Technical Textiles
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Lecture - 06
Textile Reinforced Composites (contd.,)

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Hello everyone. So, we will continue with textile reinforced composite. Now, we will discuss the textile structures which are used for advanced composite materials. This textile structures are basically known as prepreg or preform. Preform as basically the basic textile structure without the incorporation of matrix material. Only the textile reinforcing materials are there, on the other end prepreg is there it is a preform, but impregnated or incorporated matrix materials are there itself.

So, basic requirement of textile structures for advanced composite materials, it requires a high degree of structural integrity. This is required to prevent delamination to increase resistance to interlaminar shear, distribution of dynamic stress and, obviously, to facilitate ease of handling. Basically that the preform if we cannot handle easily, then it will be problem. So, here you have higher characteristics better characteristics. So, control distribution of yarns in the prepreg or preform is important, proper orientation of yarns are required to have better characteristics.

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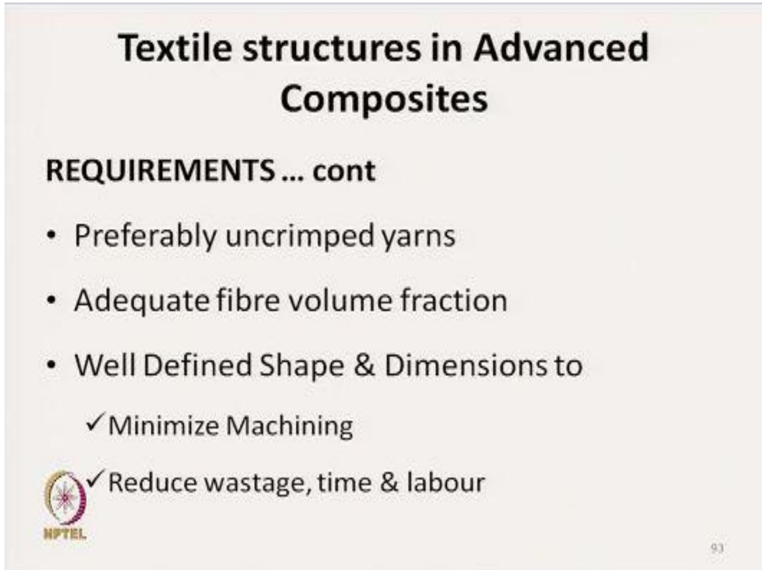

Normally in weaving the yarns are in crimped form, but for composite, it is preferable to have crimpless yarn, which will actually enhance the tensile characteristics better load share of the reinforcing component. Fibre volume fraction is another important requirement, so higher fibre volume production is required for higher strength and flexural characteristics and composite with well defined shape and dimensions is important.

So, that machining is minimized; wastage is reduced and it is produced in lower labor requirement and less time is required. Suppose, if we need one structure of circular cross section, circular shaped composite, it is better to have a preform in circular shape. Otherwise, it will be wastage of material and proper shape to get the proper shape we need machining. So, well defined shape and dimensions of the textile structure is required.

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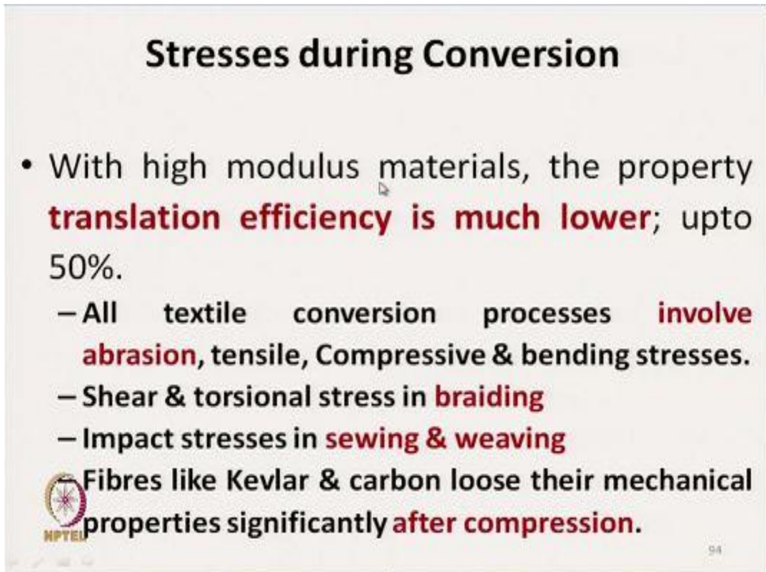

Another problem of textile reinforced composite is that high modulus materials we are using the property translation efficiency is much lower. That is the important consideration, because if we use a very strong material, but if the property translation is very low, then we have a problem. Also, in most of the textile conversion involves abrasion, tensile, compression, bending stresses. These stresses effectively damage the textile material.

These reinforcing materials. Shear and torsional stress is exerted during braiding which damaged the yarns or fibre, impact stresses in sewing and weaving also damages. Fibres like Kevlar and carbon, they lose their property significantly during compression or bending.

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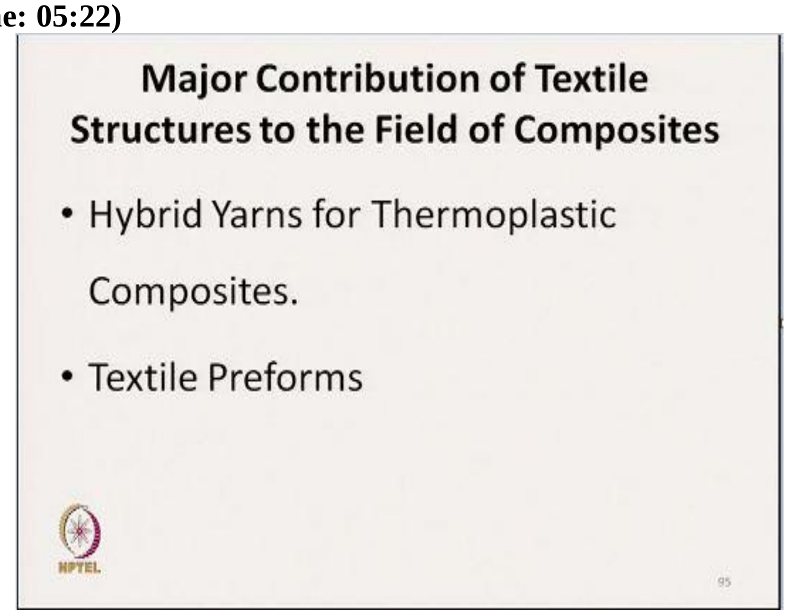

So, the major contribution of textile structure is that hybrid yarns if we can produce for thermoplastic composite that will enhance the characteristics. I will discuss in detail. The hybrid yarn means the reinforcing material, reinforcing fibre is mixed with the matrix material in the form of fibre and the hybrid yarn is produced with both the components and textile preforms is another yarn another area where the major developments have taken place. So, we can directly convert the textile material in the shape of final product. So that we do not need any stitching, any joining and which will ultimately result in better quality of composite.

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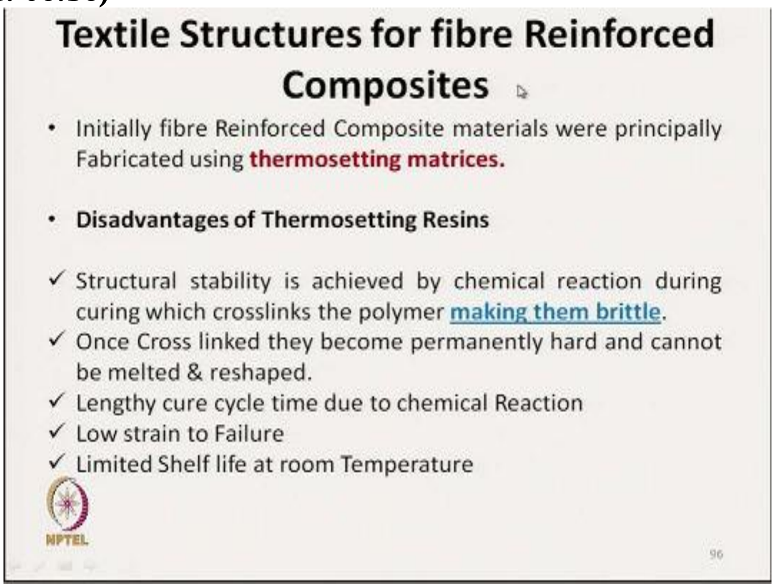

The textile structures for fibre reinforced composites, initially, fibre reinforced composite materials were principally fabricated using thermosetting matrices. The main disadvantages of thermosetting matrices are the structural stability it is achieved by chemical reaction during curing, which is cross linking of polymer. So, that makes the matrices or composite, it is brittle and the transmission is basically permanent.

As I have already mentioned. Lengthy curing cycle; low strain to failure and limited shelf life at room temperature. These are the disadvantages of thermosetting resin. That is why the textile structures are developed nowadays using thermoplastic matrices.

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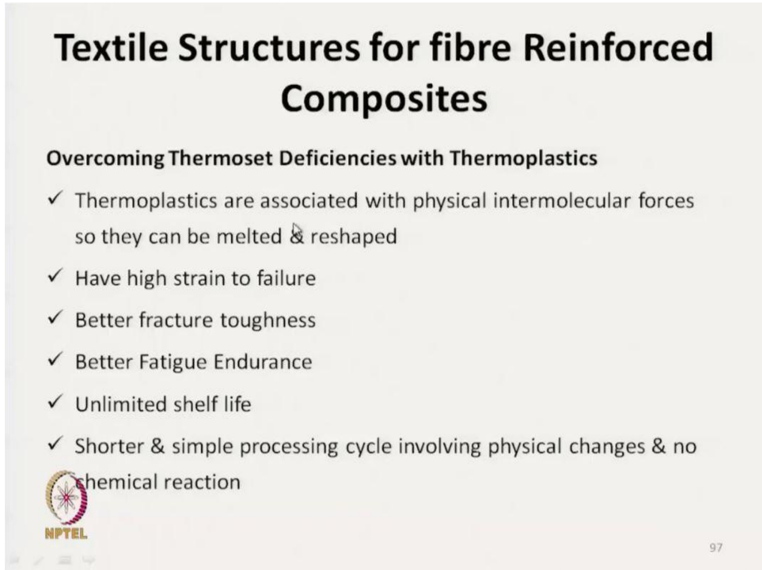

So thermoplastic matrices, these are associated with physical intermolecular force, so that they can be reshaped again. On heating they can be melted, they have higher strain to failure as compared to thermosetting matrices, better fracture resistance, fatigue resistance is better, unlimited shelf like, see in thermo set metrics we have discussed the limited shelf life if we can preserve the thermoplastic matrix properly the shelf life is very high and this important characteristics are shorter and simple processing cycle involving only physical changes, no chemical, by hitting it gets melted and on cooling, it is against solidifies, no chemical reactions are there.

So, that makes the thermoplastic matrix so popular. So, all these positive features are there which is, these are the characteristics which make the thermoplastic matrix popular for modern composite manufacturing.

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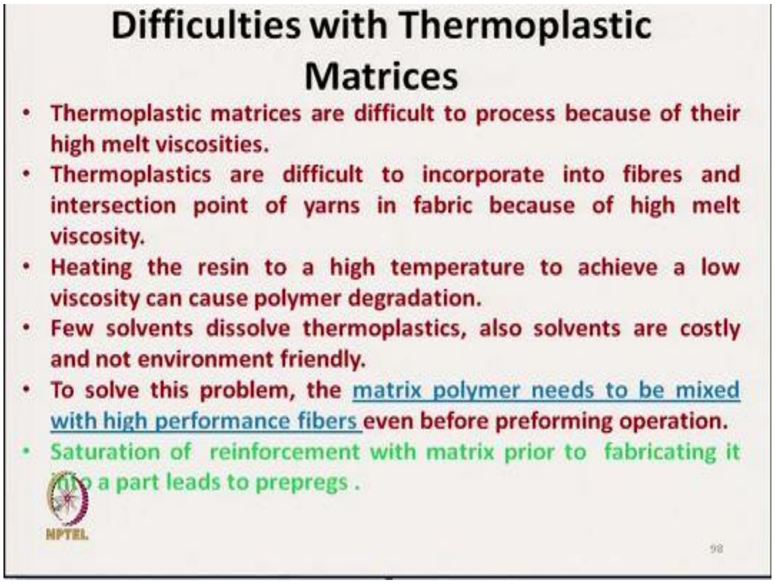

But there are some difficulties. The main drawbacks are, they are difficult to process because they are high melting viscosity. High melt viscosity due to this the penetration within the structure is very difficult. Unlike thermoset matrix, initially their melt viscosity is very low so they can penetrate between the fibre spaces. The thermoplastics are difficult to incorporate into fibre and intersection point of yarn in fabric because of their high melt viscosity.

If we want to reduce the melt viscosity, we have to increase the temperature and that will in turn deteriorate the properties of the matrix. Also, if we want to incorporate in between the yarn intersection point we have to have very high pressure. So, heating the resin to a high temperature to achieve low viscosity can cause polymer degradation. There are few solvents which can be used for thermoplastic but they are very expensive and are not generally environment friendly. That is why they are not so popular.

So, what is the solution? So, to solve all these problems that solve the problem is that high melt viscosity and we cannot reduce the viscosity by increasing temperature due to degradation problem. So, the main way the basic system to solve these problems are to incorporate matrix within the preform structure. The matrix polymer needs to be mixed with the high performance fibre even before preforming operation, that if we can do then we can solve all these problems. Saturation of reinforcement with matrix prior to fabrication which leads to the formation of prepregs.

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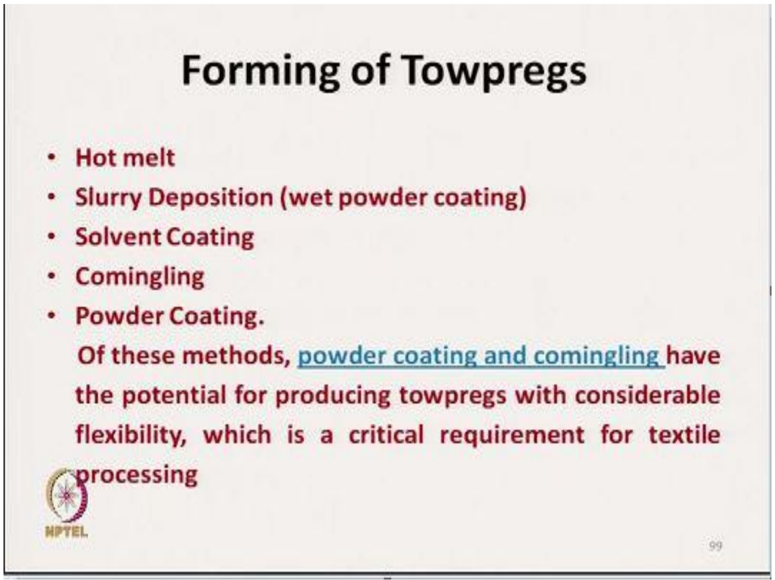

So, there are different ways to form prepreg, by hot melt process, by slurry deposition, which is known as wet powder coating, solvent coating, commingling, powder coating. Of all these methods, powder coating and commingling have the potential for producing towpregs with considerable flexibility. So others methods are also used, but if we want to convert this towpreg to prepreg which we need to have lower flexibility and the lower flexibility is required for textile processing. So, if we have stiff towpreg, we cannot form the fabric or you cannot process in any other textile processing.

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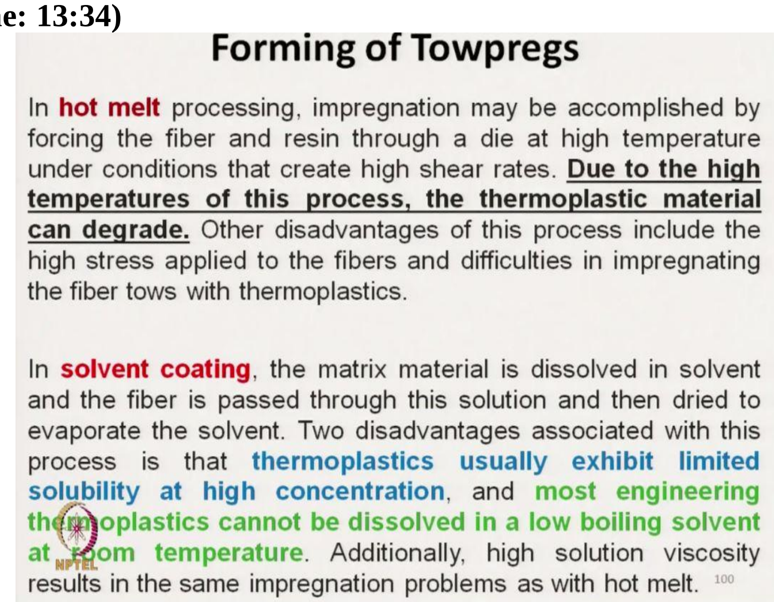

So, in hot melt processing the impregnation may be accomplished by forcing the fibre and resin through a die at high temperature under conditions that create high shear rate. Due to the high temperature of the process the thermoplastic material can degrade, that is the problem of hot melt process. And solvent coating is that the matrix material is dissolved in the solvent and then the tow is passed through that and the towpreg is formed.

The main problem is that the thermoplastics usually exhibit limited solubility at high concentration and most engineering thermoplastic cannot be dissolved in low boiling point, boiling solvent at room temperature. So, these are the problems.

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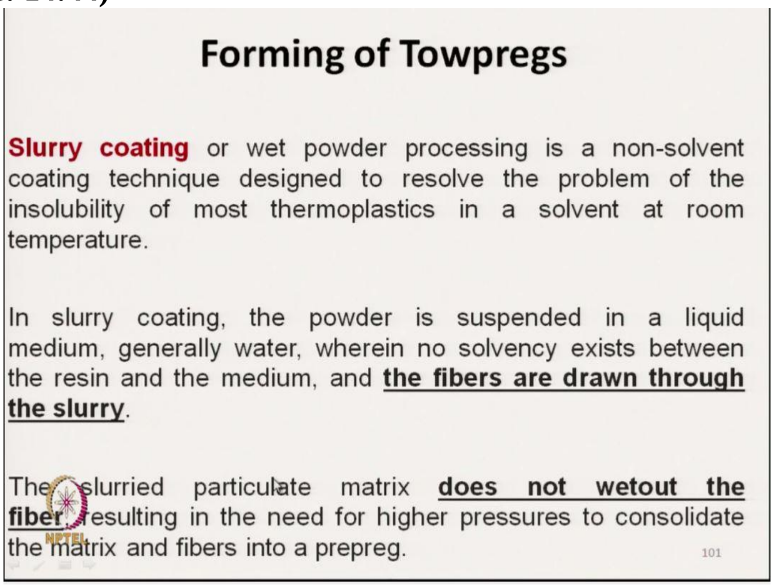

Slurry coating is also there where the matrix, that is known as also wet powder coating. The non-solvent coating techniques, here the solvents are not used. The powder of the thermoplastic materials are actually formed suspension in the liquid powder suspension, which is in slurry form and the tows are drawn through that slurry and the thermoplastic materials are deposited on the surface.

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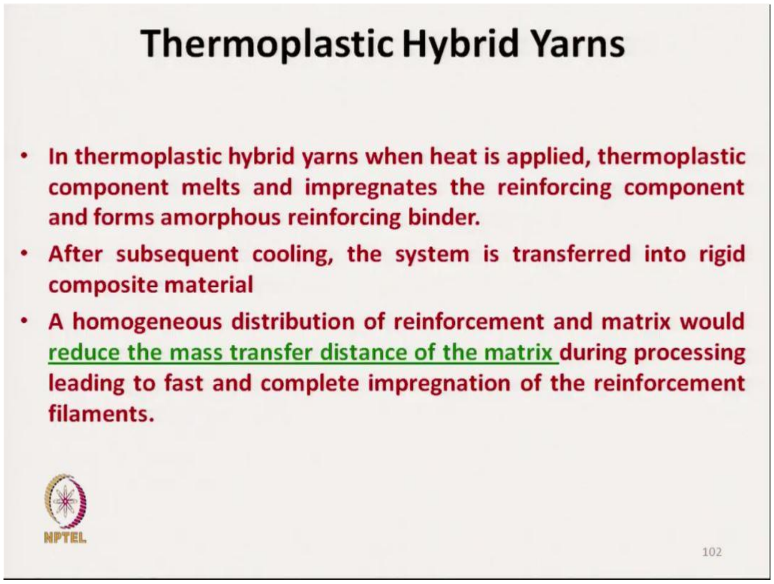

But all these 3 processes which we discussed, hot melt, solvent coating and slurry coating they are not that popular due to the reason that sometime they may degrade the polymer or it is basically it is not in environment friendly. But thermoplastic hybrid yarns, they actually overcome all these problems. Here in the hybrid yarn, there are different methods of manufacturing hybrid yarns.

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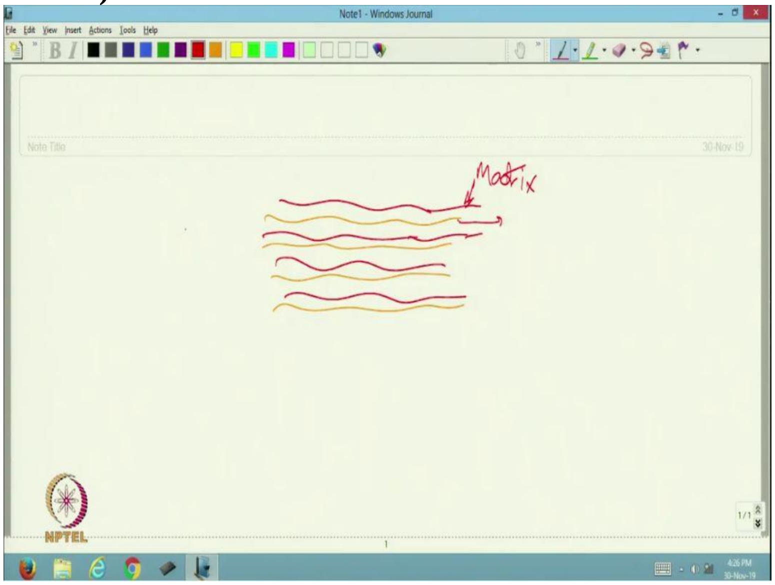

These are the, suppose reinforcing fibres and mixed with fibres or matrix, this is matrix fibres and reinforcement fibres. So this hybrid yarns actually it is a blend of both reinforcing fibre component and the matrix component and they are flexible and when heat is applied the thermoplastic components melt and which impregnate the reinforcing component and these are partially melted, if it is partially melted and which forms amorphous reinforcing binder.

In this case the flexibility is still maintained, which helps in formation of textile preform, textile structure. So after subsequent cooling the system is transferred into rigid composite material. So, that if we can reform the in the form of woven fabric, if we use the hybrid yarn and make woven fabric, then melted directly we can get composite material. Here main advantage is that will get homogeneous distribution of matrices and reinforcing material. As matrix material is already present in the in between the reinforcing fibre. So, mass transfer distance of metrics is reduced drastically, which leads to faster and complete impregnation of reinforcement filament.

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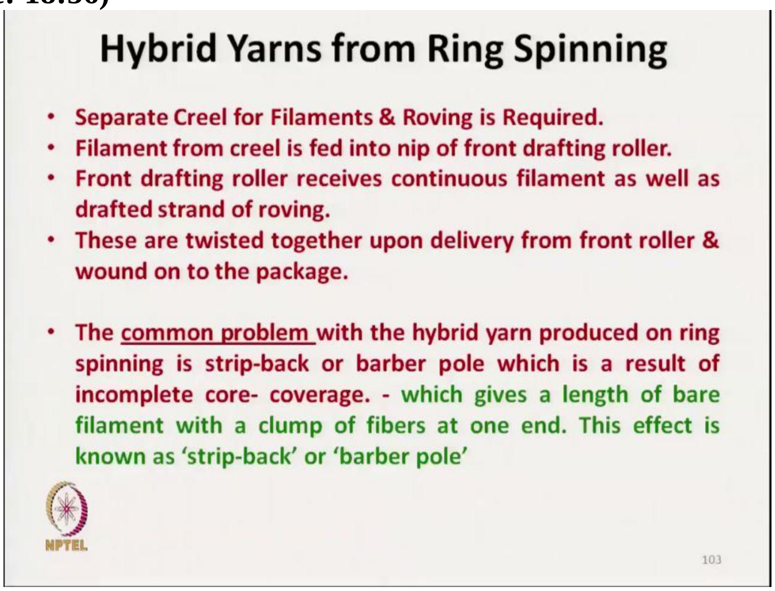

There are various methods of manufacturing hybrid yarn, this can be made using being spun yarn ring spinning process, rotor spinning process, air-jet spinning process, commingling, so there are various processes. In ring spinning we can produce the hybrid yarn using core spun technology.

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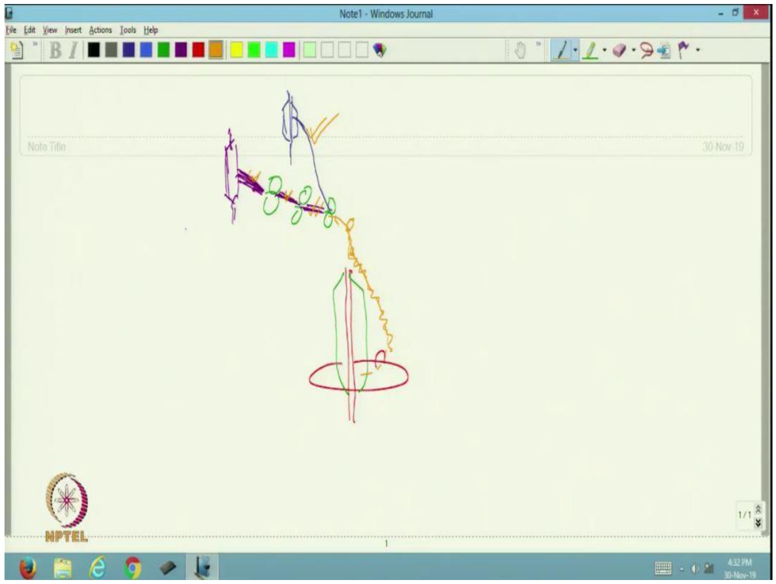

Where these are the drafting rollers and here you have roving of staple fibre, which is actually matrix fibre, and the reinforcement fibre that may be filament or may be staple, reinforcing yarn directly fed to the front drafting roller. From there this form core spun yarn, this is core spun yarn is formed here, where the reinforcing filament or yarn which is not drafted directly is being wrapped by the matrix fibre.

Which is thermoplastic fibre and the core spun yarn is formed. Separate creel for filament and roving is required, filament for reinforcement and roving is staple fibre roving for the matrix. Filament from creel is fed into the nip of the front drafting roller, the drafting roller receives continuous filament as well as the drafted strand of roving the front drafting roller and then twisting, which forms the core sheath yarn.

The main problem of this type of hybrid yarn is that it is a barber pole effect is there, that is improper core coverage. In some places you will find that the core filament is not properly covered that means, the proper matrix will not be formed there may be a chance of void content.

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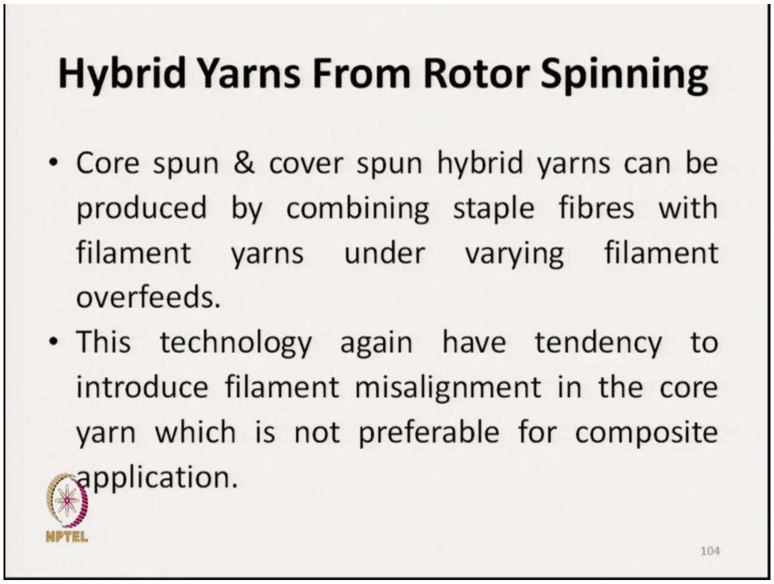

In this type of matrix. Core spun yarn or cover spun yarn can also be produced using modified rotor spinning technology, where the filaments can be covered by the staple. So, here again the problem of misalignment of the fibres that is why it is not preferred for composite application.

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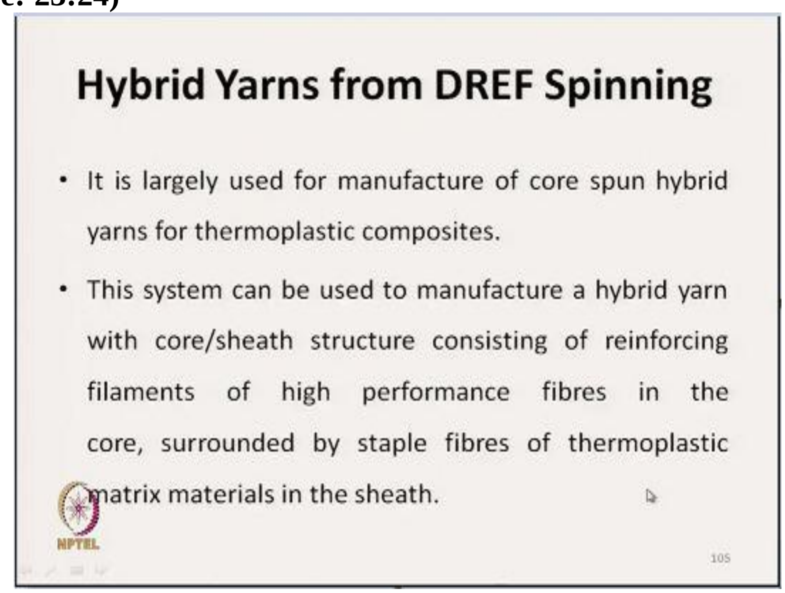

DREF spinning is the technology which is very widely used for technical textile application. And core spun hybrid yarns are used for thermoplastic composites in this system. In the core again the filaments are inserted for reinforcement. The main advantage here is that the filaments are not being twisted. So, strength is retained and thermoplastic components are wrapped around the core component.

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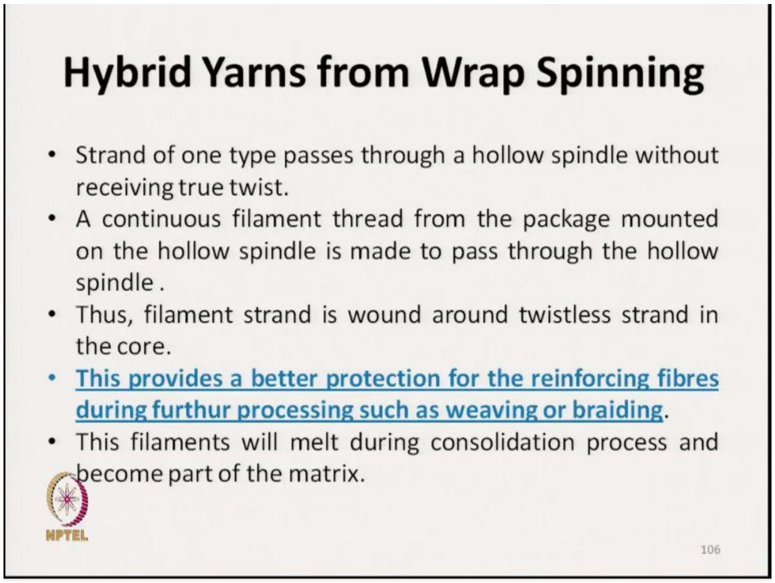

In wrap spinning also where the reinforcing fibres reinforcing filaments are being wrapped by the matrix filament. So, suppose we want to produce the carbon filament with the polypropylene. So, carbon continuous filament will be actually will be mounted on a hallow spindle and it will be allowed to pass through the hollow spindle and around that, say polypropylene thermoplastic filament will be wrapped and this wrapping in addition to the formation of the sheath of thermoplastic, it provides the protection.

So, during the further process the carbon filament is protected by the wrapped polypropylene filament in the weaving or braiding, so they do not come directly in contact with the missing component. And also, the core component remains twist less.

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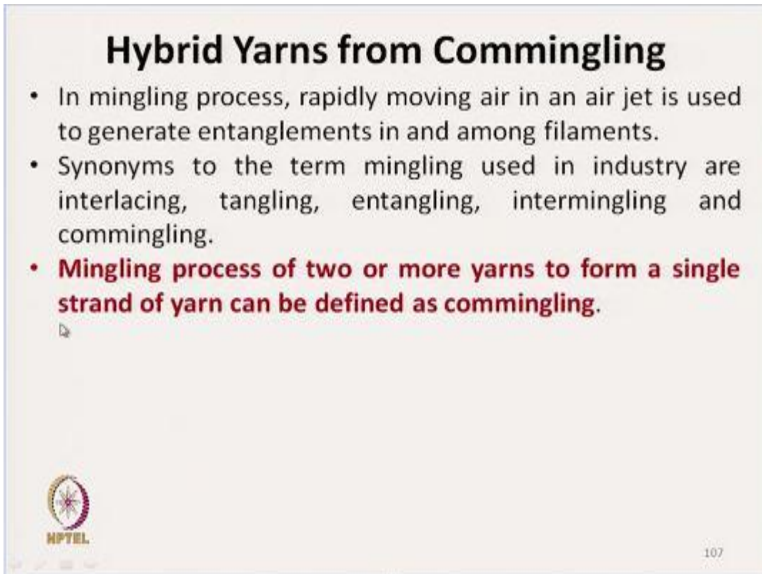

Commingling is another process of thermoplastic composite hybrid yarn. So here rapidly moving air-jet is used to entangle the reinforcement filaments and the matrix filaments. Mingling process of 2 or more yarn to form a single strand of yarn can be defined as commingling. So, we can have more than 2 components if we want. And this mingling is generally done by air-jet.

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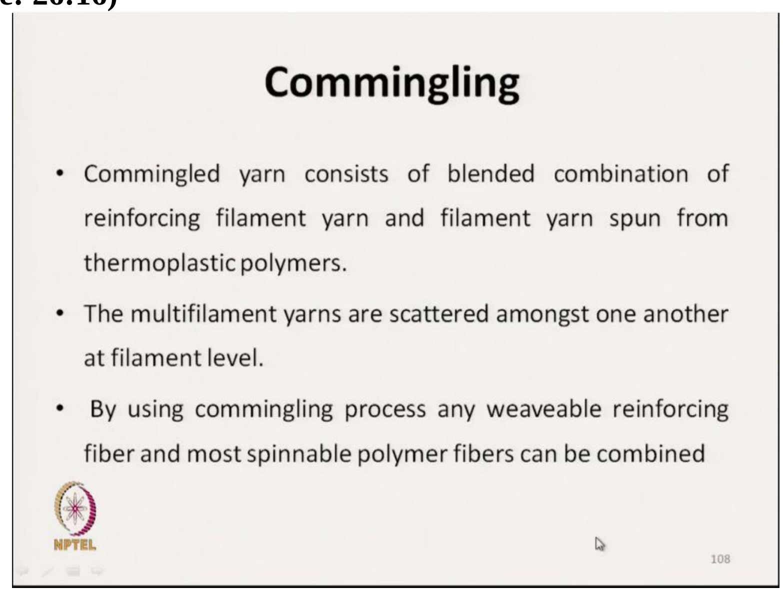

So commingling yarn consists of blended combination of reinforcing filament yarn and filament yarn spun from thermoplastic componente. The multifilament yarns are scattered amongst one another at filament level.

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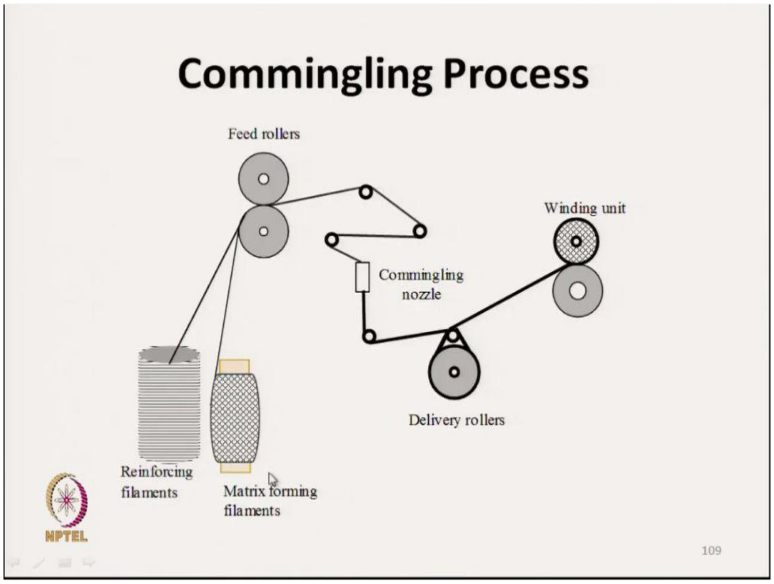

So this is the commingling process, where reinforcing filament and this is the matrix filament. And this is air-jet nozzle where these are mingled together and in commingling these filaments have to be multifilament. So that proper mingling takes place. After that, we can wind and this commingled yarn we can use for converting to fabric or other structure.

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This commingling provides good blend of reinforcing fibres and metrics. The blend is then converted into fabric by any of the fabric production techniques like weaving, knitting or even braiding. And then this formed fabric is subjected to consolidation by direct compression molding. So, here we can control the fibre volume fraction also.

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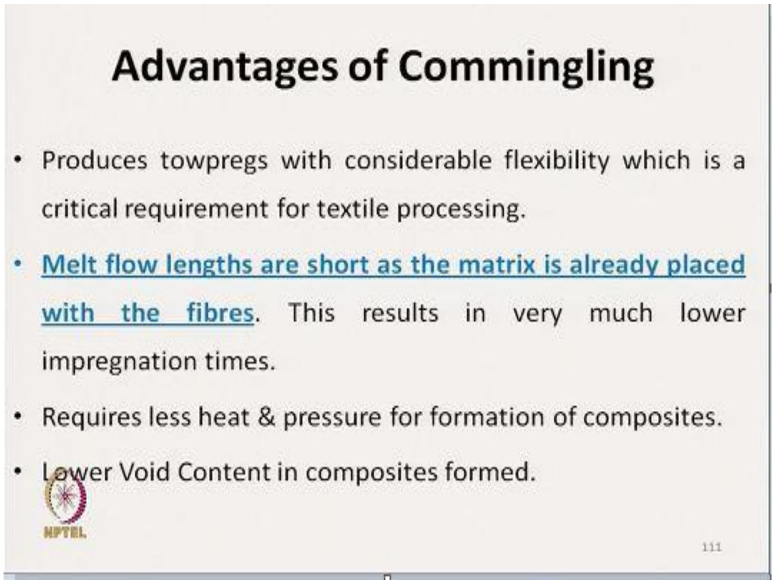

So, main advantage of commingling; the advantages are this towpregs which we produce, these are very flexible and which is required for textile conversion, for weaving knitting, we need flexibility. As this matrix materials are present within the reinforcing fibres, so melt flow lengths are short. So, this result very much lower impregnation time, immediately it gets impregnated, that means the reinforcing fibres get impregnated.

As we do not need to have very low heat viscosity, so less heat is required, ok, only melting is enough. And as the flow length is less, so pressure requirement for composite formation is also less. So, lower void content is there due to already present matrix component within the structure. So it is apparently it is a very good alternative for better quality thermoplastic composite.

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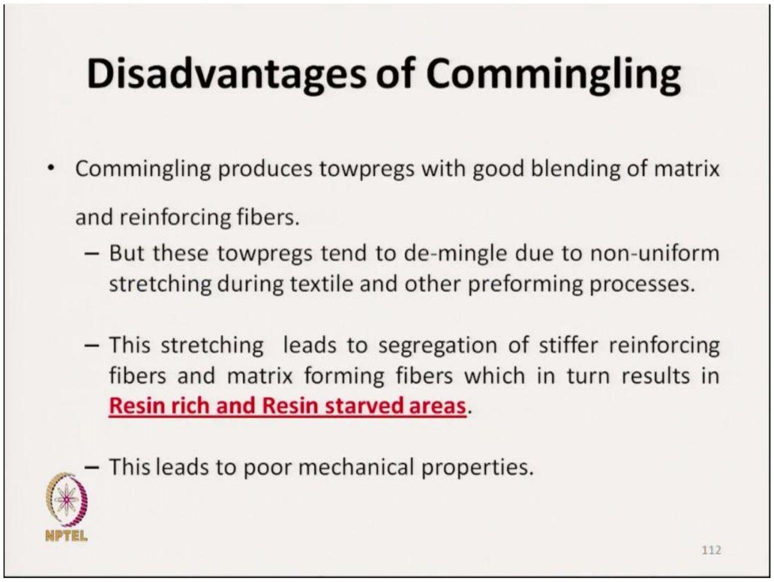

So, apart from these advantages there are a few disadvantages. Main disadvantages are that towpergs tend to de-mingled. So, because these are mingle due to the air vortex so, these are not that uniform. On stretching, they may get de-mimgled in some places so, reorientation of matrix and fibre components, the reinforcing component are there which actually results uneven distribution of resin that is resin rich and resin starved area. So, this leads uneven characteristics and deteriorates the mechanical properties.

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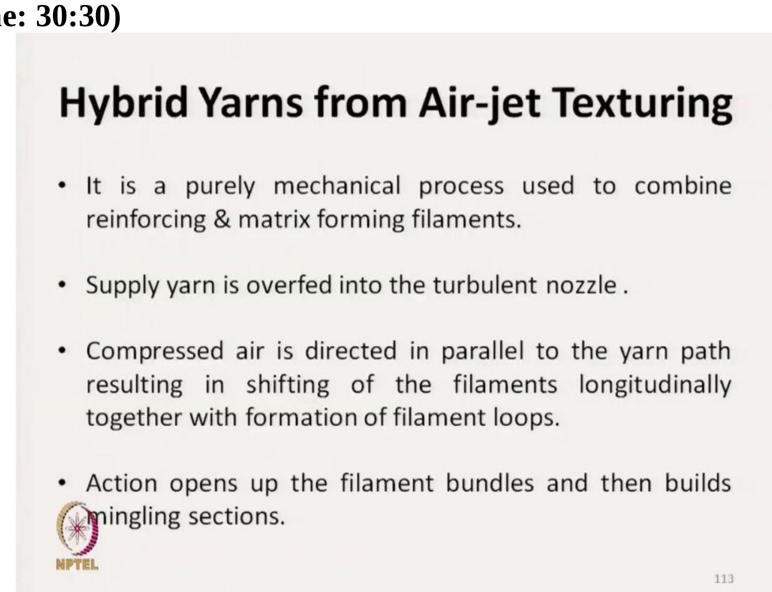

Hybrid yarns are also produced from the air-jet texturing techniques, almost similar process of air-jet spinning, air-jet texturing. Where reinforcing fibre and matrix forming filaments are combined. Similar to commingling process.

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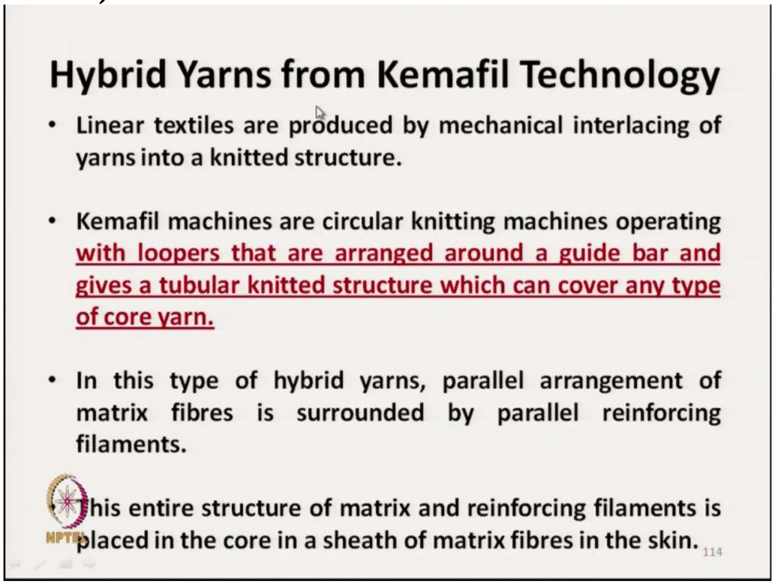

Kemafil, technology is also available where it is a circular knitting machine operating with loopers that arranged around the guide bar and gives a tubular knitted structure which can cover any type of core yarn. So, that here the knitted structure is covering the core yarn and in the core yarn can have both the reinforcing fibre and metrics filament also. But in the sheath it is a matrix filaments are there.

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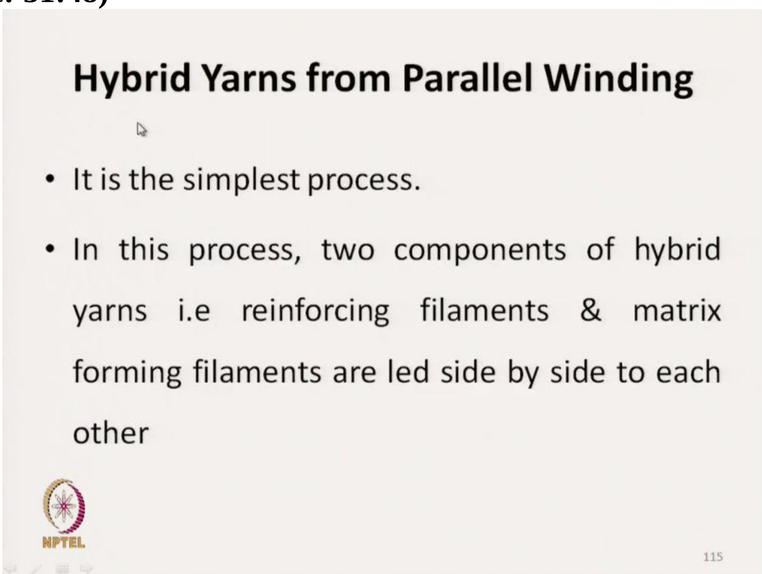

Hybrid yarns are also made from parallel winding. It is a simplest process. 2 components of hybrid yarns that is reinforcing filament and matrix forming filaments are led side by side and wound in parallel form. But here the problem is that the penetration in between the multiple elements of the reinforcing fibre, it is difficult.

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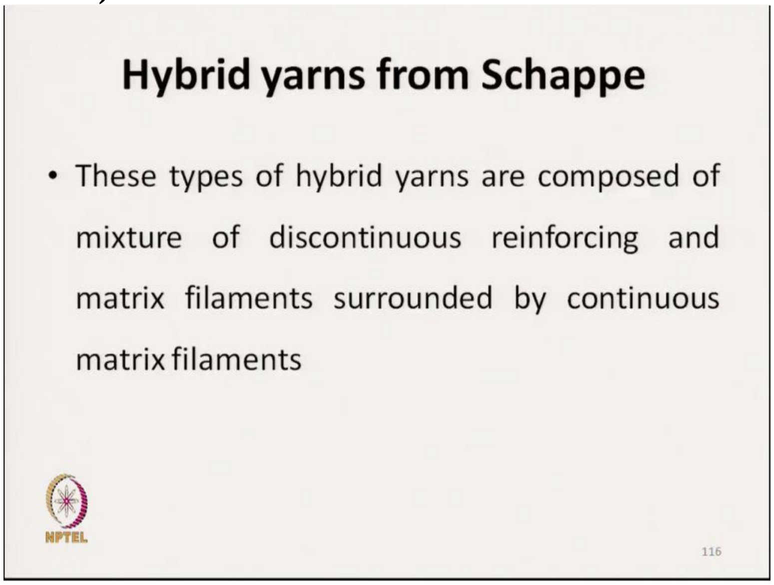

There is another technique; it is a schappe technique, discontinuous reinforcing and matrix filaments surrounded by continuous matrix filament. So that is also one technique of typically it is a type of wrap spun yarn little bit.

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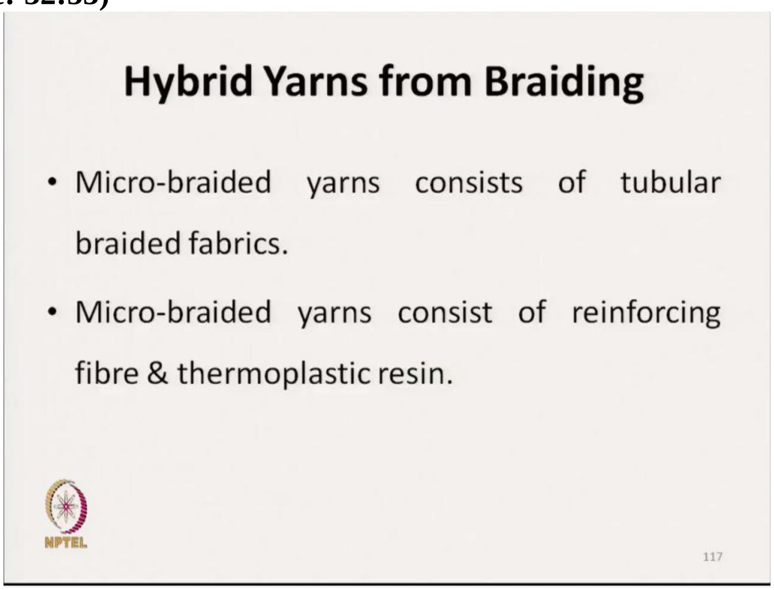

That hybrid yarns are, also formed by braiding. So micro braided yarns, that is a very fine braided yarns are produced consisting of tubular braided fabric. So, here the reinforcing filaments are normally kept in the core, covered by the thermoplastic filament. The next technique is that that hybrid yarns from powder coating. This is the technique which has great potential in thermoplastic composites manufacturing for very high end application.

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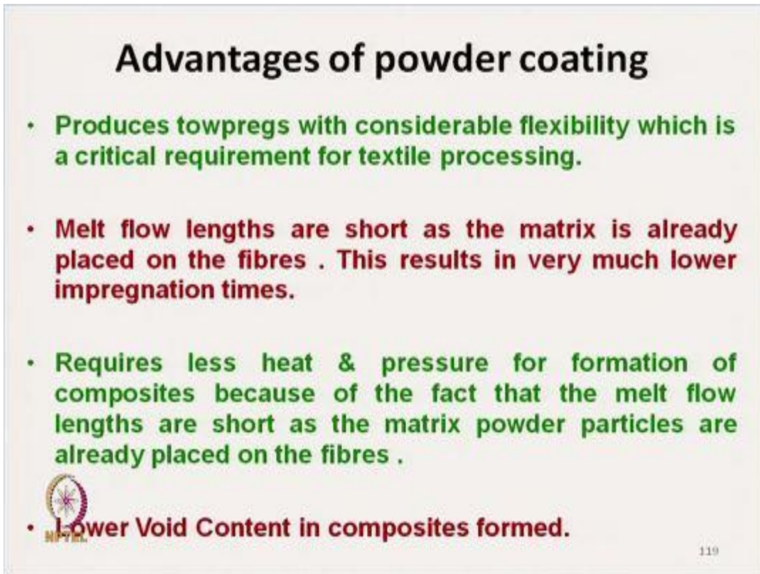

The advantages are produced towpregs with considerable flexibility which is critical requirement of textual processing. So, towpregs basically here are the reinforcement component, that reinforcing filament covered by the powders of the matrix component. So, flexibility is always maintained.

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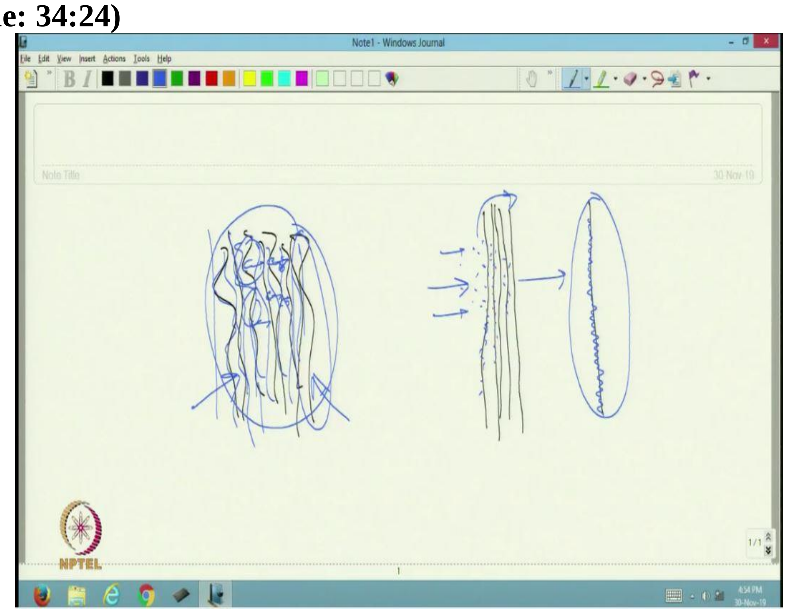

Now, let us see in hybrid yarn what we have seen, suppose this is these are the reinforcing components and these are metrix components. So, we assume that in hybrid yarn matrix component will melt and it will be in between this space of the reinforcing fibres. But we cannot guarantee here that all the filaments will be coated or covered with the matrix component evenly and also there are chances that the reinforcing component this all initially although these are twist less or there is no crimp.

It was straight but after commingling process, there will be misalignment or hybrid yarn formation. So, definitely there will be chances of non uniform distribution of matrix within the state structure, but the powder coating theoretically there should be proper uniform distribution of matrix components. Suppose these are the multi filaments and there is no crimp, straight filaments and the matrix powders are coated around the filament, each and individual filaments.

And once it is coated and if we apply a little bit heat, if we melt, this individual filaments will be totally coated with the matrix material. Here we are not talking about the total yarn, we are talking about individual filaments. So, if it is done properly, so, individual filaments are coated with the powders and that will help in developing the better quality of thermoplastic composite with much more uniformity. As the individual filaments are coated, so melt flow length are very short and this results very much lower impregnation time.

It is again requires less heat and pressure for formation of composite. And most important thing is that this results very low void content of the composite. Other hybrid yarns, there are chances of void content, higher void content due to non uniform distribution of matrix fibre. But here the void content chances of void contents are the least.

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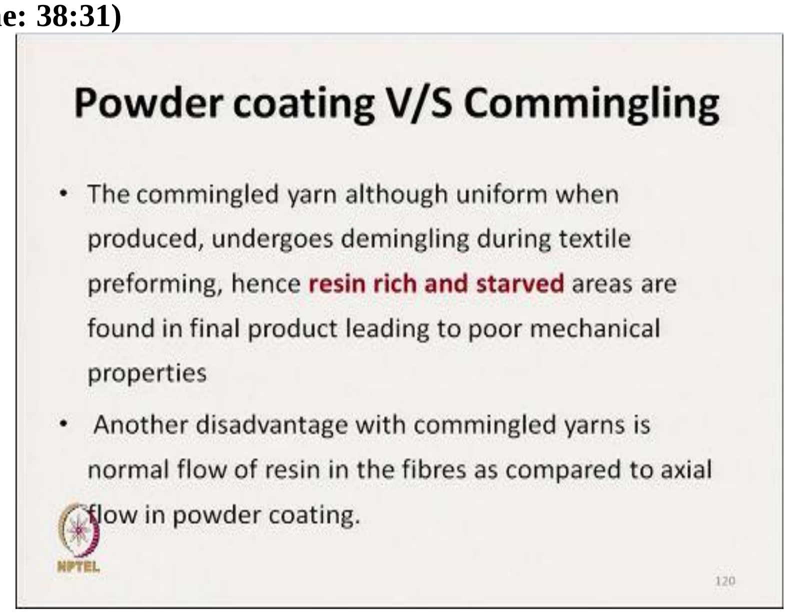

Now, if we see the competition between powder coating and commingling the commingled yarn as I mentioned, it is although uniform at the time of production, but in further processing, due to application of stress, demingling take place, which results resin rich and resin starved area, that is non uniform distribution and which leads to poor mechanical characteristics due to higher void content. The other disadvantage of this yarn is that normal flow of resin as compared to axial flow in powder coating. In powder coating we do not need normal flow because all the individual filaments are coated, but in this commingling we need we have actually normal flow of resin.

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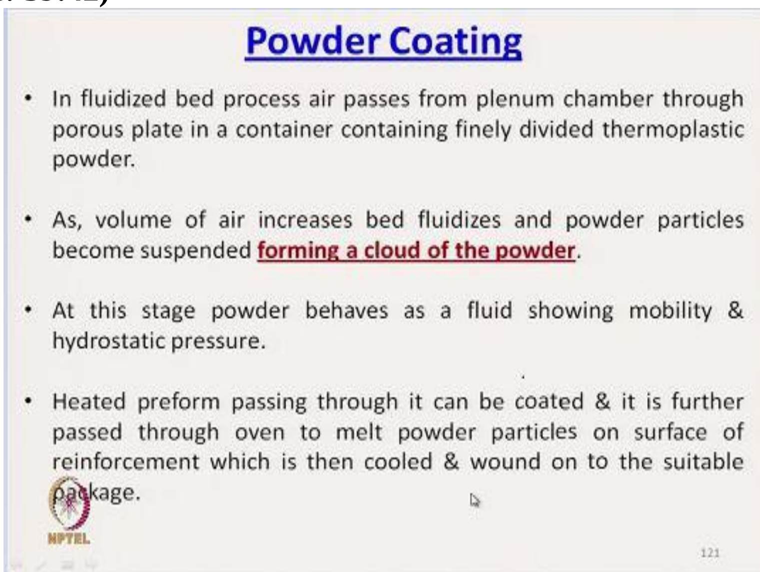

Now, I will discuss the powder coating. The powder coating is done through fluidized bed. What is fluidized bed? In this process, the air passes from a plenum chamber through porous plate in a container containing finely ground thermoplastic powder. As the volume of air increases the bed fluidize and powder particles become suspended forming clouds of powder.

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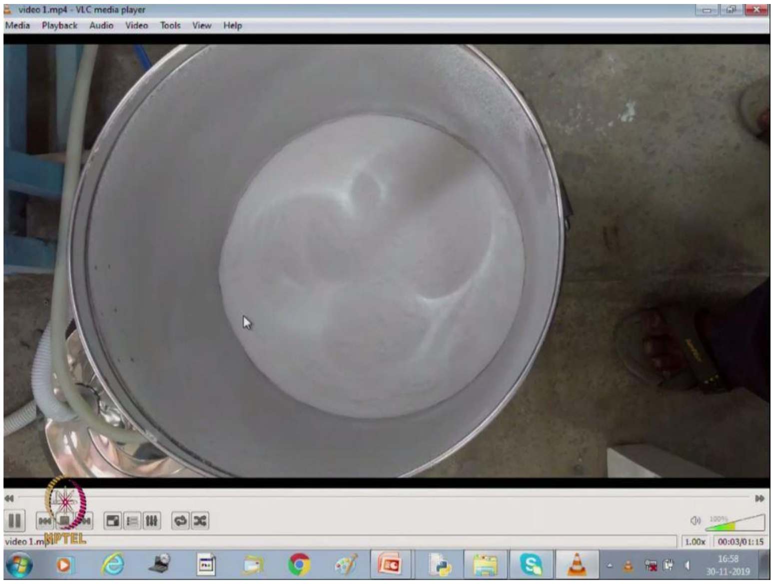

Now let us see here these are the powders of thermoplastic matrix. Now air is being supplied at the bottom, now gradually we will see this bed will become fluidize and the powder will start escaping from that. This is just like it is boiling. So this is and due to the air supplied and while doing this the particles will form cloud. So, as the volume of air increases the bed fluidize and powder particles become suspended, it will start forming the cloud of powder.

So, at this stage, the powder behaves like a fluid, it will just like fluid just like it so, it was just like boiling and it will the particles will have mobility and the heated preform after coating when it passes through the oven, and this powdered melts and covers the surface of the reinforcing fibre. And after that it is cooled down and the prepreg it is so flexible we can wind in a package. So, this is the powder coating method, basic method and I will continue discussing the powder coating techniques and detail the methods of powder coating in next class. Till then thank you.