Technical Textiles
Prof. Apurba Das
Department of Textile and Fibre Engineering
Indian Institute of Technology, Delhi

Lecture No- 39
Additional Lecture on Composites (contd…)

Hello everyone. So we will continue with the electrostatic spray coating. So today we will discuss the optimization process of the system which we have seen in last class the fabrication of that system. So here, what we will discuss today, the effect of different process parameters. So the different process parameters we can vary in that instrument and those factors affect the resin weight fraction.

So, how the take-up of the resin that we can vary the effect of different parameters that I will just discuss.

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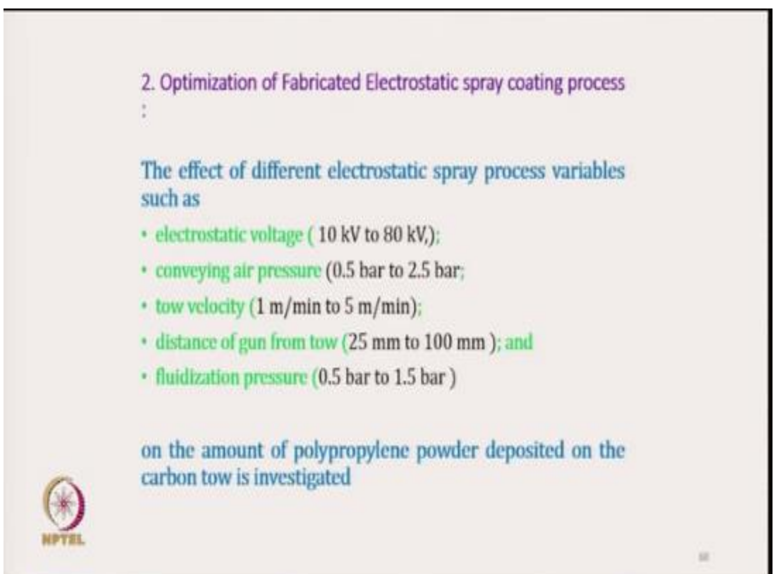

On the resin fraction we will see here the process parameters are the electrostatic voltage this we can vary. So here the electrostatic voltage is varied from 10 kilo volt to 80 kilo volt then, we can vary the conveying air pressure. So, in our study it has the range from point 5 bar to 2.5 bar, other variable is tow velocity. So with the change in tow velocity that is the take up speed, the resin content changes.

So here tow velocity was varied from 1 meter per minute to 5 meter per minute, distance of gun from the tow which is very important. So that affects again the volume fraction of the carbon fiber that is the matrix content we can vary, then fluidization pressure it affects the proper formation of cloud that also affect ultimately the resin content. So, all these factors affect the polypropylene powder deposition on the carbon tow.

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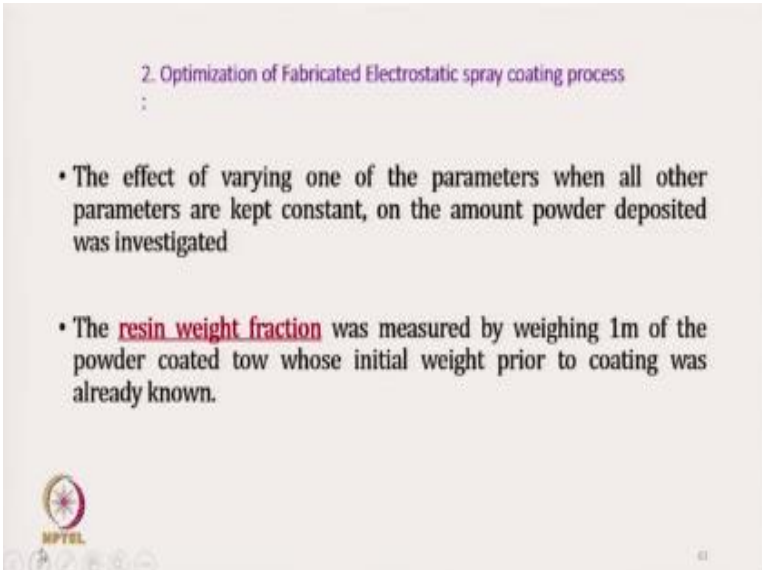

So here what we have done? Here we have changed one parameter at a time keeping all other parameters constant and to investigate the amount of powder deposited on the carbon tow. That is called resin weight fraction and this is done by measuring the weight of the carbon tow before deposition and after deposition, that will give us the indication of the resin weight fraction.

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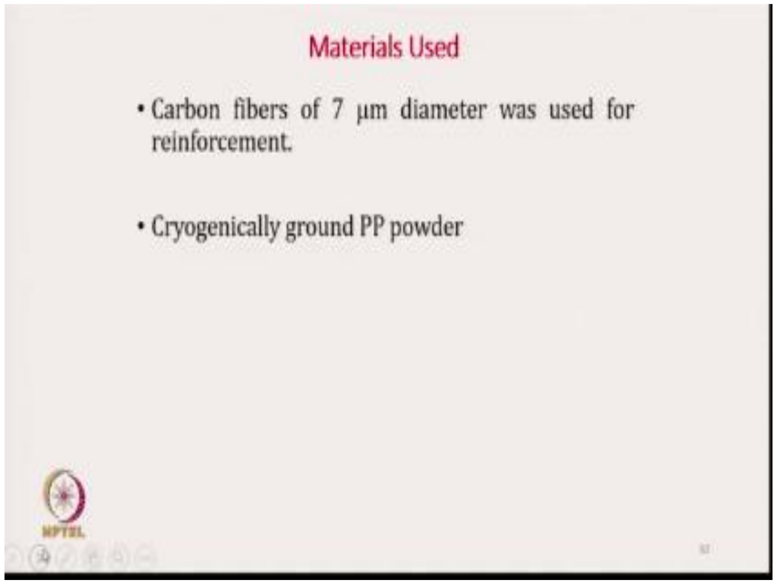

Carbon fiber as I mentioned, we have used the 7 micron diameter carbon fiber and cryogenically ground PP powder.

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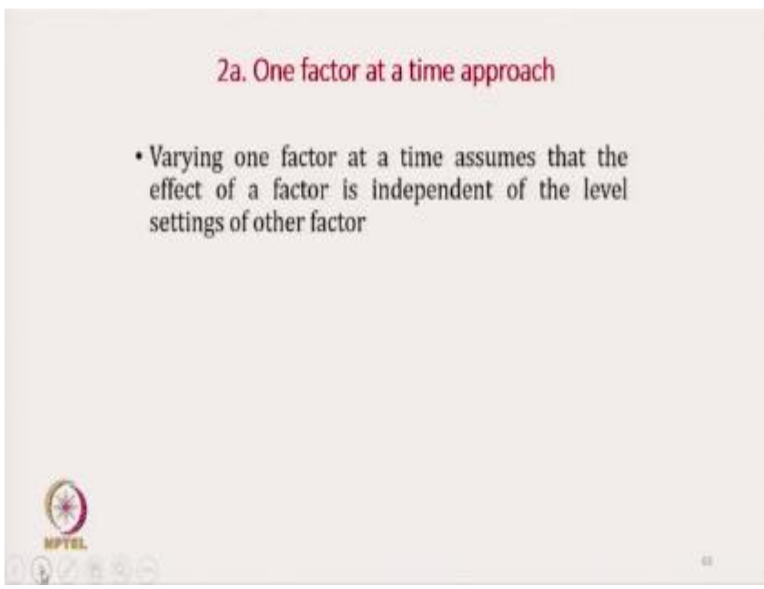

So here one parameter at a time we have varied.

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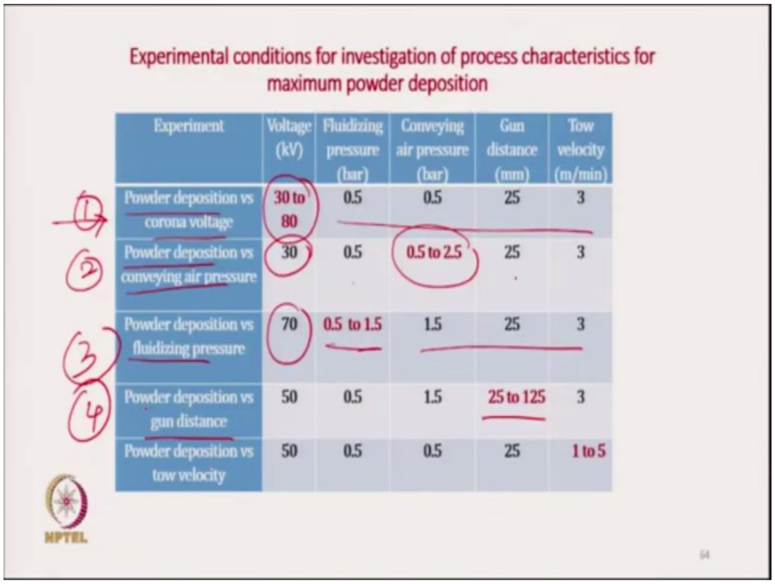
Experimental conditions for investigation of process characteristics for maximum powder deposition

Experiment	Voltage (kV)	Fluidizing pressure (bar)	Conveying air pressure (bar)	Gun distance (mm)	Tow velocity (m/min)
Powder deposition vs corona voltage	30 to 80	0.5	0.5	25	3
Powder deposition vs conveying air pressure	30	0.5	0.5 to 2.5	25	3
Powder deposition vs fluidizing pressure	70	0.5 to 1.5	1.5	25	3
Powder deposition vs gun distance	50	0.5	1.5	25 to 125	3
Powder deposition vs tow velocity	50	0.5	0.5	25	1 to 5

So, these are the different parameters we have used. So here in first experiment what we have done here powder deposition versus corona charge. So here corona charge varies from 30 to 80 kilo volt and rest other parameters like fluidizing pressure, conveying air pressure, gun distance and tow velocity were kept constant. Similarly in the second experiment what we have done powdered deposition versus conveying air pressure.

Conveying air pressure changes from 0.5 to 2.5 bar where the voltage corona voltage is kept at 30 kilo volt and other parameters were kept constant. In the third experiment what we have done, we have changed the fluidizing pressure from 0.5 to 1.5 bar with the voltage here we kept 70 kilo volt and also other parameters were kept constant. Similarly in the fourth experiment gun distance was changed from 25 to 125 millimeter that gun distance from the tow that distance was changed.

And in fifth experiment what we have done is tow velocity was changed from 1 meter per minute to 5 meter per minute keeping all other parameters same where voltage was kept at 50 kilo volt. This was the experimental setup.

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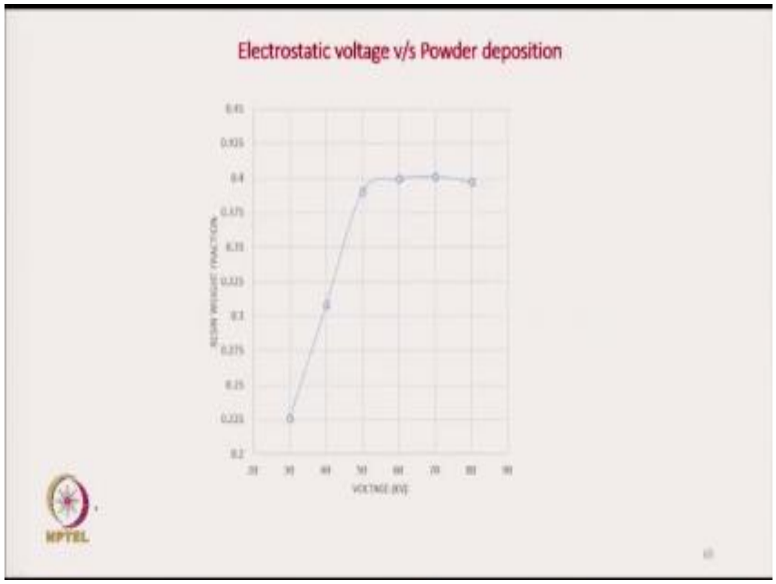

Now the first experiment was done, both voltage was changed the corona voltage was changed and what we have observed with the increase in voltage initially there is a very sharp increase in the resin weight fraction, from say point, 0.225 to 0.4 and after that so after reaching the 50 kilovolt, it is almost stabilized. So after 50 kilovolt, the resin fraction is stabilized, there is no further increase in the resin weight fraction.

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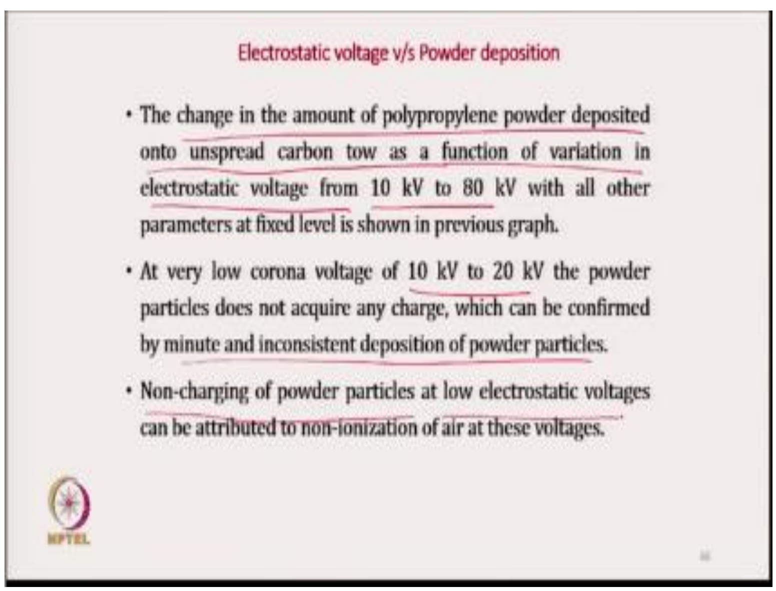

The reason behind this is that the change in the amount of polypropylene powder deposited onto unspread carbon tow as a function of variation in electrostatic voltage from 10 to 80 kilovolt was there when other parameters were kept constant. So at very low corona voltage from 10 to 20, the powder particle does not occurred any charge. So that there was no deposition, inconsistent deposition was there, there was no charge was there.

So non-charging of powder particles at low electrostatic voltage can be attributed to non-ionization of air at these voltages.

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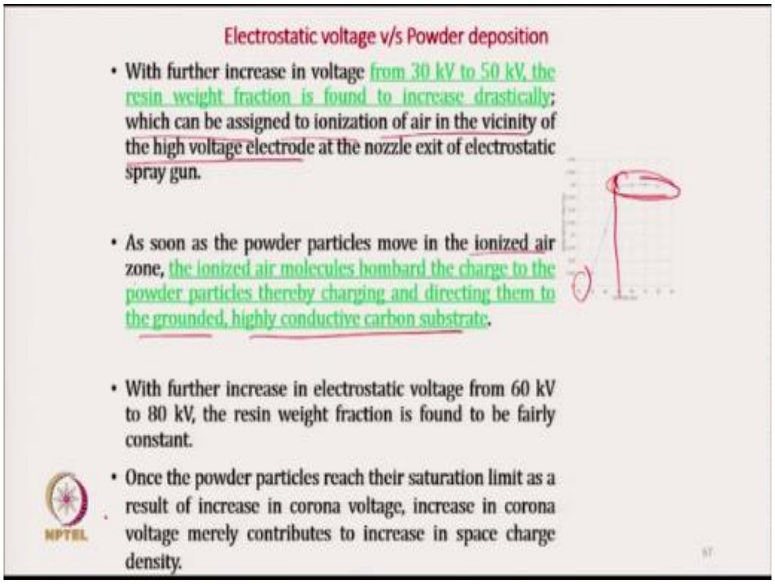

So that is why up to 20 there was no such deposition, with further increase of voltage from 30 to 50 kilo volt, the resin weight fraction is found to increase drastically. As I have mentioned which can be assigned to ionization of air in the vicinity of the high voltage electrode at the nozzle exit point and that helps in that attraction of the particles by the carbon tow. So as soon as the powder particles move in the ionized air zone.

The ionized air molecules bombard the charge to the powder particles, thereby charging them and directing them to the grounded, highly conductive carbon tow. So that will automatically deposit on the carbon tow but with further increase, because at that at 50 kilo volt it has already got saturated. So with further increase in electrostatic voltage from 60 kilo volt to 80 kilo volt, the resin weight fraction is found to be fairly consistent, there is no change.

Once the powder particle reach their saturation limit as a result of increase in corona voltage, the increase in corona voltage further does not help. So, we can say around 60, 50 between 50 to 60 is the optimum voltage which we can use here.

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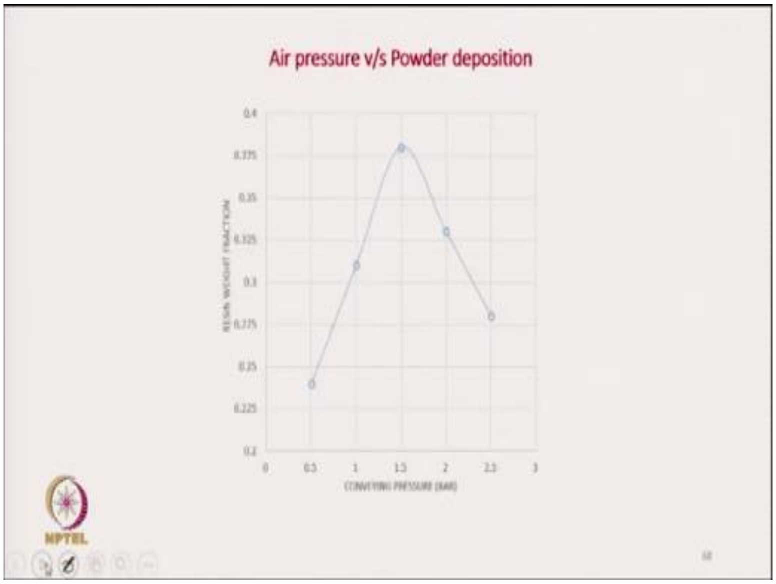

The next experiment is that effect of conveying air pressure on powder deposition. Here we can see as we increase the conveying air pressure from point 0.5 to 1.5, there is a sharp increase in the resin deposition, but once it is more than 1.5 bar, so there is a sudden drop in the powder deposition.

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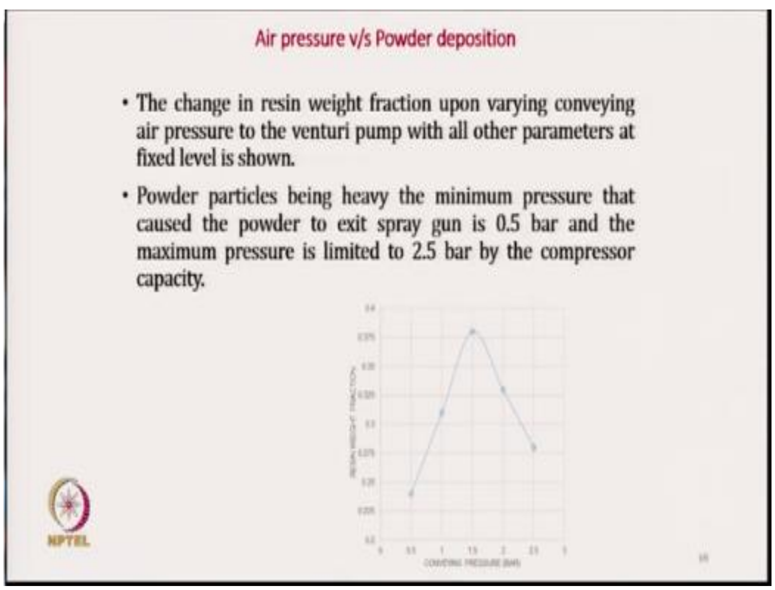

So this is attributed due to the fact that the change in resin weight fraction upon varying air pressure it is basically due to the fact that as we increase the pressure;

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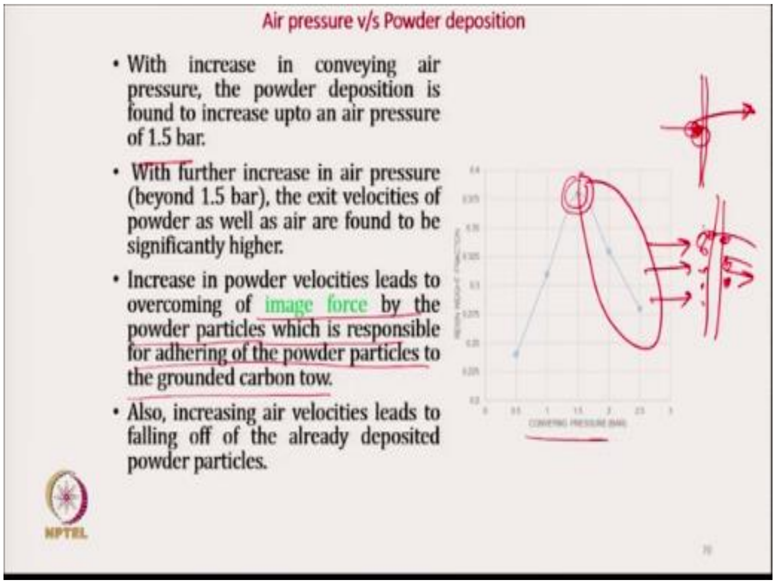

The powder deposition is found to increase up to the 1.5 bar and beyond that significant decrease. The increase in powder velocity leads to overcome the image force by the powder particle, which is responsible for adhering the powder particle to the grounded carbon tow. So initially the powder, the conveying force was required here, so that forces, along with the voltage the powder require some velocity, some speed.

So with that speed the powder with that pressure the powder moves towards the carbon tow but if we increase further beyond 1.5 bar then it will try to overcome the image force by the powder particle. So that here powder comes at very high speed high pressure, then adhering force overcome the adhering force and powder will move beyond that, will be separated, so in addition to that further increase in air velocity leads to falling off of the already deposited powder particles.

So if we increase the air pressure here, so already formed particles were there and then air pressure if we increase, conveying air pressure then already formed particle, and deposit particle will get separated. So this will effectively leads to decrease in the resin weight fraction. So initially, we need some air pressure to help in deposition, but if it is beyond certain level, here level is 1.5 bar, in that case what will happen? It will overcome the image force which helps in attraction, plus the already deposited particles will get separated.

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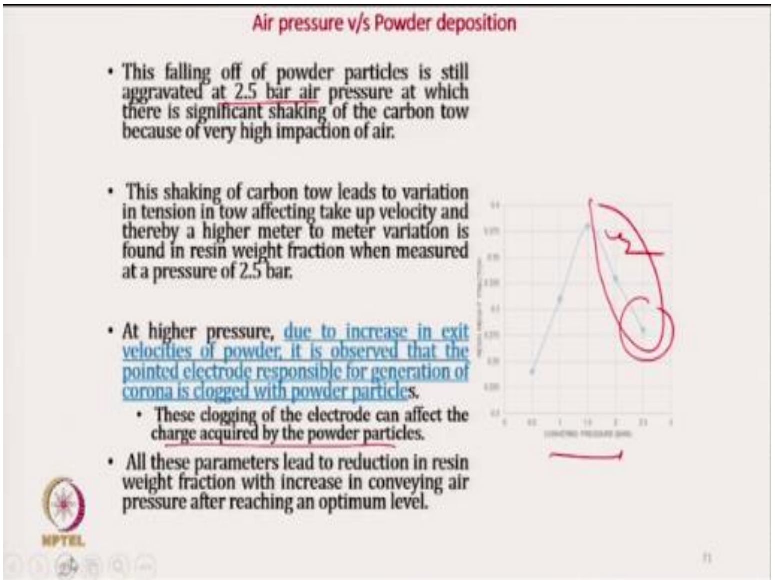

So the falling off is at the further continues with the above 2.5 bar. So there will be shaking action beyond 2.5 bar pressure, so there will be very less resin deposition, okay. So at higher pressure due to increase in exit velocity of powder, it is observed that the pointed electrode responsible for generation of corona it is clogged with the powder particle so at higher pressure it gets clogged. This clogging of electrode can affect the charge acquisition by the powder particle.

So this also affects the charging, if it clogs then charging will not be proper. So all this parameters, this is responsible for reduction in resin deposition beyond certain level of conveying pressure.

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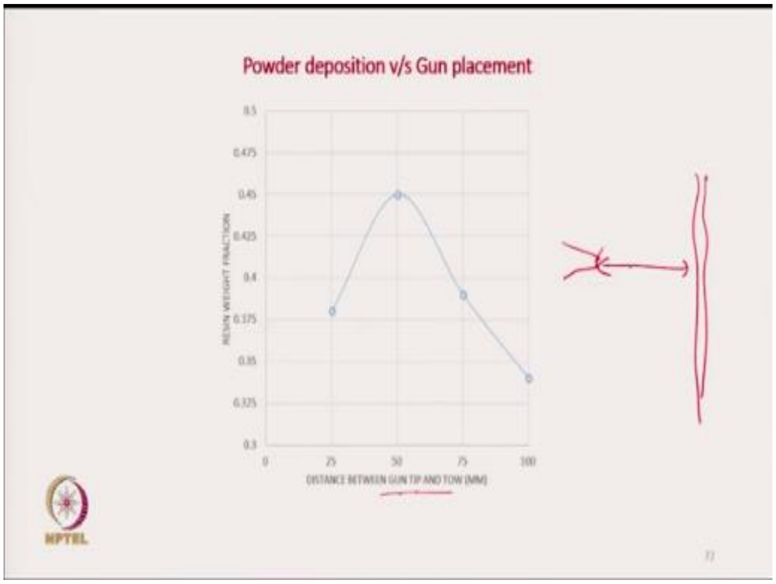

Our next experiment was the effect of distance between gun point gun tip and tow with the powder deposition. So this is the tow and here it is a gun tip. So this distance we have changed.

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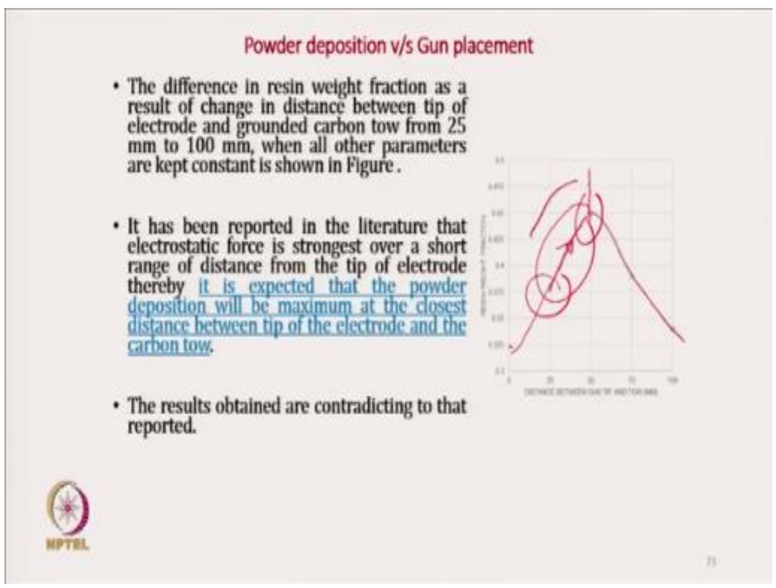

What we have observed initially it increases if we reduce the distance, the deposition is reduced and with the increase in distance, deposition increases up to say 50 millimeter and beyond that if we further increase the distance the resin deposition drops drastically. So from 25 to 100 we have observed here. So it has been reported in the literature that the electrostatic force is strongest at the short distance.

So it is strongest at lower distance. So it was expected that the powder deposition will be maximum at closest point say 25 millimeter, at that point it was expected that the charging as the charging is maximum. So powder deposition should have been maximum but we have observed at lower if we reduce the distance from 50 mm, so gradually the deposition reduces and that is why we have got a contradictory result, the optimum value what we have got is 50 mm.

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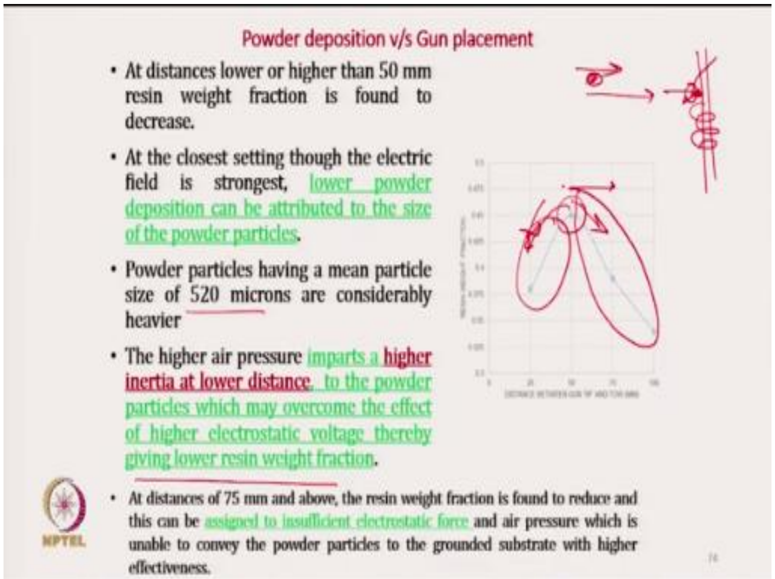

So as the distance is lowered from 50 mm the weight fraction is found to decrease at the closest setting though the electric field is maximum, it is strongest, lower powder deposition can be attributed to the size of the particle. So at that such lower distance, the size of particle is little bit larger, so it has got very high inertia at that inertia if it strikes the tow, it will immediately bounce back or it will not be sticking to the surface.

It will reflect because at lower distance the inertia is very high, so powder particles 520 micron. So at high air pressure which imparts at higher inertia at lower distance as I have mentioned, so this may overcome the effect of high electric voltage. So that is why it gives lower weight fraction in this zone if we reduce this but beyond certain distance like 50 mm if we increase the distance then the charging effect dominates, so lower charging will be dominating and which will ultimately affect the resin deposition.

So here in this zone, the reduction is due to the electric charge and in the left zone reduction is due to the inertia.

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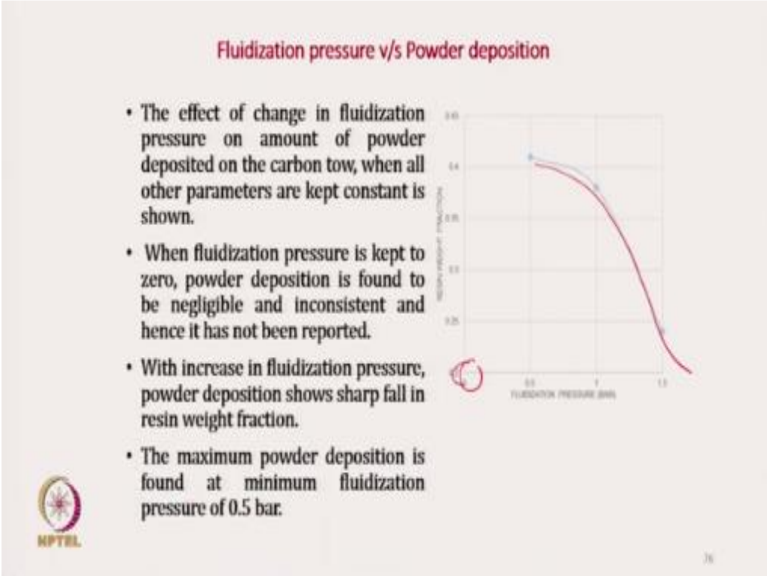

Next is the fluidizing pressure, we have changed here fluidizing pressure from 0.5 bar to 1.5 bar and the diagram shows that it consistently reducing initially at the lower rate and after that it is at high rate, the resin fraction it reduces consistently. So other parameters were kept constant, when the fluidizing pressure is kept zero, so there is no powder generation. So powder deposition is found to be negligible so that is why you have not taken that part.

With increase in fluidizing pressure powder deposition shows sharp fall in the weight fraction, the maximum powder deposition is at 0.5 bar.

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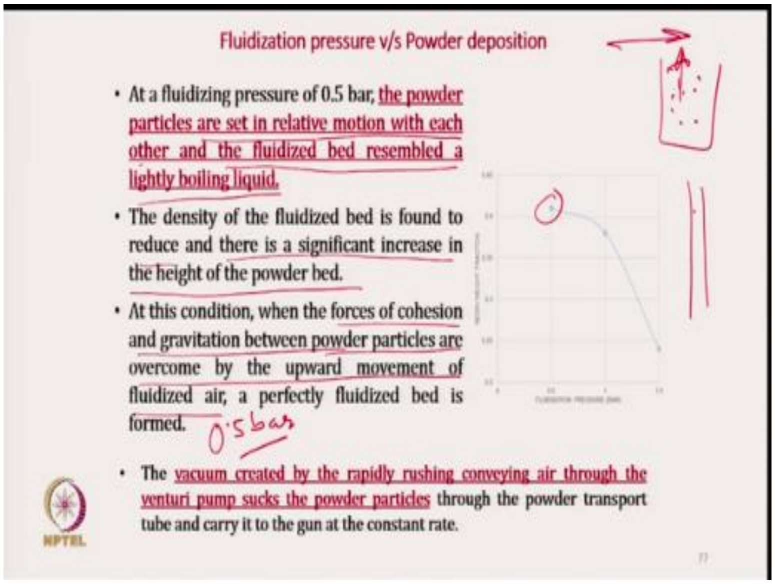

At a fluidizing pressure of 0.5 bar, the powder particles are set in the relative motion with each other which helps in conveying of powder and up to the tow, they set in relative motion with each other and the fluidized bed resembles lightly boiling liquid. The density of fluidized bed is found to reduce; there is a significant increase in height of powder bed. So, that powder bed height will increase that will affect the deposition.

So that at this condition when the force of cohesion and gravitation between the powder particles are overcome by the upward movement of fluidizing air, so at 0.5 bar pressure this things happen. So this vacuum created by the flowing air which helps in sucking the powder particles.

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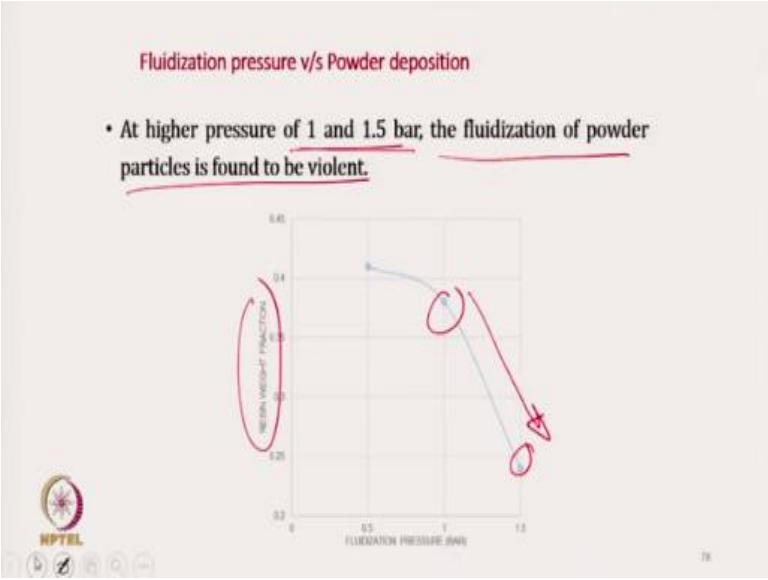

At high pressure, so 1 and 1.5 bar, the fluidization of powder particles found to be violent. So that violent nature is not required and due to this violent nature the powder behaves erratically, the clogging may take place which results in reduction in the resin weight fraction. So for proper deposition we need proper cloud function, it is not that the particle should move violently there should be smooth, light movement should be there.

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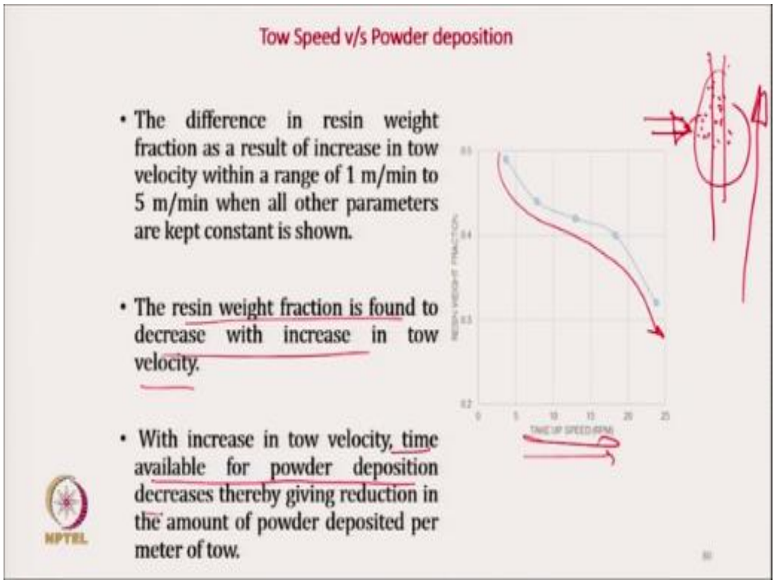

Next experiment was the effect of tow speed on powder deposition. The difference in resin weight fraction we can see with the increase in take up speed it consistently reduces which is basically can be explained by the residence time. If we increase the residence time, then residence time in the chamber, this is the jet gun, powder, if the residence time is more that means more and more powder, will get deposited.

If the residence time is less, the less time will be available so powder deposition will be less. So it is very simple, so if we increase the speed residence time is less so less powder will get deposited. So it is a resin weight fraction is found to decrease with the increase in velocity. The time available for powder deposition decreases so that is why the weight fraction reduces.

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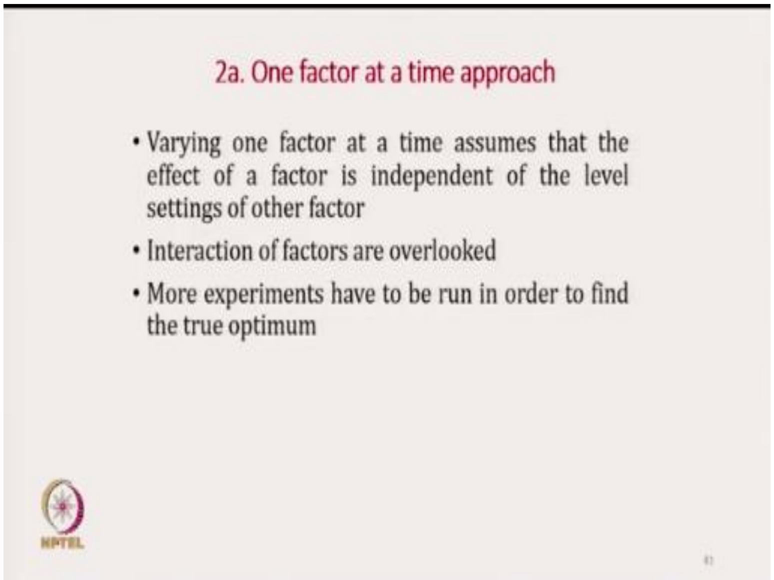

So in one factor at a time approach, so here what we have done, we have changed one parameter and kept other parameters constant.

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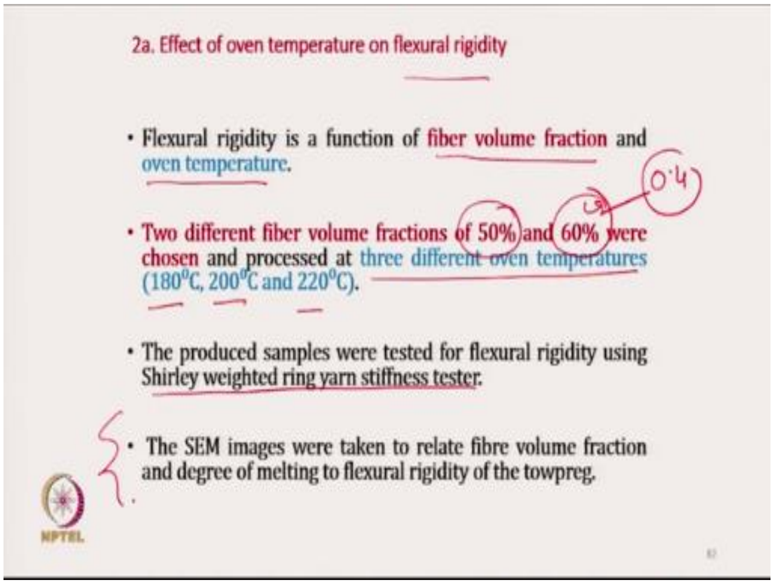

So in this approach we have done other experiments also so we have changed the oven temperature and we have studied the flexural rigidity of the towpreg, so flexural rigidity is a function of fiber volume fraction and oven temperature. So these two parameters we have changed one at a time. So two different fiber volume fractions were taken, 50% and 60%, 60% fiber volume fraction means 40% is the resin weight fraction.

So 0.4 is the resin weight fraction here and three different oven temperatures were taken 180 degree celsius, 200 and 220 degree celsius and we have tested the flexural rigidity by Shirley weighted ring yarn stiffness tester and scanning electron microscope images were taken.

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This is the picture of the Shirley stiffness tester.

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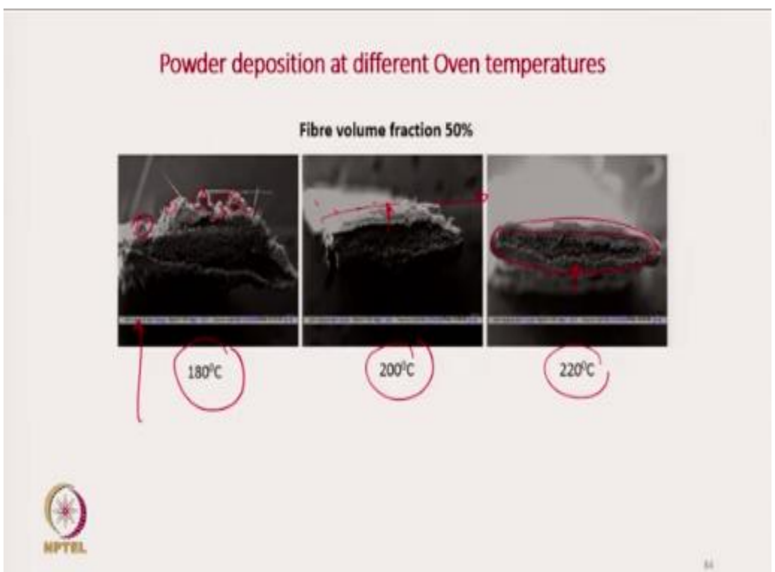

And scanning electron microscope image of the towpreg is there. It is 180 degree Celsius we can see here the powders are not melted properly and it is not deposited evenly but here at 200 degree Celsius this is melted and at further if we can see it is melted and the thickness here at the

220 degree Celsius, thickness of the coating is less than 200 degree Celsius, which means that it has melted and penetrated inside the carbon fibre, carbon filament.

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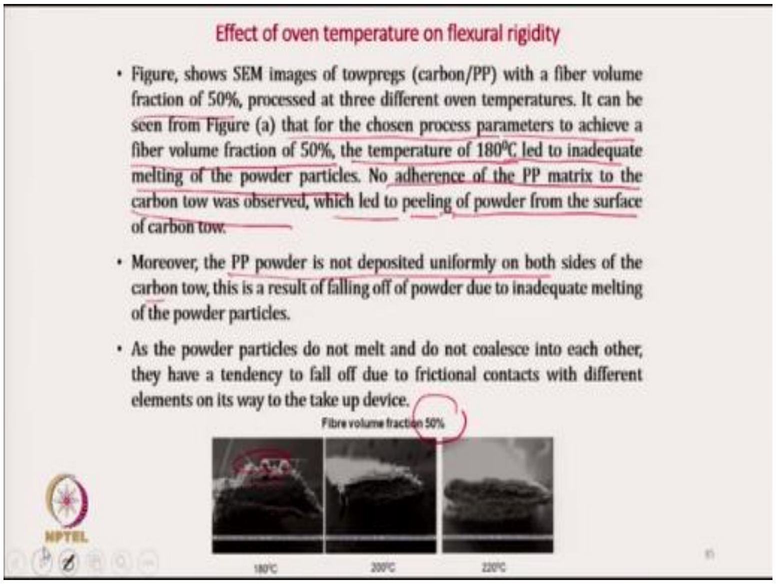

So effect of oven temperature on flexural rigidity if we see so as we have mentioned here, the scanning electron microscope picture with the fiber volume fraction 50% here, it can be seen here that for the chosen process parameters to achieve the fiber volume fraction of 50%, the temperature of 180 degrees led to inadequate melting of the particle, so inadequate melting of the particle.

No adherence of PP matrix to the carbon tow was observed which led to peeling of powder from the surface, it gets peeled off. We can see it is very clearly the powder gets peeled off and also the PP powder is not deposited uniformly on both sides. So here and both sides of the carbon tow, it is not uniform because of the improper melting of the polypropylene.

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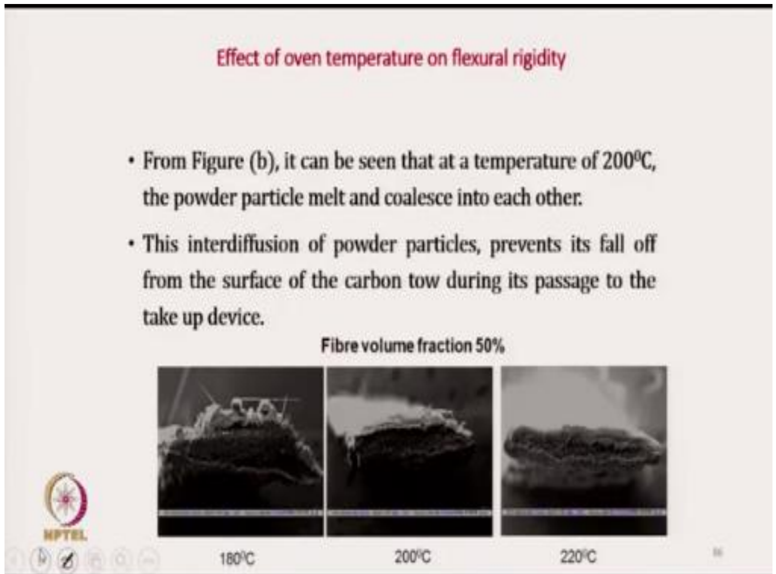

And in figure b this is the figure b which is at temperature 200 degree Celsius powder particle is melted properly and inter diffusion of powder particles were there which prevents its fall off. Inter diffusion is there and at 220 degree Celsius the degree of melting is very high and the reduced reduction in thickness as I have already mentioned.

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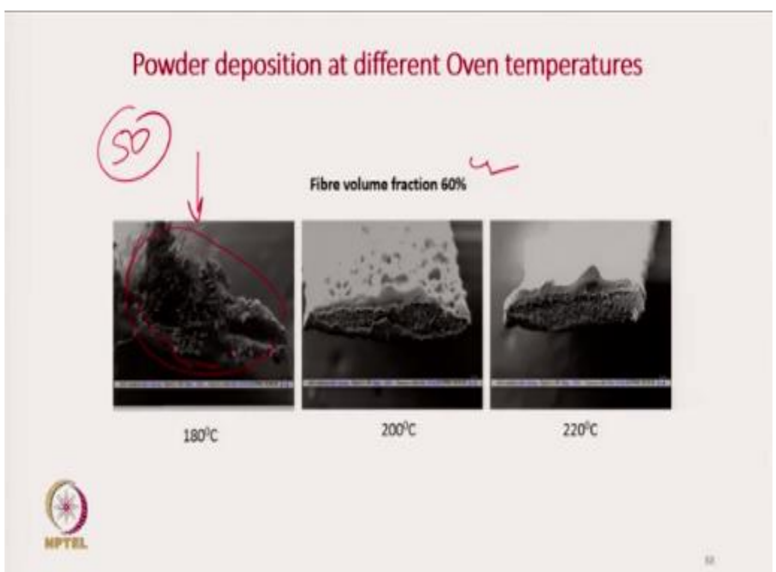

So we can see here the powder deposition. It is improper powder deposition is there, it is peeled off at 60% volume fraction and at 60% volume fraction, so fiber volume is more. It is severe and at 180 degree Celsius, the effect is much more severe than 50%, at 50%, the fraying of the carbon filaments were not there, but at 60% volume fraction, that means the polypropylene coating was 40%. So at lower volume fraction of the polypropylene it was much more severe.

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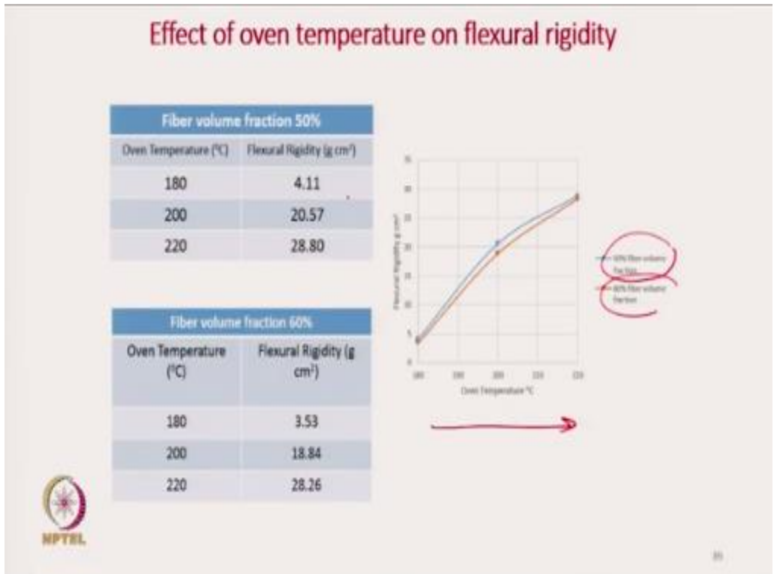

So if we see the effect of oven temperature on flexural rigidity flexural rigidity increases with the increase in oven temperature and this is true for both 50% fiber volume fraction and 60% volume fraction. So there is a consistent increase in flexural rigidity and both 50% and 60% we have observed.

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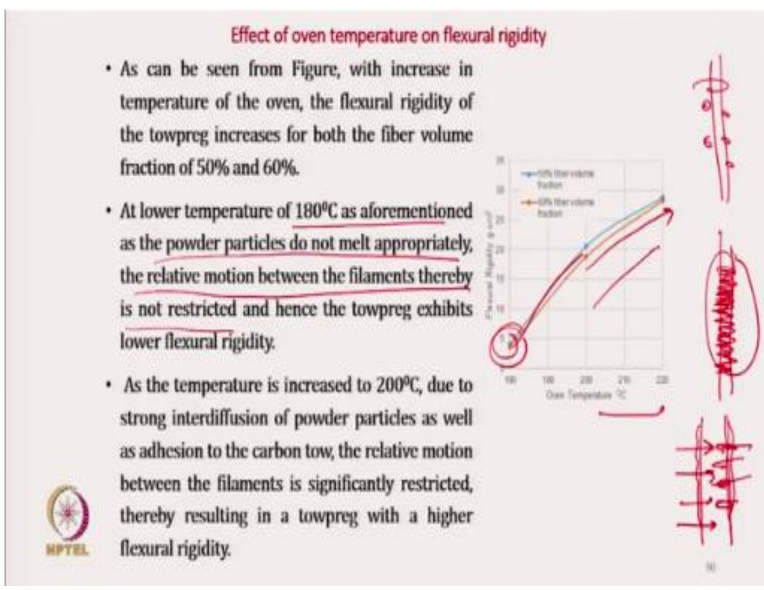

So there is increase, at lower temperature 180 degrees Celsius the powder particles do not melt appropriately. So what happens if it does not melt then there will be relative motion between the filaments. So there is no coating, proper coating, there is fiber, these are the particles. So there will be relative motion between the filaments thereby it is not restricted, the movement is not restricted, so tow exhibits lower flexural rigidity.

But at higher temperature what happens, these particles get melted covered as we have seen in the scanning electron microscope photograph and due to this the bending rigidity, flexural rigidity increases. It further increases as the temperature goes up to 220 degree Celsius because at that stage in addition to the surface melting presence the polypropylene matrix penetrates inside the carbon tow. So that helps in enhancing the flexural rigidity.

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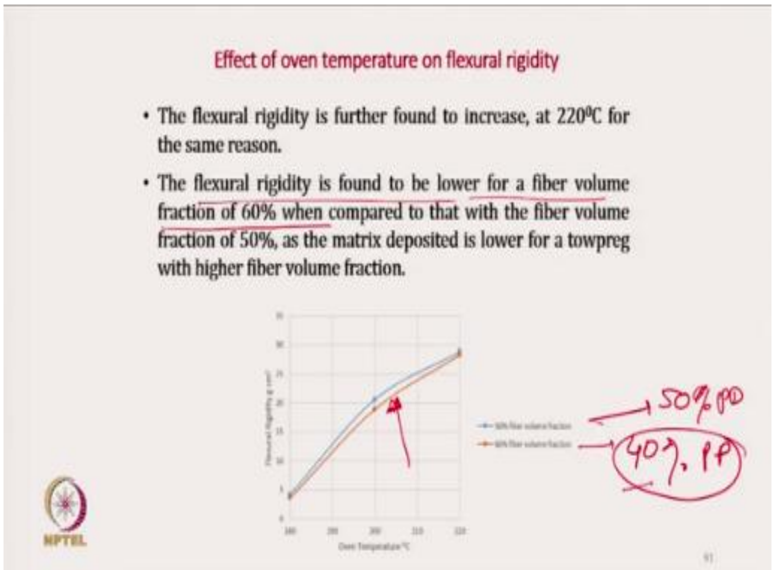

The flexural rigidity is found to be lower in case of 60% volume fraction. So 60% volume fraction, this is the 60%, it is lower. Here the polypropylene, which is responsible for enhancing the flexural rigidity, the content of polypropylene is lower. So 60% fiber volume means 40% is PP, here 50% PP, so due to lower quantity of polypropylene, so that here the flexural rigidity of 60% volume fraction is lower than the 50% volume fraction.

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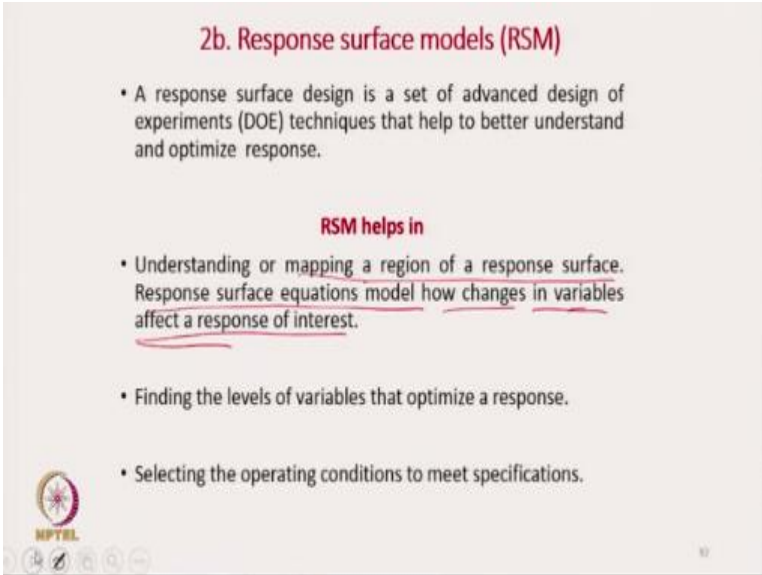

After that, we have done the response surface model. So three variables at a time we have used, so it helps in understanding or mapping a region of response surface and which ultimately helps in optimizing the parameters. Response surface equation model, how changes in variables affect a response of interest. So that is a response surface model. So we have taken three variable response.

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We have used Box and Behnken model, most widely used system.

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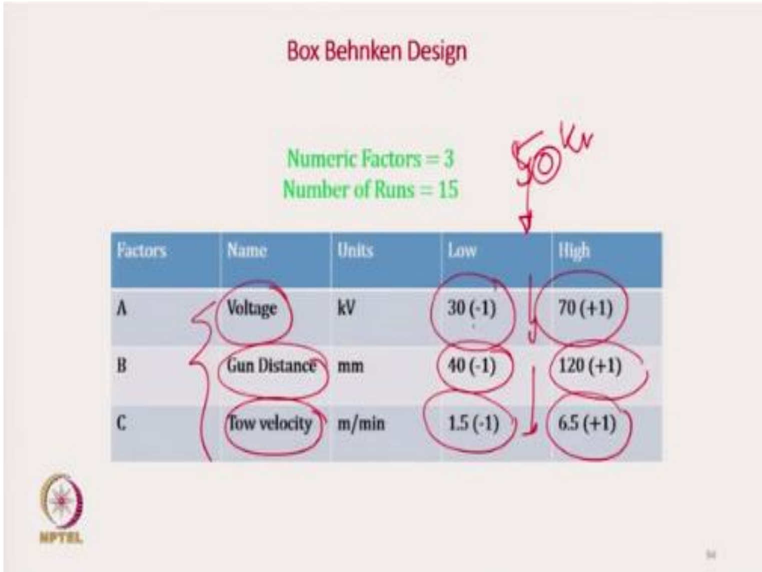

Now here the three variables are voltage, gun distance and tow velocity. These parameters we have seen earlier one at a time but here in combination we have changed the voltage with the lower value is 30 and higher level is 70 kilo volt. Gun distance from 40 to 120 millimeter and tow velocity from 1.5 meter per minute to 6.5 meter per minute and in between at the center value.

We have taken like here it is a 40, 30, 50 and 50 kilo volt. So middle value have taken as a third level so 0 level. So this is -1, +1, and 0 level we have used.

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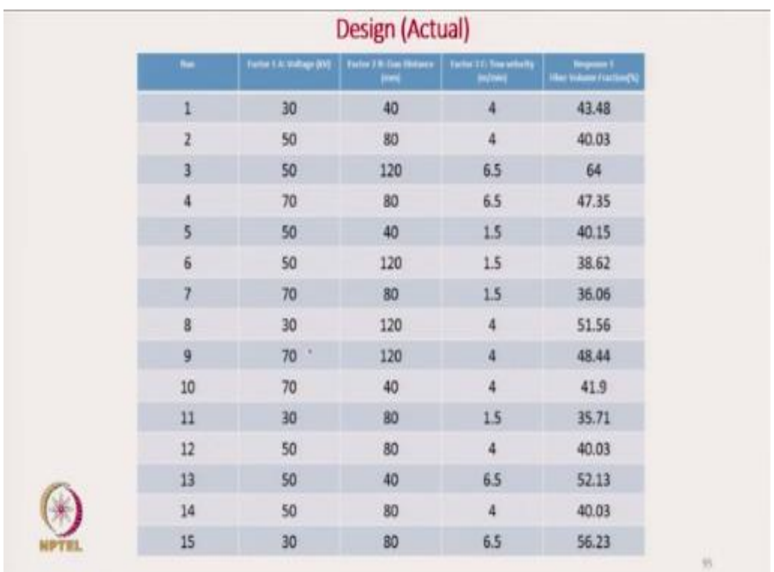

Design (Actual)

Run	Factor 1 A: Voltage (kV)	Factor 2 B: Gun Distance (mm)	Factor 3 C: Tow velocity (m/min)	Response 1 Fiber Volume Fraction(%)
1	30	40	4	43.48
2	50	80	4	40.03
3	50	120	6.5	64
4	70	80	6.5	47.35
5	50	40	1.5	40.15
6	50	120	1.5	38.62
7	70	80	1.5	36.06
8	30	120	4	51.56
9	70	120	4	48.44
10	70	40	4	41.9
11	30	80	1.5	35.71
12	50	80	4	40.03
13	50	40	6.5	52.13
14	50	80	4	40.03
15	30	80	6.5	56.23

And the total combinations of the parameters are there, there are total 15 set of experiments.

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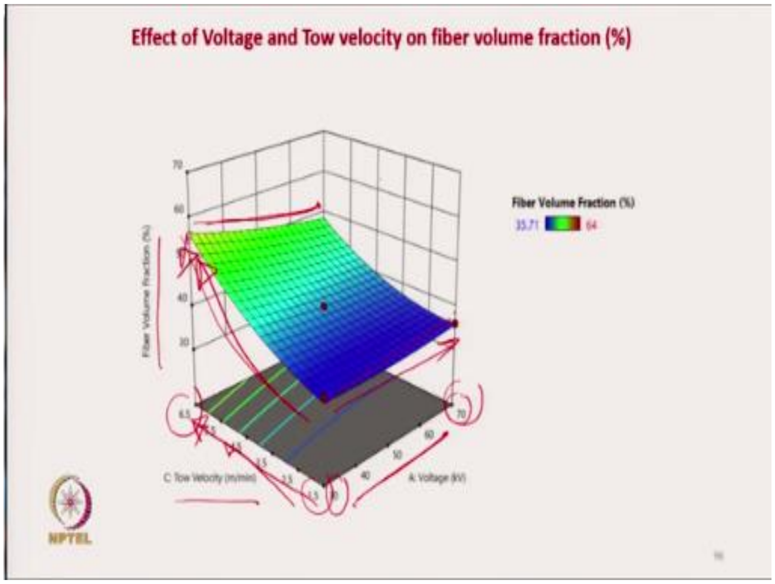

Now, we can see here the same trend that we have got earlier for single variable testing, single variable experiment but here we will get the total response surface. So if we see here the tow velocity, with the increase in tow velocity, the fiber volume fraction increases, means earlier what we have seen with the increase in tow velocity, the resin fraction reduces. It is same, it is with increase in tow velocity, fibre volume fraction increases, that means it is the reduction in resin content.

But the advantage of this response surface means we can get within this experimental zone that rate the trend of the parameter at different level like at 30 voltage, 30 voltage is the rate of change of say volume fraction with the increase in tow velocity is higher than at 70 kilo volt, at the 70 kilo volt if we keep the voltage here and we change the tow velocity here the rate of increase in fiber volume fraction is lower.

Similarly if we see here at higher level of tow velocity the effect of voltage, effect of charging is higher than, its prominent it is significant, but at lower level of tow velocity the charge effect is not that significant it is almost horizontal, there is no change. So here by having the response surface equation we can get the trend, the total trend of experiments or of the parameters in this experimental zone.

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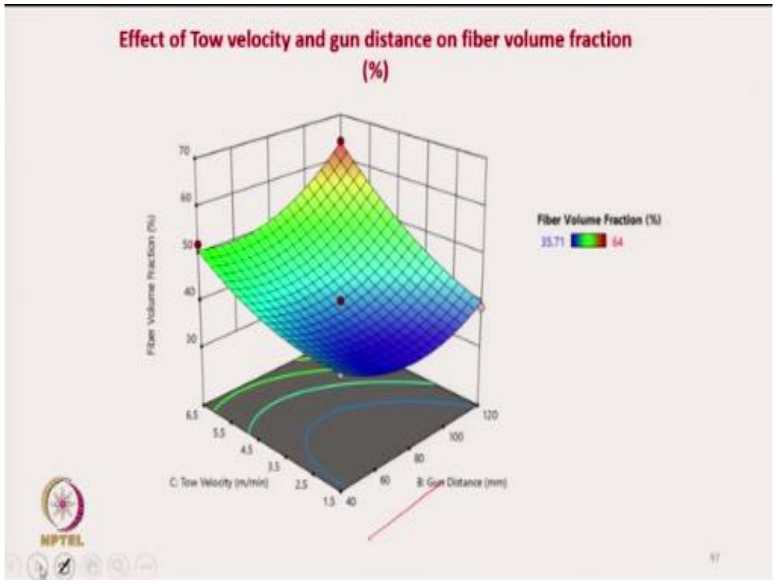

Similarly here this response surface shows the effect of tow velocity and gun distance on fiber volume fraction, so it is showing like as we increase the gun distance here, it is changing. So we can optimize the parameters depending on our use.

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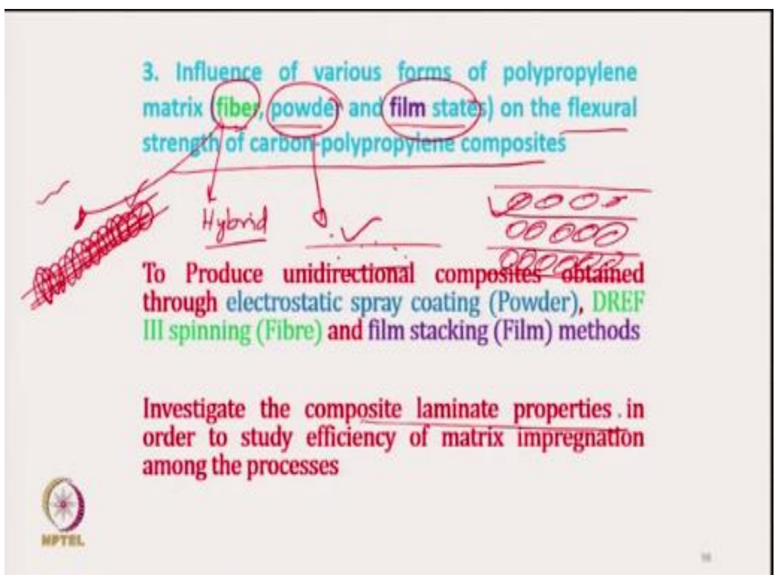

Now what we have seen? In our experimental setup, we can optimize the parameters; we have seen the different factors which affect the resin content. Now we will see the influence of various forms of polypropylene matrix on flexural strength of carbon polypropylene composite. Now we will come to the composite making. So the matrix formation here, the polypropylene matrix are in the form of fibre, in the form of powder and in the form of film.

So when we will use the fiber we will form the hybrid yarn, hybrid yarn will form. So fiber and hybrid yarn we have to form so polypropylene fiber we have to use and carbon tow we have to use. So in this case polypropylene staple fiber, we will use. So for that what we have done we have used the DREF friction spinning where polypropylene fiber staple fibers were taken and polypropylene staple fibers were wrapped around the carbon filament.

And powder we will be using whatever we have explained the powder coating stem is used and film stacking we will take the polypropylene film and the stacking will be done. This is the carbon filament and polypropylene will be stacked on that in this fashion, so that is how we will see and this three type different types of structures how these structures affect the flexural property of the composite.

So electrostatic spray coating when we will use has a powder, DREF three spinning when we will use as polypropylene matrix as fiber and film stacking as film method. Composite laminate process, so we will make the composite laminate.

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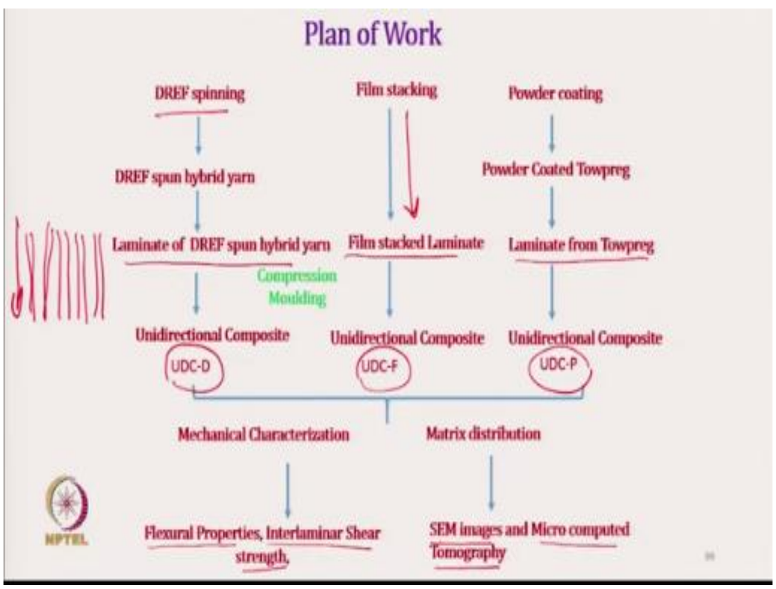

So the total plan of work is that first DREF spinning we will be doing for using a fiber as a fibre polypropylene fiber, film stacking and powder coating. The DREF spun hybrid yarn, powder coated towpreg then film stacking will be done. So film stacking directly on the carbon tow, then we will form the laminate, okay and laminate of DREF spun yarn, film stacked laminate and lamination from towpreg from the powder coated towpreg.

Then compression moulding will be done to form the composite so from DREF we will make the unidirectional composite that means the filaments will be or yarns will be at parallel unidirectional where the carbon filaments will be along the axis, parallel to the axis, When it is made from DREF spinning, so it is called UDC-D, when it is a made from the film stacking UDC-F and powder coating UDC-P.

And then we will study their mechanical characteristics and matrix distribution. Mechanical characteristics will be using the flexural property, interlaminar shear strength and matrix distribution will be done using the scanning electron microscope and micro computed tomography, this is the total experimental plan.

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The same material we will be using here the carbon fiber 7 micron diameter and for DREF spinning polypropylene fiber as a sheath will be using on the carbon fibre for producing DREF spun hybrid yarn and for powder coating as the same powder coating principle we will be using with the cryogenically ground polypropylene powder and film grade polypropylene granules were used to manufacture film of certain thickness for film stacking method.

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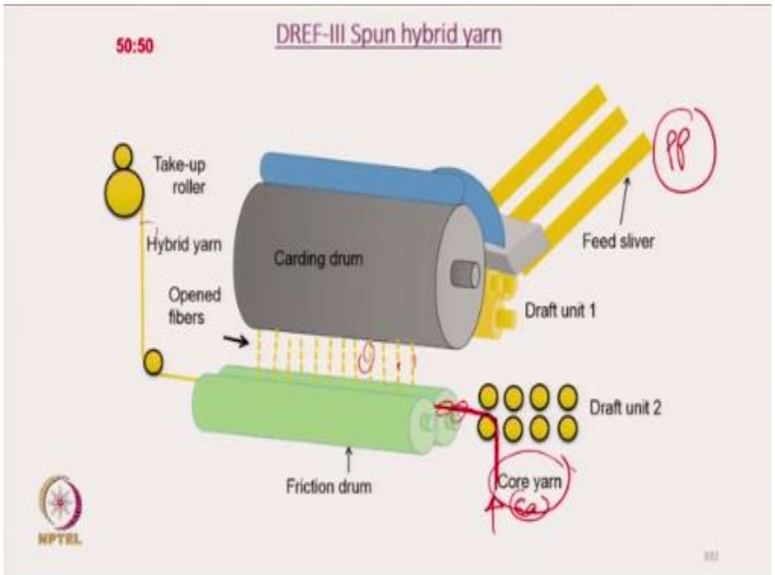

So hybrid yarn production here it is a DREF yarn three systems is used here, carbon tow and drafting unit one the polypropylene staple fibers are used here and its getting opened here by using a carding drum and for core we will be using the carbon tow and the drafting unit two is not used as a drafting system here from the front it is just fed here and the staple fibers are wrapped around the surface of the carbon tow and finally the hybrid yarn is taken. It is wound on this package. Let us see the process here.

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This is the DREF spinning process to form the hybrid yarn, this is the carbon tow. Here it is going to the drafting unit two; it is the front roller from the front roller is used. It is entering in the and finally it is wrapped here, propylene wrapped, hybrid yarn is there and this is a sliver it is going to the drafting unit and finally we get the hybrid yarn.

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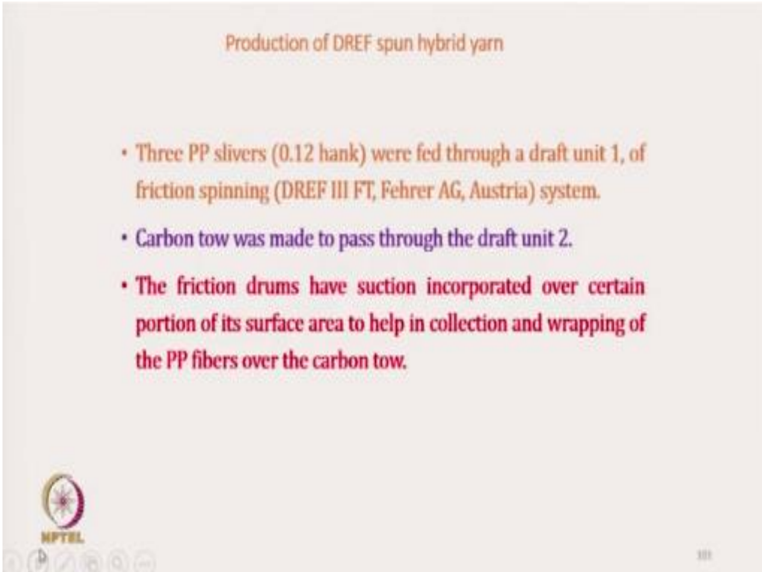

So these are the different parameters used.

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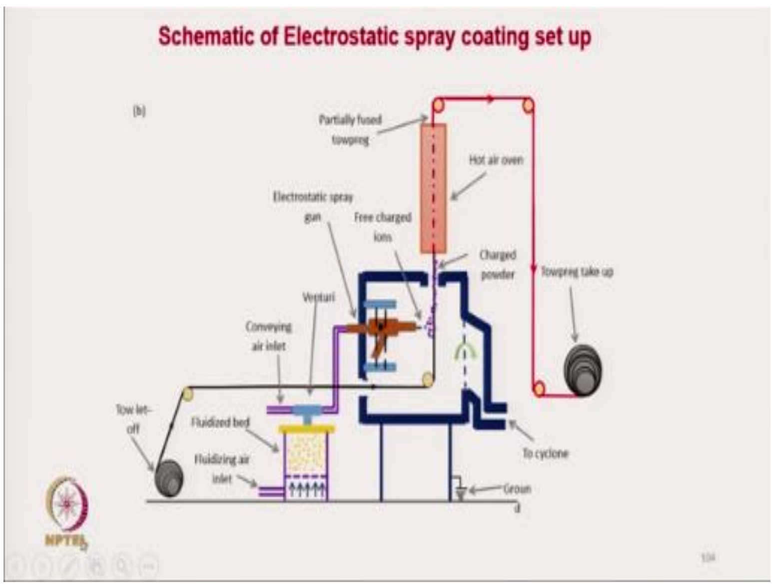

And this picture we have already explained in detail the schematic of the spray coating where we get the powder coated towpreg.

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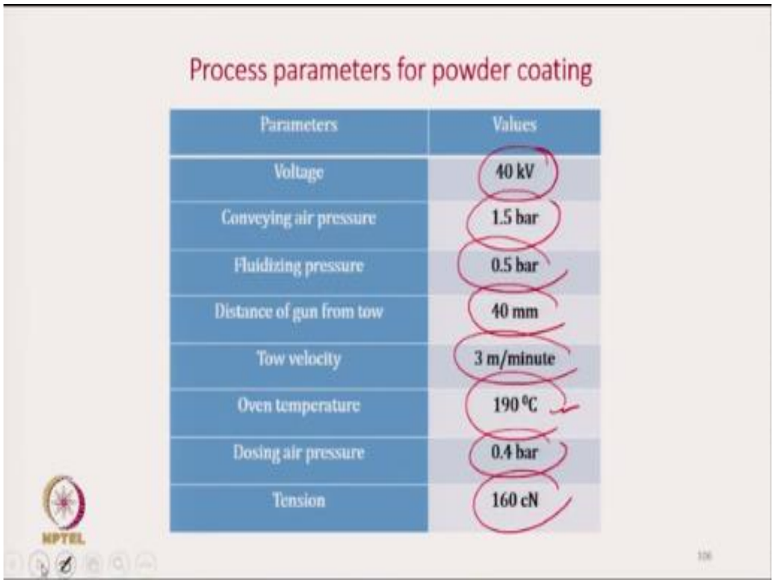
Process parameters for powder coating

Parameters	Values
Voltage	40 kV
Conveying air pressure	1.5 bar
Fluidizing pressure	0.5 bar
Distance of gun from tow	40 mm
Tow velocity	3 m/minute
Oven temperature	190 °C
Dosing air pressure	0.4 bar
Tension	160 cN

These are the parameters which have been used in the powder coating. Voltage, 40 volt we have used here, conveying air pressure 1.5 bar, fluidizing pressure 0.5 bar, the distance of the gun from the tow 40 millimeter, tow velocity 3 meter per minute, oven temperature 190 to keep the flexibility intact, otherwise at 200 and 220 we have seen at that temperature flexibility reduces.

Ultimately that finally we have to use this powder coated towpreg for weaving. Dosing air pressure 0.4 bar and tension 160 cN.

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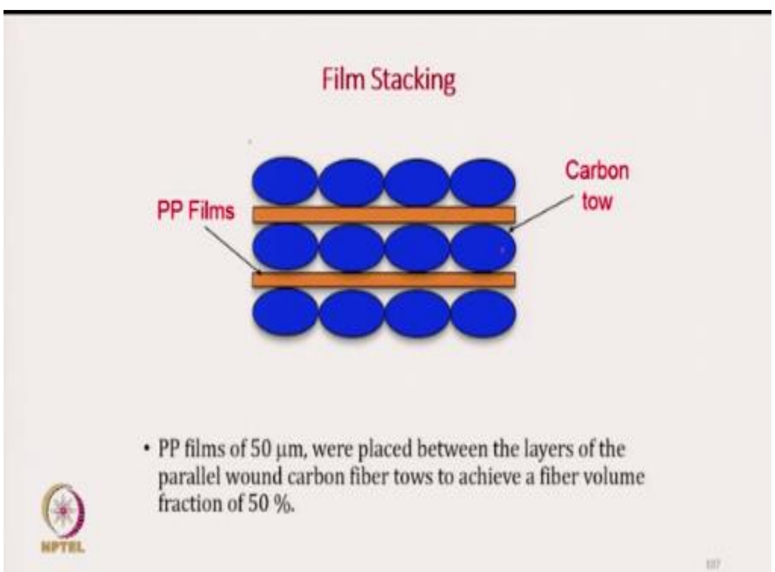

And for film stacking this is the carbon tow, the blue colour it is carbon tow and alternatively the one carbon tow layer and one film layer we have used.

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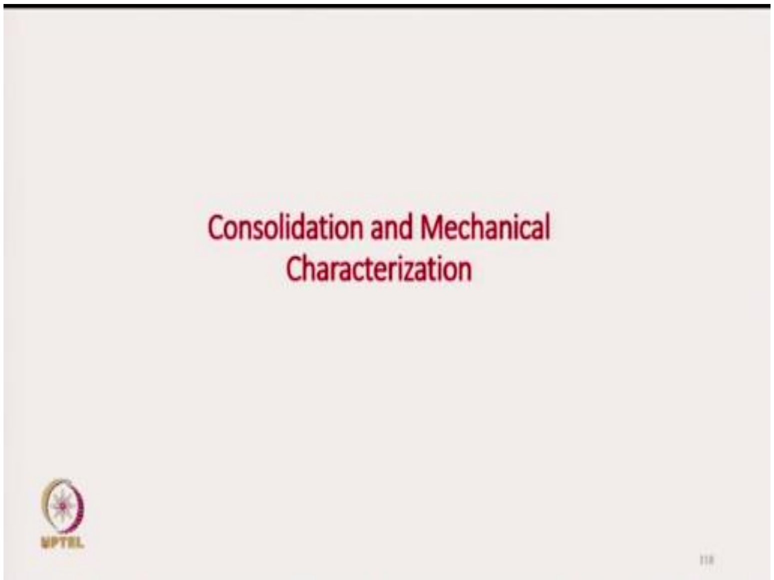

And consolidation method and mechanical characterization.

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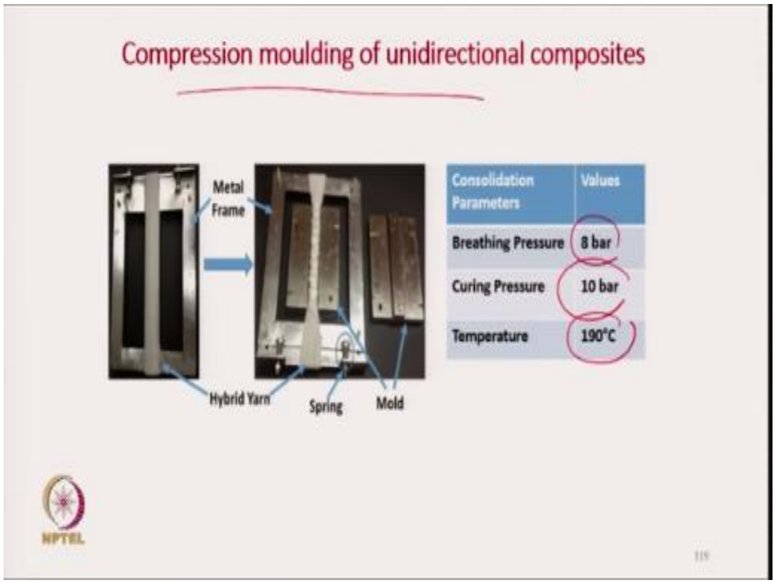

So this is the consolidation method means here we have made the composite, okay. After wrapping number of layer air in the compression moulding machine is used with a breathing pressure of 8 bar and curing pressure of 10 bar and temperature of curing is 190 degree Celsius. And these are the moulds male female moulds are there and this is pressed against each other in between that there is a towpreg is there.

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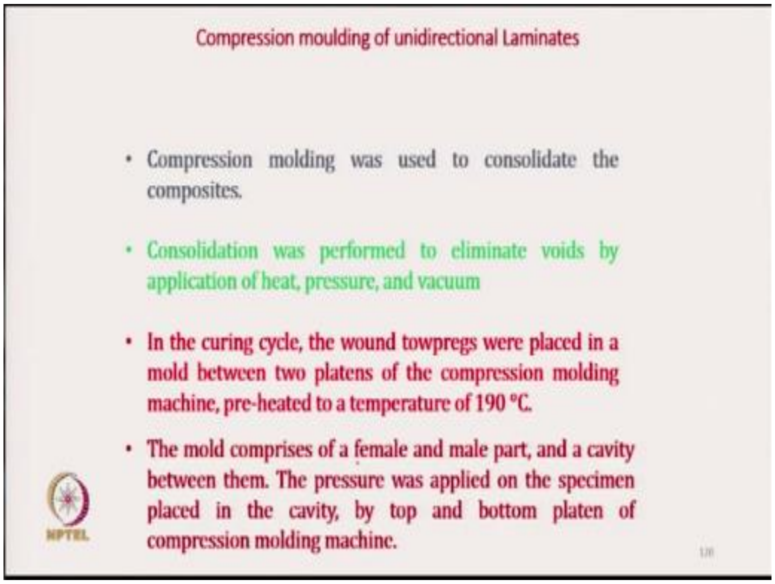

So compression moulding was used to consolidate the composite. So this we have the mould compressor of female and male part and a cavity between them.

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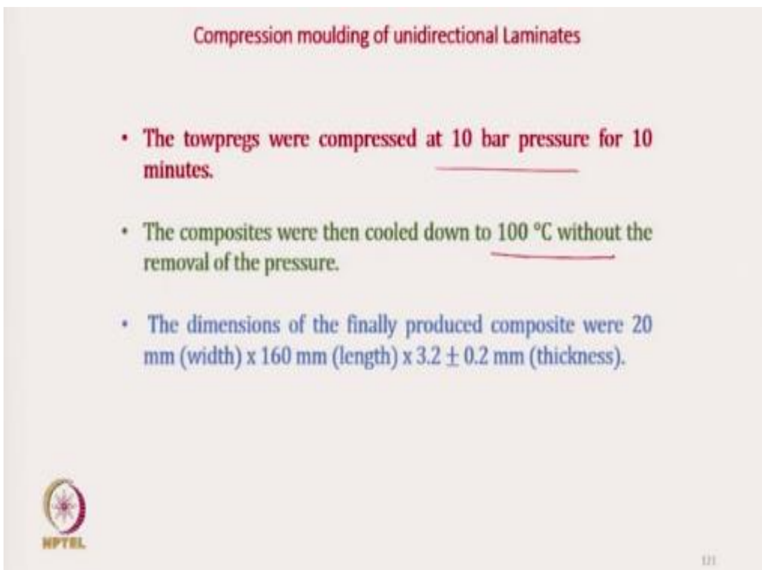

So towpreg was compressed at 10 bar pressure for 10 minutes, the composites were then cooled at 100 degree Celsius without removal of pressure, so pressure was kept and final dimension of the composite was 20 millimeter in width, 160 millimeter in length and 3.2 millimeter approximately it is + -0.2 mm thickness.

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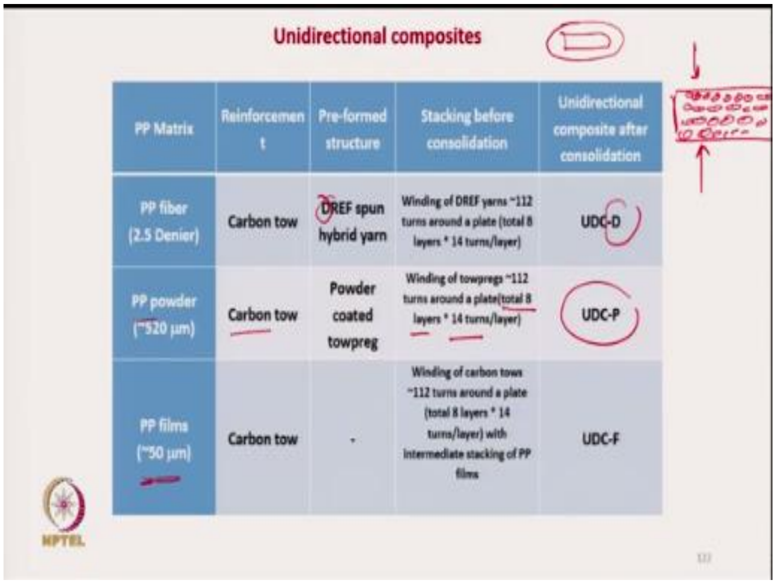

And what we have done we have prepared the unidirectional composite and these are the parameters of unidirectional composite. So with PP fibre, what we have used polypropylene fibre 2.5 denier polypropylene staple fiber we have used and as a matrix here and carbon reinforcement for all three samples where carbon tow was used so and pre-formed structure is a DREF spun hybrid yarn as we have seen here and then for stack making for stacking before consolidation where 8 layers were there with 14 turn, 14 number of turns.

So there are turns we have seen, this is a plate suppose and there is a turn, one turn means one wrap, so that is 14 turns will be there. These are the 14 turns and such 8 layers will be there, eight layers, then it is this total system the total material is put under the compression moulding and we get the compression moulded composite and as it is made from DREF, so that is why UDC-D, similarly carbon tow powder.

Similarly, 8 layer and 14 turns so UDC-P, so unidirectional composite made from powder coating and for PP film it is on film we have taken, it is a 50 micron thickness, with carbon tow is there and in this case here 8 layer of 14 turns was there but in between the films were there so UDC-F.

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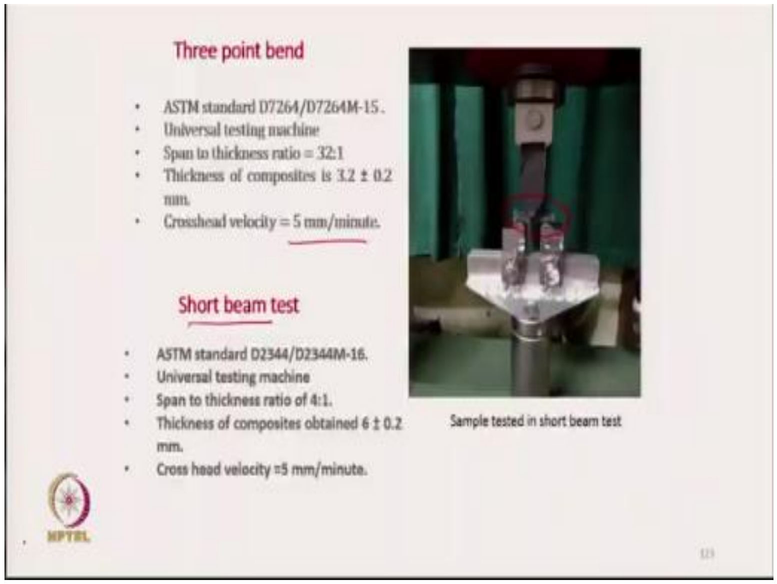

And the testing what we have done for the 3 point bending testing with these parameters where crosshead speed is 5 millimetre per minute, and at the same time it is a short beam test, which is shown here, the short beam test. So to get the flexural characteristics of the composites and we have done a detailed study for all these composites made from DREF spun hybrid yarn, from film stacking and powder coating and we have compared their result and all these results will be discussed in the next class. Till then thank you.