Technical Textiles
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Lecture - 11
Textile Reinforced Composites (contd.,)

Hello everyone. In evaluation of composite characteristics what we have already discussed the characterization of matrix material and characterization of reinforcing material. Now we will discuss here the testing and characterization of composite materials.

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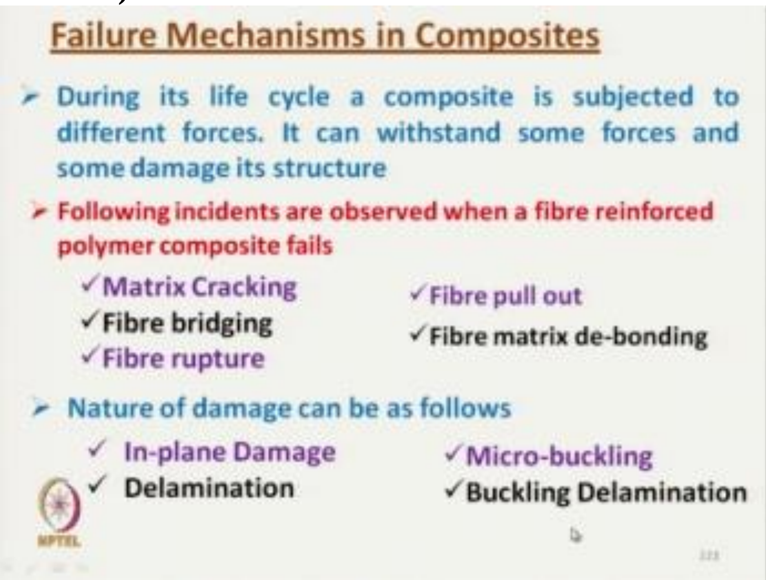

So before testing you must know the mechanisms of failure in composites then only we can understand the requirement of different test techniques. So during its life cycle a composite is subjected to different forces and it can withstand some forces and some other forces which damage its structure. So the following incidents are observed when a fibre reinforced polymer composite fails, these are the incidents through which the fibre reinforced composite fails.

It is by matrix cracking, fibre pull out, fibre bridging, fibre matrix de-bonding and fibre rupture. These are the different mechanisms different processes by which a matrix can fail. So we must understand, we must know this phenomena and we must know how to test or how to characterize the matrix, to know all these processes. So, nature of damage can be by in-plane damage, by micro buckling, by delamination or by buckling delamination.

So, these are the different natures of damages, the main issue in composite is that it is made of 2 entirely different components and their adhesion it is very important. It is not a homogeneous material it is a heterogeneous material. So this in-plane damage, micro-buckling, delamination, buckling delamination, we must understand.

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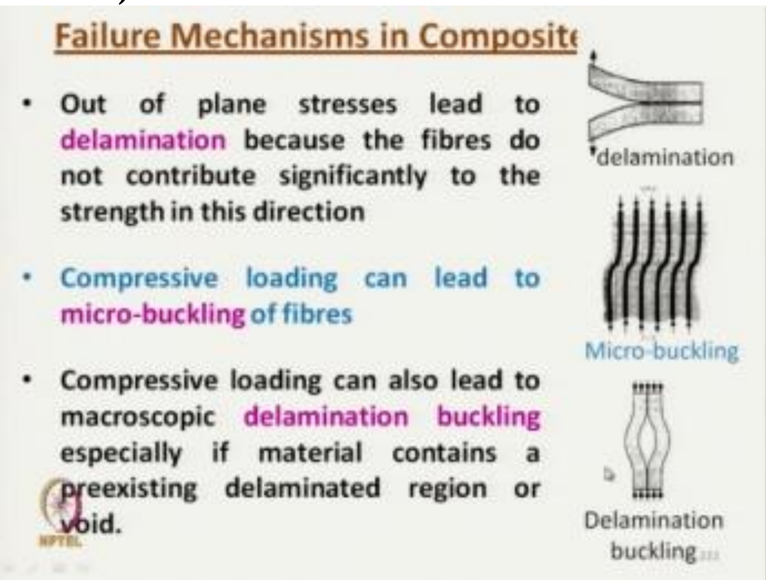

So out of plane stress leads to delamination, because the fibres do not contribute significantly to the strength in that direction, this is delamination. It is out of plane like we have made composite, very good composite with the fibres aligned in the this length direction, this is the fibre alignment direction and these are the matrix components. If we apply force in this direction the matrix will show very good characteristics.

But as there is no fibre in the this direction this say Y direction cross plane direction, so once we apply this force in this direction this matrix may get delaminated. Although fibres are there in that this direction due to this force, out of plane force, this matrix will get damaged, this process is known as delamination. Next, is that compressive buckling, so compressive load can lead to micro-buckling of fibres.

So, once the compressive load is applied this micro buckling of fibres take place. Because these reinforcing fibres they cannot compress lengthwise axially where as the matrix can get compressed because of their higher elasticity that result micro buckling. So this is one of the reasons of composite damage, composite failure due to high pressure. Compressive load also leads to microscopic delamination buckling so, delamination buckling especially if the material contains pre existing delamination region. So in this zone there were some delamination there that is why due to compressive load this delamination buckling took place.

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These are the failure mechanisms, so composite laminate tests are tensile characteristics, bending characteristics, impact properties, compressional behaviour, here we are talking about the axial compression, fibre matrix bonding which is very important as per as the tensile load distribution is concerned inter laminar strength characteristics, viscoelastic and dynamic properties, density and void content, void content is very important we must know the void content ideally there should not be any void present in the composite, presence of any shorts of void deteriorates the quality of composite drastically.

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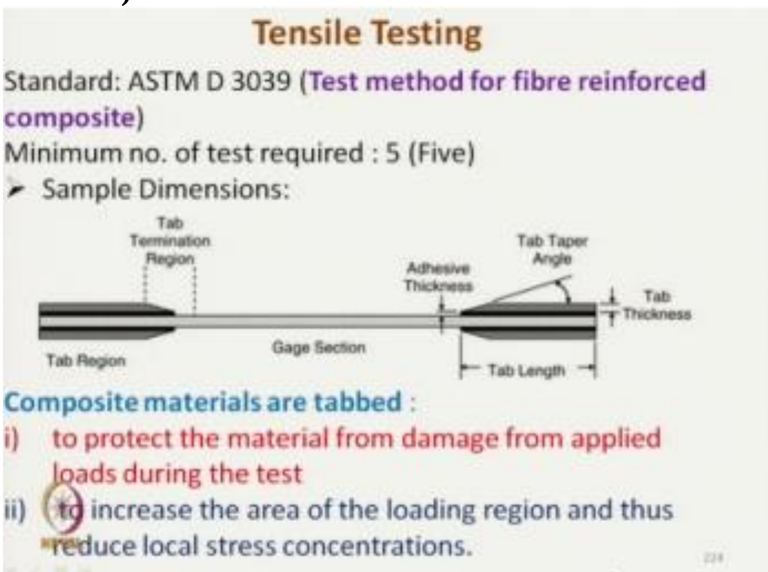

Now as per as ASTM D 3039 test this is actually specifically for tensile testing of fibre reinforced composite. It suggests at least 5 specimens has to be taken, the specimen dimensions are given here where tab is required of certain thickness, this tab is required to protect the material from damage from applied load during testing. Because there will be jaws if we do not provide tabs then the matrix may get damaged.

This is tab region, tab length and tab is attached to it that composite by adhesive. So tab is required to increase the area of loading region and thus reduce localized concentration of stress. So using tab the total stress is divided into, distributed to the larger area throughout the width of the specimen so it results reduction in local stress concentration.

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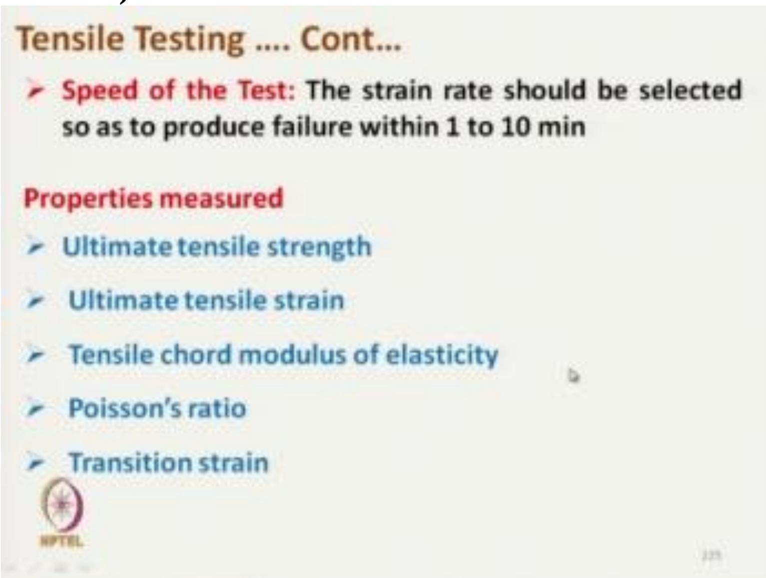

So as per the standard the strain rate should be selected so as to produce failure within 1 to 10 minutes, the properties here can be measured that ultimate tensile strength, ultimate tensile strain, tensile chord modulus of elasticity, poisson's ratio, tensile transitions strain.

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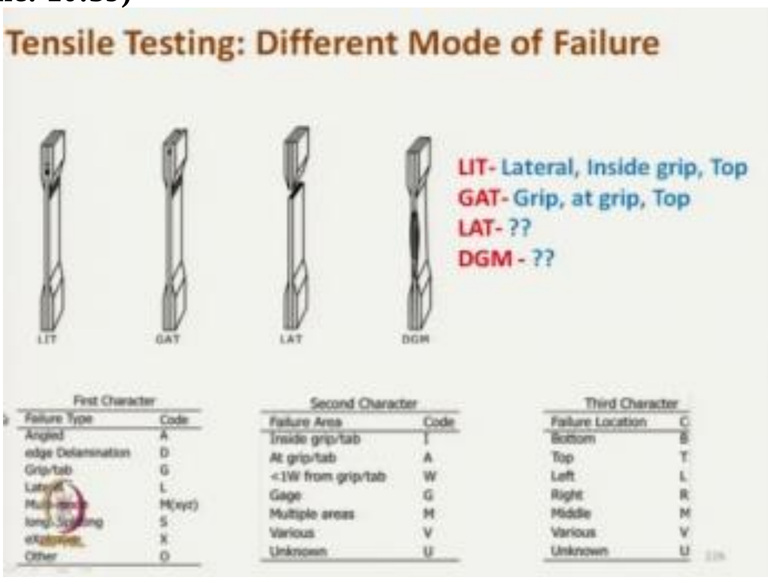

Now tensile failure if we try to see the modes of failure in composite it is not like the data, data of tensile strength of 2 composites maybe same. But we must also understand the way it fails during tensile loading. Similarly for compression for even bending we can get this type of mode and this mode of failure shows the detail by knowing by knowing this mode we can predict the characteristics of failure or nature of failure of composite after applying say tensile load.

The mode is expressed in terms of 3 letters, the first letter which shows the failure type, of failure and second letter it shows the area where failure took place and the third letter which is showing the location of failure. Let us see LIT, what does it mean? L in first letter means lateral this is LIT it is a lateral failure. It is not along the direction of load it is across the direction of load that is a lateral this is the failure.

I means inside grip it is the at the grip, inside the grip point here this is a failure point and location of failure it is a top, T is for top. Here, it is so LIT by knowing that term we can guess it has taken place inside the grip the type of failures lateral failure and it has taken at top jaws top of the samples. Now we have to decide whether this data we would like to take or not. if the failure took place inside the grip that means there are some problems in the grip.

We have to receive this data. Similarly GAT means G means here from the first character that is a grip it took places at grip point not in between the jaws it is at the grip point and failure area is also at the grip and at the top grip. That means it is expected that there are some problem with the top jaw, top grip so we can reject that also. LAT lateral A means at grip, T means at top so in this way we can get idea.

DGM, D means edge delamination so you can see here it has taken place during tensile loading edge delamination took place, G means at gauge means between the grip point. So there is no problem with the grip and M means at the middle location. So, in addition to the numerical value we can get idea we must get idea about the type of fracture type of failure takes place. Because in the composite we must knows the type of failure if it is taking place due to delamination that means we have to improve upon the delamination process, so here it guides us the way to improve the manufacturing process.

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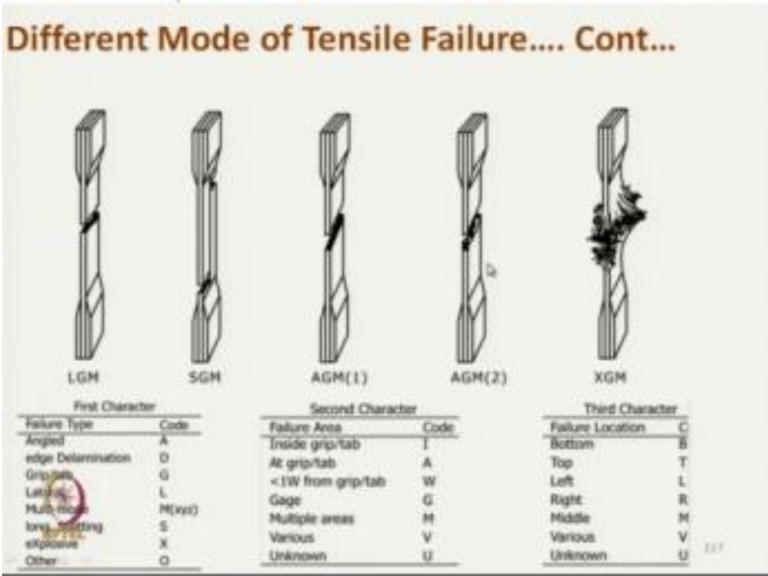

So we can see different other mode of failures, let us see XGM what does it mean. X means explosive suddenly it broke so this is the explosive G means at gauge in between there is no problem with the grips and aim is at the middle. So if we see SGM and say AGM, A means angled G at the gauge and at the middle. So from these two, only difference is that here it is an explosive suddenly broken and here it is little bit in angle form it has broken.

So from these modes, this 2 modes of failure even if the composite they have the similar or same failure value the stress at failure value still we will get some idea about the internal structure or we can predict the performance of this composite.

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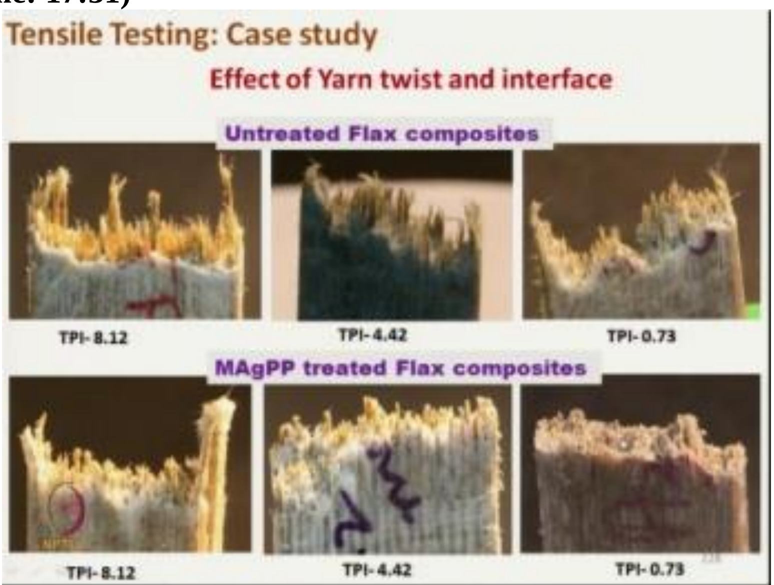

So these are the different photographs of flax polypropylene composite after failure, tensile failure, we can see in untreated flax composite the failures are not straight failure because of the fact that there were less bonding between the flax and polypropylene but once we treat the polypropylene with MAgPP PP the bonding improved and we can get sharp breakage. So load carrying capacity has improved and here we can see the fibre slippage took place.

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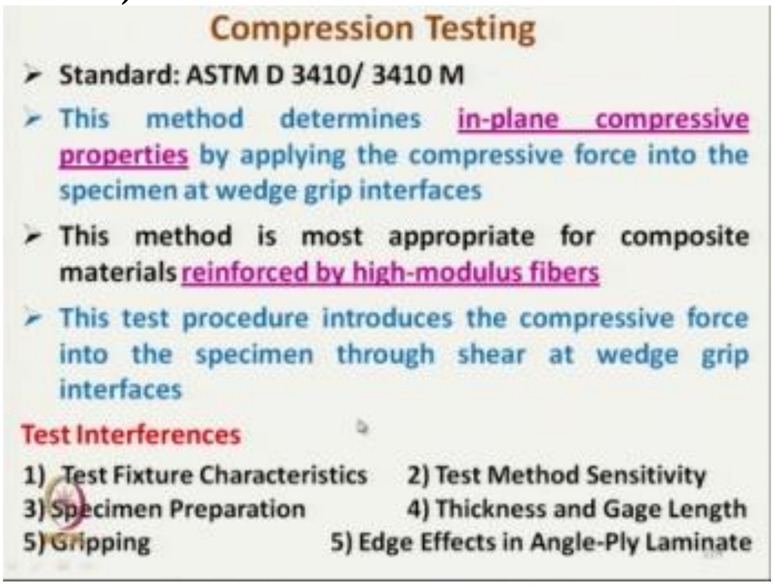

Next testing is that compression test, here we are not talking about the cross plane compressive property which we use for fabric testing. Fabric testing we cannot do in-plane compression because of the flexibility and in composite the in-plane testing is although important but in in-plane composite testing is more applicable here. Because once, we use composite in load bearing purpose the loads are placed or applied on composite in in-plane direction but in textile fabric loads are applied in cross plane direction.

That is why in composite in plane compressive properties are important this method is most appropriate for composite material reinforcement by high modulus fibre.

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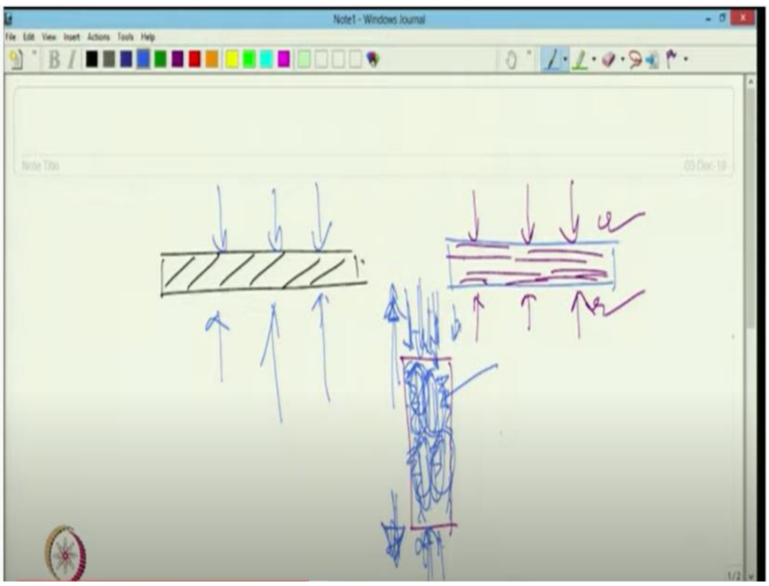

Now let us see, this is a textile fabric, textile fabric, it is flexible and we apply loads in cross plane direction. But in composite in case of composite if we say use this is composite material, if we use in-plane compression this will little bit compressed and we will not get idea about the usability about its performance in the long run but, if we apply load this is a composite material, if we apply a load in in-plane direction in that case that there will be loading here.

And this is specifically used for high performance fibre where tensile strength is very high but if it fails due to the matrix because as we are applying using high performance fibre here tensile strength will be very high. But the compressive characteristics here mainly depends on the matrix material and also on the matrix and fibre bonding. So that it if it is very strong in tensile direction it we must know.

Because in tensile direction the load is carried by the this high performance fibre. But once it is compressed in in-plane direction the load is not there on the, this high performance fibre load is mainly carried by the matrix material. So that is why in case of composite we must test for in the in-plane compression so this is used for high modulus fibre or say carbon composite or kevlar composite we must use this technique.

This test produce induced compressive force and the specimen actually it is a specimen it forces into the specimen through shear at the wedge grip interface. So the test result is influenced by test fixture characteristics, test methods sensitivity, specimen preparation how do we prepare specimen, thickness and gage length if we change the gage length the test result will change, type of grip, edge effect in the angle-ply laminate. So these are the different factors which affect the test result.

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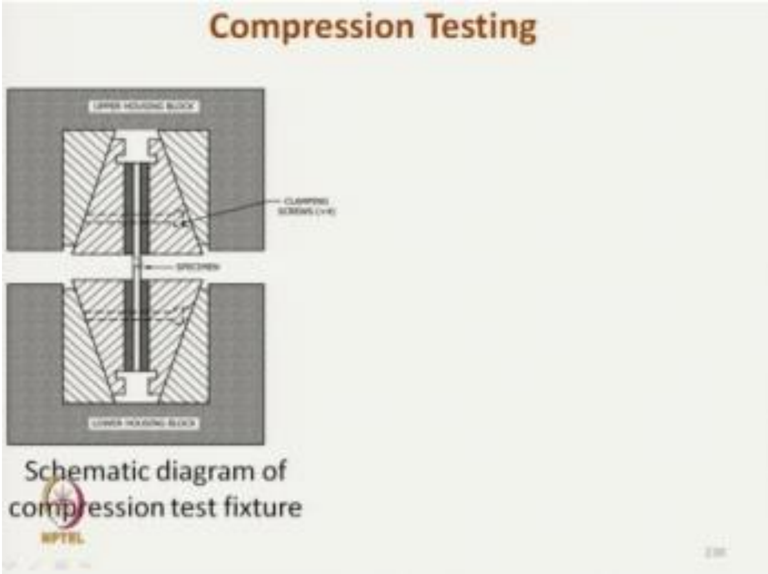

So in this picture you see this is the composite sample specimen and here these are clamped this is specimen and this is the top jaw, upper jaw and this is the lower. This is basically it is upper jaw, lower jaw and once it is coming down they are coming closer the compressive load the in-plane compressive load will be imparted on the this specimen and we can test this we can get the compressive strength value.

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Compression Testing

Minimum no of test required : 5 (Five)

- **Sample Dimensions:**

Fiber Orientation	Width, mm [in.]	Gage Length, mm [in.]
0°, unidirectional	10 [0.5]	10–25 [0.5–1.0]
90°, unidirectional	25 [1.0]	10–25 [0.5–1.0]
Specially orthotropic	25 [1.0]	10–25 [0.5–1.0]

- **Compression test specimen thickness depends on the gauge length, Expected compressional strength and longitudinal modulus**

Minimum number of tests as per standard is 5 and sample dimensions are given here. Compression tests specimen thickness depends on the gauge length, expected compressional strength and longitudinal modulus. So the thickness of the composite we can we have to change depending on the this parameters.

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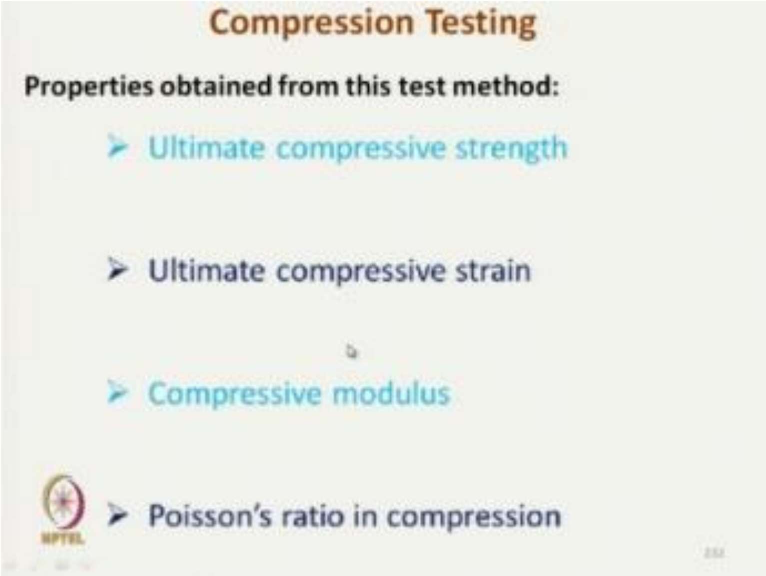

So we can get the results in terms of ultimate compressive strength, ultimate compressive strain, compressive modulus, Poisson's ratio, these are the parameters.

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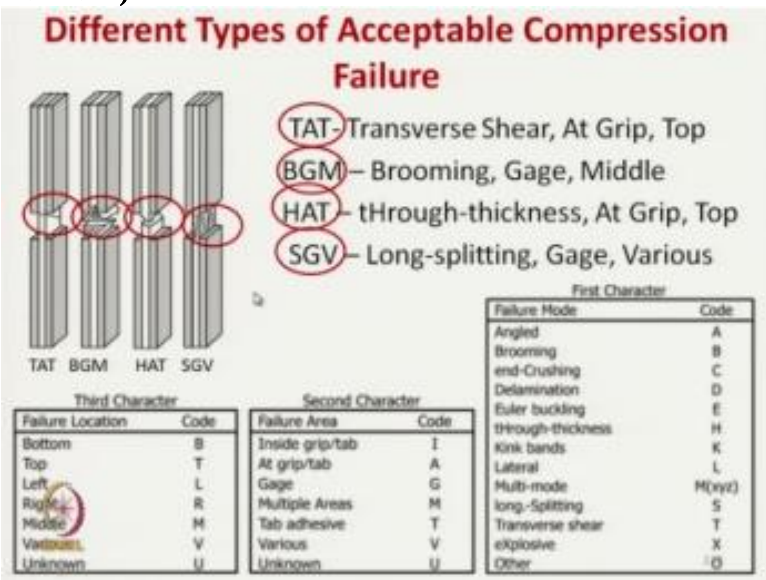

Again if we see the compression the type of failure is also important here, the first letter first character it said mode of failure, second is the failure area similarly and third is the location of failure. Now here the comprehensive failure is expressed in terms of TAT, T means here transverse shear this is transverse shear, A is at grip this is that the top and T is the location it is at the top that means here compression.

Compressive failure has taken place at the top grip and it is at the grip and it is transverse failure. Let us see next one BGM, B it is a brooming, it is brooming effect means it is a buckling has taken place the lamination is taking place so that it forms a broom like structure so brooming due to compression and brooming takes place due to say very poor interface between matrix and reinforcing material and also the poor quality of reinforced matrix.

Even if we can use very strong, very high modulus fibre this if this brooming type of this type of failure takes place then we cannot use this. So this type of failure will not occur during tensile loading so, for high performance fibre that is why a compressive failure is important, comprehensive testing is important. So BGM brooming is at taking place G is at the gage and M is at the middle so, looking at the failure type we can take decision.

We have to adjust our process parameter we have to change the matrix characteristics quality of matrix. So HAT, H means it is through thickness so this is through thickness it has taken place, A is at grip and T at the top. So this way we can get all this type of failure. SGV long splitting at gage and at various point so, long splitting took place. So these are the different failure characteristics there are many others other combinations can take place.

This is HAT SGV so we have other characteristics now these are the failure here earlier you have discussed these are the failure which are acceptable failure during testing. Actually these are the failures if take place then we can get actual idea about the performance of the composite and we can take preventive measures.

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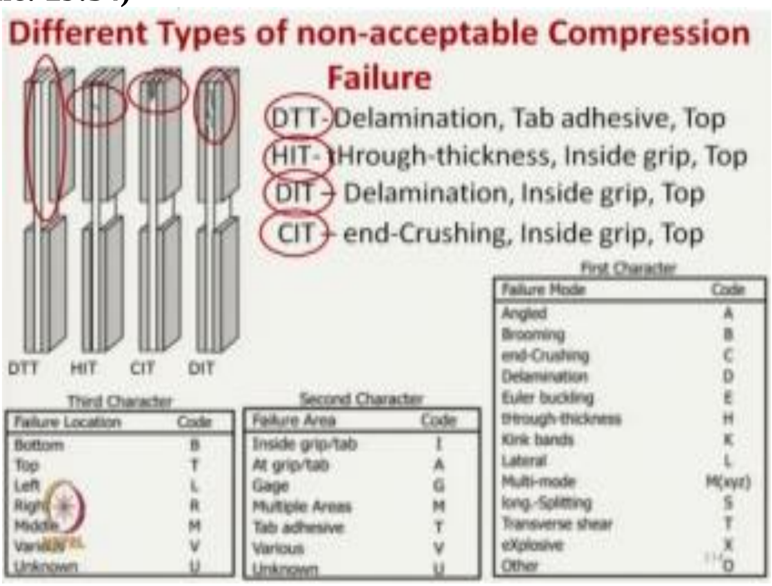

But these are the failures which are non-acceptable in terms of compression failure like DTT delamination, tab adhesive at top. So here in tab adhesive during testing tab adhesive delamination took place. So which is not actually the failure due to the composite characteristics, it is due to the testing technique like throughout thickness inside grip at top, this is the throughout thickness.

Here HIT inside grip, if the failure takes place inside grip that means there is no problem with the composite it is a problem with the gripping. DIT delamination inside grip. So inside grip there is some problem so, if the failure takes place inside grip or due to grip we do not accept that failure these are the failures these failures will not taking into account we will reject the result.

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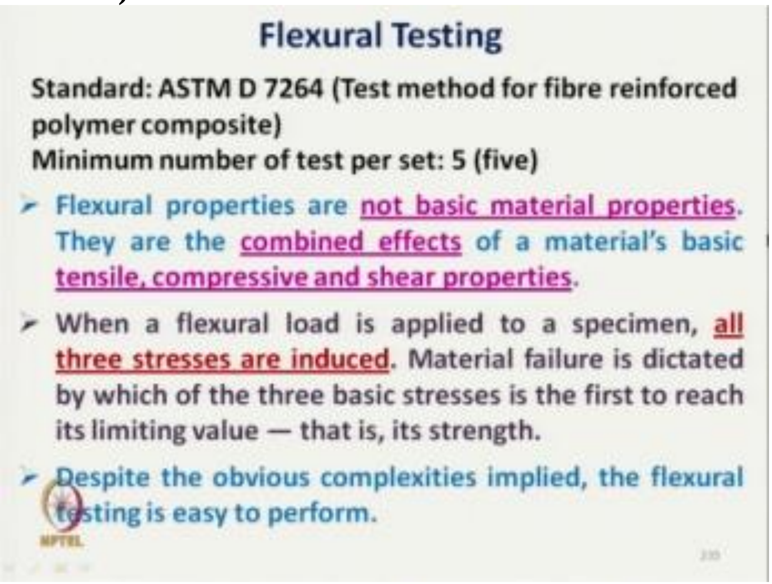

Next is the bending testing or flexural testing it is as per ASTM D 7264 we take 5 specimens. If we see the unlike tensile, shear or compression the flexural failure is not the basic material characteristics they are actually combined effect of tensile, compression and shear. Once we take the flexural testing once the composite bends either tensile or compression or shear takes place so at while bending at outer side the tensile test takes place.

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Let us see here now this is a composite when it is bending this outside it is a tensile this is compression and in between there will be shear. Now while testing we can reduce shear to some extent by readjusting the say this is the thickness and here if we bend this is bending or it is the length of the sample specimen so length and thickness ratio if we change we can readjust or we can manipulate the shear component.

So typically what we try, we try to reduce the shear component by readjusting the selecting the l by t ratio. But during bending tensile failure or compression failure takes place. Suppose the tensile strength is low that means it will fail at this compression strength is low so it will fail at this zone. So this is indirectly it shows the that flexural testing it actually it is a combination of tensile, compression and shear properties, when a flexural load is applied to the specimen all 3 stresses are induced.

Material failure is dictated by which of the 3 basic stresses is the first to reach its limiting value that is strength. As I have mentioned if tensile strength is low it is reaching at first so it will fail immediately, if compressive strength is low it will reach first. But the understanding of flexural testing is complex but the testing it is very simple, ok if we perform so here itself testing method so, to simplify the test stress strain.

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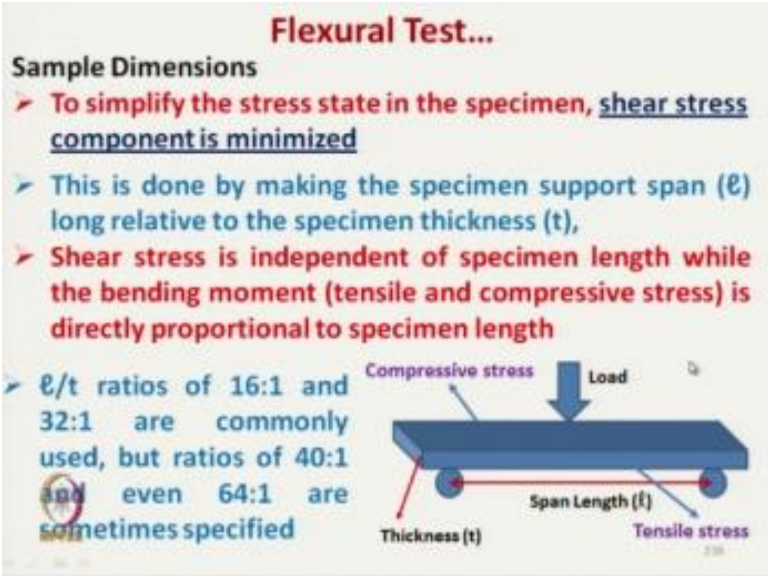

In the specimen shear stress component is minimized as I have mentioned. So there are 3 components so shear stress we can minimize this is done by the support length and thickness. So l / t ratio if we increase l / t ratio will reduce the shear stress component and only the tensile and compressive stress is there and shear stress independent of specimen length, while bending moment that is tensile and compressive stress is directly proportional to the specimen length so, if we increase the length that will affect the tensile and bending stress.

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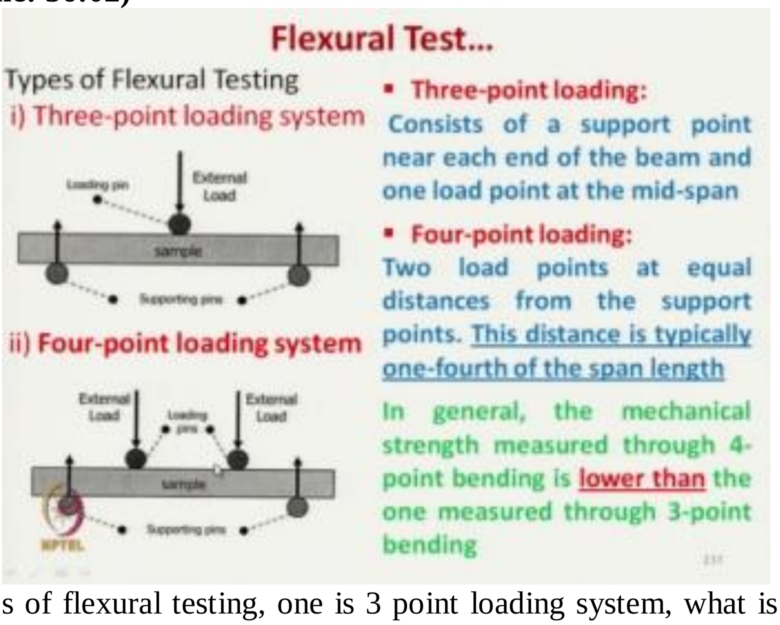

There are 2 types of flexural testing, one is 3 point loading system, what is 3 point loading system? Here there will be 2 support points another is the external loading points from the top and another is the 4 point loading system there will be 2 support and 2 external loading point. So, 3 point loading consists of a support point near each end of the beam and one load point at the middle and 4 point loading.

Here 2 support points and these are typically the distance between 2 loads are typically one fourth of the of this total length of the composite, in general the mechanical strength measured through 4 point bending is lower than the one we test in the 3 point test. So this here in at 4 point testing mechanical strength we get lower value.

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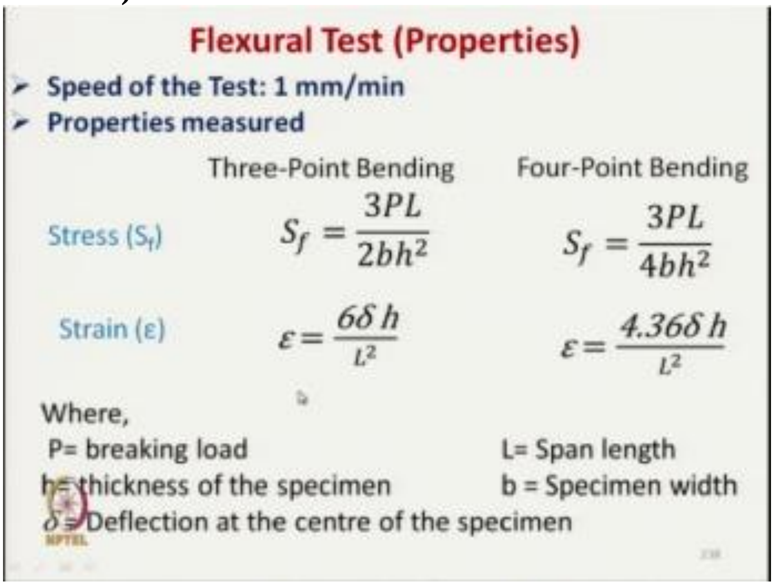

So this is the stress and strain now, let us see P is the breaking load and L is the span length, h thickness of the specimen, B is the specimen width and delta is the deflection at centre. So if we keep all these parameters same for 3 point and 4 point bending we will see this 4 point bending stress is lower than 3 point bending. Whereas strain in 3 point bending is higher than the 4 point here so strain is higher and here stress is lower.

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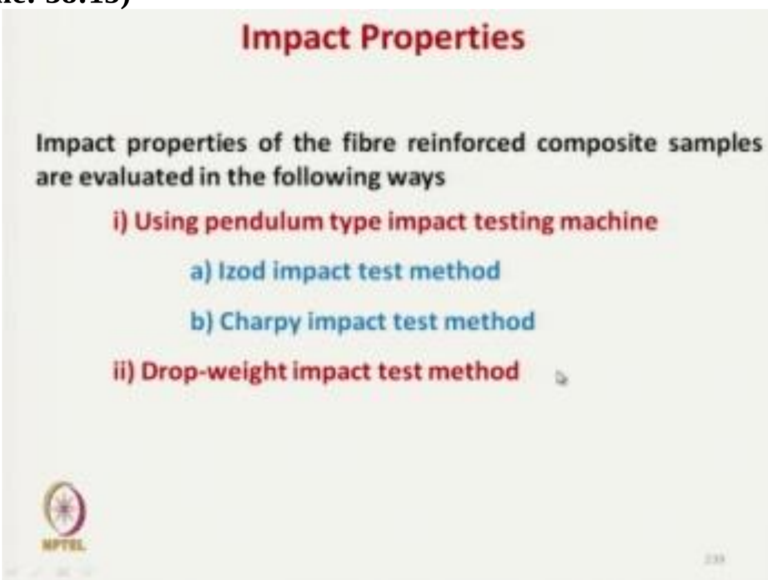

Next property is which is very important property it is a impact property. Impact property of the reinforced composite sample can be evaluated using either pendulum type impact testing machine or drop-weight impact testing machine. So pendulum types are of 2 types typically use Izod impact test method and Charpy impact test method.

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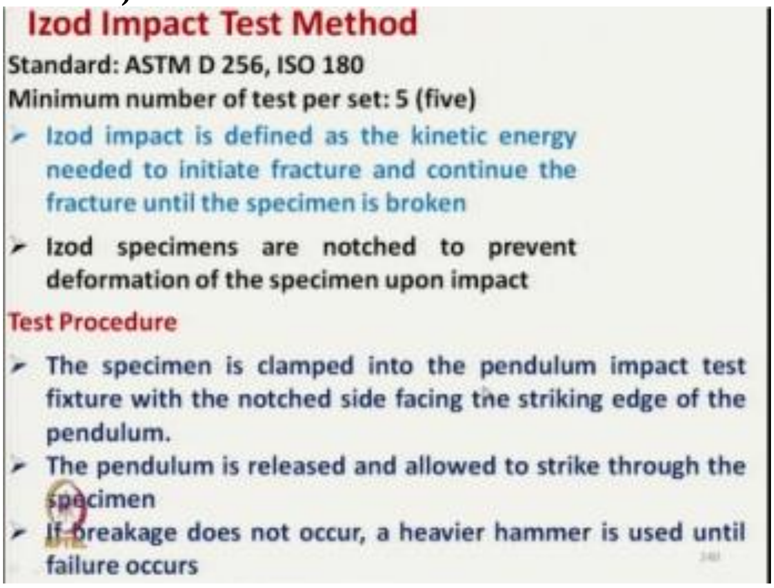

So Izod as per ASTM D 256 or ISO 180 so the Izod impact is defined as the kinetic energy needed to failure the initiated fracture. So to initiate fracture and continue fracture until the specimen is broken so there will be fracture initiated. So then we will measure the total kinetic energy the notches are created so to prevent deformation of the specimen upon impact.

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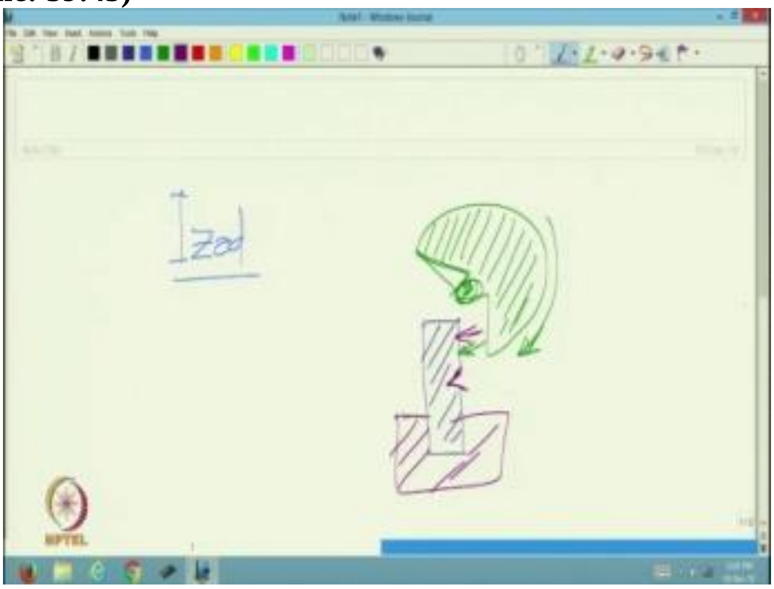

So here if we see the system here Izod impact testing what we do here this is composite with notch created and another impact are normally let us draw here notch is created so there will be one impactor pendulum impactor which is used for typically you can see in case some tear strength Elmendorf tear strength that type of pendulum is used and once it is released this will have impact on this upper side. Here it this side is gripped and this will impact this will have impact and the failure will take will be initiated at this point because it has notch has already been created and the failure will take place.

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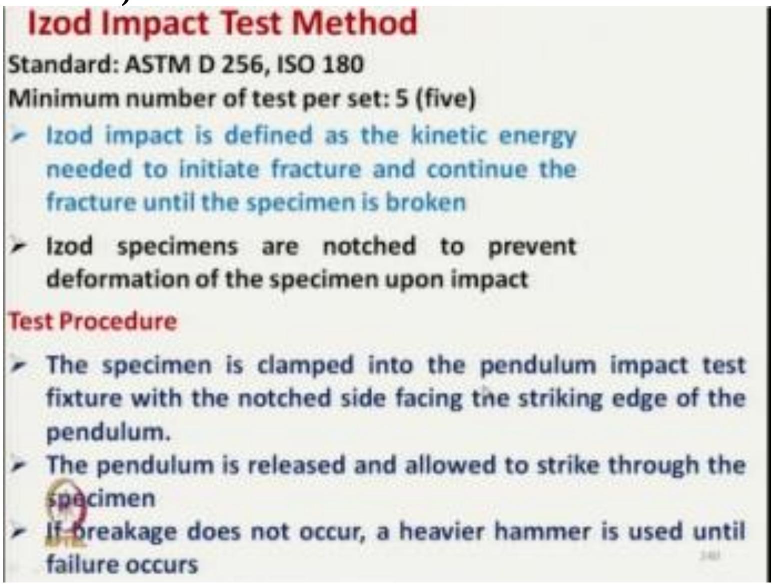

So the specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum the pendulum is released and allowed to strike through the specimen, if breakage does not occur so in case of breakage is very strong material in that case we can increase the weight of the hammer.

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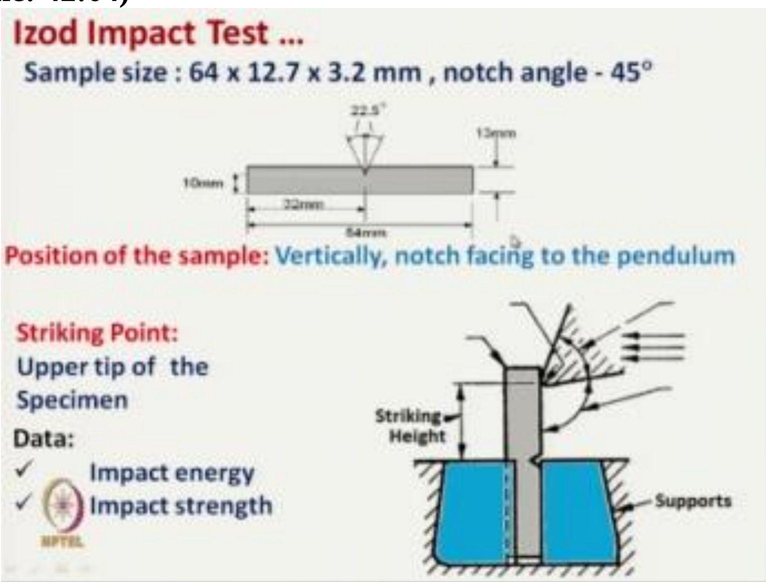

So here this is the support strike height we can adjust and here is this is the impact direction this is it is after swinging it will have impact so all these dimensions are important. This is the sample specification standard specification here striking point the upper tip of the specimen at this point the striking will take place and the data which we get is impact energy and impact strain so these are the data we get and notch angles are it is 45 degree angle.

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And here this photograph shows the specimen after Izod impacted this is a type of failure so here you can see it is a notch was created after that failure took place here.

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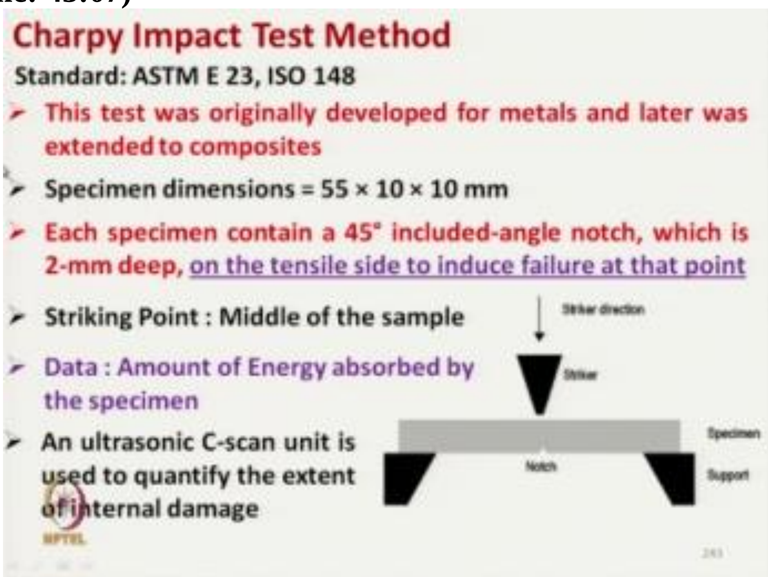

Another technique is the Charpy impact test method, this test was actually it is ASTM E 23 or ISO 148 originally developed for the materials and later it is extended to composite, dimension 55 by 10 by 10 millimetre each specimen contents 45 degree angled notch on the other side of the loading striking point at the middle of the sample so here the this is a striking point ,amount of energy absorbed by the specimen that is the data.

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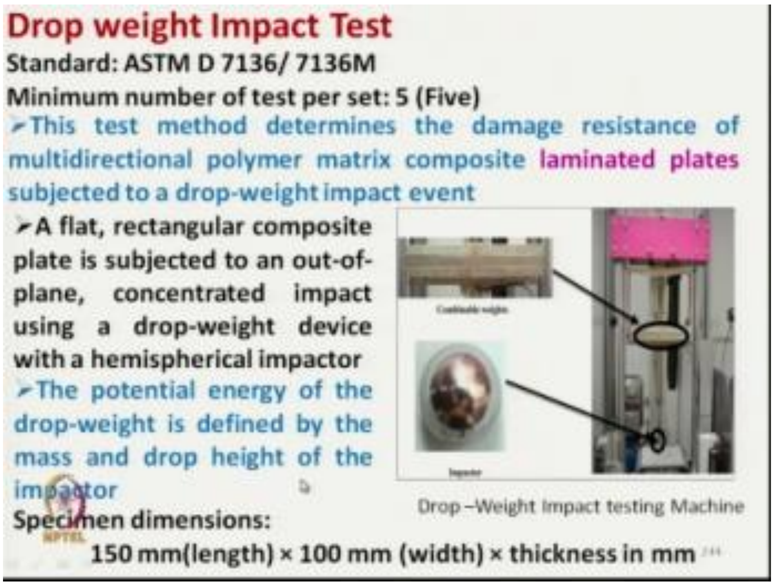

Another test is the drop test by ASTM D 7136 this test method determines the damage resistance of the multi directional polymer matrix composite. It is a laminated in laminated form, this is showing the impactor flat rectangular composite plate is subjected to an out of plane concentrated impact so potential energy of the drop-weight is defined by the mass and drop height so you can change the mass of this impactor and height of this impacted and there will be freefall and it will impact on the composite material the specimen dimension 150 mm by 100 mm and thickness is as per the specimen.

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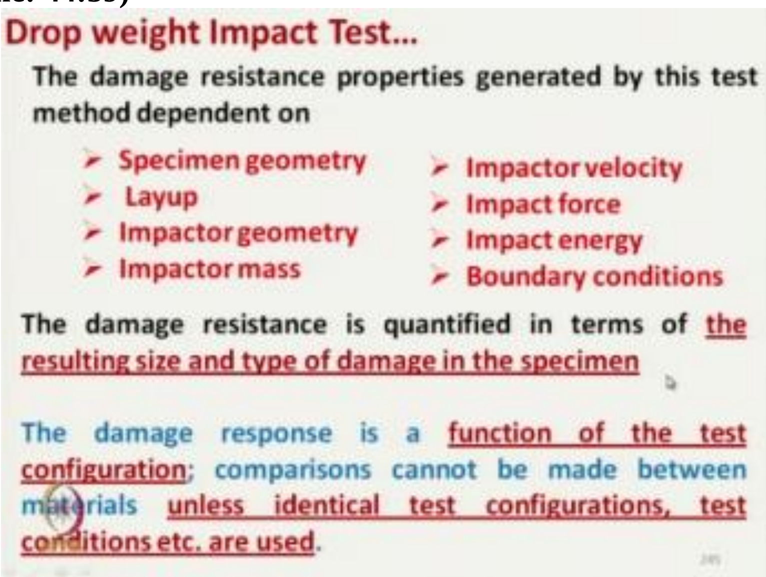

So the damage resistance property generated by the test method depends on the specimen geometry, impactor velocity, layup impacted force these are the different parameters which will affect the test result so we have to keep all these parameters standard. The damage distance is quantified in terms of the resulting size and type of damage of the specimen as we have already seen earlier the damage size is also important the damage response is a function of the test configuration.

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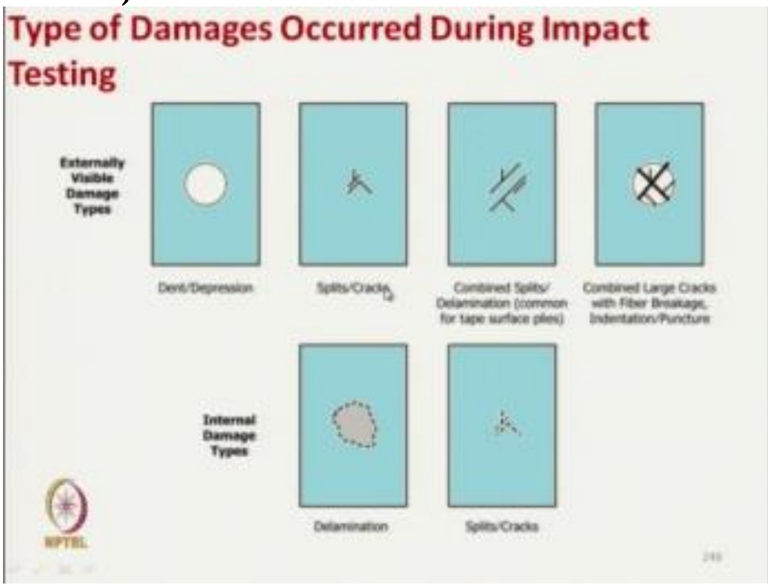

These are the different types of damages depth depression split or crack combined so these are the different types of damages during the impact testing.

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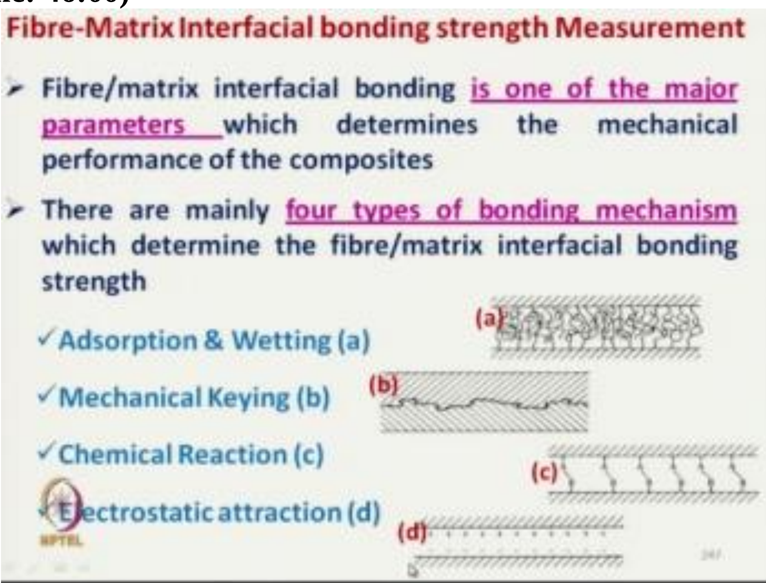

So fibre matrix interface bonding is also important so we must know it is very important as far as fibre reinforced composite so we must study we must know the fibre matrix interface bonding strength. So there are basically 4 different types of principles or mechanisms of bonding between fibre or reinforcing material and matrix one is this is the adsorption and wetting so that means the matrix material will get adsorbed and wet the reinforcing material.

So that type of bonding takes place, mechanical keying is also one of the mechanisms where the rough surface of reinforcing material is created so that there is a mechanical bonding, mechanical keying thickness which enhance the bonding strength, chemical reaction between reinforcing material and the matrix and electrostatic attraction. So electrostatic attraction is one of the methods where we can get the matrix adhere to the fibre surface.

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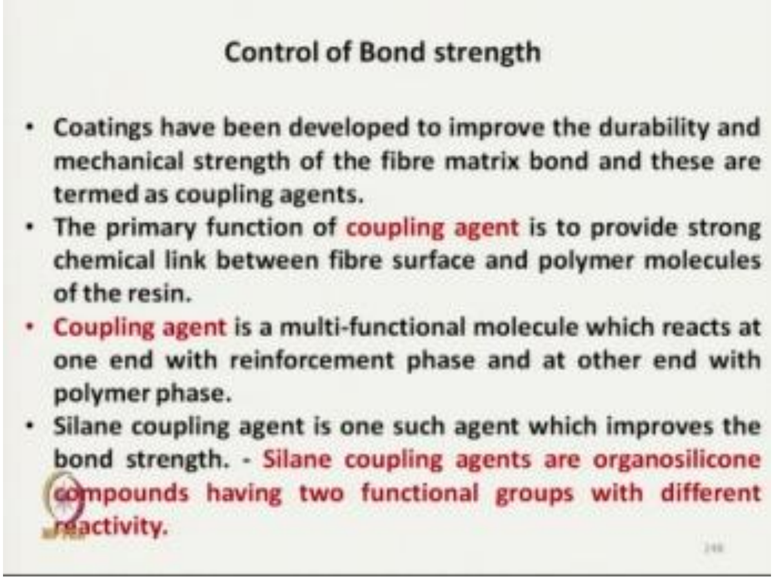

So bonding strength can be controlled by a coupling agent that we have already discussed using an experiment using MAgPP silane coupling agent is one such agent which improves the bond strength so we can increase the bond strength by a coupling agent.

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The bond strength can be measured by different techniques these are single fibre Pull out test, single fibre push out test, fibre push down test, full fragmentation technique. The following assumptions are made during the interfacial bond strength measurement no shear strain in the fibre during pullout no shear strain is taking place. No transfer of normal stress across the fibre end so normal stress is not getting transferred to the composite or adjacent fibres these are the basic assumptions.

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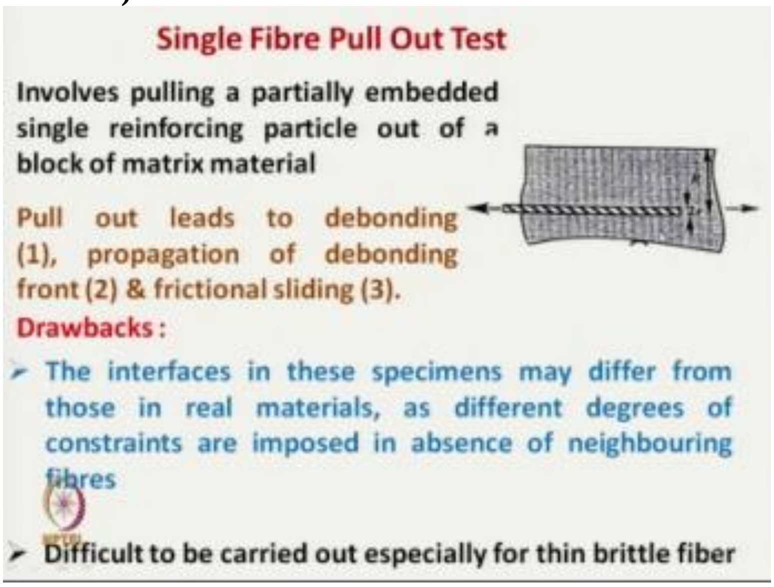

Now in single fibre pullout test one single fibre is gripped this is the fibre is gripped and here is the composite is gripped here it involves pulling of particularly embedded single reinforcing particle fibre out of a block of matrix this is a matrix block and one single fibre has been placed so debonding it take debonding can take place, propagation of debonding and frictional sliding, it takes place in 3 stages at fast debonding starts.

Then this debonding propagates throughout the interface then frictional sliding will start so that will give us an idea about the interfacial bonding. The drawbacks of this method are the interface of the specimen may differ from those in real material as different degree of constrains are imposed in absence of neighbouring fibres so that is basically it is a it gives us an idea because in actual composite there will not be a single fibre.

There will be many other fibres there may not be 100% complete covering by the composite materials that matrix material there will be other interference of neighbouring fibres there will be differences in manufacturing techniques. So the technique gives a rough idea and it is very difficult it is difficult to carry out especially thin brittle fibre so thin fibre and which is brittle in nature we cannot use this technique.

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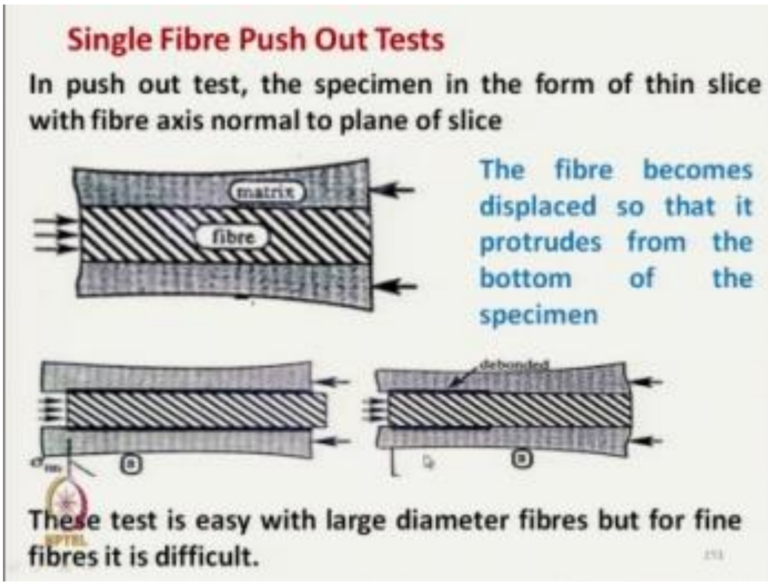

Single fibre push out test again here we prepare composite and then in we prepared in the slice form this here it is showing one width of the slice or thickness of the slice this thickness is very small maybe in terms of millimetre a few millimetres and then the fibre this is the fibre is pushed against the matrix material which is gripped here it is pushed out and this distance is very small and during pushing again the debonding and all these will take place.

And the fibre becomes displaced so that it protrude from the bottom of the sample it is displacing here debonding is started from there then it has propagated and then fibre then sliding frictional sliding took place. Main drawback here is that we have we cannot use this technique for very fine fibre, fibre with a larger diameter we can definitely use.

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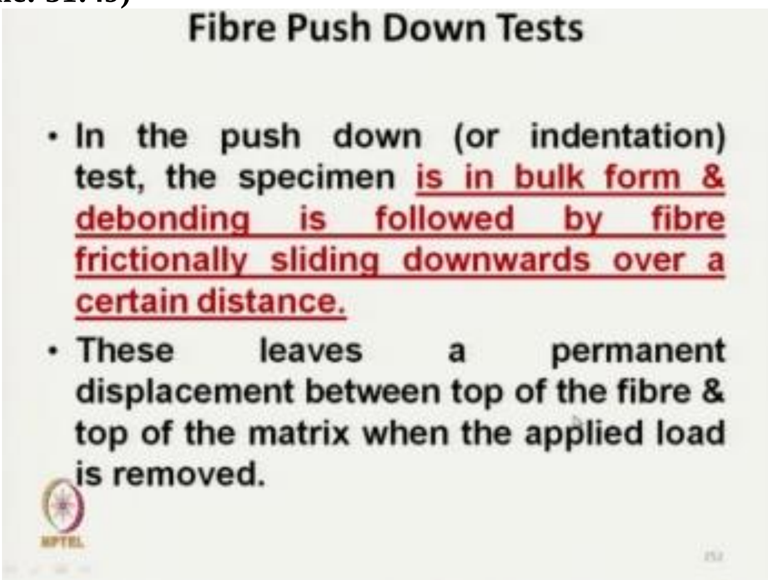

Fibre push down test, here again in push down test bulk fibres are taken and that will be that is pushed down by applying force so this leaves a permanent displacement between the top of the fibre and the top of the matrix and that we can get idea about the interface.

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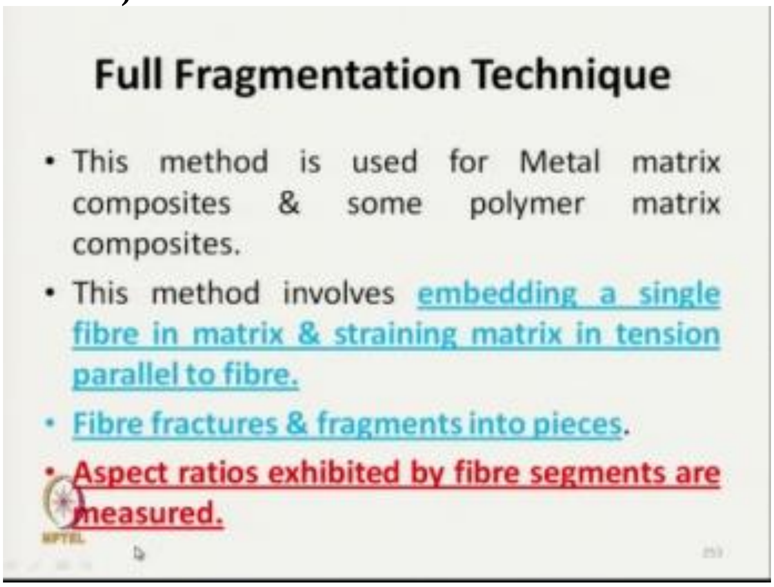

Another technique is the full fragmentation technique this method is used for mainly metal matrix composites sometime polymer matrix composite.

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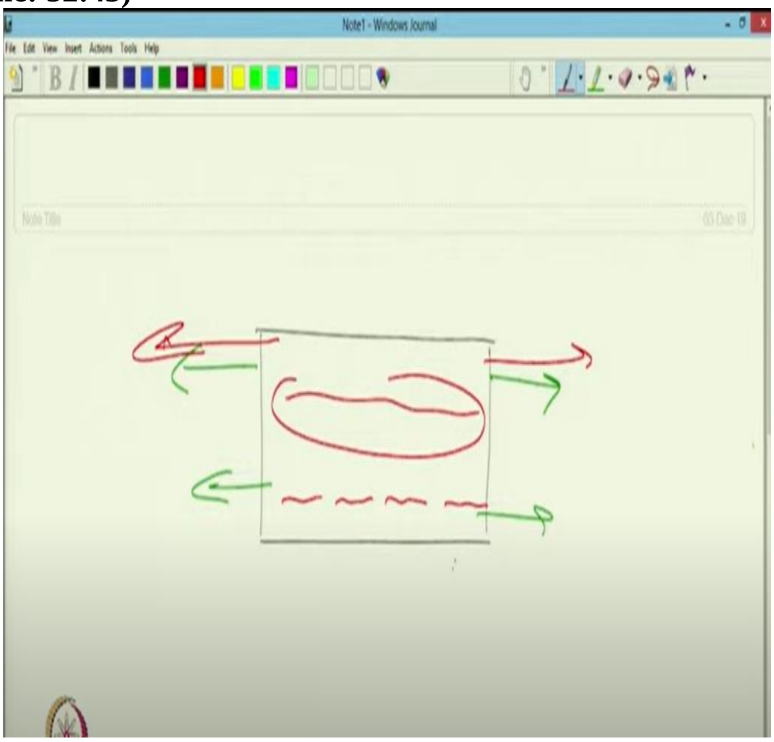

Now we can see here typically the for fibres with very high modulus fibre we can use where extensibility is less this is the matrix if we see this is the fibre this is fibre now once we apply load once we apply axial load if the bond strength is high then the fibre will fragment like this. But if the bond strength is not high the fibre will not break and there will be extension in the composite or matrix material.

So that by knowing this length ratio we can get an idea about the bond strength this method is used for mainly metal matrix composites and we can use this for high modulus fibre in this method involves embedding a single fibre in the matrix and straining matrix in tension parallel to the fibre as I have already shown fibre fractures fragment into pieces aspect ratio exhibits by the fibre segment are measured. So if the fibre does not damage does not actually break we can get idea that there is less bonding strength. Next parameter is that void content which is very important.

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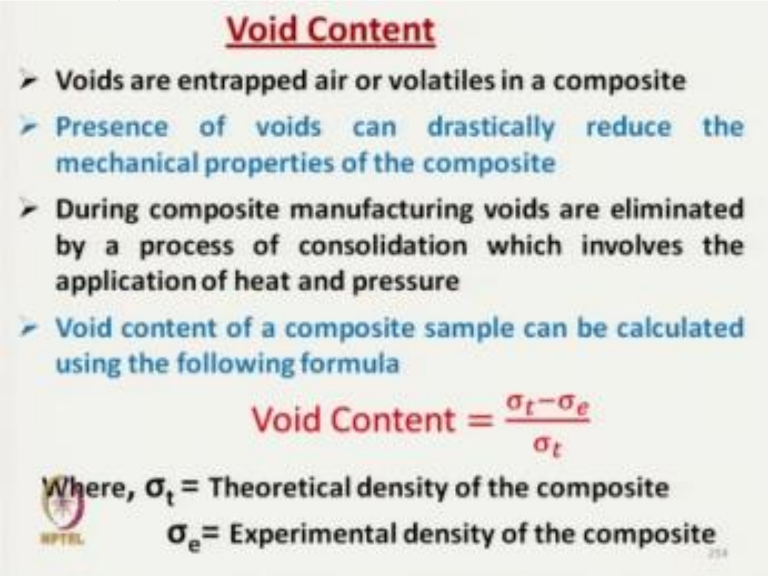

The void content is actually higher void content deteriorates the quality of the composite drastically and void content is by measuring the density of material.

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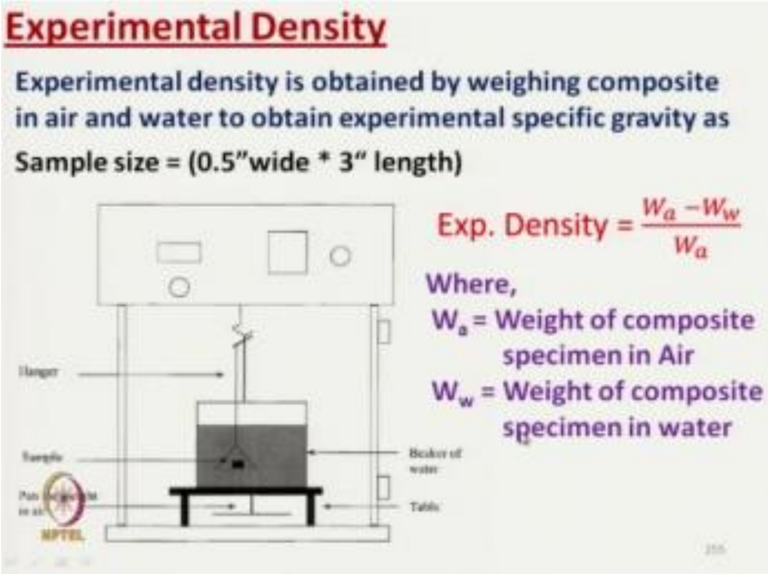

Experimental density is measured by experimentally then we can measure.

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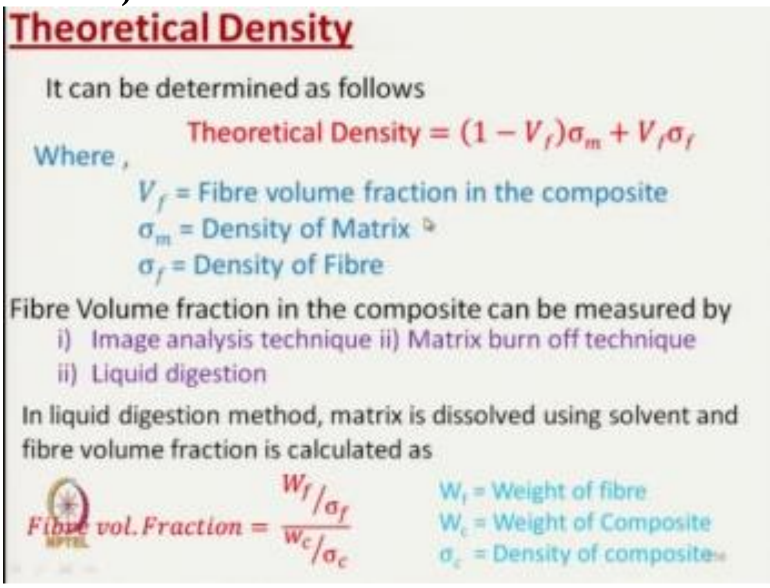

The theoretical density this is a theoretical density by knowing the density of matrix and density of fibre and volume fraction and fibre volume fraction we can we know these things so from there we can calculate the void content. So void content is from where presence of actual voids that we can get to know and which actually deteriorates higher void content deteriorates the matrix quality to a great extent.

So we will stop here, in next session meant we will discuss few testing techniques which are non-destructive in nature. Earlier techniques we have discussed all the specimens are destructive in nature and what we have seen though for those who have to prepare specimen and test but there are some situations where we cannot take out the matrix material during use, application, if we want to test whether there is any damage, what are the characteristics there those we can test only by non destructive method. So non destructive testing of composites we will test in the next segment, till then thank you.