Technical Textiles
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Lecture No- 40
Additional Lecture on Composites (contd…)

Hello everyone, so we will continue with the unidirectional composites. So this we have discussed in last class that unidirectional composites were prepared from fibers as matrix through DREF spinning technique, powder coating technique and film stacking technique.

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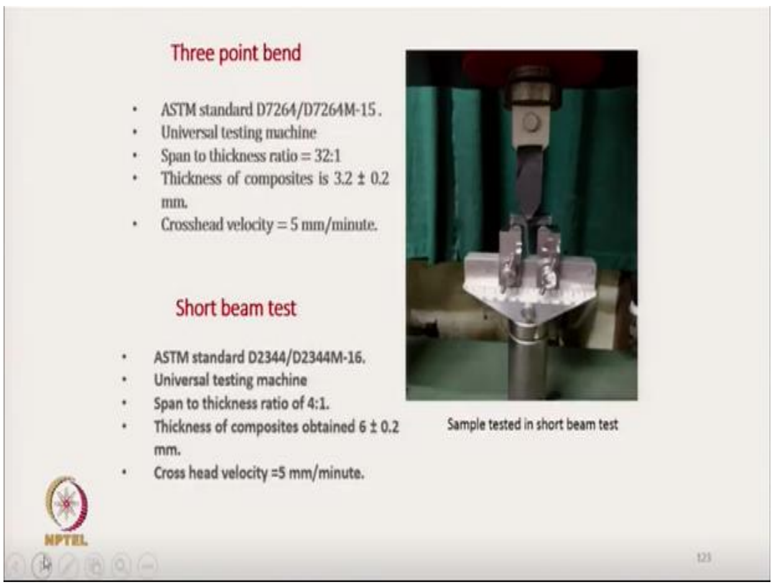

And these are tested for their 3 point bending testing and short beam testing.

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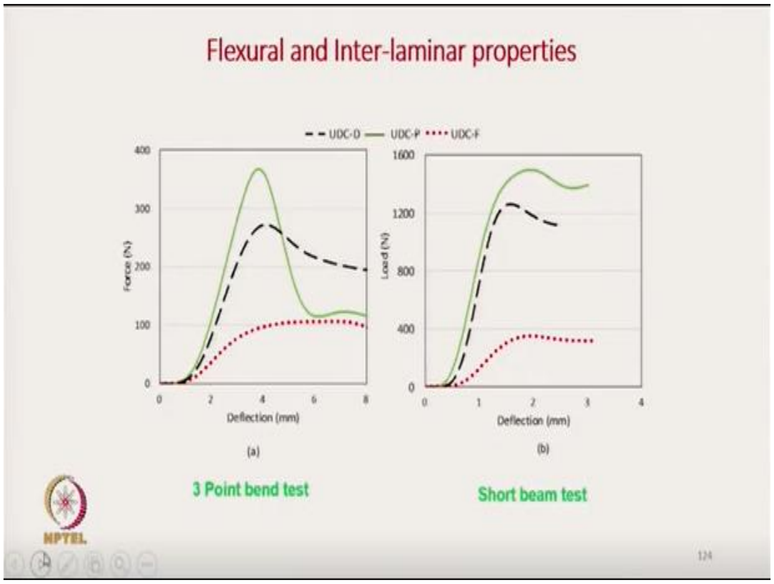

Now here if we see the 3 point bending test is mainly for the flexural strength and short beam test is basically inter laminar property. So from this diagram if we see the UDC-P has got highest flexural strength as well as the short beam test that highest flexural strength we get from the powder coating, whereas the film stacking technique it results very poor flexural characteristics.

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Flexural and interlaminar properties for unidirectional composites

Sample	Three-point bend test		Short beam test
Unidirectional Composite	Average flexural strength (MPa) $S = \frac{3PL}{2bd^2}$	Average flexural modulus (GPa) $E_B = \frac{L^3 m}{4bd^3}$	Short beam strength (MPa) $F^{sbs} = 0.75 \times \frac{Pm}{b \times h}$
UDC-D	188.20	33.19	12.21
UDC-P	232.12	43.67	14.91
UDC-F	73.01	8.14	3.51

So we can see here that average flexural strength here it is 232, on the other hand for film stacking it is very low.

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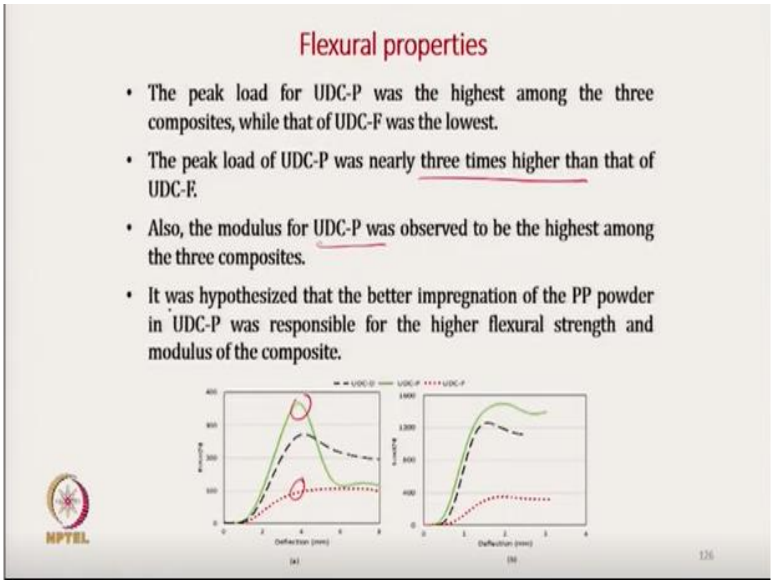

The peak load for UDC-P was the highest among the three as I have seen, I have discussed it is nearly three times higher than the UDC-F. So it is nearly three times higher. Also the modulus, the modulus of UDC-P is observed to be highest. It was hypothesized that the better impregnation of PP powder in UDC-P was responsible for higher flexural strength because the powder is already present inside the structure, so that is why it is very high. The peak load is highest among the three composites, it is four times highest.

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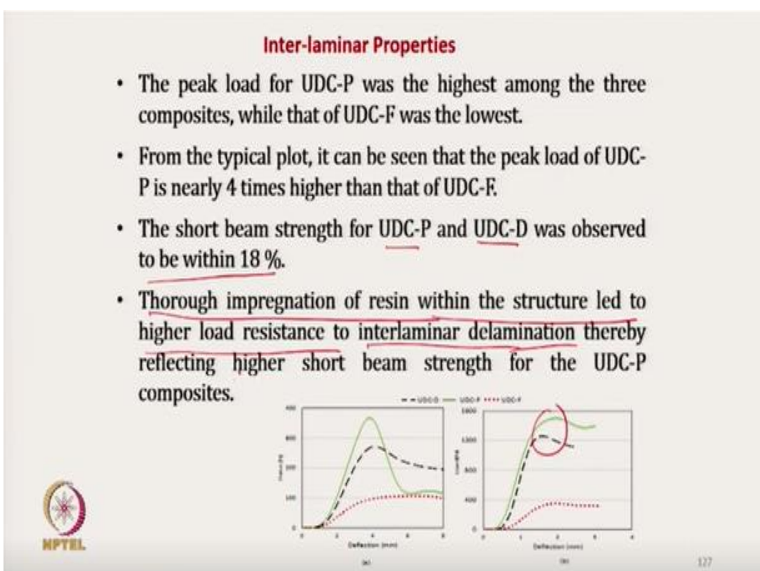

In short beam strength for UDC-P and UDC-D was observed to be within 18%, so that is within 18%. So, why is it so? The thorough impregnation of resin within the structure led to higher load resistance and interlaminar delamination process that is, that interlaminar delamination is restricted here. So, that is why it gives a higher short beam strength so due to the proper impregnation.

Although the outer coating has got very good impregnation, still the DREF spun yarn also shows the hybrid yarn shows the better performance as compared to the film stacking technique.

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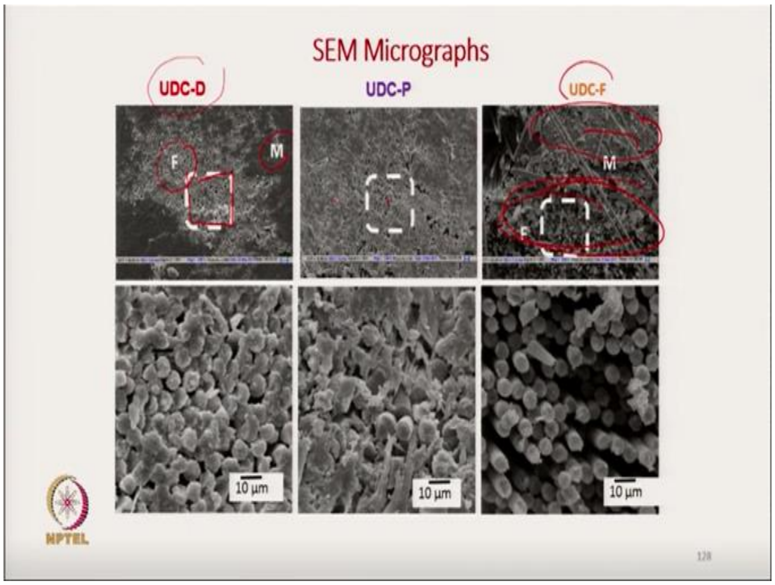

So here we can see here that, this is the DREF spun yarn here. In DREF spun yarn we can see clearly clear the fiber zone and matrix zone it is separated. So this is the fiber zone cluster of fiber and similarly in film stacking we can see the matrix and fibers are totally separated this is fiber here it is a matrix but in case of powder coating the penetration of powder, penetration of matrix is very good within the reinforcing material, these are uniformly distributed. That is why it results very good flexural strength.

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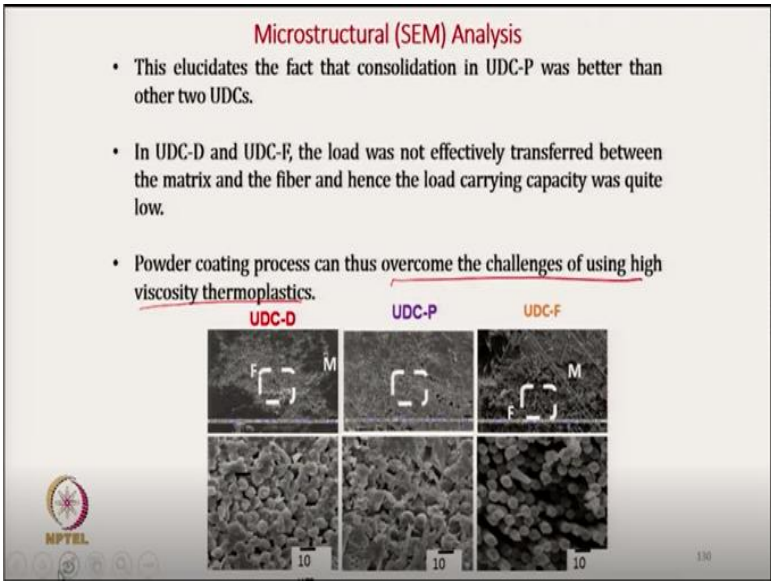

So scanning electron microscopy shows that the carbon fiber if and matrix they are very good intermixing is there as I have already mentioned, same powder coating process can thus overcome the challenge of using high viscosity thermoplastics. So that is why the problem of thermoplastics are the problems main problem is that the due to the high viscosity its penetration within the reinforcing material is poor it needs very high pressure and it also results a void content but the powder coating is the solution in that direction.

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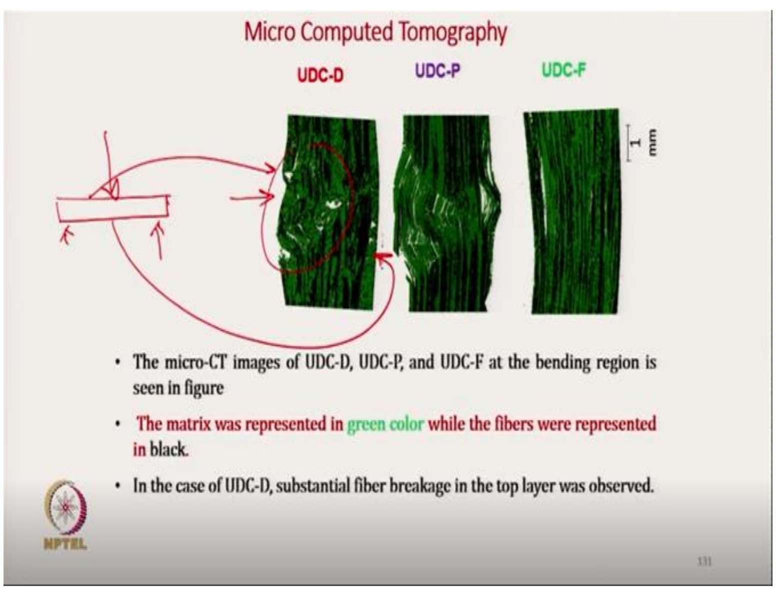

Micro computed tomography of the composite after the flexural testing was done here, in this diagram the matrix was represented by green color, this green color is matrix and black color is the carbon reinforcing material. In UDC-D which is made from a DREF yarn, hybrid yarn we can see here this is the top side during the bending study 3 point bending this is the top side so in 3 point bending this is the composite base and here it is a bending.

So this is the top side is shown here and this is the bottom side. So in top side what we have observed there is a significant fiber breakages are there in the compression side also.

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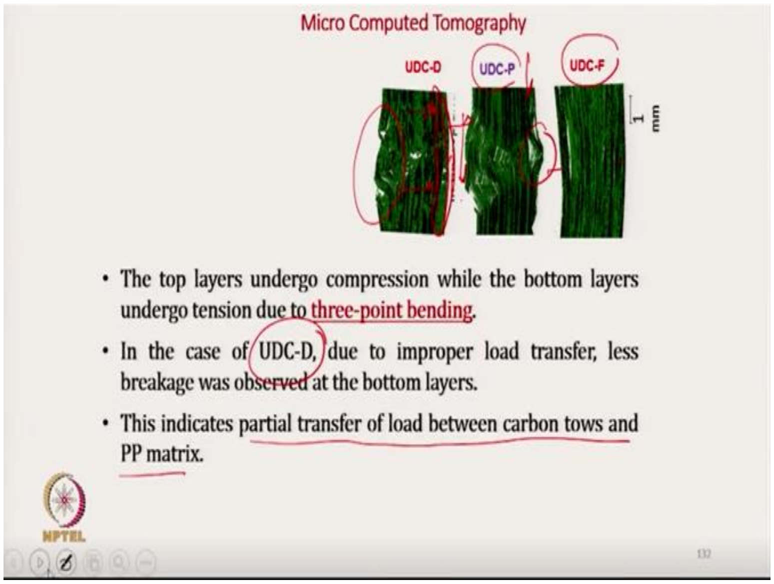

And bottom layer undergoes the tension here, not that much breakage took place here that means inter, there is no proper bonding is there due to relatively higher void content. So this at the top side, at the compression side the breakage is due to the pressure that the damage of fiber, but at the extension side there is not significant breakage was observed. On the other hand if we see the powder coated composite the breakage was there, both in top and bottom side.

That means the load is being shared by the reinforcing material at the back side also. That is why it gives very high flexural rigidity. If we see the film stacked composite absolutely there is no breakage of carbon fiber the reinforcing fiber. What does it mean? There is a clear sliding between the carbon filament and the matrix. So that is why the proper load bearing is not there. So this has been explained here, I have already explained.

So this indicates partial transfer of load between carbon tow and PP matrix for UDC-D at the other side, back side there is no transfer of load is there.

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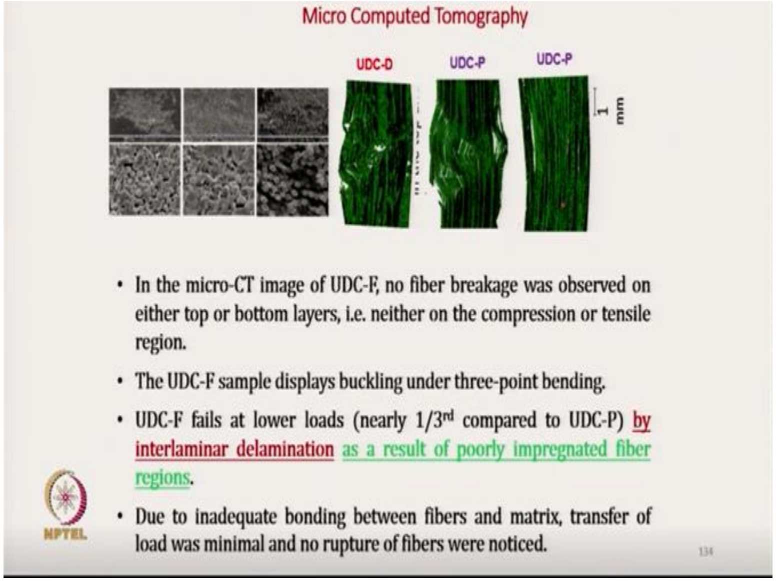

And UDC-P that is a powder coating we have already explained that it is proper impregnation is there. That is why proper load sharing is there. That is which result very high flexural strength and here simply it is slide is there, that is why there is no load sharing or very less load sharing.

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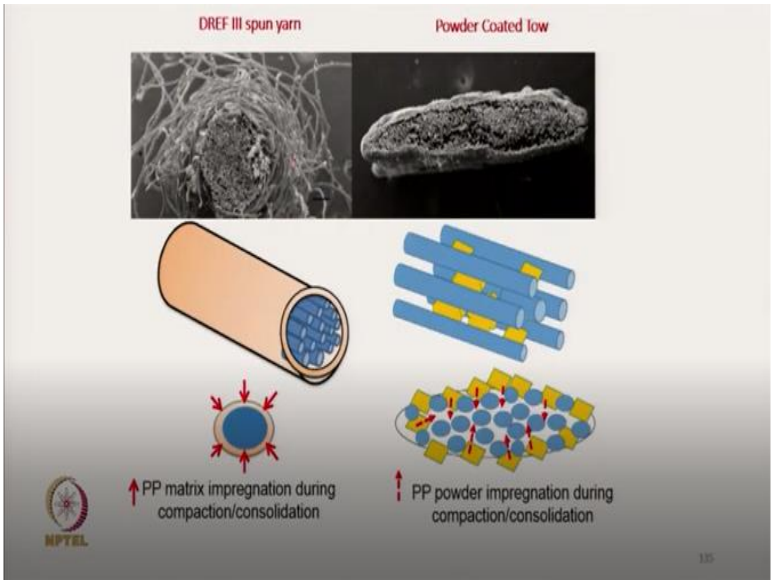

Now you can see schematically here this is the fiber and powder coating is there. That is why proper penetration of the powder, the proper penetration of matrix component is there inside the carbon tow.

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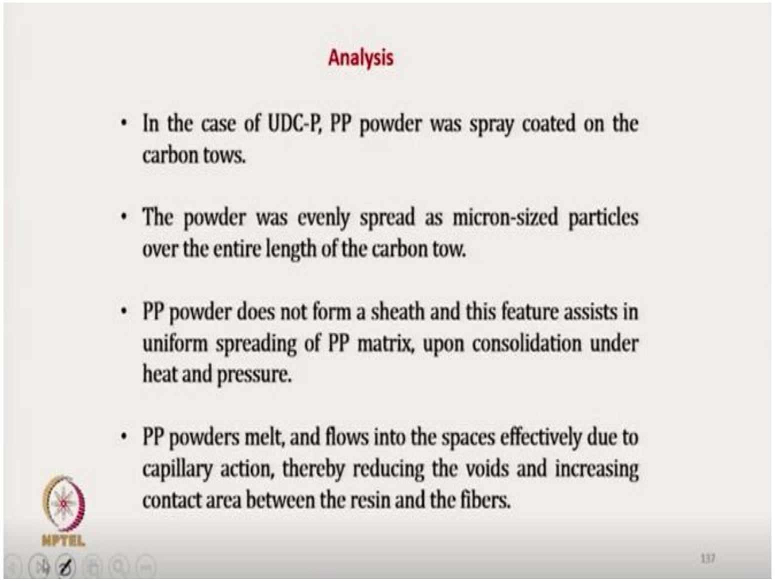

This we have already discussed here.

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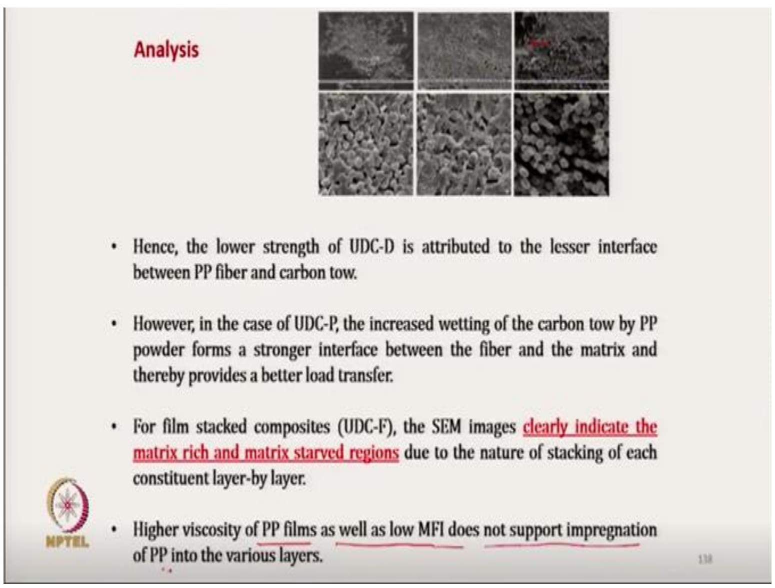

For film stacking composite the same image clearly indicates that matrix rich and matrix starved portion that we have already seen, layer by layer. So, higher viscosity of polypropylene film as well as low melt flow index does not support impregnation of polypropylene into the various layers, so these are the different reasons.

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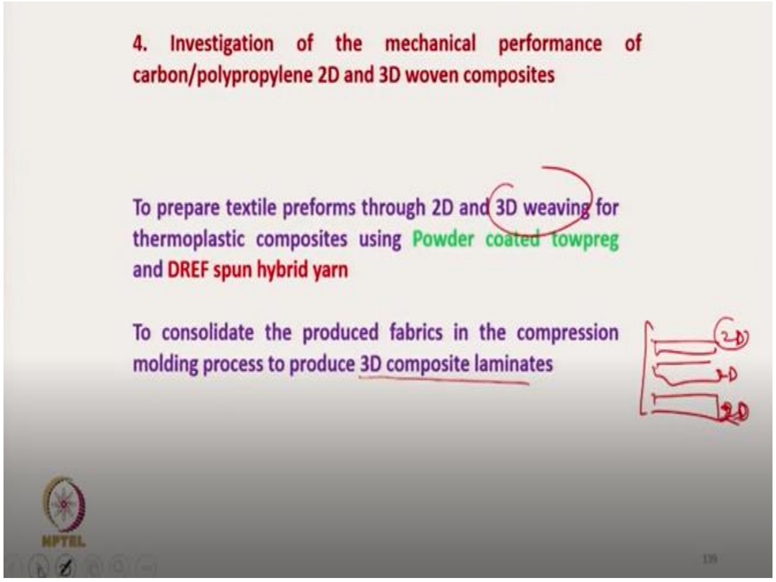

And our last experiment is that the investigation of the mechanical performance of carbon polypropylene 2 dimensional and 3 dimensional woven composites. So that from the DREF spun yarn that is a hybrid yarn and from hybrid yarn towpreg and the powder coated towpreg we have produced 2D woven fabric and 3D woven fabrics and from there we produce composites. To prepare textile preforms through 2D and 3D weaving for thermoplastic composite using powder coating and DREF spun hybrid yarn.

To consolidate the produced fabric in the compression molding process and to produce 3D composite laminates. Now from 2D fabric we have to produce 3D composite laminates. Here what we have done, we have used 3 layers of 2D fabric. This is 2D woven fabric, 3 layers to keep the mass per unit area same as that of 3D weaving, 3D woven fabric and to investigate their properties. Now let us see the plan of work.

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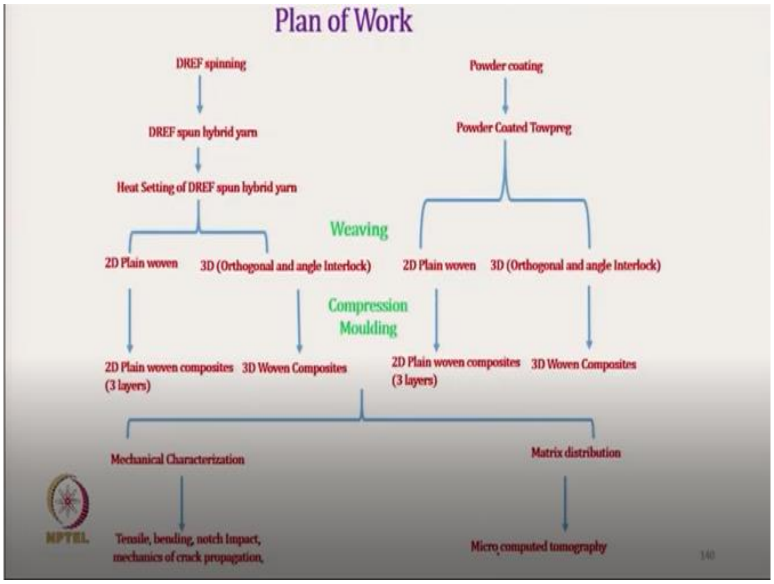

So we have used two techniques here. Two techniques are DREF spun hybrid yarn and powder coated hybrid towpreg. So powder coated towpreg is there. Then heat setting of hybrid yarn is required powder coating system involves the heat setting, so we do not need heat setting here. Then we have weaving. So we have woven in 2D fabric and 3D we have used two different structures orthogonal 3D and angle interlock 3D for both powder coated and DREF spinning yarn.

And then we have used compression molding, for 2D plane woven composite we have used 3 layers as I have mentioned to maintain the mass per unit area and then 3D composite, 3D woven composite using the compression molding, we have studied the mechanical characteristics and also as well as matrix distribution. In mechanical tensile, bending, notch impact and mechanics of crack propagation, this we have discussed and micro computed tomography.

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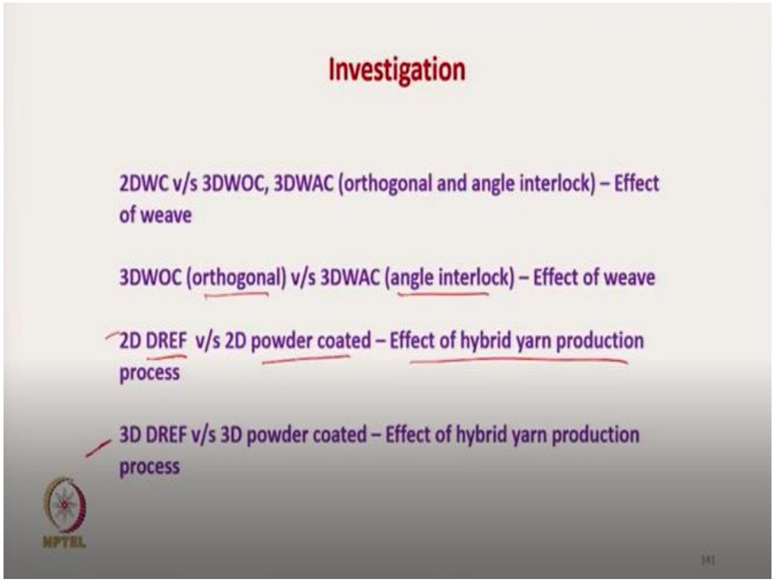

So what we have done? We have studied 2D versus 3D. So orthogonal, effect of weave we have studied, then what we have studied? Effect of fabric structure that of 3D woven fabric that angle interlock and orthogonal, effect of weave here, then effect of hybrid yarn production using powder coating and DREF system and effect of hybrid yarn production of both for 2D and 3D. These are the factors we have studied here.

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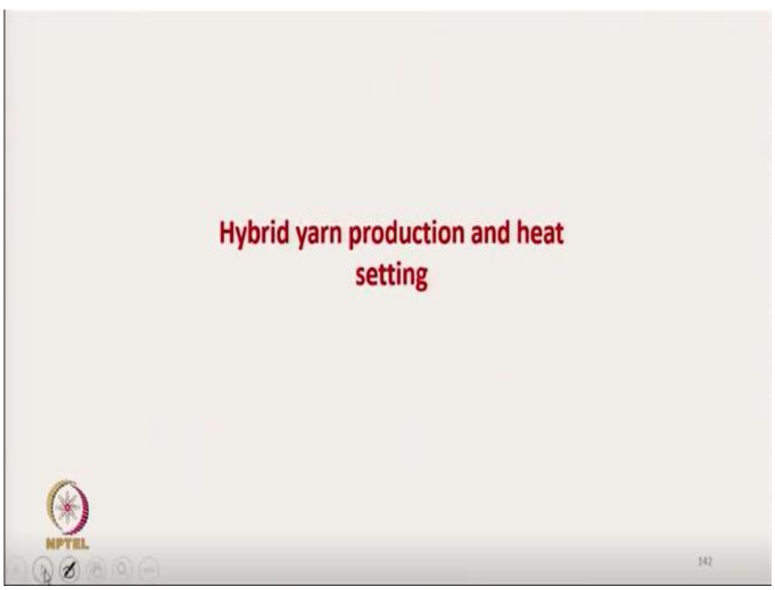

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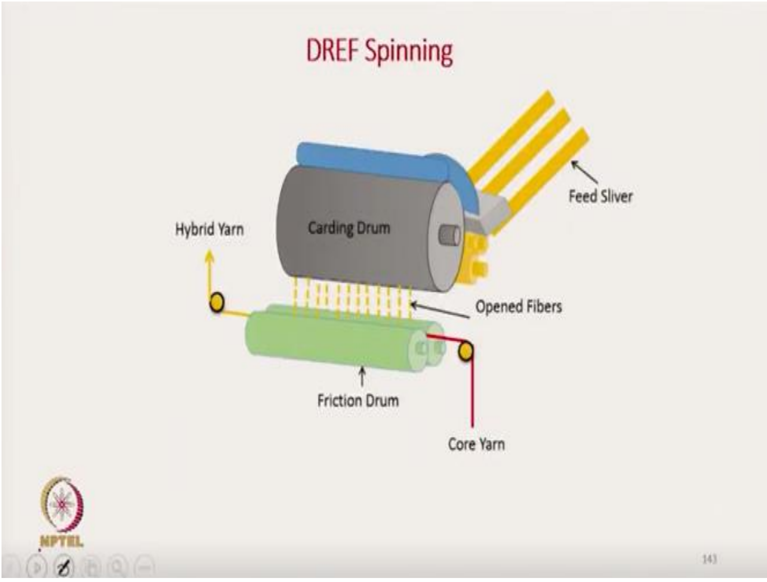

So hybrid yarn production DREF spinning that we have already explained.

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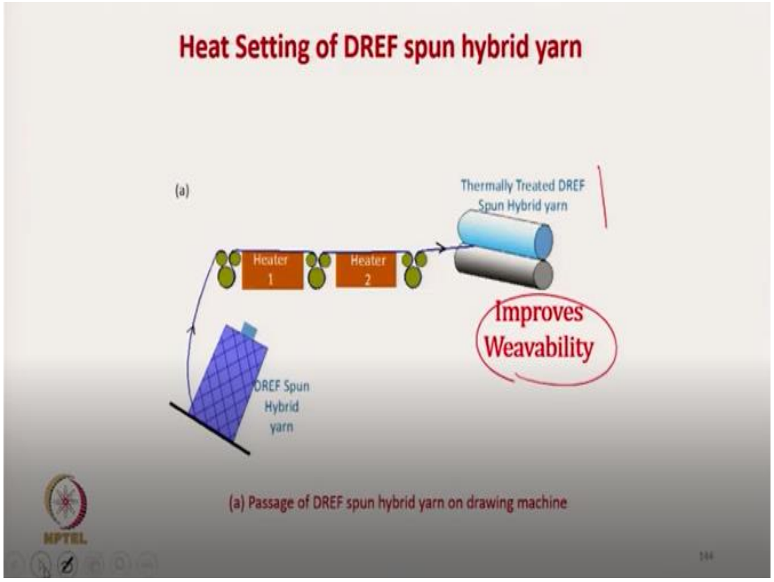

After DREF spinning we have what we have done we have here treated with heat treatment, two heaters were there, so heater 1 and heater 2. So thermally treated DREF spun towpreg is produced to improve the weavability, otherwise there will be fraying of the sheath fibers that is why to improve the weavability we have used.

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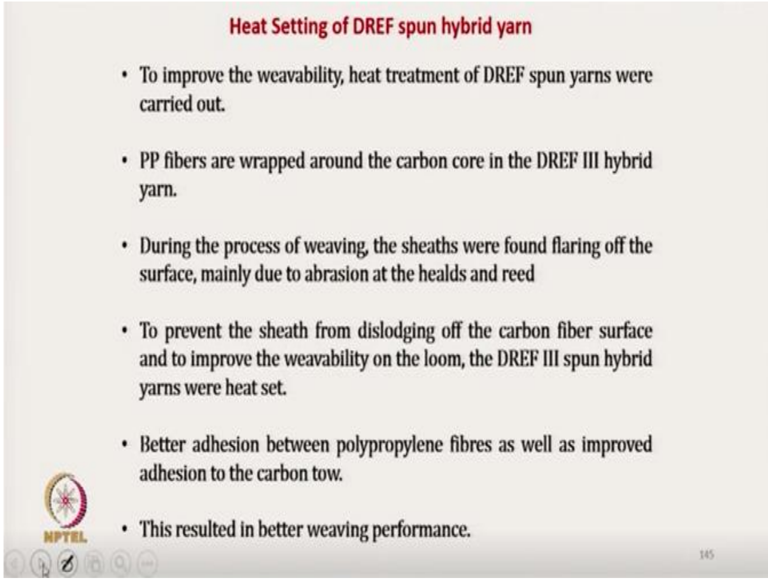

So these are the various steps or reasons for heat setting. So for better weaving performance, we have to set the heat setting.

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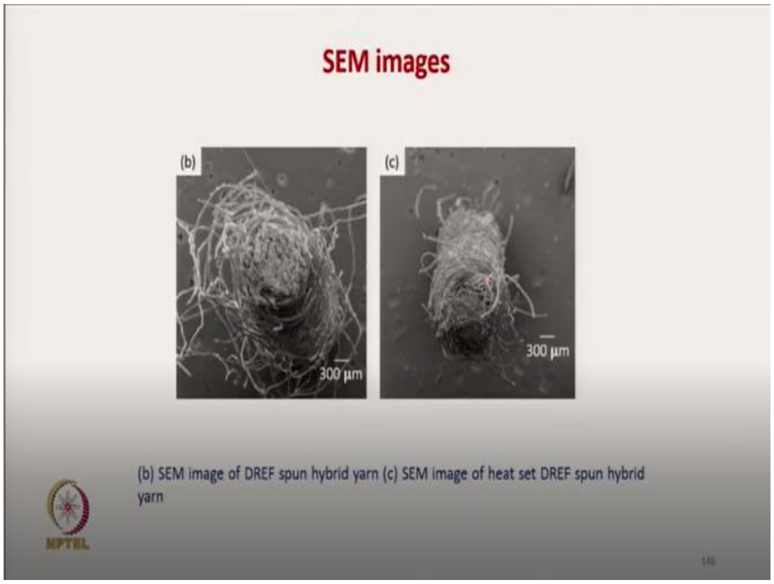

So before heat setting the SEM image and this is after heat setting, partial melting is there. We do not need complete melting; complete melting will increase the flexural rigidity that will create problem during weaving. So partial melting is required to have a better flexibility also.

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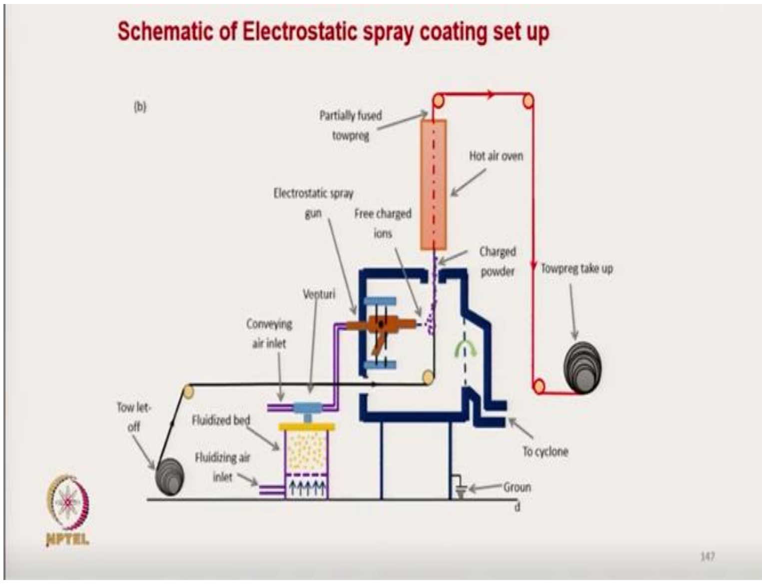

And electrostatic spray coating that we have already explained so this is used for powder coating.

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And then we have taken these yarns for weaving of 2D weaving and 3D weaving.

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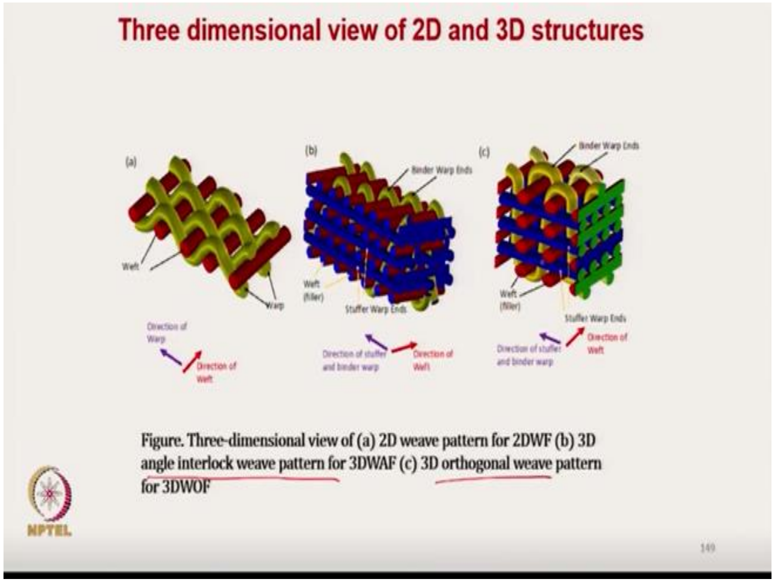

The 2D weaving woven structure is here. So it is a plain woven fabric one up one down and this structure is that the 3D angle interlock, where we have weft yarns. These are the weft yarns and warp yarn, there we have two types of warp yarns, one is the stuffer warp yarns which are almost straight in alignment and another is the binder warp end. This structure is a 3D interlock structure and 3D orthogonal structure.

Here again the yellow color threads are the binder warp threads and this blue are the stuffer warp threads, which are little bit straight.

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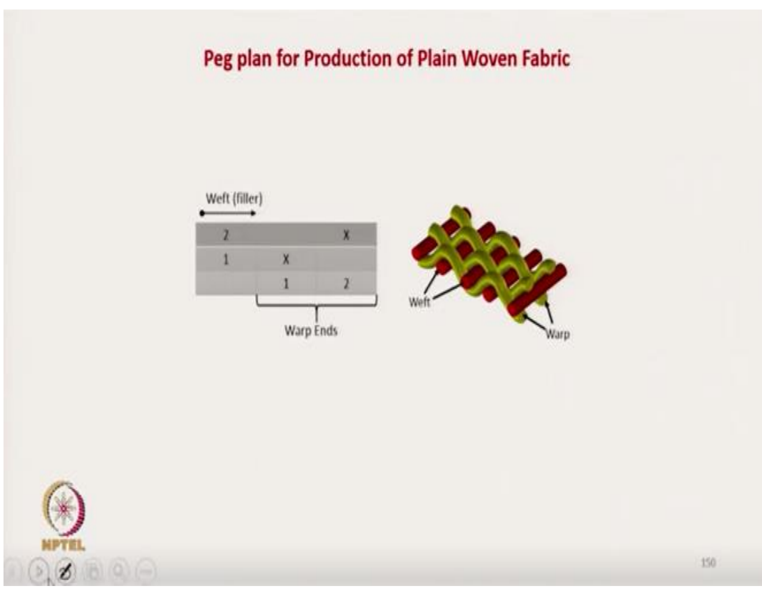

These are the structure one by 1 up and 1 down, peg planning is there.

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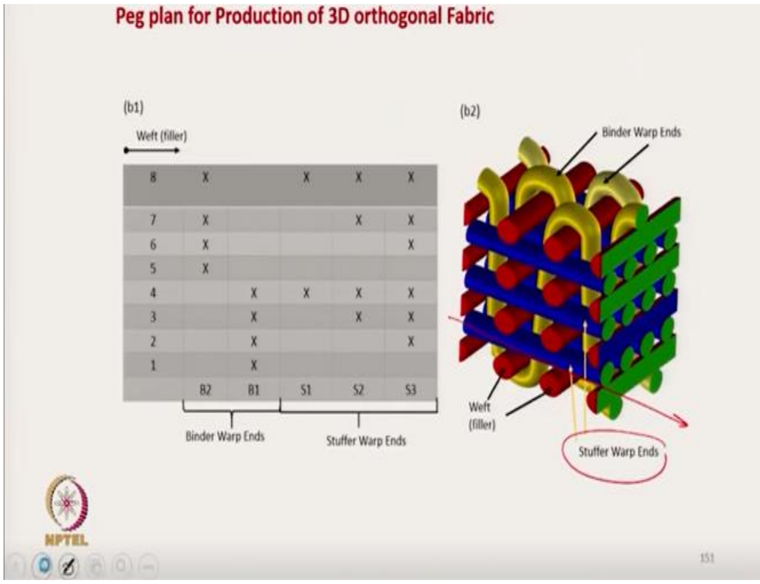

And peg plan for the orthogonal structure, this is the peg plan, detailed peg plan is there. Here in orthogonal structure you can see here the binder yarns binder warp yarns there it has got very high crimp. So if we apply the stress in the warp direction the mainly the stuffer warp ends are straight because as the, it is stuffer warp ends are stressed because of the fact that they are almost straight.

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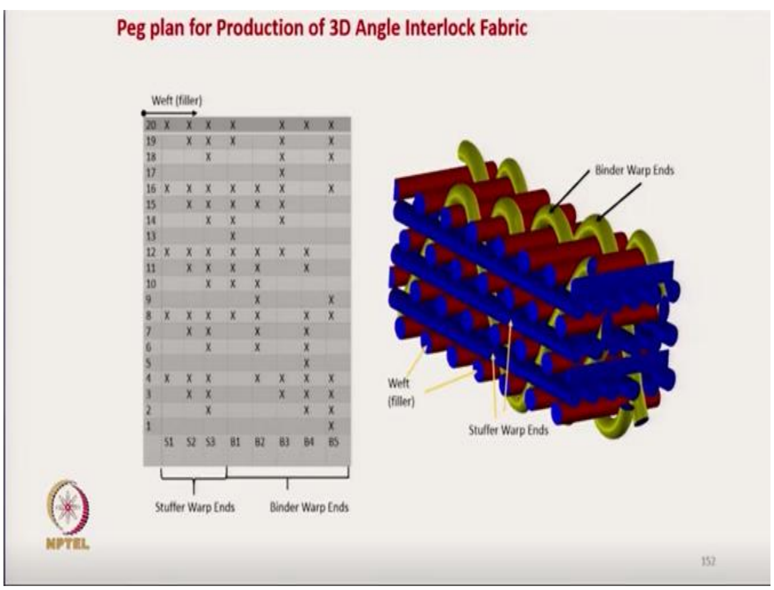

Similarly, the angle interlock these are the peg plan, this binder threads are little bit angled. So here you can see the crimp is relatively lower here, crimp of the binder yarn.

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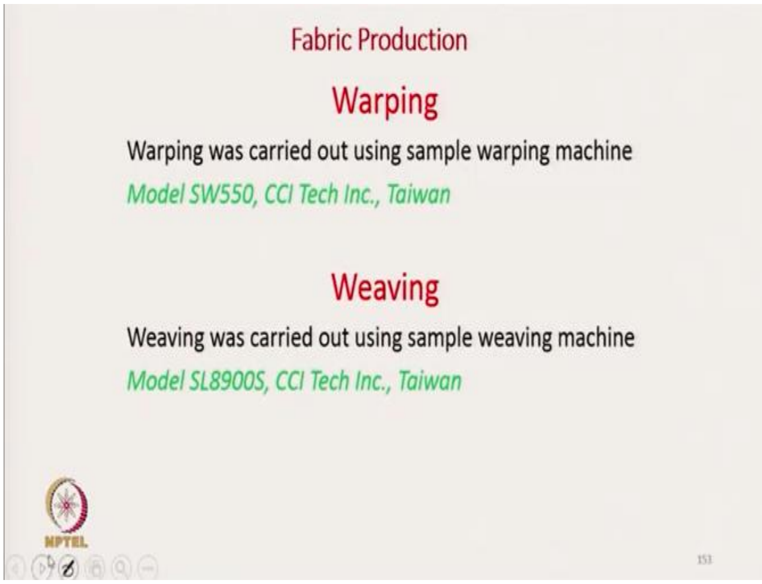

So warping and weaving was done using CCI loom.

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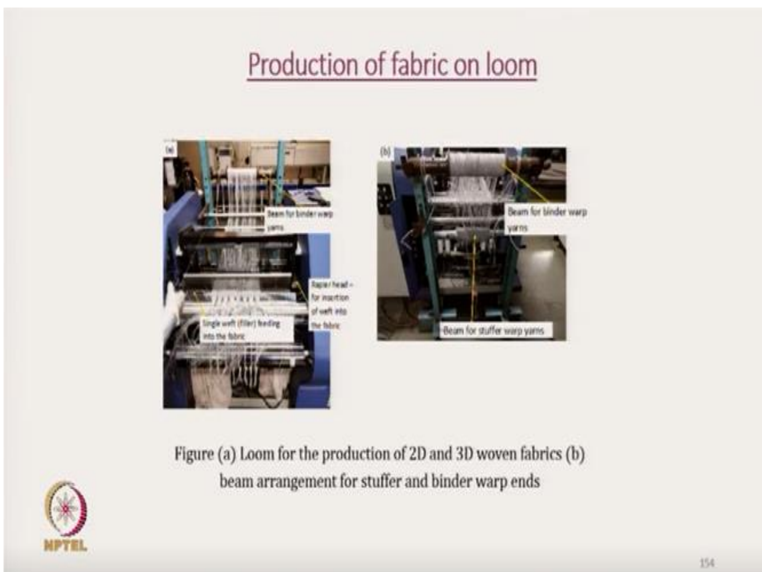

This is the production of fabric, here this is the beam for binder warp yarn beam for stuffer warp yarn. There are two types of beams are used here and the loom is of repair type loom.

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Now if we see here this is the weaving of the 3D fabric, this is a small loom, one is binder another is the for stuffer warp, finally we get the 2D and 3D fabrics.

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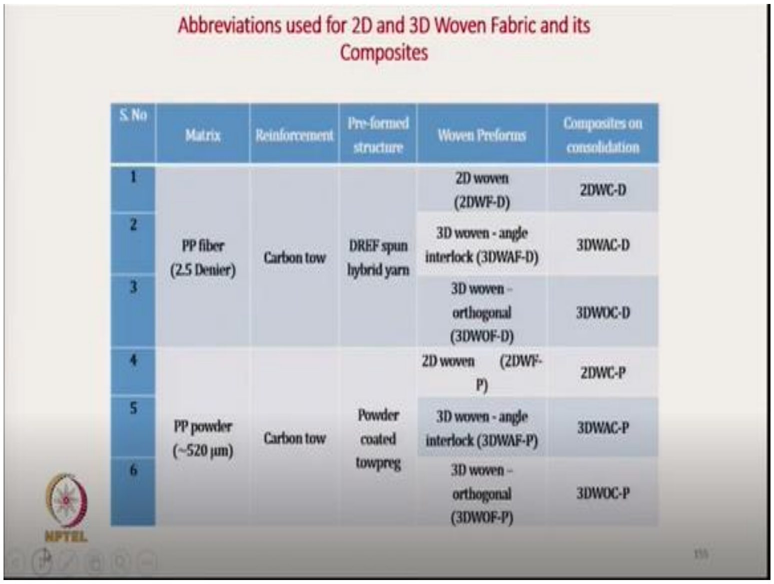

S. No	Matrix	Reinforcement	Pre-formed structure	Woven Preforms	Composites on consolidation
1	PP fiber (2.5 Denier)	Carbon tow	DREF spun hybrid yarn	2D woven (2DWF-D)	2DWC-D
2				3D woven - angle interlock (3DWAF-D)	3DWAC-D
3				3D woven - orthogonal (3DWOF-D)	3DWOC-D
4	PP powder (~520 μm)	Carbon tow	Powder coated towpreg	2D woven (2DWF-P)	2DWC-P
5				3D woven - angle interlock (3DWAF-P)	3DWAC-P
6				3D woven - orthogonal (3DWOF-P)	3DWOC-P

Now the abbreviations of the composites were, this is 2DWC-D means 2 dimensional made up 2 dimensional fabrics, woven fabric, composite made from DREF yarn and 2DWC-P from the powder coating, similarly 3D is the angle interlock and orthogonal structure. In this way, we have prepared a samples of 6 different samples were prepared.

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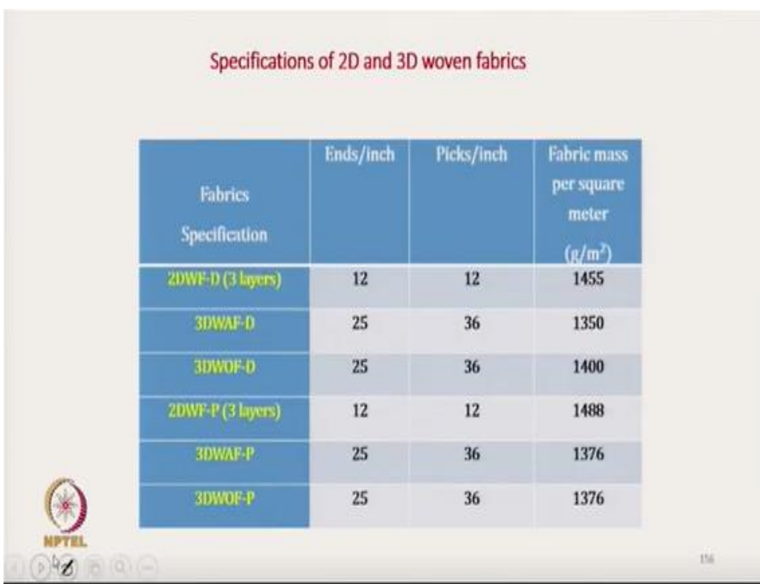

Fabrics Specification	Ends/inch	Picks/inch	Fabric mass per square meter (g/m^2)
2DWF-D (3 layers)	12	12	1455
3DWAF-D	25	36	1350
3DWOF-D	25	36	1400
2DWF-P (3 layers)	12	12	1488
3DWAF-P	25	36	1376
3DWOF-P	25	36	1376

Now 2D fabrics are 3 layer, so ends per inch, picks per inch is given and here the mass per unit area is almost very close to each other, so they are equivalent.

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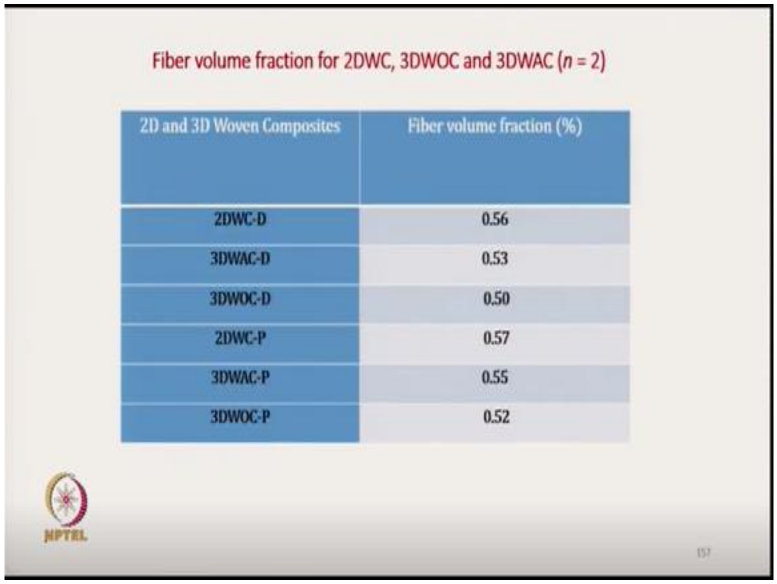

Fiber volume fraction for 2DWC, 3DWOC and 3DWAC ($n = 2$)

2D and 3D Woven Composites	Fiber volume fraction (%)
2DWC-D	0.56
3DWAC-D	0.53
3DWOC-D	0.50
2DWC-P	0.57
3DWAC-P	0.55
3DWOC-P	0.52

Fiber volume fractions are almost equal. So they are almost same, very close around 50 to 55 %. So it is a fraction it is not;

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Mechanical characteristics.

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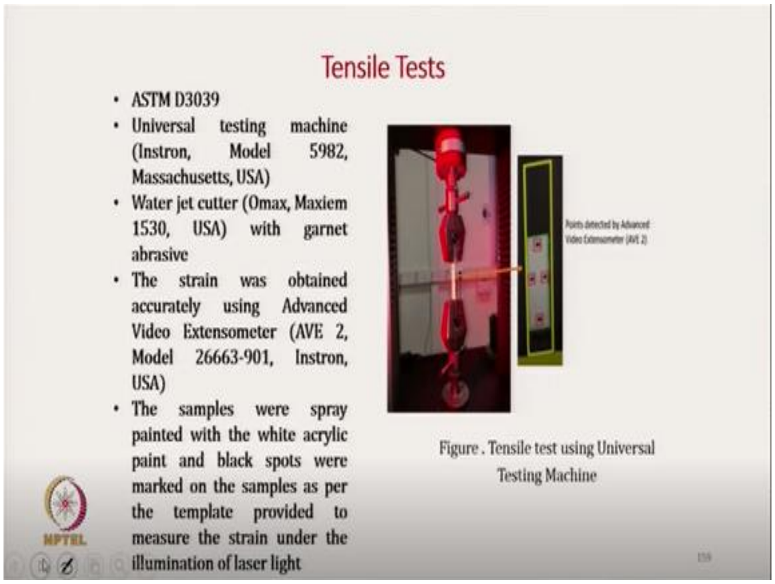

We have done tensile characteristics here using universal tensile machine following the ASTM standard test method.

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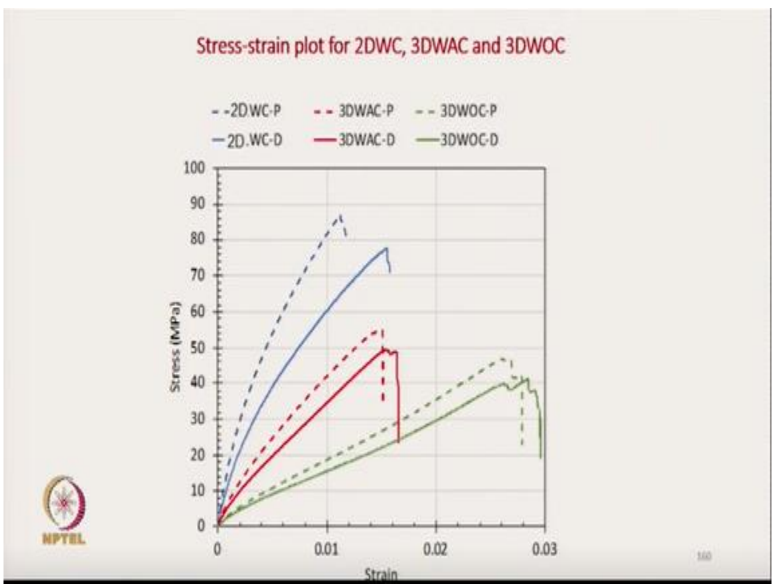

Now, if we see here the tensile stress, it is highest in case of 2D woven composite made from the powder coating and 3D from angle interlock, it is followed by angle interlock and then 3D orthogonal is the least strength. So basic reason is that due to the very high crimp and these are tested in the warp direction, very high crimp in the binder threads, they are not carrying the load but in case of 2D all the warp threads were carrying loads simultaneously, here the loads are carried only by the staffer threads which are relatively less crimped.

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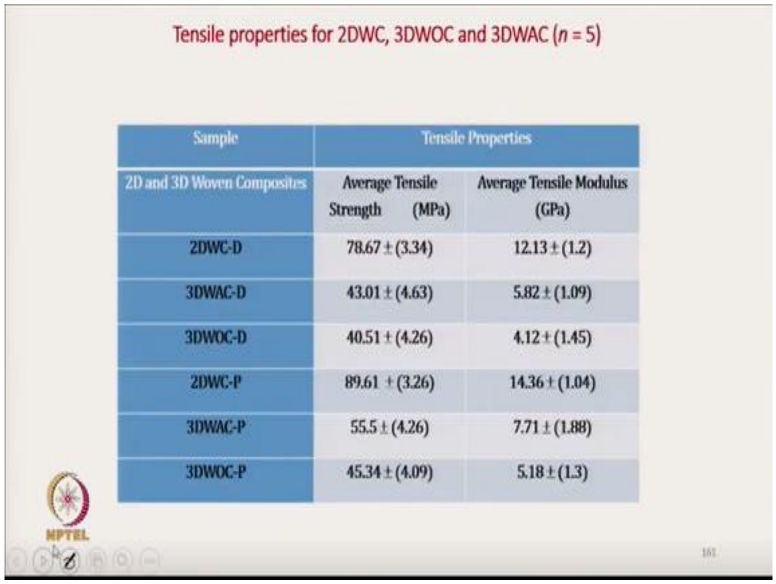

Tensile properties for 2DWC, 3DWOC and 3DWAC (n = 5)

Sample	Tensile Properties	
2D and 3D Woven Composites	Average Tensile Strength (MPa)	Average Tensile Modulus (GPa)
2DWC-D	78.67 ± (3.34)	12.13 ± (1.2)
3DWAC-D	43.01 ± (4.63)	5.82 ± (1.09)
3DWOC-D	40.51 ± (4.26)	4.12 ± (1.45)
2DWC-P	89.61 ± (3.26)	14.36 ± (1.04)
3DWAC-P	55.5 ± (4.26)	7.71 ± (1.88)
3DWOC-P	45.34 ± (4.09)	5.18 ± (1.3)

We can see here the, both the modulus and the tensile strength are higher in case of 2D composite, 2D woven composite, 3D composites are less.

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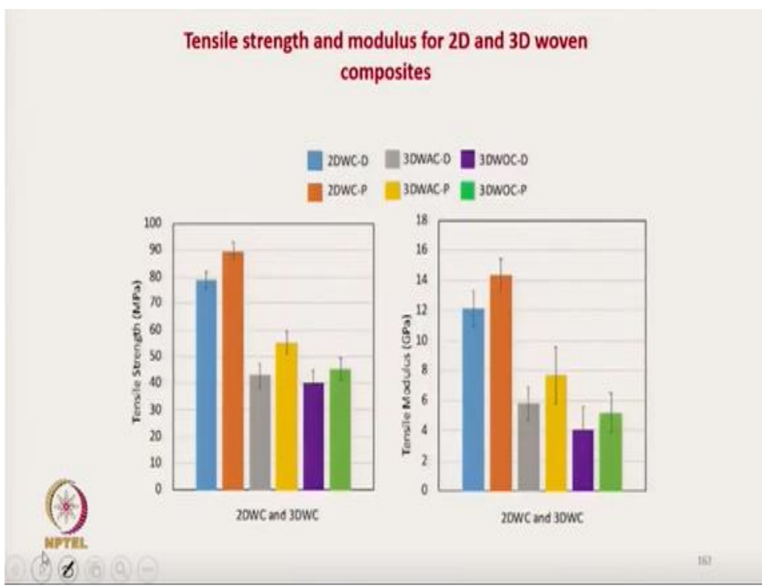

This picture shows that and but if we compare the DREF with the powder coating, always powder coating is higher than DREF for same for all the structures. This is mainly due to proper impregnation of powder or matrix within the reinforcing material, here it is a tensile modulus, the same trend is observed here.

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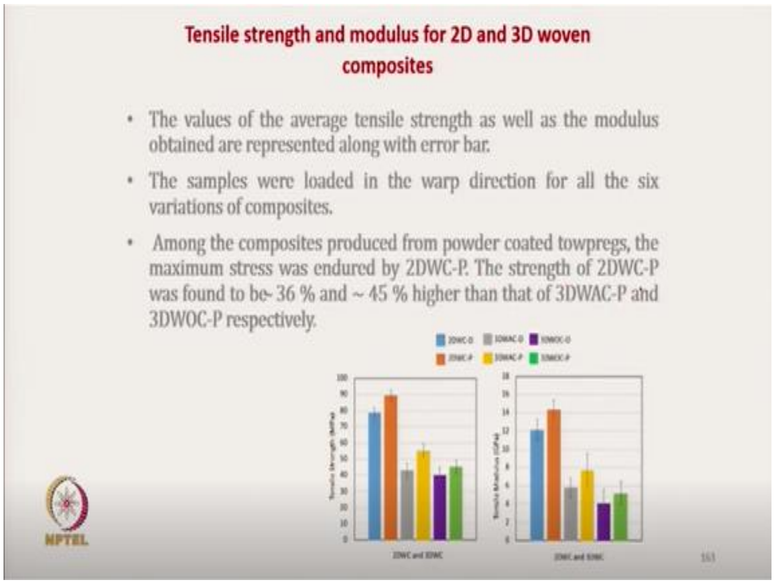

So the values of the average tensile strength as well as the modulus obtained are represented here. So this we have already seen here that 2D is higher, so the strength of the 2D composite was found to be 36% and 45% higher than angle interlock and orthogonal respectively.

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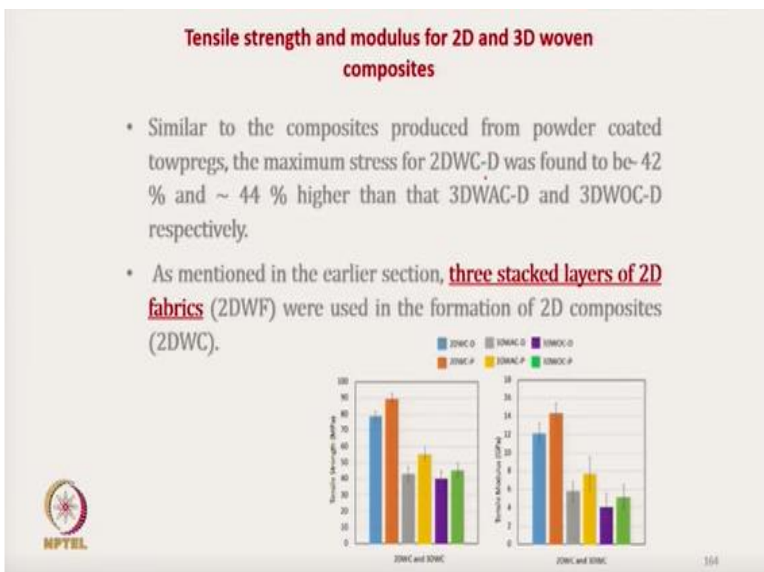

Similarly the composite produced from powder coated towpregs, the maximum stress of this, so for this is for a DREF spun and the powder coated the strengths are same.

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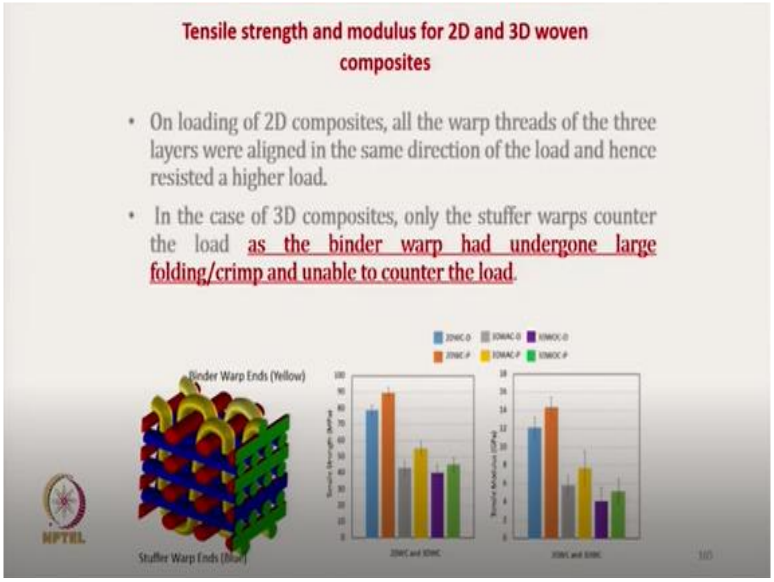

As I have already explained, on loading the 2D composites all warp threads, they share the load. But in case of 3D composites only the stuffer shares the load as the binder warp had undergone large folding or crimping during weaving. This is the large folding is there, so they do not share the load. That is why the 3D fabrics, so very low modulus and strength.

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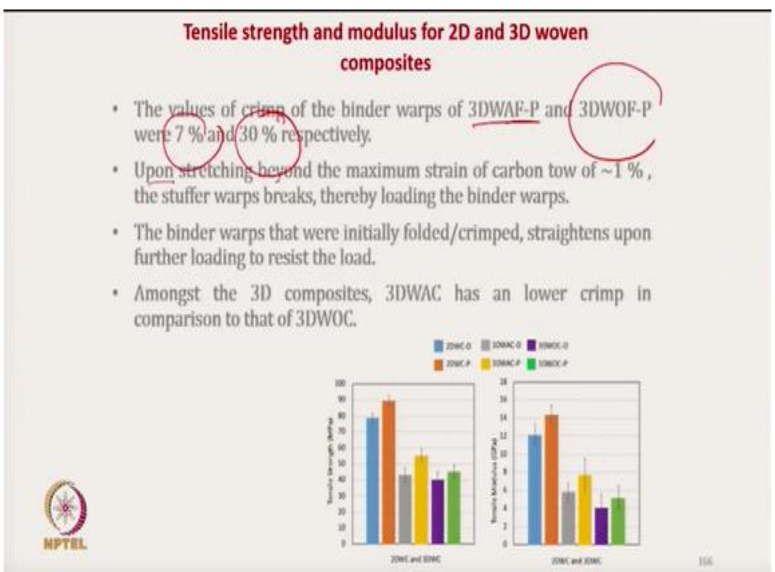

So value of crimp, so for angle interlock it is 7% and the binder thread and 30% for orthogonal that we have seen. But upon stretching beyond maximum strain of 1 % carbon breaks. So that is why the, in 3D composite the binder threads they do not take part in loading.

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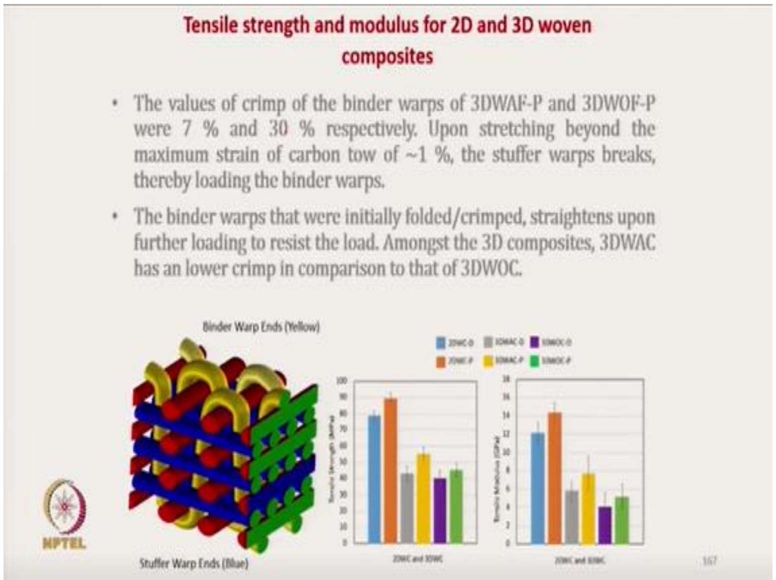

The values of crimp of binder warp threads as we have seen here 7 and 30 % respectively.

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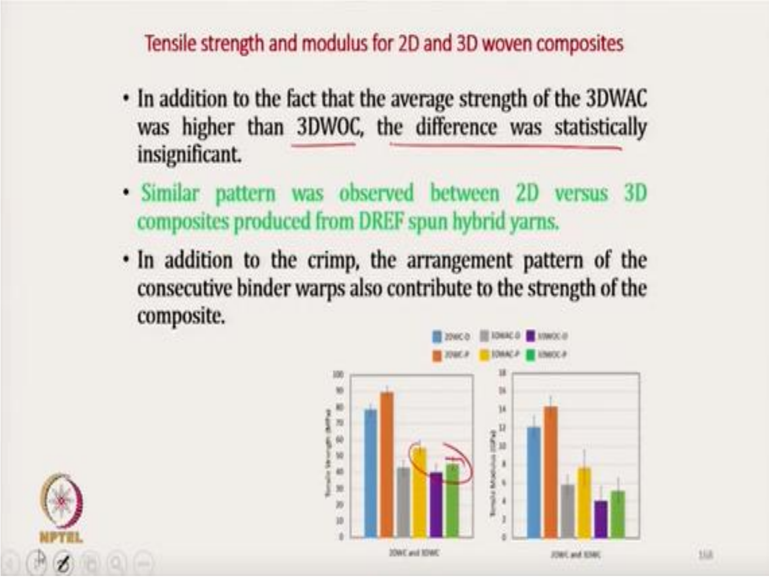

So in addition to the fact that average strength of 3D angle interlock composite was higher than 3D orthogonal, the difference was statistically insignificant. This are the, this difference was statistically significant, although it is little bit higher. So the same pattern was observed for DREF spun yarn hybrid yarn that composite made of DREF spun hybrid yarn. So this is the same pattern was there given and this is these are for powder coating and these are for DREF.

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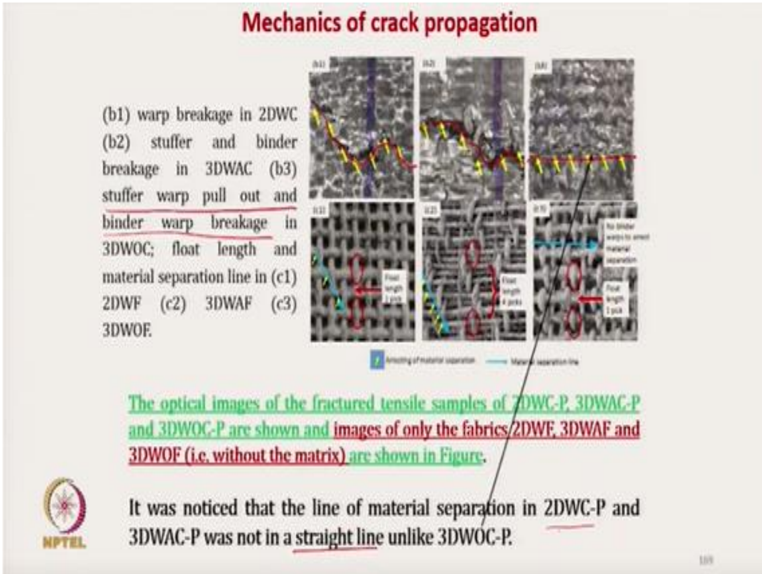

Now, let us see the mechanics of crack propagation. So in the, if we see the crack propagation, so after the tensile breakage, we have studied the crack propagation here in 2D crack propagation was not in straight line. Similarly here the crack propagation was not straight but this one is the orthogonal, b3 is the stuffer warp pull out. You can see there, it was noticed that the line of material separation in 2D composite and 3D angle interlock were not straight line, unlike this is a straight line.

This can be attributed to the fact that the, here this is the line of the optical image of fractured, here it is a fractured sign. Now the here material separation line it is straight, here material separation line is angled. So due to the structure of the base fabric the characteristics of crack is there it shows the similar characteristics, okay?

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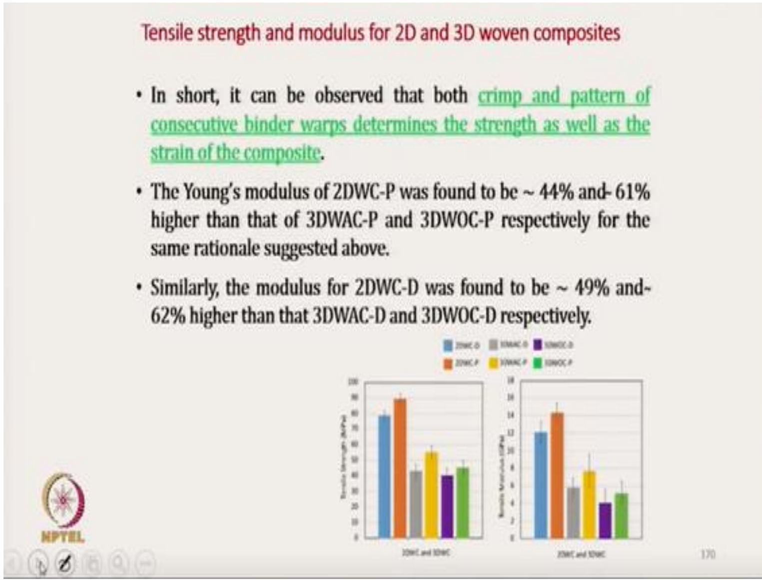

So what we can observe the crimp and pattern of consecutive binder warp determines the strength as well as the strain of the composite, okay? There is a binder.

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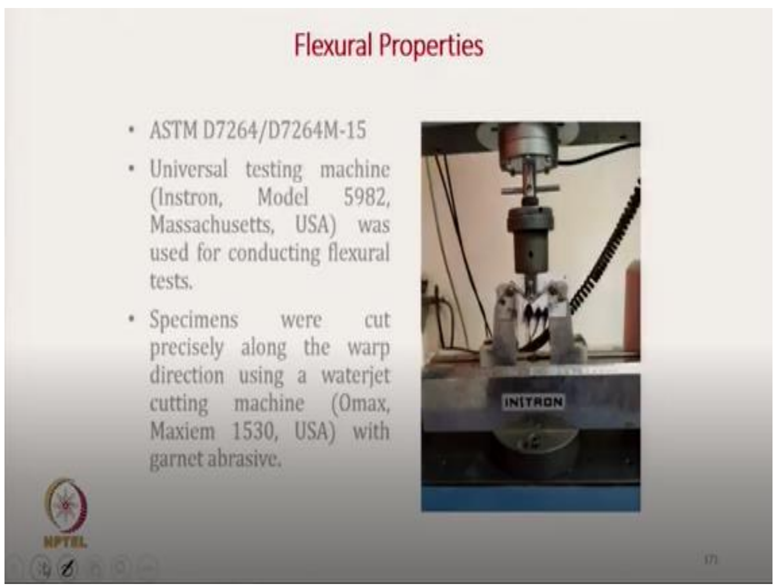

And in the last part we will discuss the flexural properties of these composites made from 2D and 3D fabrics.

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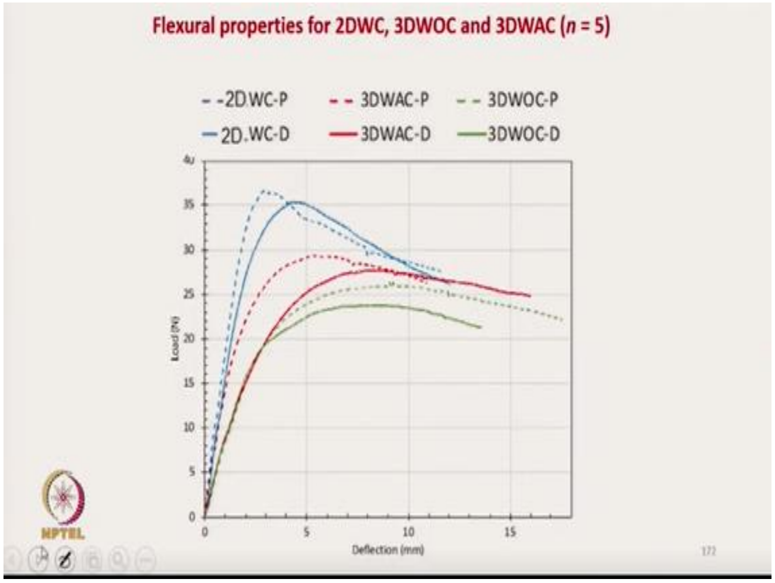

Now here in 2D we can see here again the bending rigidity of 2D is higher than the 3D fabrics. But the powder coated fabrics were higher little bit than the DREF, the reason we have already explained;

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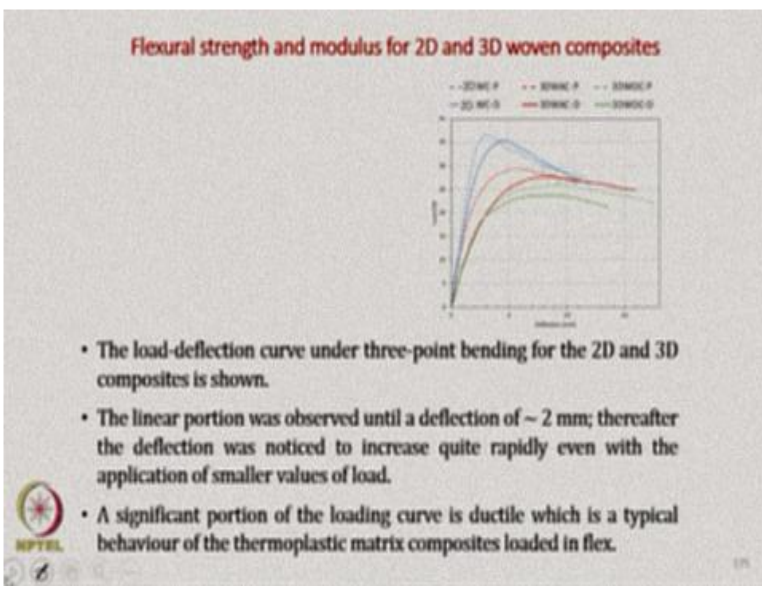

Flexural strength, it shows the similar trend to that of the tensile, the reason is almost same here.

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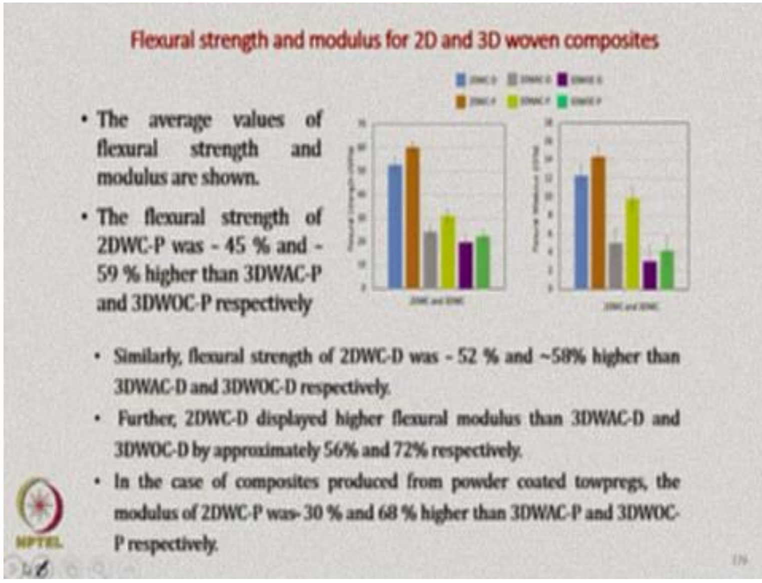

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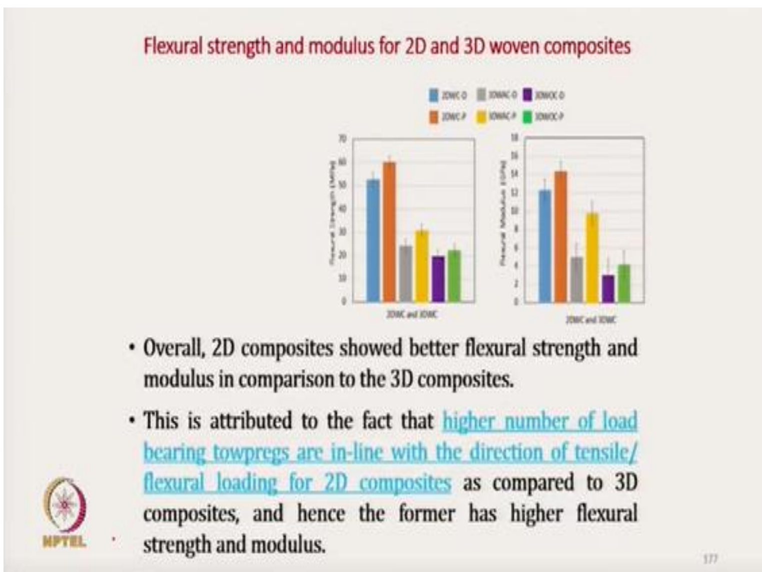

So overall, the 2D composite shows better flexural strength and modulus as compared to 3D fabrics. This is attributed to the fact that higher number of load bearing towpreg are in line with the direction of tensile and flexural, flexural loading for 2D composite. So that is the basic reason here for having higher flexural and tensile strength of 2D composite, although 2D composite here we have used the 3 layers of fabrics to make it equivalent.

But coming to the impact, notch impact test where we have used Izod notch impact testing, here the impact method we have already explained earlier. Now if we study the tomography, micro computed tomography;

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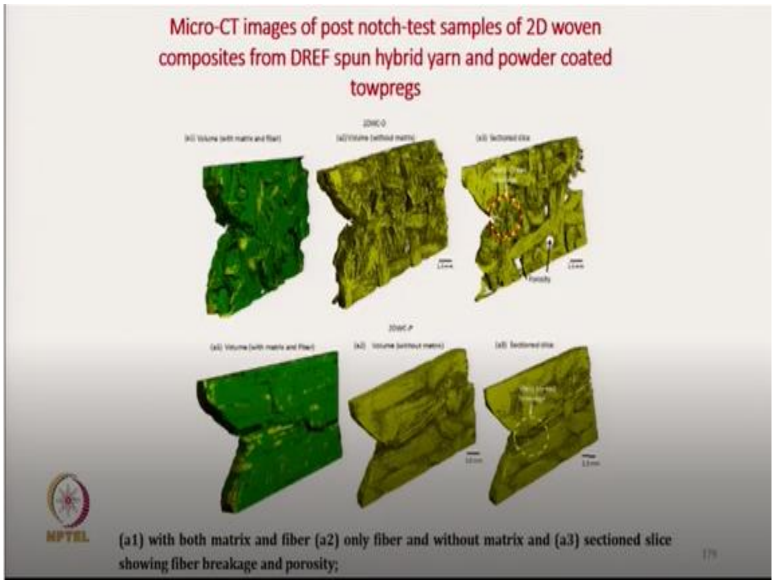

We can see here it is a 2DDREF and 2D powder coating and this one is with matrix and fiber, this is with matrix and fiber, here only the fiber without matrix and sectioned slice showing fiber breakage, here it shows the fiber breakage part.

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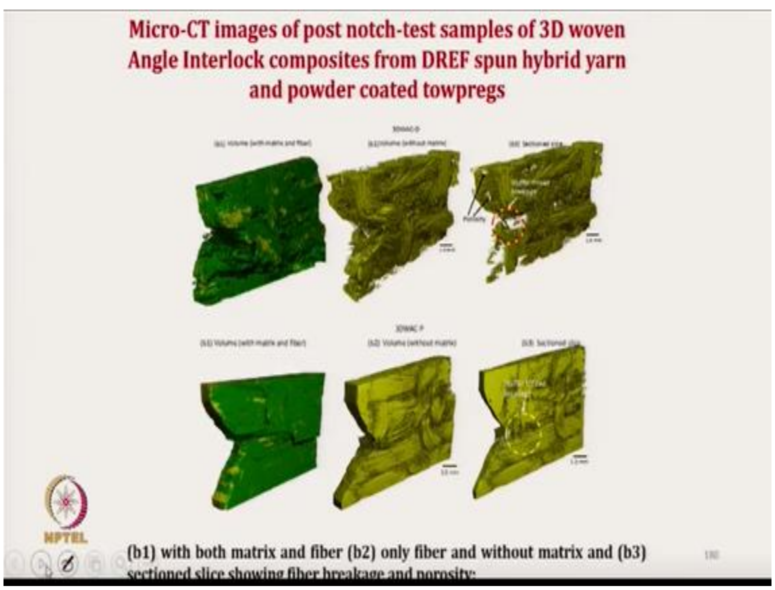

Towpreg, this is for 3D woven angle interlock earlier it was 2D, now 3D orthogonal.

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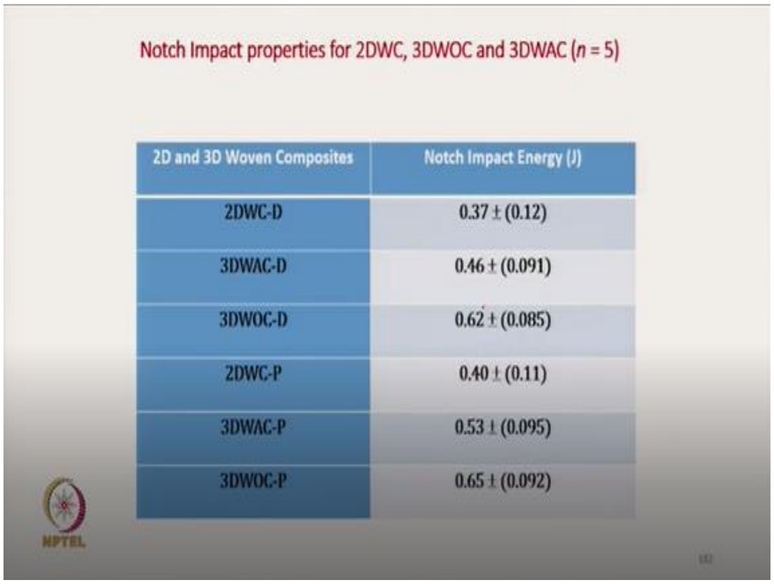

2D and 3D Woven Composites	Notch Impact Energy (J)
2DWC-D	0.37 ± (0.12)
3DWAC-D	0.46 ± (0.091)
3DWOC-D	0.62 ± (0.085)
2DWC-P	0.40 ± (0.11)
3DWAC-P	0.53 ± (0.095)
3DWOC-P	0.65 ± (0.092)

Here we can see here, now 2D and 3D impact strength. Now we can see the impact strength of 3D orthogonal is much higher than the 2D, although tensile and flexural strength was high in case of 2D woven composite but, in case of 3D orthogonal it is very high followed by the 3D angle interlock. Similar trend is there for powder coated composites.

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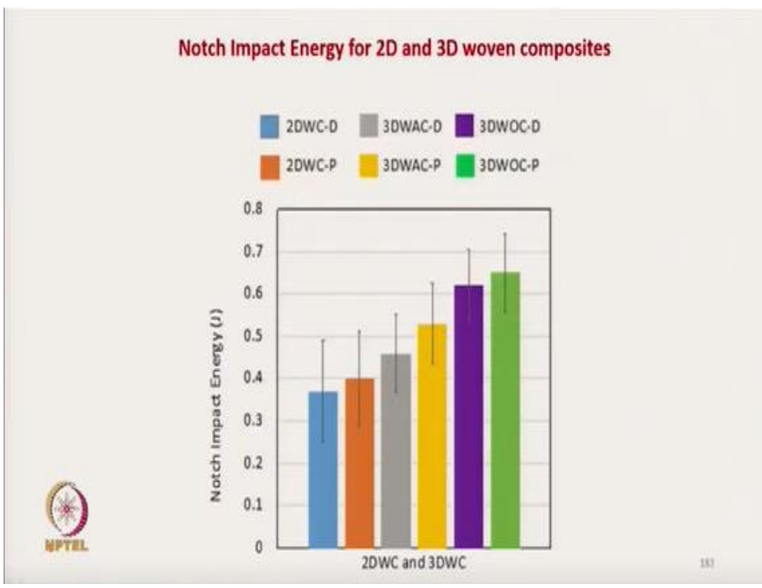

Now you can see here, so this is the powder coated 3D orthogonal composite, it is high.

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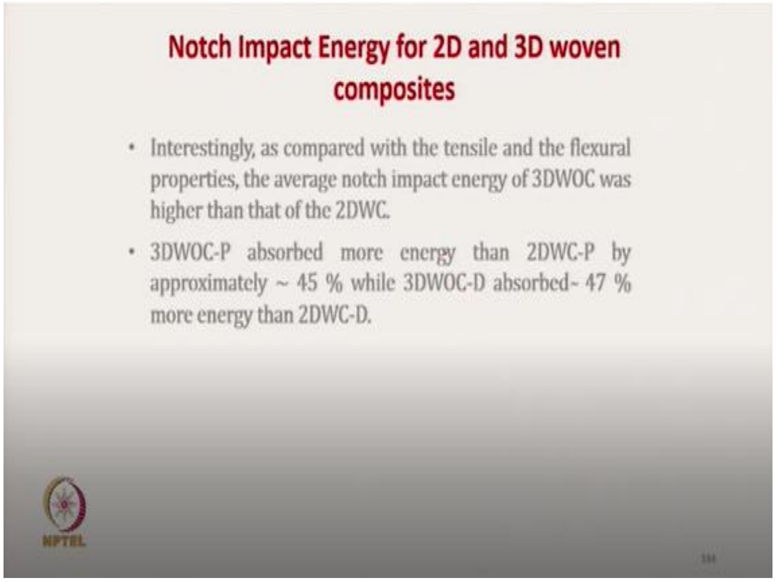

So 3D orthogonal composite absorbs more energy than 2D by approximately 45%, while 3D orthogonal made from DREF yarn, it is again approximately 47%.

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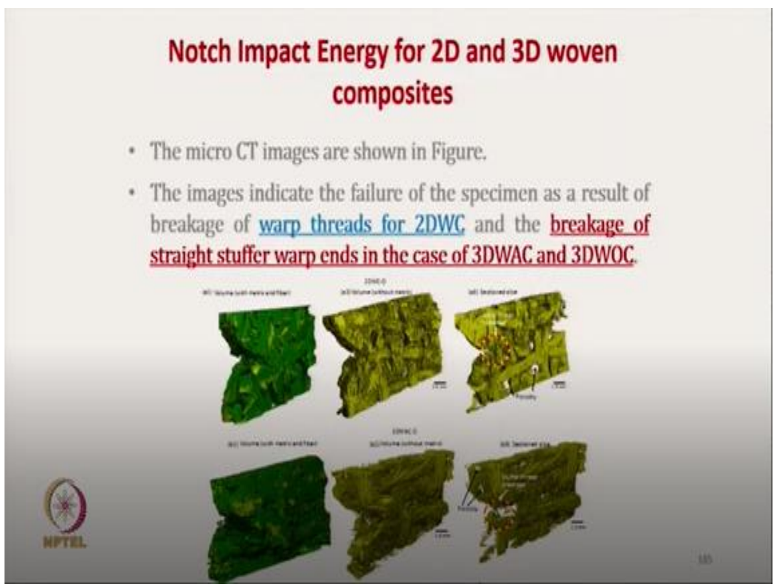

Shows that the image indicates the failure of the specimen as a result of breakage of warp threads in 2D fabric composite and the breakage of straight stuffer warp threads in 3D angle and orthogonal. Now here breakage is there only in the in 3D fabric, only in this stuffer warp threads. But the load is carried can be carried by the binder also.

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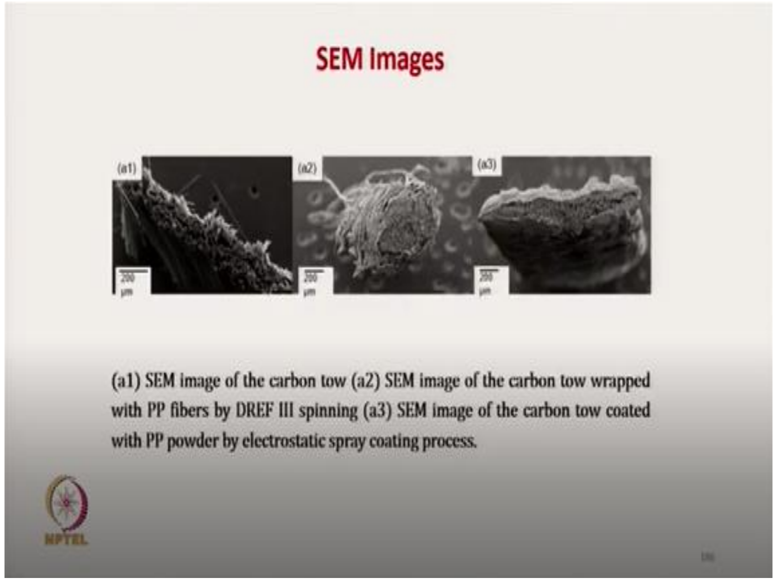

This is same image we have seen.

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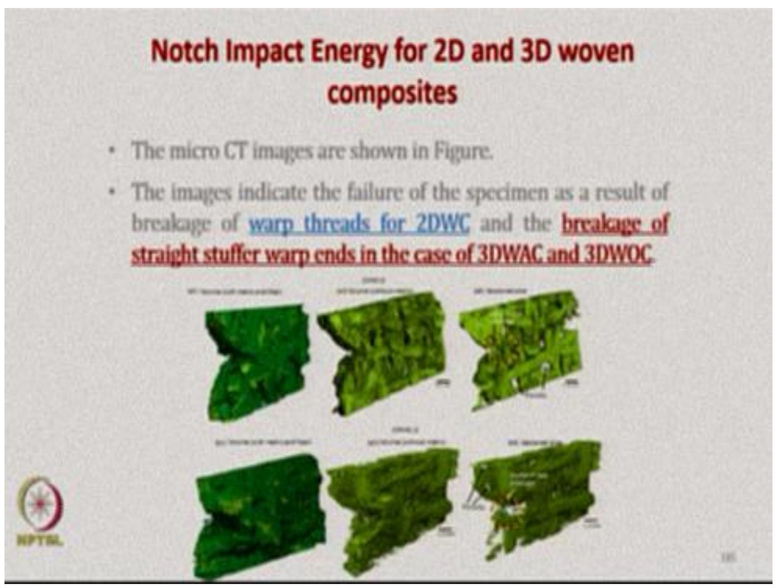

So that is why the energy, notch impact energies much higher in case of 3D woven composite.

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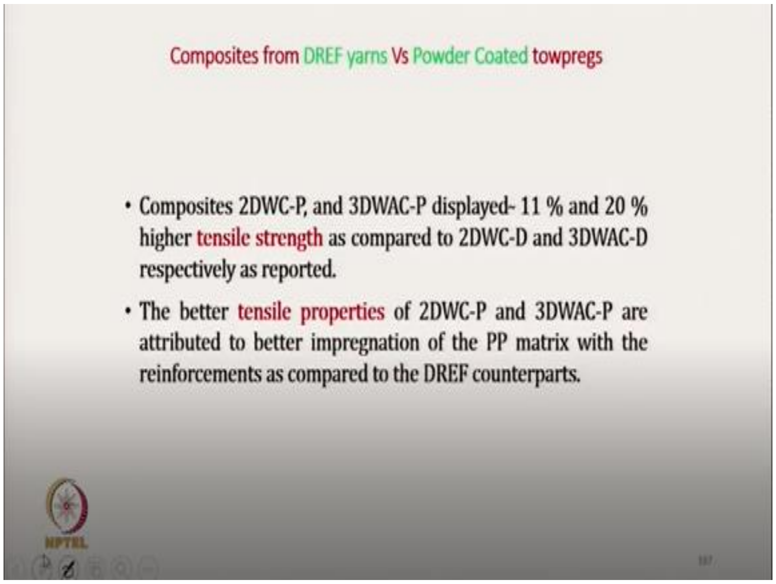

And if we compare with the DREF spun yarn, composite made from DREF spun and powder coated, so powder coated is little bit shows a little bit higher in tensile strength, typically 11 and 20% respectively as we have observed here and this is basically due to better impregnation as we have already explained here better impregnation in case of powder coating.

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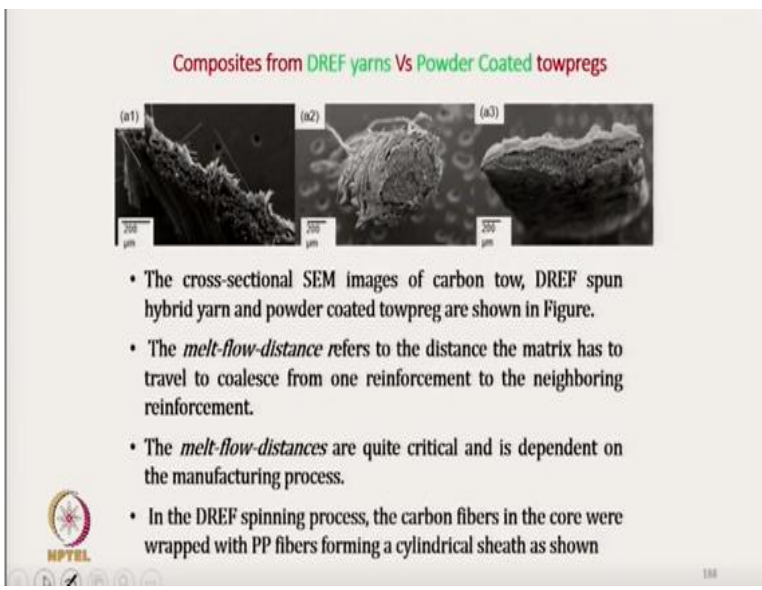

So the melt flow distance refers to the distance that matrix has to travel within the reinforcing material and melt flow distance is required is low in case of powder coated. So in DREF spinning process the carbon fibers are present in the core, so melt flow distance is required is very high.

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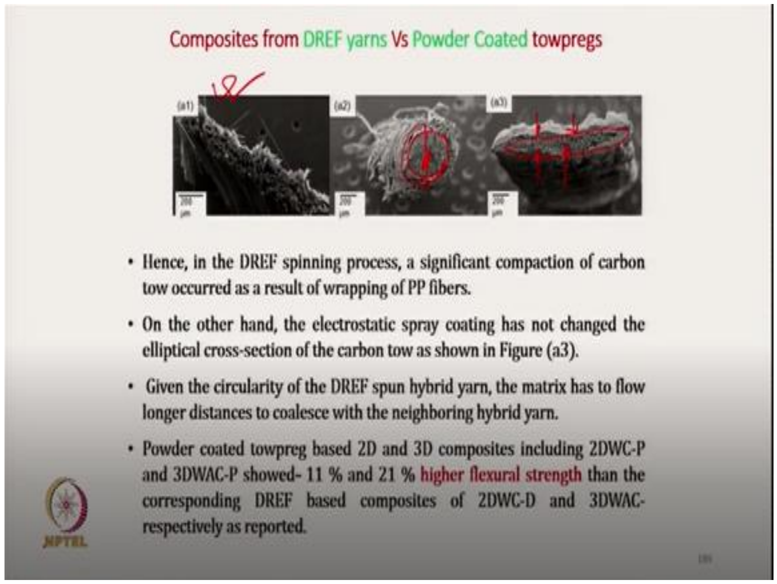

And that is why proper impregnation is not there. So on the other hand the electrostatics spray coating; it has not changed the elliptical cross section of the carbon. So here it has become circular and this is the carbon tow. If we see it is carbon tow without any matrix, but once we produce the yarn, DREF yarn, it has become circular, so this flow distance needed is higher but in case of powder coated tow it the shape remains almost same.

So flow distance required is much lower here. This has been explained here. So powder coated towpreg based 2D and 3D composite including 2D woven composite and 3D angle interlock composite is that shows that 11 and 21% higher flexural strength than corresponding DREF based composite here.

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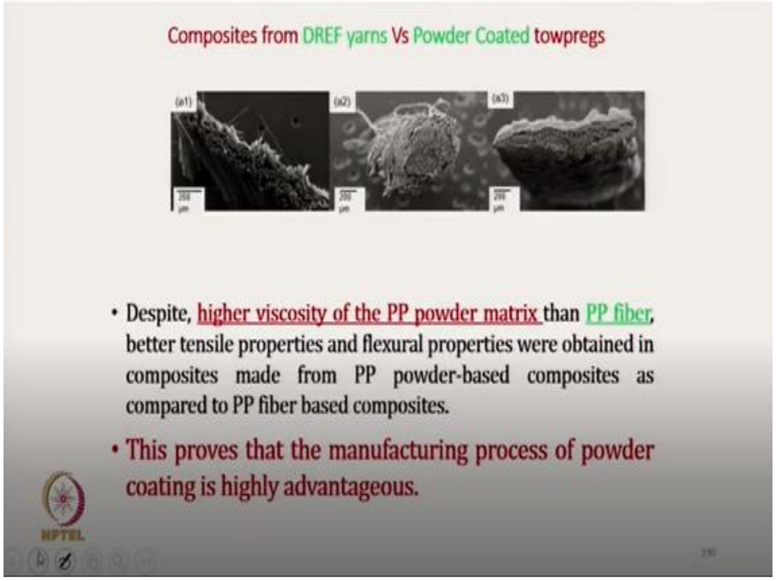

So despite higher viscosity of PP powder matrix than PP fiber, PP fiber matrix has got very low lower viscosity and PP powder we have seen that viscosity is very high, despite that fact better impregnation of powder coated takes place and this proves that manufacturing process of powder coating is highly advantageous.

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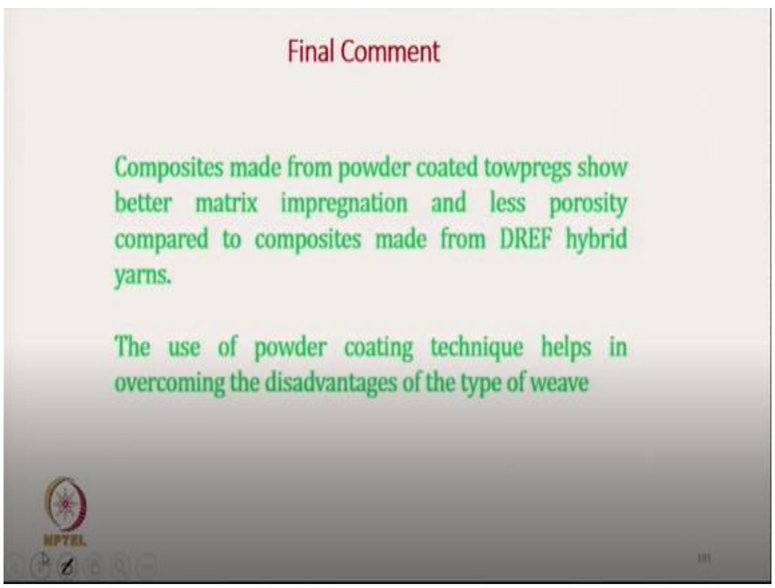

Now the final comment is that the composites made from powder coated towpregs, so better matrix impregnation and less porosity compared to composite made from DREF hybrid yarns. So hybrid yarn shows little bit higher porosity, void content was there. And the use of powder coating technique helps in overcoming the disadvantage of hybrid type yarn and from our basic study, we are very confident that the powder coating has got its bright future after eliminating few short comings like speed of production.

That volume of production or some factors we need commercial grade machine also. So we are very hopeful. Now I will finish the topic of composite here.

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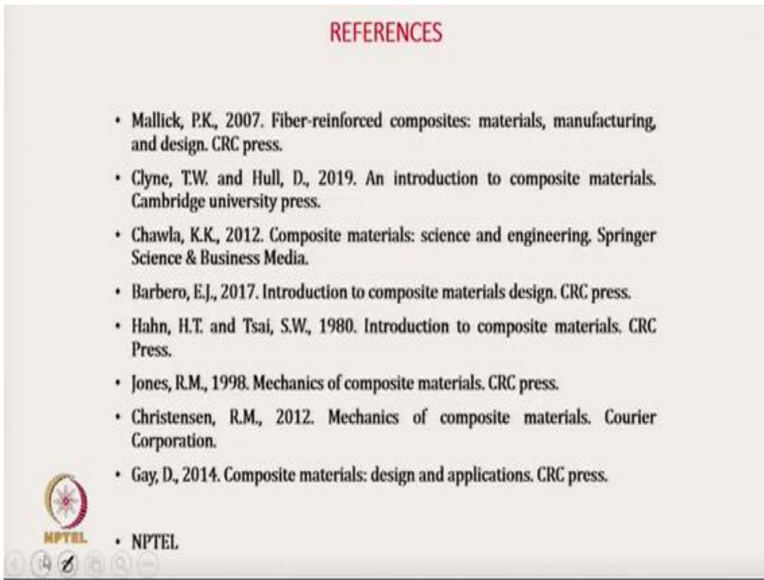

And these are the references we have used from different sources. So there are many other areas left but it is not possible to cover everything here. So we have here it has been tried to cover the, to get the broad overview of the area of technical textiles. I hope you have enjoyed this course, thank you.