Testing of Functional & Technical Textiles
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Lecture - 12
Testing of Fibre Reinforced Composite Materials (contd...)

Hello, everyone. We are discussing the Testing of Fibre Reinforced Composite Materials. In last class we have discussed the tensile testing methods of composite. And now we will discuss the compression testing of composite material. The compression testing is it is along the plane normally in textile material which is flexible in nature; the compression is carried out across the plane.

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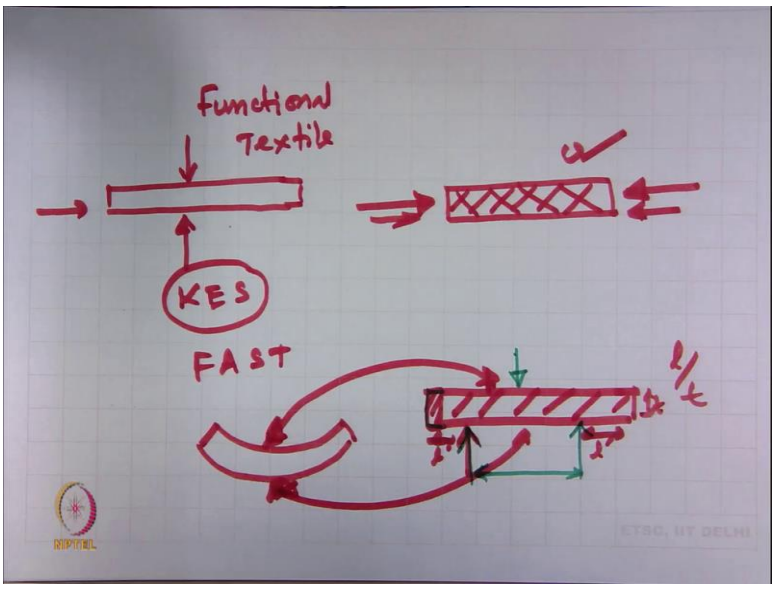

Now, suppose this is one flexible soft textile material, the compression is carried out across the plane like functional textile. In functional textile testing we have seen in Kawabata Evaluation System or FAST, we have discussed the testing method of compression which is across the plane that is across the thickness.

But the composite material as this composite materials are stiffer in nature, it is a hard material that is why here the compression testing is carried out along the plane. Force is applied parallel to the plane of the composite material. And composite materials like fibre reinforced composite, there the load compressional load is applied in this direction that is along the plane direction when this materials are used for structural fabrication.

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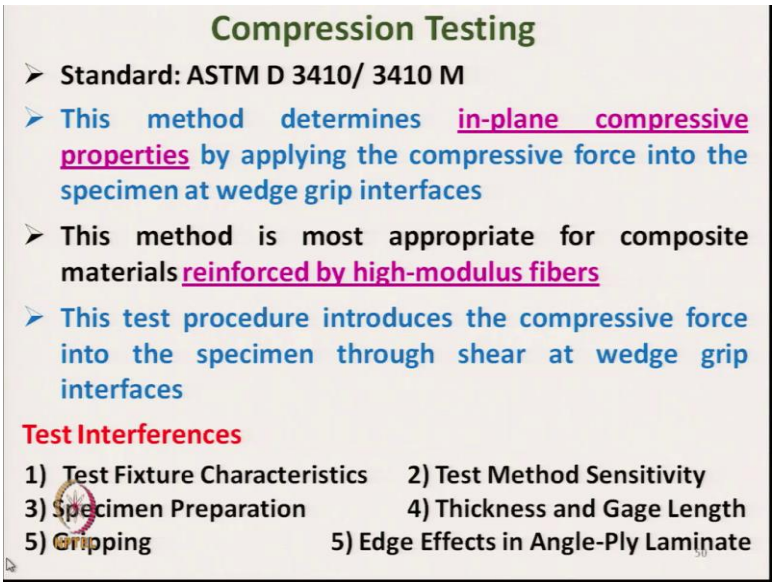

So, this compression here is along the plane. So, the standard which is followed here it is the ASTM D 3410 or 3410 M. This method determines in plane compressive properties by applying the compressive force into the specimen at wedge grip interface. This method is most appropriate for composite material reinforced with high modulus fibers.

The test procedure introduces the compressive force into the specimen through shear at wedge grip interfaces. Now, let us say the compressive force, it is the test interferences are the test fixture characteristics, test method sensitivity, test specimen preparation, thickness and gage length of the specimen, gripping and edge effect in the angle ply laminate.

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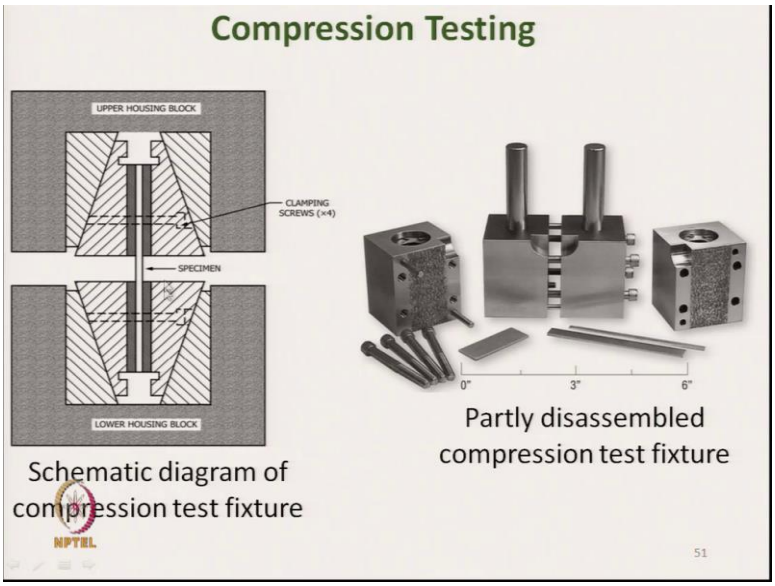

Now, this picture shows the compression testing fixture and when this fixture is disassembled it looks like this. So, here the fabric specimen that this compression testing, the composite specimen here this is the actual specimen here it is showing and which is gripped by the clamp and which are the clamp the composite material is tabbed and tabbed portion is being clamped by two clamps, upper clamp and lower clamp and it is tightened by screw. And during the testing the upper housing block comes down gradually and which applies the compressive force in the specimen.

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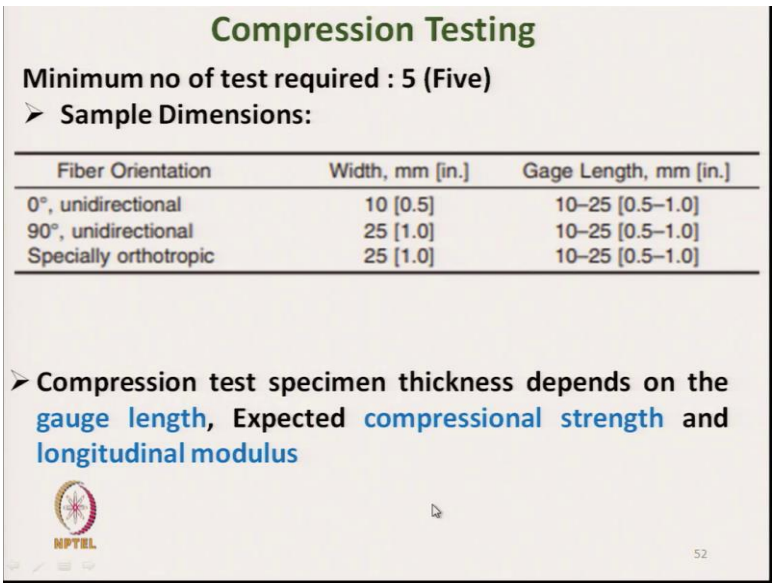

And the dimensions are as I have already mentioned in last class it is a for 0 degree that is unidirectional fiber orientation, the width is smaller 10 mm. And for other direction the width we can use little bit higher that is 25 mm approximately 1 inch. The gage length we can keep almost same it is between 10 to 25 mm. So, compression test specimen thickness depends on the gauge length, expected compressional strength and the longitudinal modulus.

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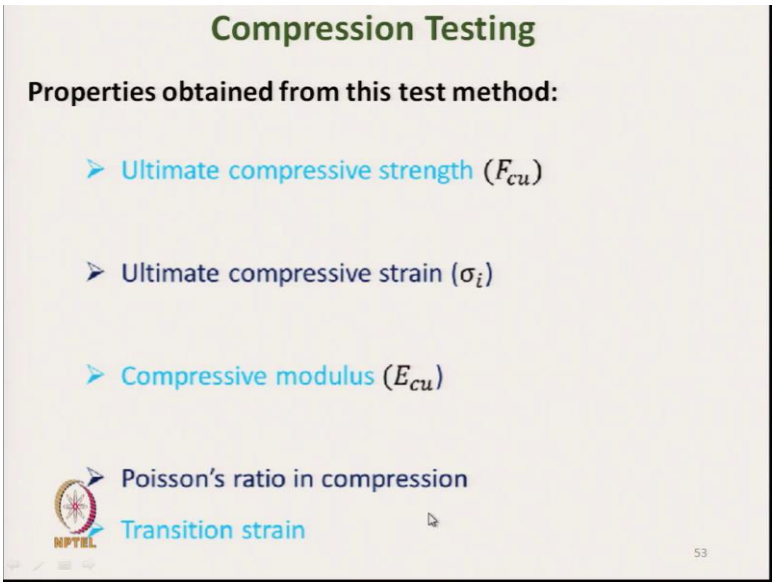

The properties which we can get during compressional testing it is a ultimate compressive strength, ultimate compressive strain, compressive modulus, Poisson's ratio in compression and transition strain. So, these parameters are similar to that which we have discussed during tensile testing.

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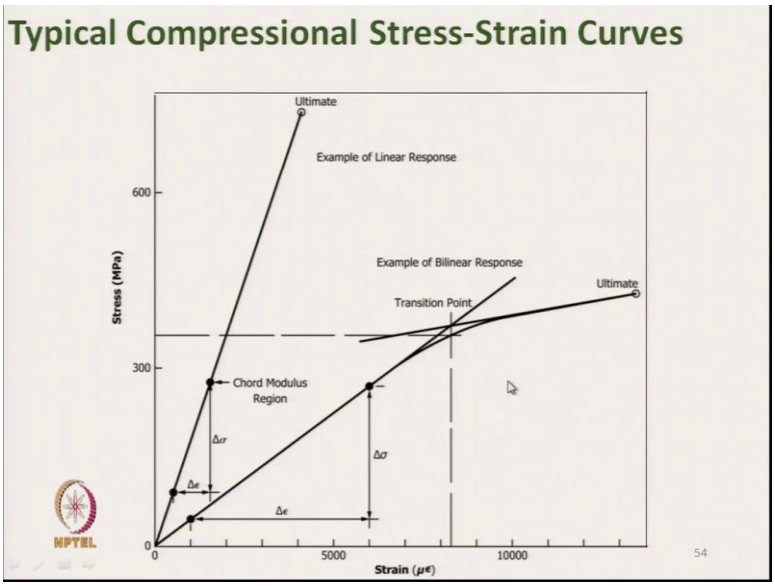

So, we get curve which is stress strain curve from where we can get all these parameters. Also we can get chord modulus which is nothing but the modulus between two points.

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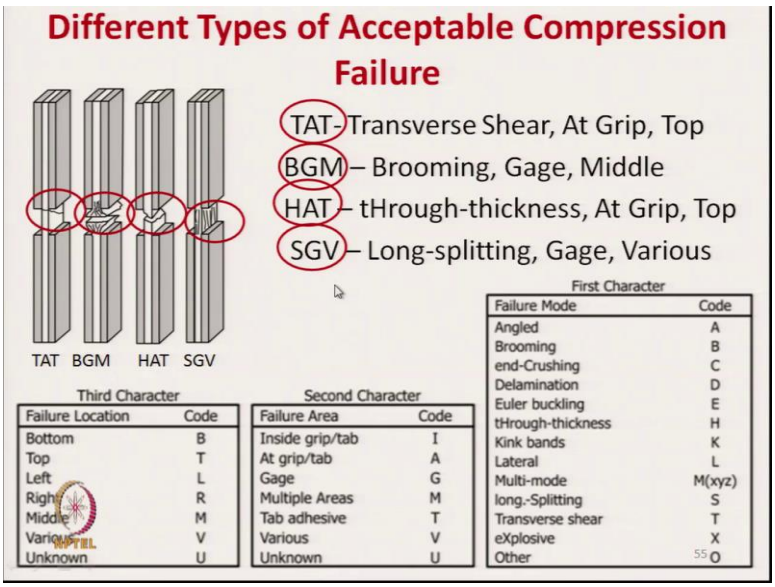

And again like the tensile fracture, tensile failure, the compression failure can be divided can be termed can be expressed by different terms. Here we can also use three characters; first character shows the failure mode that is mode of failure, second character is the area of failure and the third character is location of failure. And compression failure can be broadly divided into two types; one is acceptable

compression failure which is due to the actual failure of the composite material. And another type of compression failure take place that is non-acceptable compression failure which is due to the problem in test method, I will discuss after sometime.

Now, acceptable compression failure these failures can be expressed by three characters as I have mentioned. Let us take one example like TAT which means Transverse Shear that is a failure mode is the transverse shear, failure area which is at grip and failure location is at top. So, here we can see it is a TAT which is acceptable compression failure means it is failed during the testing at the gage point not inside the grip.

So, looking at the failure type we can see this is the transverse shear type failure. The failure is a like shear type failure and it is at the grip point close to grip point, so it is at grip. At grip means; A, TA and T means it is location is at top. If the similar failure was there in at the bottom then the terminology would be TAB transverse shear at grip and at bottom location.

The next one is BGM; B from the first character table we can get B here, it is a brooming; that means, during compression the brooming take place. It splits out the composite material is actually during compression the brooming take place. So, failure mode is brooming here and location is at gage in between the jaws, in between the grip and the location is at the middle. So, area is in between that point this grips and location is at middle.

Similarly, the third one is HAT; H here it shows through thickness; that means, the failure is entirely across the thickness and it is at the grip point and the top location HAT. SGV; what is SGV? S stands for long splitting, G is at gage and V stands for various failure location. It is not at particular location, when the failure takes place at different location then we can term it as V. So, simply by putting these three characters we can express the location of on type of failure in addition to the actual value of say extreme point. Now, the failure modes for non acceptable compression.

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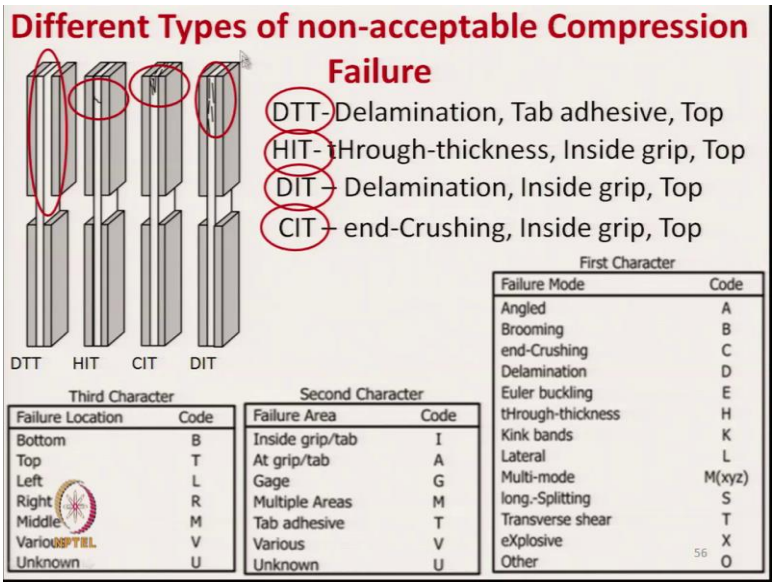

So, non acceptable compression failures are; so first one is a DTT. What is D? D stands for delamination at tab adhesive and at top jaw; at top grip point the tab adhesive has been delaminated. So, that the test failure is due to the problem in test method which is not acceptable. Similarly, next one is HIT through thickness it is through thickness inside grip, inside grip and at top grip.

So, through thickness although there is failure, but the failure is within the tab which is not acceptable. Third one is DIT; that means, delamination is taking place inside grip and which is at top location. And CIT which is end crushing due to high pressure of the grip the end crushing is taking place which is inside grip I and at the top. So, these type of failures are not acceptable.

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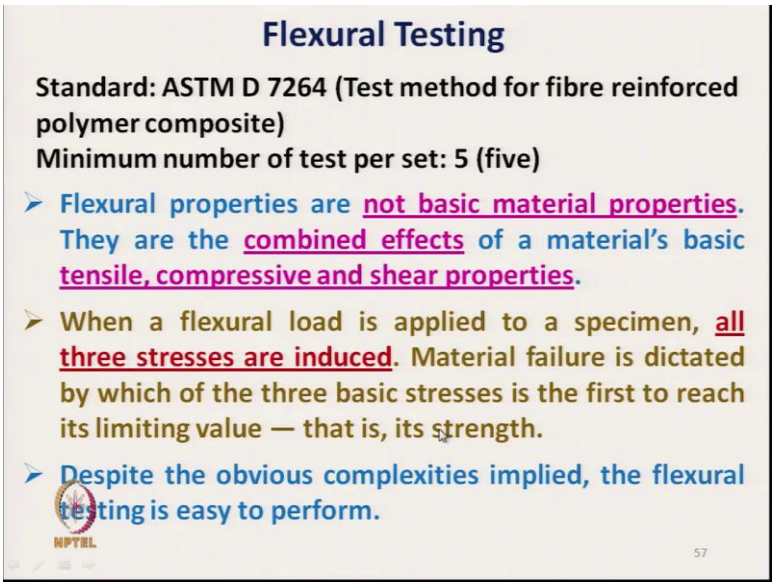

After compression, now we will discuss the flexural testing. The standard which is followed is ASTM D 7264. So, which is test method for fibre reinforced polymer composite and it is a flexural testing. So, maximum number of test per set is 5, flexural properties are not basic mechanical properties of the material. It is actually combined; combination of tensile, compressive and shear properties.

So, whatever the flexural strength we get these are combination of materials; tensile property, compression property and shear property. When a flexural load is applied to a specimen, all these three stresses are included, but the material failure is dictated by which the three basic stress is the first to reach ok. So, here which component will reach first that will show it is compressive or tensile or shear. So, it will show it is flexural testing.

So, that will be the flexural strength of the material. So, material failure is dictated by which of the three basic materials characteristics. Despite the obvious complexities implied that why is it complex? Because it is a combination of tensile, compression and shear, but the flexural testing is easy to perform. So, although the principle or mechanism is complex, but the test method is simple.

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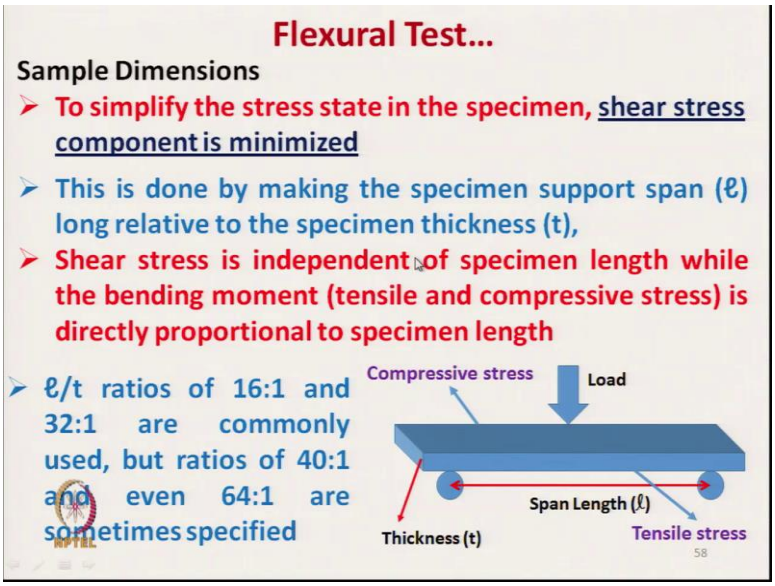

Here there are basically two types of testing. One is 3 point bending testing another is called 4 point bending testing of composite. The sample dimensions are to simplify the stress state in the specimen, shear component is minimised. So, only to keep the compressive and tensile component we have to minimize the shear component. So, it can be minimized by changing the ratio of length and thickness.

So, this is done by making the specimen support that is support span l is sufficiently long as compared to specimen thickness. So, if we keep the l by t ratio very high then we can minimize the shear stress component. And shear stress is independent of length while the bending moment that is tensile and compressive steps is directly proportional to the specimen length. So, l by t ratio we can keep 16:1 or 32:1 these are commonly used.

But we can sometime go little bit higher up to say 64:1 just to minimise the shear stress component. And this is showing 3 point bending where the specimen is supported by two point and load is applied from the top at the other surface that is vertically downward direction. And the distance between these two support points is known as span length. And during the application of load from top side, one side will be compressed and other side will be extended.

Now, suppose this is the composite material and this is these are the bottom supports and the distance is known as span length and we apply the force from the top which is exactly at the centre and this two support points are typically the similar same distance

away from the edge of the composite material, the distance l^1, l^1will be same and during bending of this composite. So, once this is bend, this beam is bend, so, this top side will be compressed and this bottom side will be extended. So, here both compression and extension like tensile loads or tensile deformations are taking place. And we can minimise the shear by changing the length is to thickness ratio this is thickness.

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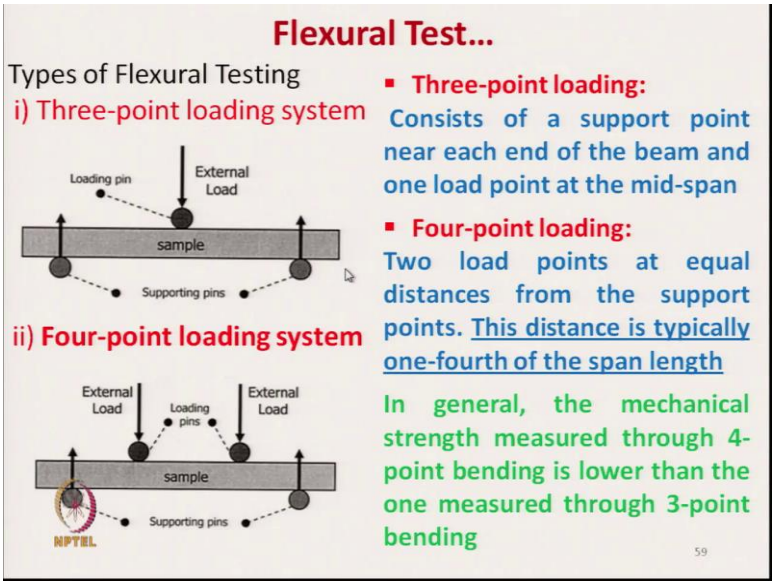

So, three point loading system and this picture shows the four point loading system. The three point loading system where two support pins are there and this is the sample and external load is applied from the top. So, the three point loading consists of a support point near each end of the beam, near each end of the beam a support point will be there and one load point at the mid span. So, this is the span length and at mid span there will be one load.

And in four point loading system two load points at equal distance there will be two load point from the support points this is this distance support point. From the support point the distance will be equal and this distance is typically one-fourth of the span length. The general, the mechanical strength measured through 4 point bending system is lower than the bending strength measured by 3 point bending system. So, in general this is lower than the 3 point bending system, the value of bending strength.

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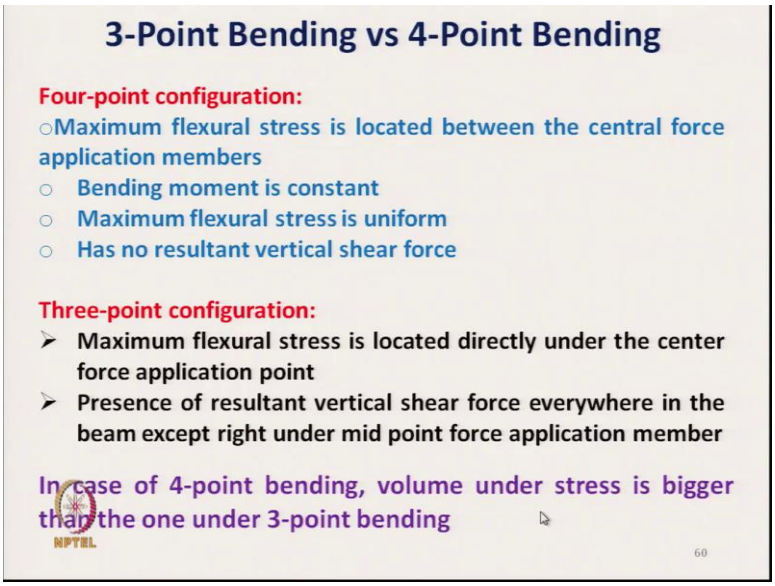

So, if we compare the 4 point bending with the 3 point bending system. So, in four point configuration the maximum flexural strength is located between the central force applied application member. That is the two loads which we are applying that maximum stress will be in between that. And bending moment is constant, maximum flexural stress is uniform, it has no resultant vertical shear force due to presence of 4 points.

And in three point configuration maximum flexural stress is located directly under the center force application point. So, when we apply the force in single point the maximum flexural stress will be just below that. The presence of resultant vertical shear force is everywhere in the beam except the right under the midpoint where forces applied. In case of 4 point bending, volume under stress is bigger than the one under 3 point bending system.

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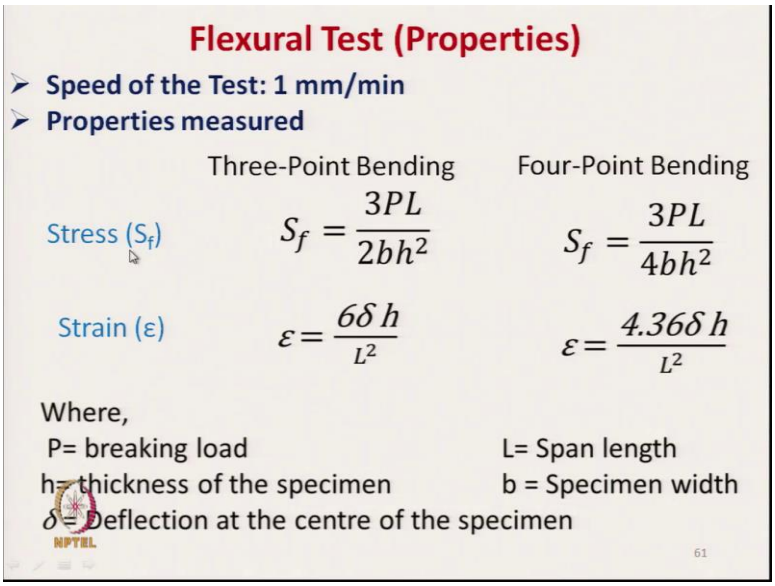

Now, if we compare the different parameters and their derivations we can get the stress strain we can express by different derivation. And the test speed is kept 1 mm/minute as per the standard and flexural stress Sf in case of 3 point bending is

$$S_f = \frac{3PL}{2bh^2}$$

Where,

P= breaking load L= Span length

h= thickness of the specimen b = Specimen width

δ=Deflection at the centre of the specimen

Similarly, in case of 4 point bending, the stress will be just half of that of 3 point bending. Because here we are using two different loading point and this is expressed by

$$S_f = \frac{3PL}{4bh^2}$$

And whereas, strain is expressed in terms of

$$\varepsilon = \frac{6\delta h}{L^2}$$

And in case of 4 point bending, it will be

$$\varepsilon = \frac{4.36\delta h}{L^2}$$

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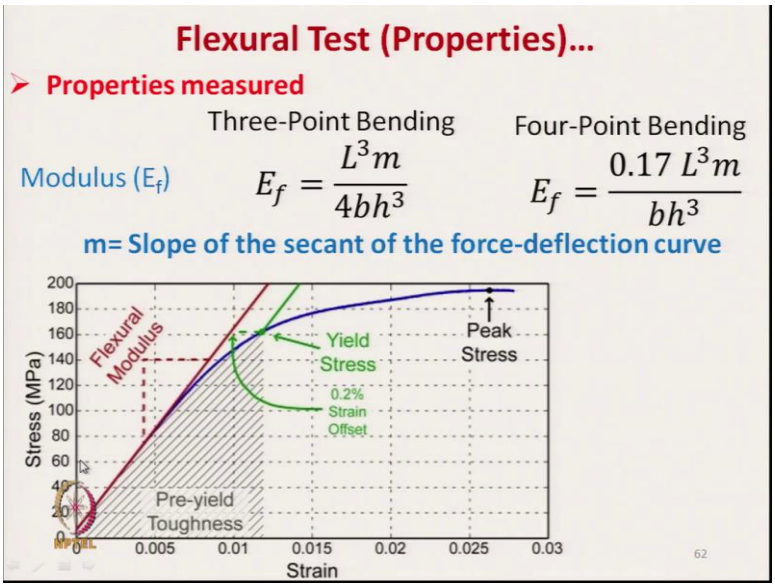

So, modulus can be expressed in terms of

$$E_f = \frac{L^3 m}{4bh^3}$$

And for four point

where m is the slope of the secant of force deflection curve. So, that is the slope of the curve.

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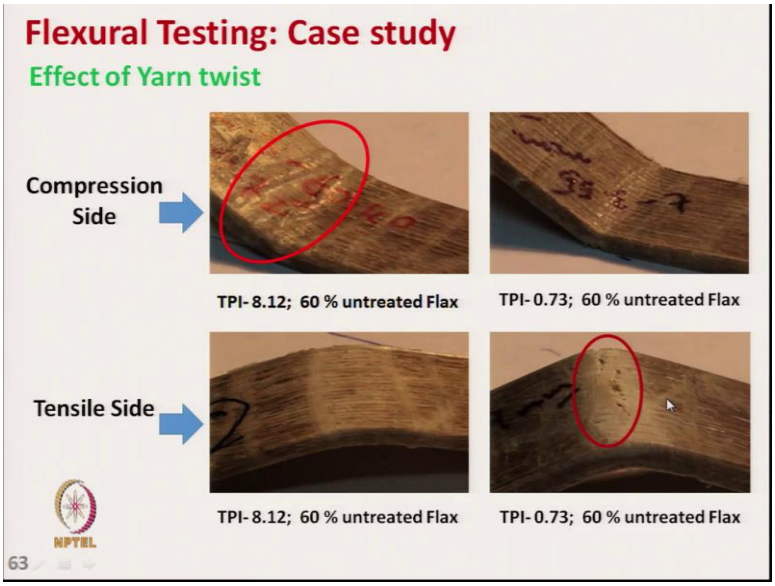

Now, let us try to see few case studies in case of flexural testing where we will discuss the effect of twist in the material reinforcing material and effects of the treatment surface treatment with and without MAgPP treatment on flax roving. Now here 60 percent means 60 percent is the volume fraction. And here we have taken the reinforcing roving flax is of with two twist level. One is TPI one 8.12 another is TPI 0.73.

And the pictures are showing in two different sides; one is compression side that is the top side from where the load is being applied and tensile side where it is opposite side. So, this picture shows here as the twist is reduced the proper penetration of matrix material was there that is why the sliding of reinforcing material and or matrix failure was not there with high twisted roving it is showing some wrinkle portion.

That means, there were sliding it was the grip was not proper and this roving's the flax was untreated. Once we see the other side tensile side the composite made from low to a state flax it showing there is a proper breakage proper damage of the composite it is a crack formation. Whereas, in case of higher TPI there is no crack formation simple the composite got extended. That means, there was slippage or sliding between matrix and

reinforcing material proper gripping was not there.

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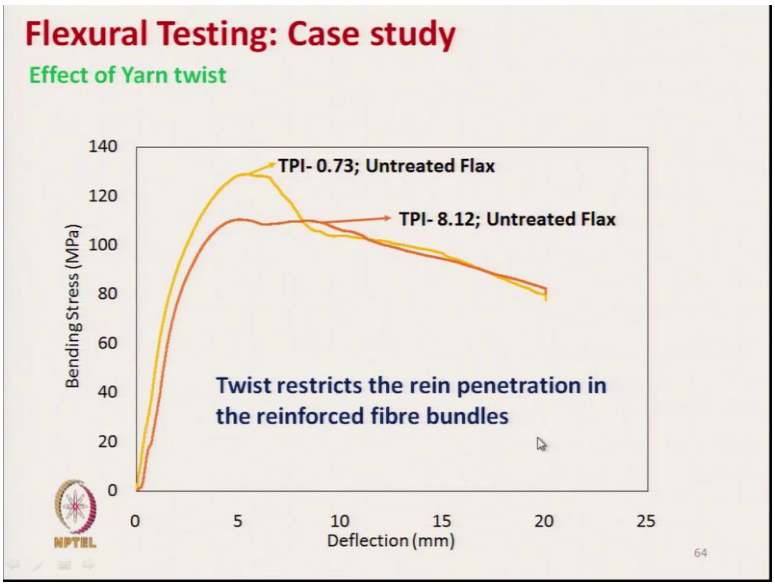

So, we can see by stress strain curve that is the bending deflection and bending stress curve this shows that the composite with lower twist the TPI 0.73 shows higher bending stress. Whereas, the composite with higher twisted roving that is 8.12 TPI it shows lower bending stress. That means, the twist restricts the resin penetration in the reinforced fibre bundle. So, due to twist application the fibres become compactly packed. So, resin penetration was not proper.

Now, the effect of the presence of surface treatment the left side this is showing the untreated flax and in right side this picture so the flax treated with MagPP. During compression again the presence of MAgPP that surface treatment it forms proper binding between the flax that is reinforcing material and the MAgPP and the matrix material. So, MAgPP helped in proper bonding between the matrix and reinforcing material that is why the proper breakage proper load carrying capacity has been improved here the twist present in the roving are kept constant.

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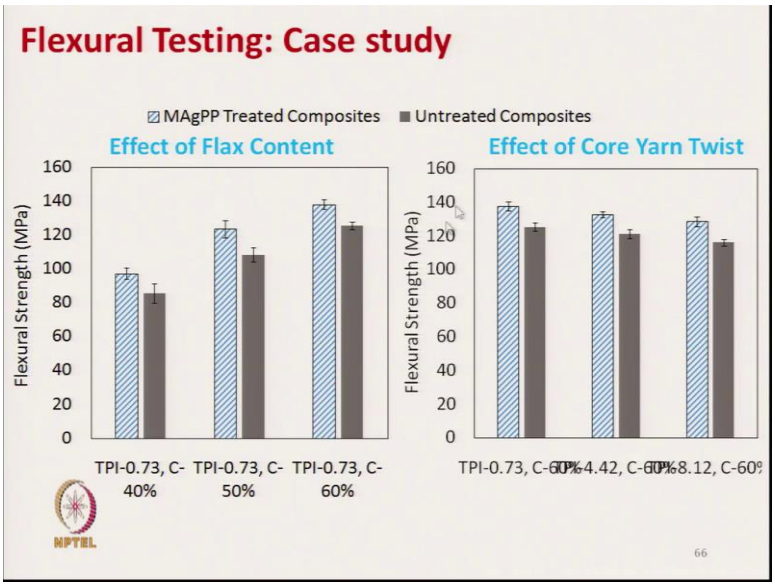

So, from this diagram it is clear that the flexural strength is higher in case of flax treated with MAgPP as compared to untreated composite. And this is true for all the different the fibre volume fraction that is 40 percent, 50 percent and 60 percent when we keep the twist in the roving constant. Also if we see the effect of core twist with the increase in core twist, the flexural strength reduces; the reason which I have already explained.

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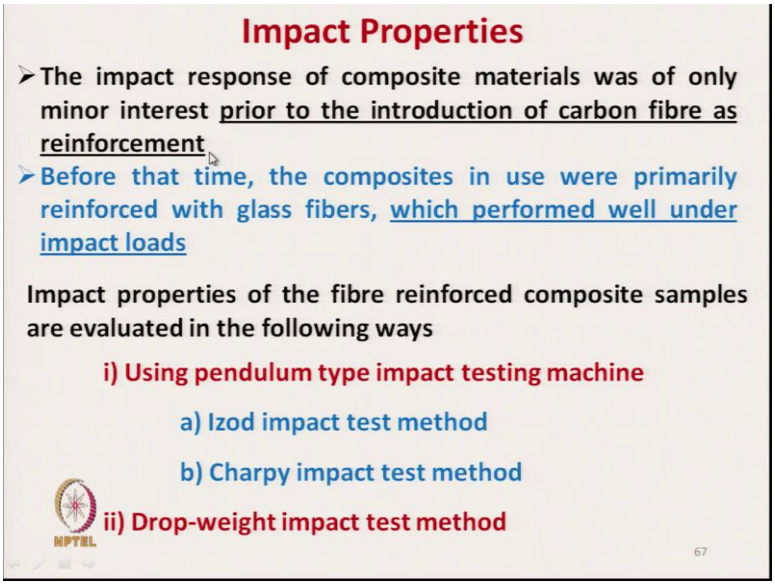

After bending, we will discuss, the next property which is impact properties of composite. The impact response of composite material was of only minor interest prior

to the introduction of carbon fibre as reinforcing material. So, earlier when we used to use the glass fibre reinforced composite the impact property was not that important. Because the most of the applications which we used the composite for mainly tensile testing.

But impact resistant is extremely important for composite material for different application. So, impact properties of the fibre reinforced composite sample are evaluated following different following ways ok. So, this impact properties are basically evaluated in two approaches. This approaches are one is using pendulum type impact tensile testing machine. So, pendulum type impact testing machine, another is drop weight impact test method. So, in pendulum type impact testing machine we have two different types of impact tester.

One is Izod impact test method and other is Charpy impact test method. And in drop weight impact test method the sudden pointed weight is actually impacted on the laminated composite surface and the damage is assessed. First we will discuss the Izod impact test method. So, Izod impact test method it is basically there will be one pendulum type impact tester that is pendulum type impacting surface.

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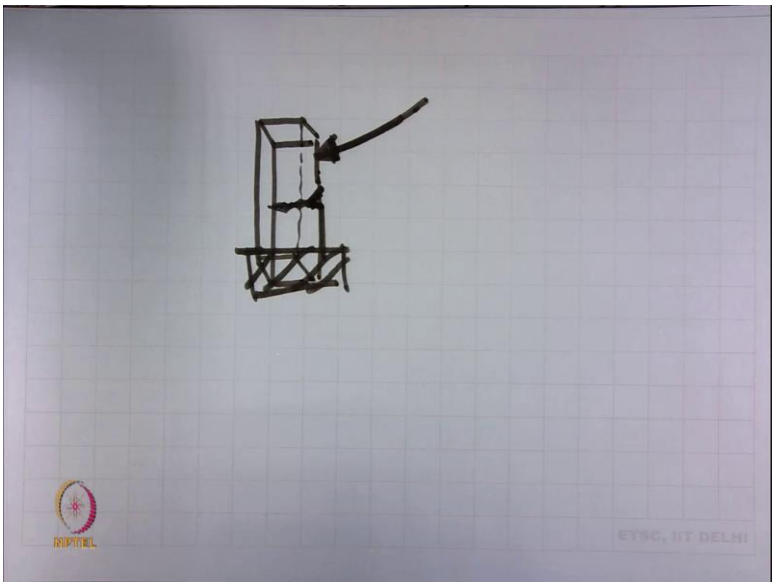

Suppose this is our composite material is composite material ok. And here in one surface we are making some notch cut. And this is the bottom portion is gripped firmly this is gripped firmly and from top they it will be some impact pendulum type impact will be

there. The impactor will strike at the top and due to the pre cut of this composite there will be the damage ok.

So, this will show the impact strength of the material. And this is the principle which is followed in the Izod impact test method. So, here if there is a impact, so, then there will be some crack, the damage will be there. So, first we will discuss the Izod impact test method.

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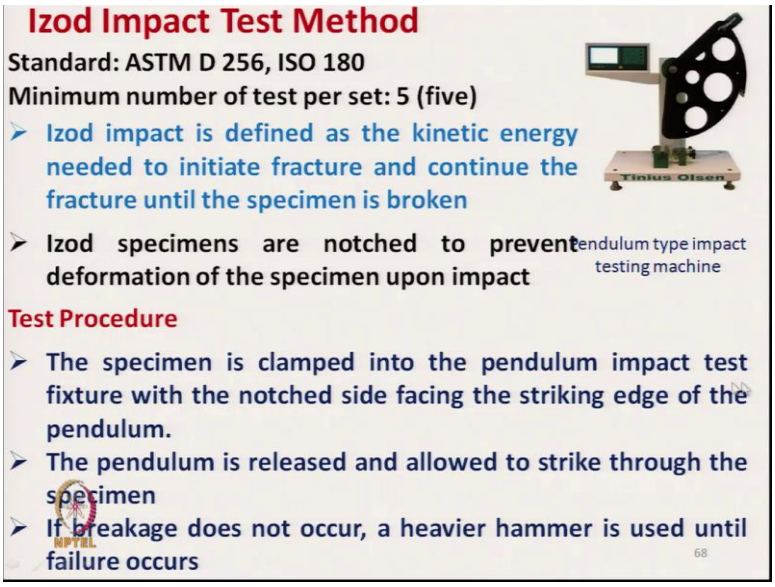

So, in this method the ASTM D 256 or ISO 180 the principles are followed. Minimum number of test per set is 5. The Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. So, there will be initiation of fracture and then it will continue till the specimen is broken and total kinetic energy required is calculated.

Izod specimens are notched as I have mentioned are notched to prevent deformation of the specimen upon impact. So, once the notch is created the flexure will be initiated at that point and the flexure will continue. If we do not create any notch then what will happen the composite will have different types of deformation like compression deformation bending or shear this type of deformation will be there which is not actually targeted.

The test procedure is the specimen is clamped into the pendulum impact test fixture with

the notched side facing the striking edge as I have shown I will just show in the next slide and this is the pendulum where the level of force can be varied by adding extra load. The pendulum is released and allowed to strike through the specimen this method is similar to what we have learned in tear test that is element of tear test principle. If the breakage does not occur a heavier hammer is used until failure occurs.

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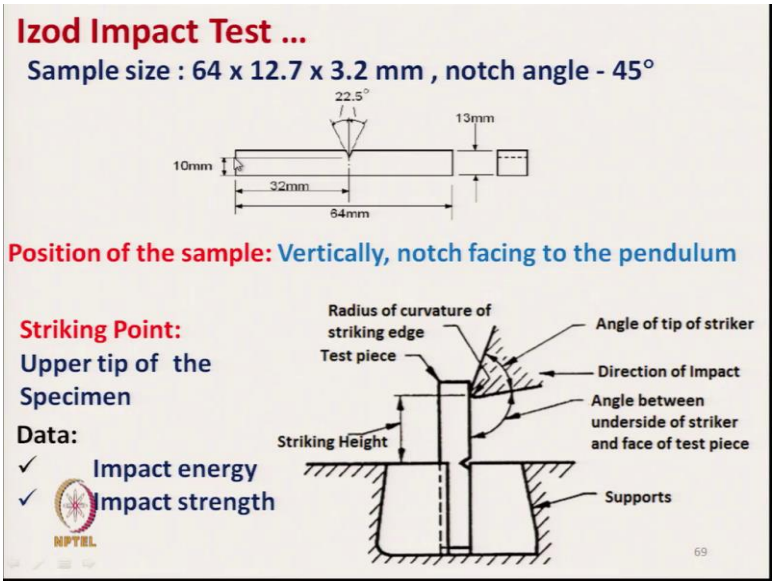

So, that I have already mentioned we can increase the weight of the this pendulum and the size of the specimen is 64 length, the width is 12.7 millimeter and the thickness is 3.2 millimeter ok. So, this is the width of the material and this is actually the damage takes place through the width of the material. So, effective width is 10 millimeter; so, effective width of failure fracture ok.

The position of the sample is that it is a we have to keep it vertically and the notch is facing to the pendulum. Now this is the arrangement where the specimen is actually gripped by the support which is holding the specimen. And this is the notch side and the pendulum is striking from the right side. And the striking height is the height from the notch point to the striking point and this is the test piece radius of curvature of the striking edge is this one at the tip.

And the angle of the tip of the striker direction of the impact from there here from right to left side and angle between the underside of the strike this is the underside of the strike and the face of the tests piece this is the angle. So, all this dimension actually affect the

test result. The striking point is that upper tip of the specimen this is the striking point at the upper tip and the data which we get is the impact energy and impact strength.

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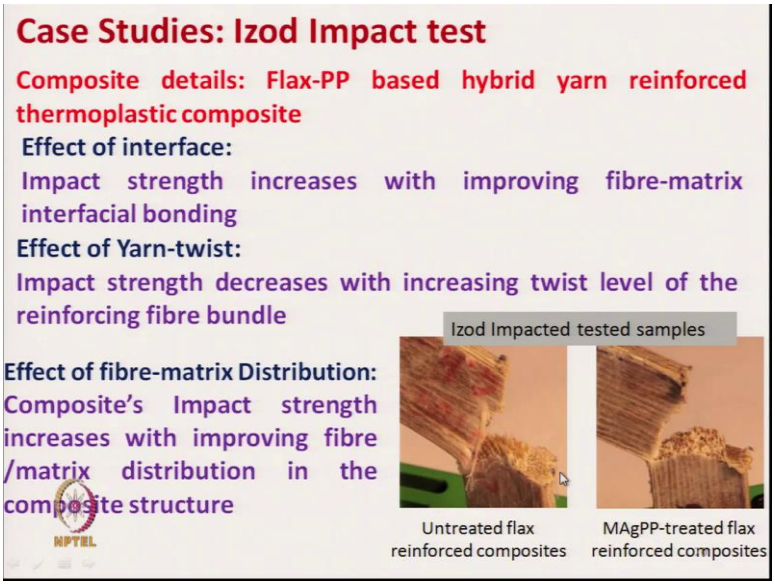

And this case study where we have carried out the Izod impact test on the Flax-PP composite both treated and untreated treated with MAgPP. So, the Flax-PP based hybrid yarn reinforced composite which is made of polypropylene which is thermoplastic matrix. So, effect of interface has been studied which is the impact strength increases with improving fibre matrix interfacial bond. So, when we treat the flax with MAgPP, the impact strength is observed to be increased.

Effect of yarn twist; the impact strength decreases with increasing twist level of the reinforcing fibre bundle because improper penetration of matrix due to higher twist. Effect of fibre matrix distribution the composites impact strength increases with improving fibre matrix distribution in the composite structure. So, as the distribution of matrix and the reinforcing material increases the impact strength increases.

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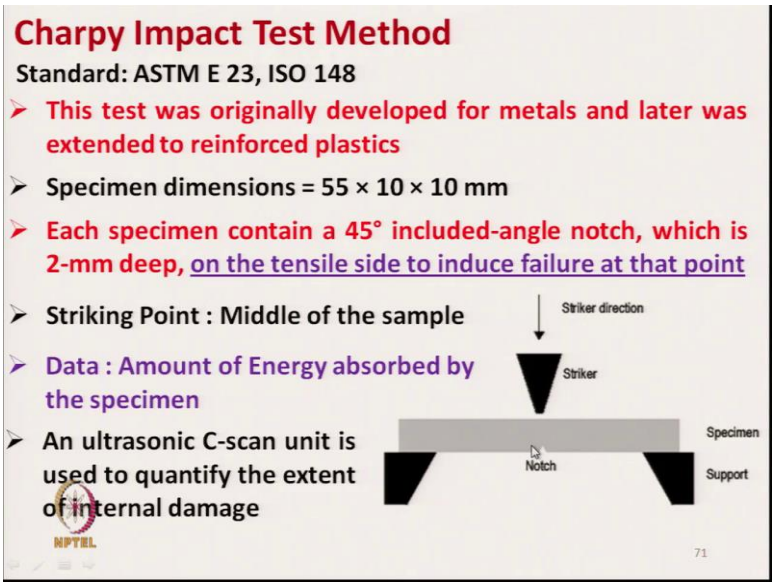

Next is the Charpy impact test method. So, in this test method it is originally developed for metal later it has been used for reinforced plastics. The specimen size is 50 millimeter by 10 millimeter by 10 millimeter. So, each specimen contains a 45 degree included angle notch ok. So, this notch is created which is 2 millimeter deep. So, the depth of the notch is 2 millimeter and placed on other side of the force applying point.

So, here in this picture the force is being applied from the top and notch position is at the bottom just opposite to the load applying point. The striking point is the middle of the sample ok. And the data which we get here is amount of energy absorbed by the specimen before it fails. Also an ultrasonic C-scan unit is used to quantify the extent of internal damage. So, extent of internal damage can also be assessed.

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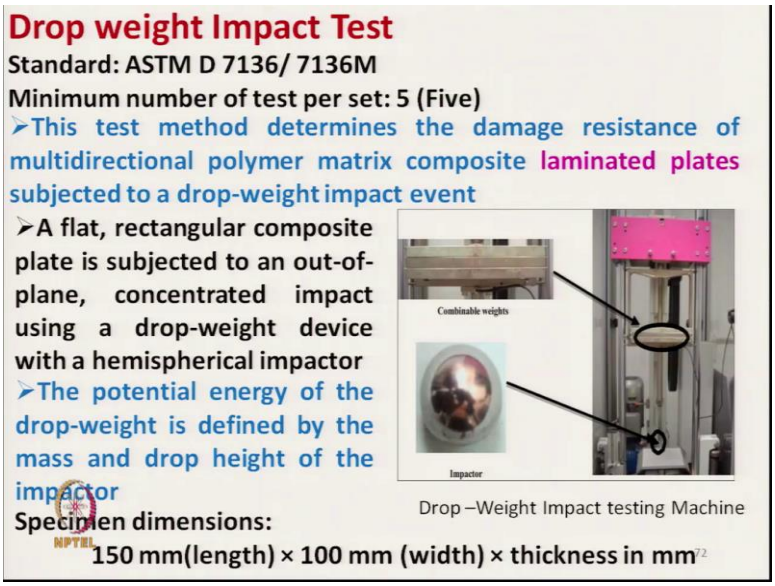

Next test method for impact test is the drop weight impact test. So, this is actually this follows the ASTM D 7136 method minimum number of test per set is 5. Here in this picture this is the striking point impactor damage and moss that is the it is a load that will be free fall of this load with the impacting point and it will fall on a laminated composite material and there will be deformation or some damage will be there. This test method determines the damage resistance of multidirectional polymer matrix composite which is laminated plate subjected to a drop weight impact event. So, here we have to use laminated plate ok.

A flat rectangular composite plate is subjected to an out of plane concentrated impact using drop weight device with a hemispherical impactor this is the hemispherical impactor. The potential energy of the drop weight is defined by the mass and drop height of the impactor. So, if the mass is changed or the height is changed the potential energy can be adjusted. The specimen dimension it is rectangular specimen of length 150 millimetre by 10 millimetre and thickness is as per requirement.

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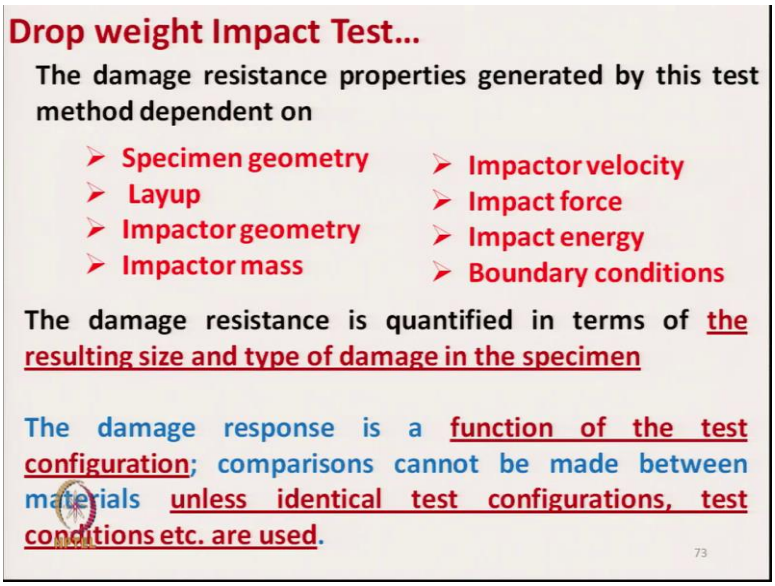

The damage resistance properties generated by the test method depends on specimen geometry laying up impactor geometry impactor mass. So, all these parameters will affect the damage property. The impactor velocity impact force impact energy boundary conditions these are the different factors. The damage resistance is quantified in terms of the resultant force and resulting size and type of damage in the specimen. So, size and type of damage will show the damage resistance characteristics.

The damage response is a function of the test configuration comparison cannot be made between materials unless identical test configurations or test conditions are used so we cannot compare. Suppose if we change the impactor geometry we can cannot compare the impact resistance of two material. So, if we want to compare the impact resistance of two composite material we have to keep all the parameters as I have mentioned the same all these parameters should be same.

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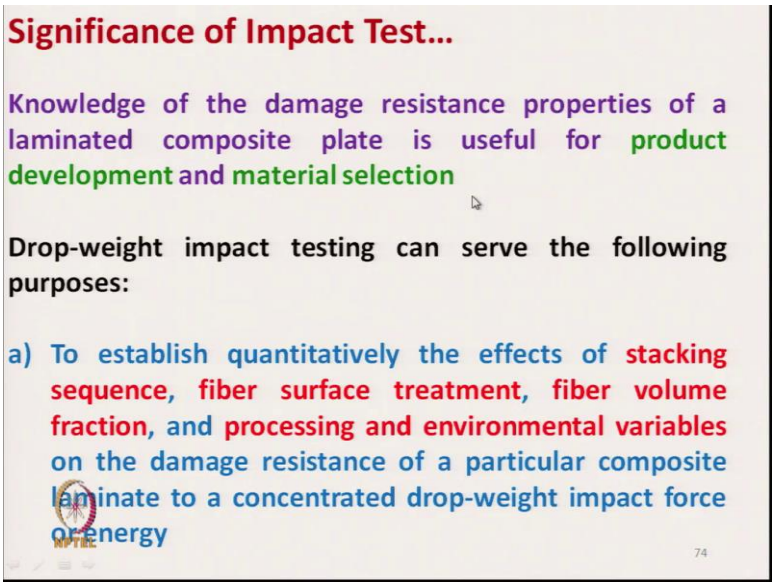

Now, what is the significance? The knowledge of the damage resistance property of laminated composite plate is used for product development and material selection. So, we have to actually know the application if at all there is some chance of impact is there then you have to assess the what is the value what is the extent of impacting force accordingly we can select the material.

Drop weight impact testing can serve the following purposes to establish quantitatively the effects of stacking sequence, fibre surface treatment, volume fraction, processing and environmental variable on damage resistance of a particular composite laminate to a concentrated drop weight impact force or energy. Like we can compare we can assess the effect of stacking or effect of fibre surface treatment on impact energy by using the drop weight test method.

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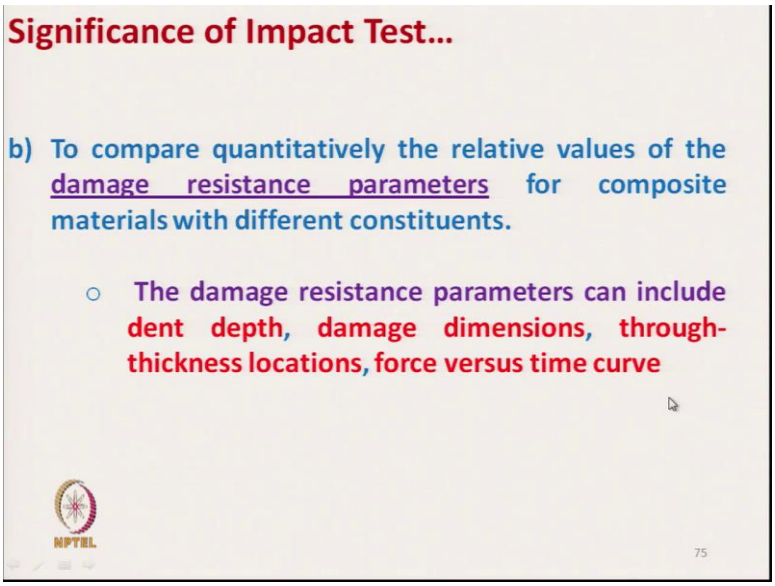

Another significance is that to compare quantitatively the relative value of damage resistance parameter for composite material with different constituents ok. And the damage resistance parameters are basically it is a dent depth, damage dimension, through thickness location, force versus time curve. So, the damage during impact can be assessed using all this parameters.

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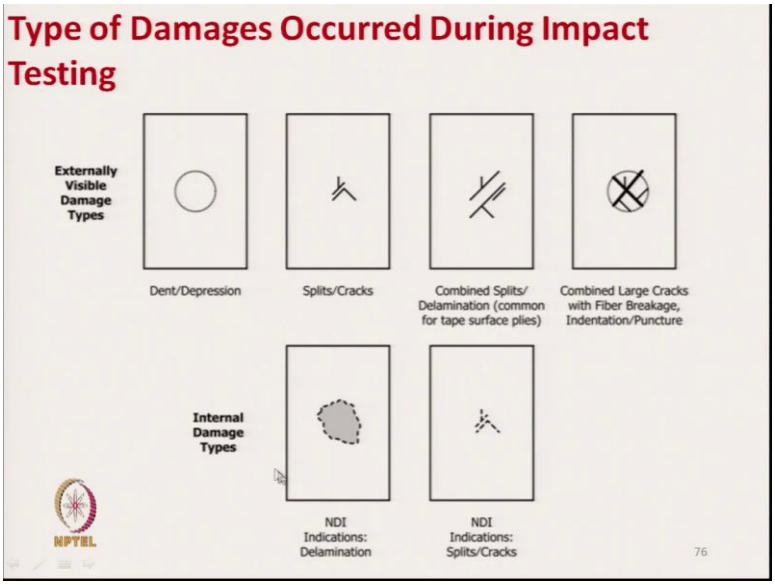

Let us see these are the different types of damages during impact testing. So, this damages at the top are actually externally visible damages and internally occurred

damages are this type of damages. So, in externally visible damages are so depression or dent, split or cracked type as well or combined split and combined large crack with the fibre breakage and internally occurred damages also.

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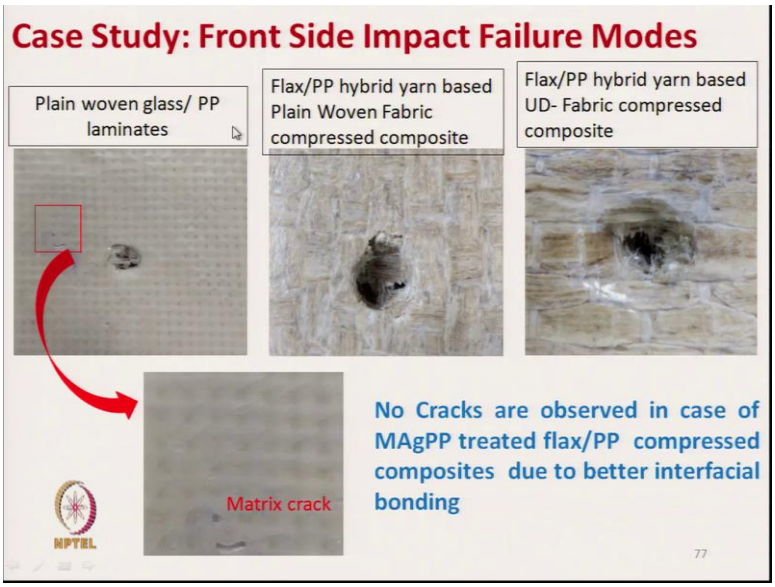

Now, the case study here front side of the failure mode. Here three different types of composite are there. One is commonly used glass polypropylene laminated composite using plain woven structure. Second one is that flax polypropylene hybrid yarn based on plain woven fabric ok. And third one is that it is not plain woven it is unidirectional fabric compressed composite which is Flax PP. So, yarn is actually led in unidirectional direction. So, here the in case of glass PP laminate, the cracks are observed here. But for Flax-PP composite no cracks are observed due to better interfacial bonding using the MAgPP surface treatment.

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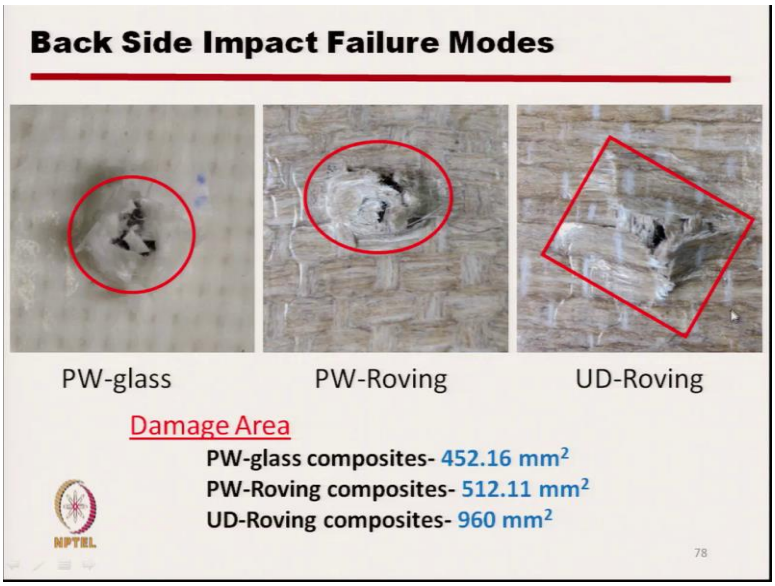

And the back side this is the glass PP and unidirectional UD and it is a woven. So, damage area dimension if we see woven glass composite it is a area is 452 square millimetre. Then unidirectional composite it is a 960 square millimetre.

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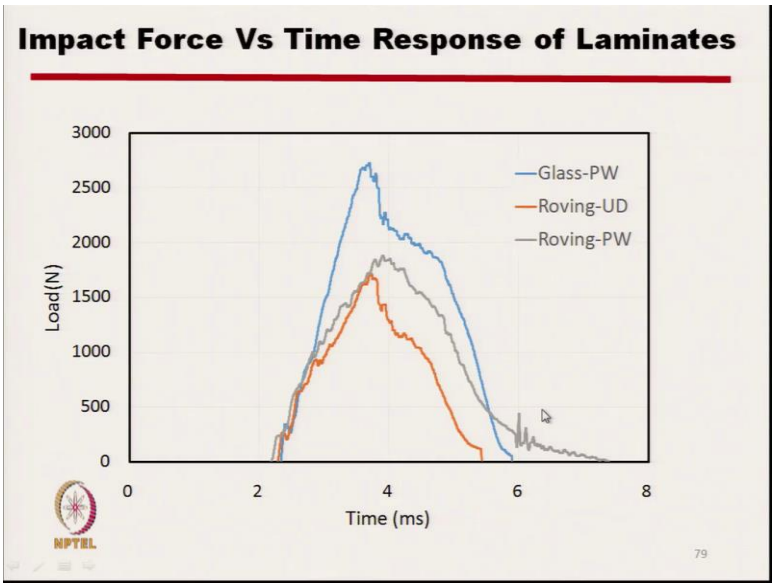

So, we can see here the glass PP composite will is having highest load concentration as compared to the flax polypropylene composite.

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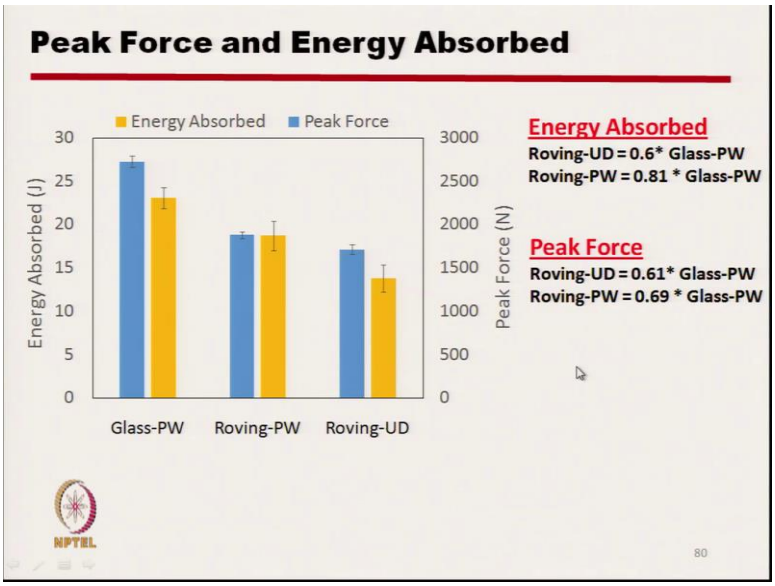

And if we see here energy absorbed; energy absorbed for unidirectional roving composite it is a 0.6 times of glass polypropylene composite. And woven roving it is a 0.81 time. So, we can calculate the energy absorbed and peak force also. So, here by this test method we can actually compare different impact test impact results ok. We will stop here. In next class we will discuss the fibre matrix interfacial bonding strength measurement.

So, till then, thank you patient hearing.