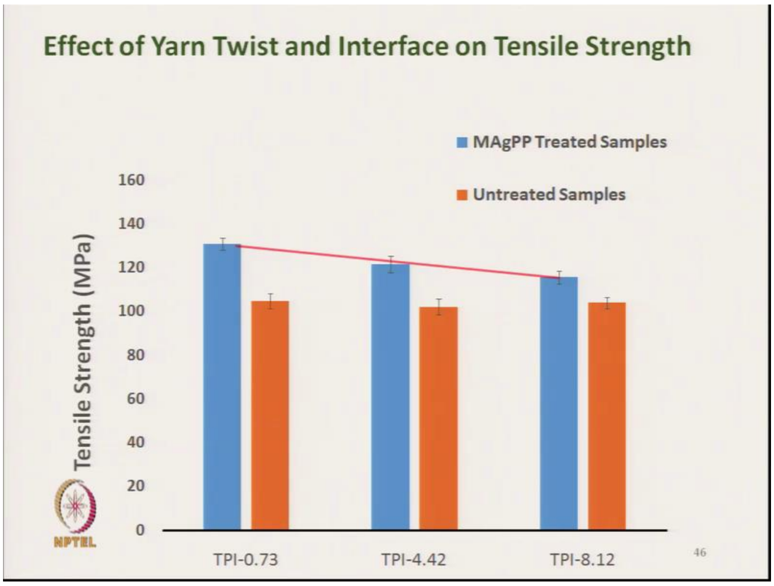

So, you can see tensile strength as we reduce the twist from 8.2 to 0.73, the consistent increasing in strength is there. And this strength is visible more in case of MAgPP treated sample ok. And if we compare with the treated and untreated samples, treated sample shows higher strength than untreated samples. These are due to the proper cohesion. There is a consistent increase.

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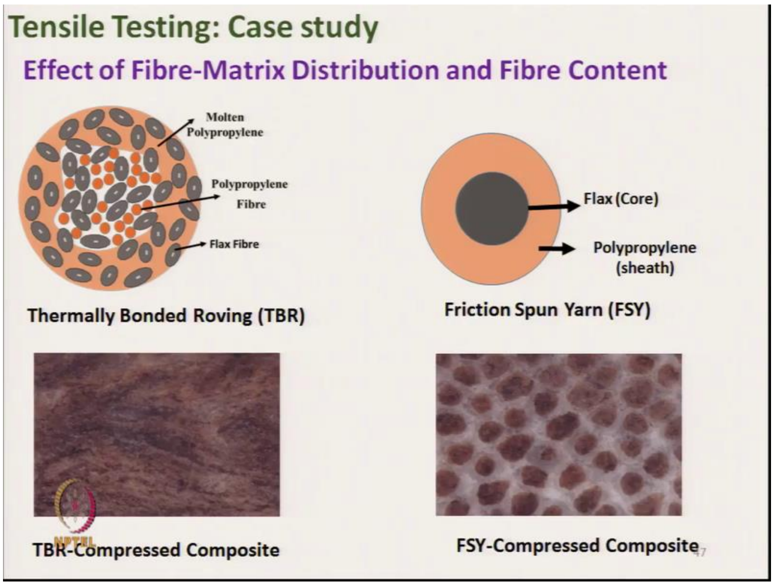

Now, effect of fibre matrix distribution and fibre content, now here what we have done we have actually produced two types of matrixes. One is this matrix are same. Here what we have done one is thermally bonded roving TBR ok, where the fibres are parallel, and the matrix materials are also parallel to that those fibres. Next is that flax yarn or fibres are placed at the core and matrix which is polypropylene which is placed in the sheath. In these two distributions, two arrangements we can clearly see that the proper penetration of matrix material is there in case of TBR - thermally bonded roving.

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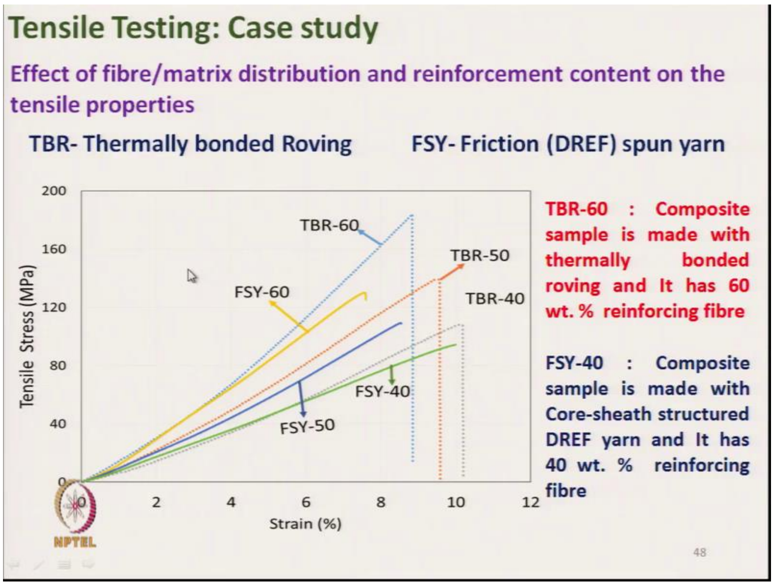

So, if we compare ~~this~~ these tensile characteristics with thermally bonded roving and friction spun yarn for different proportion of reinforcing fibre like TBR-60 which indicates the composite sample is made with thermally bonded roving. And it has the weight percent of 60 percent reinforcing fibre, FSY-40 which means composite sample is made with core sheath structure of DREF yarn, and it has 40 percent reinforcing fibre.

Now, if we compare TBR and FSY with same proportion of fibre, so TBR gives higher tensile stress than FSY for different proportion of reinforcing fibre. And also we can see as the reinforcing fibre proportion increases from 40 to 60, the tensile stress increases. So, fibre volume fraction, it has got direct correlation with the stress tensile stress of the composite material.

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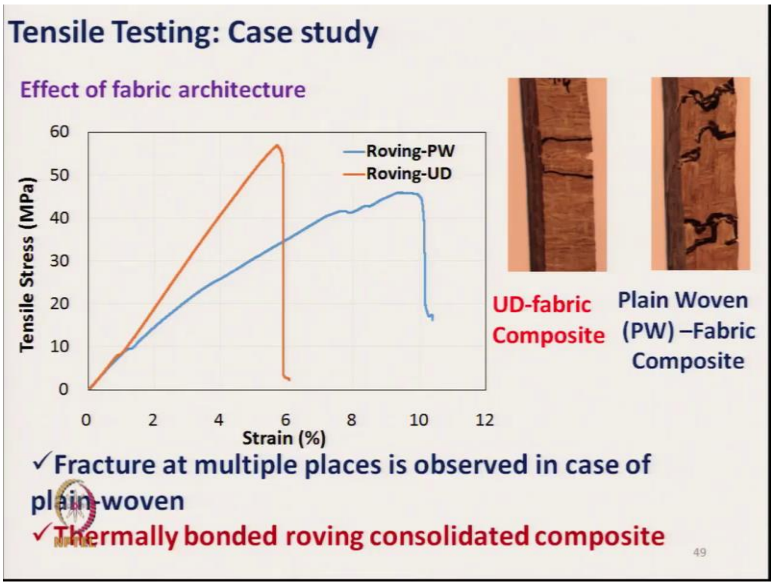

Another case studies you can see here the roving material effect of fabric architecture. So, one is that UD, roving-UD means unidirectional fabric composite. So, fabrics are made of the unidirectional orientation of roving. Another construction is that plain woven PW fabric composite, so that is ~~that~~ one is the roving UD and roving PW. Here we can see clearly the roving-UD results higher tensile stress than roving-PW that is the woven fabric, whereas the roving PW results higher strain.

So, due to higher strain in plane woven fabric composite, there in multiple breakages. So, fracture at multiple places is observed in case of plane woven fabric due to the higher extension of the reinforcing material that is the fabric structure plain woven fabric structure that is why the there will be multiple cracks are there. Thermally bonded roving consolidated composites ok. So, this thermally bonded roving with the unidirectional that will make composite very compact.

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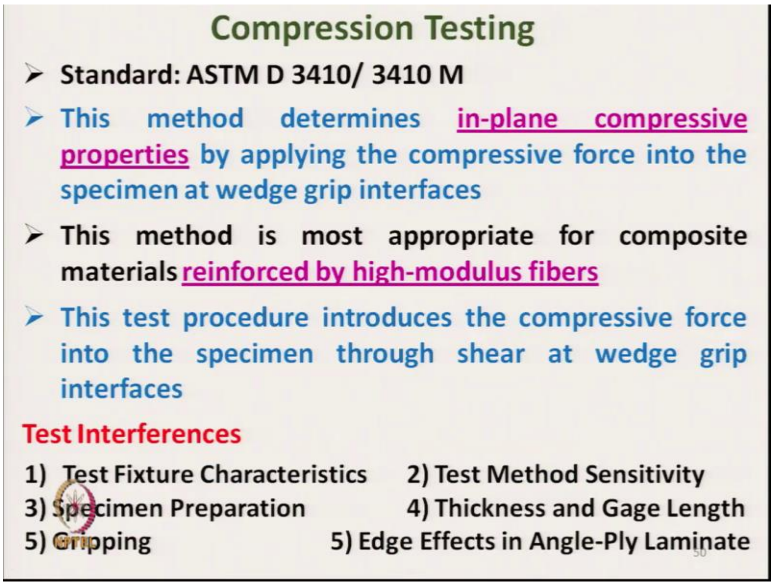

Next method is the compression testing. This method determines in-plane compressive properties by applying a compressive force into the specimen at wedge grip interface.

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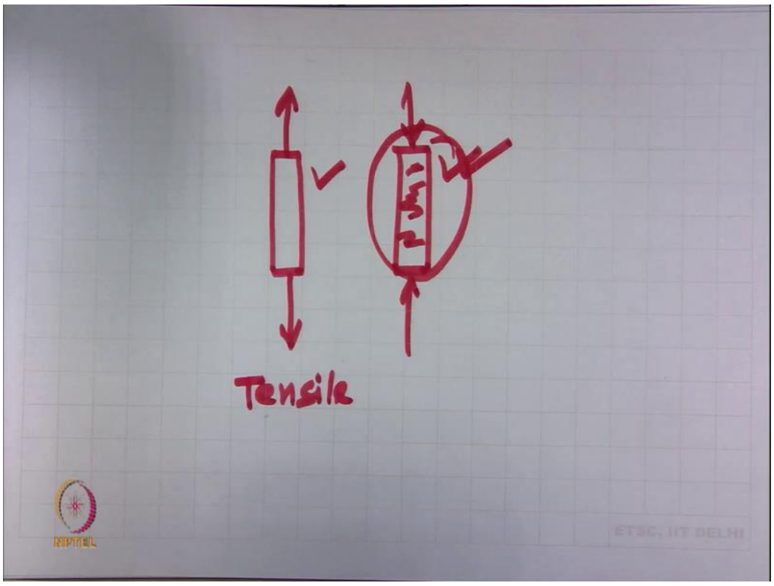

Like what we have discussed till now it is a tensile tensile characteristics, and we can measure the tensile stress, tensile modulus. But there are many applications where composite undergoes the compressive load, not the tensile load. So, tensile load is important, but compressive load in composite is also very important. And due to the compressive load, there will be a failure in composite structure and which we must understand. So, the in in-plane compressive properties is measured by applying the compressive force into the specimen at wedge grip interface.

This method is most appropriate for composite materials reinforcing by high modulus fibers like for say carbon composite ok. Carbon fibre composite material for very high modulus fiber like glass fiber reinforced composite for all this type of composite we must use the compressive test. So, compression test will show its performance due to the compression, compression of the composite, because ~~this~~ these composites may show very high tensile characteristics, but they may fail during the compression testing.

This test procedure introduces the compressive force into the specimen through shear at wedge grip interface. So, they will try to press compress towards the length direction. Test interface that is the test fixture ~~fixture~~ characteristics. So, the test parameter or test result is affected by test fixture characteristics, test method sensitivity, how do you prepare the specimen, thickness and gage length, gripping how do you grip, and edge effect and angle-ply laminate. So, thickness and gage they are interdependent that means for thicker specimen we can have little bit longer gage length ok.

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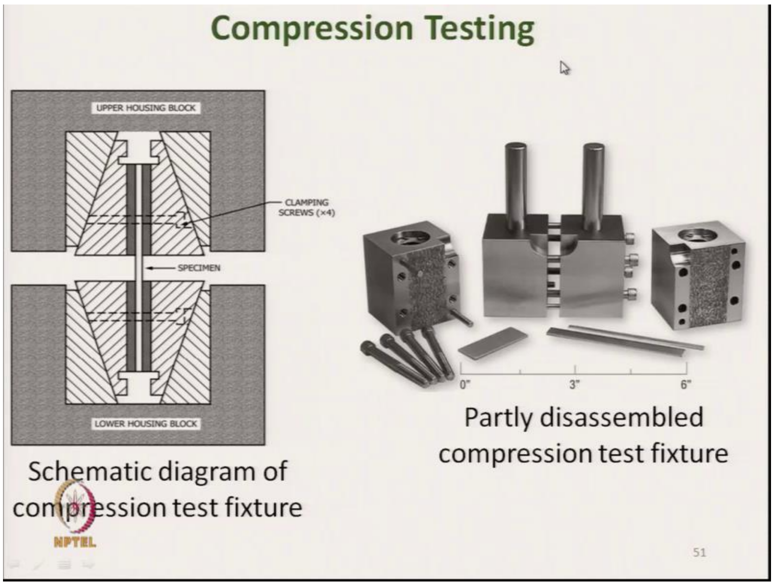

This is the compressive testing fixture where this is a specimen. And this specimen is gripped by two fixtures with the help of screw. And then they are compressed along the plane ok, not across the plane, and the compressive stress is calculated ok. These are the partly disassembled compression test fixture, so that we can use for testing.

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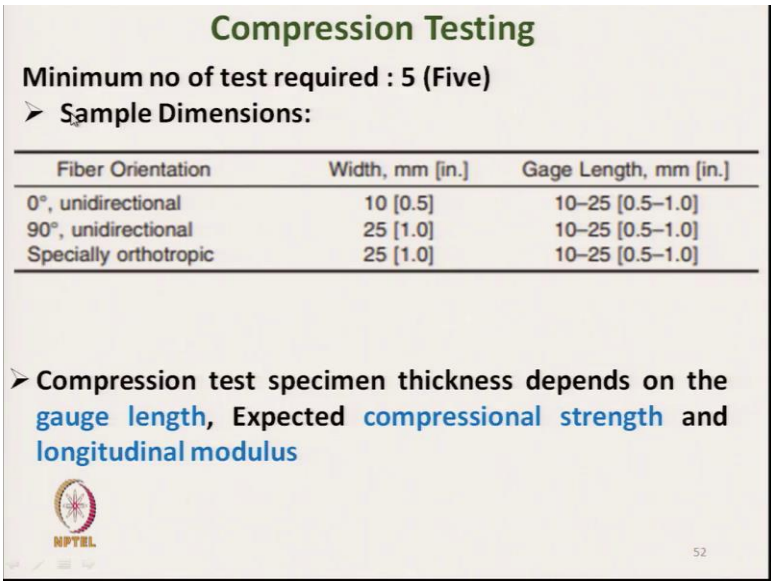

Minimum number of test required is 5, and sample dimensions are there like tensile test also for 0 degree fiber orientation. The width will be less, the required width will be less. And as we test the 90^0orientation of the fiber or some other orthotropic dimension, we need width of 25 mm. But gage length for all the fiber orientations are same, it is a typically 10 to 25 millimeter. The compression test specimen thickness depends on the gage length as I have mentioned expected compression strength and the longitudinal modulus. So, the test specimen thickness, we can change depending on these characteristics.

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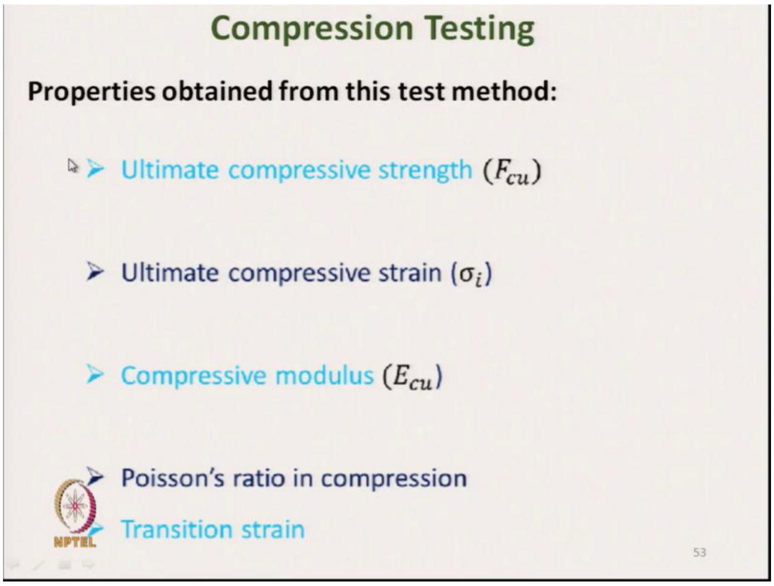

And the properties, which we get from the compression testing is the ultimate compressive strength, ultimate compressive strain, compressive modulus Poisson's ratio in compression, and transition strain. So, during compression, we will get almost similar type of stress-strain curve.

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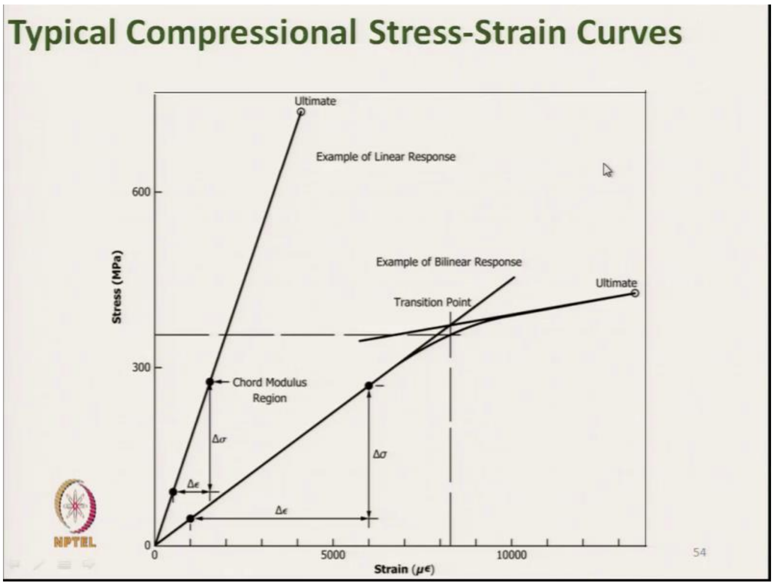

Here again it is a ultimate compressive stress here. And so this is a linear response. There may be some non-linear responses are there, and they are actually calculated in similar way the to that of our tensile stress which we have already discussed. And the failure mechanisms, type of failures can be expressed in the similar way as we have discussed earlier also.

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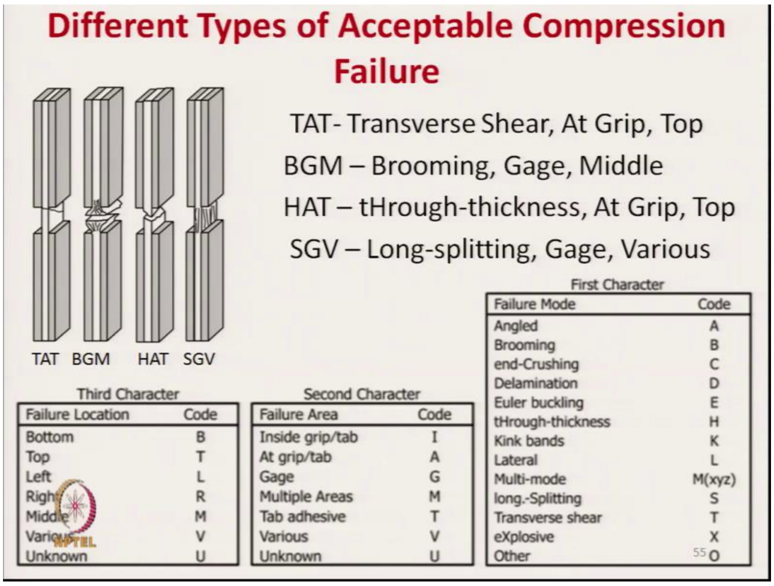

So, that this detail, the failure mechanisms we will discuss in the next class. So, different types of acceptable, compressional failures are there that we will discuss and in addition to you will, you will see there are different types of non-acceptable compressional failures. So, acceptable compressional failures are not due to our method of measurements, due to the failure of the composite material; and non-acceptable failure types are where the method of measurements, there are problems. So, all these aspects I will discuss in the next class.

Till then thank you, thank you for patient listening.