Textile Product Design and Development
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Lecture – 09
Significance of Yarn Characteristics in Design

We will discuss the importance of yarn characteristics and its role in fabric design. We are already familiar with the different types of yarns available. Yarns are generally classified into two main categories: spun and filament yarns. Within spun yarns, further classification can be made based on the type of fibre used, the preparation techniques, and the spinning system employed. Yarn is classified according to the fibre type, which is single-component yarns and blended yarns. Single-component yarns are 100% cotton, 100% polyester, or 100% wool, and blended yarns are two or more fibres blended to produce a yarn.

Examples could be a 50/50 mix of cotton and polyester, polyester and viscose or other proportions. Preparation technique-wise, if we follow the spun yarn route, there are two possibilities: carded and combed yarn. Additionally, the spinning systems used to produce the yarn can vary. Yarn can be produced using various spinning methods, such as ring spinning, compact spinning, rotor spinning, vortex spinning, or friction spinning. Each method results in yarns with distinct characteristics, which influence the properties of the final product.

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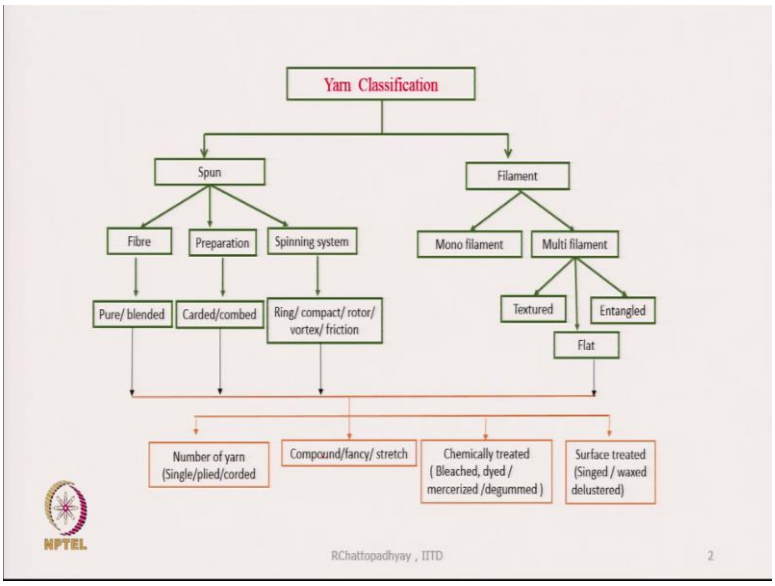

Filament yarns can similarly be classified into two groups: monofilament and multifilament. Multifilament yarns can be further divided into three categories: textured, entangled, or flat. Beyond this, different combinations of yarns can be produced. For example, compound yarns can be created by combining two different types of yarns. Additionally, yarns can be classified as single yarns or plied yarns, where multiple strands are twisted together.

Similarly, we can have fancy yarns or stretch yarns. Yarns can also be chemically treated to alter their properties, resulting in products such as bleached yarn, dyed yarn, mercerized yarn (in the case of cotton), or degummed yarn (for silk). Additionally, surface treatments can be applied to modify the physical characteristics of the yarn, such as singed yarn, waxed yarn, or delustered yarn. The world of yarn is vast, with a wide variety of yarn types available. When creating something from these different yarns, the physical appearance and properties of the fabric can vary significantly. As a designer, one has lots of choices and to manipulate or engineer the properties of the final product.

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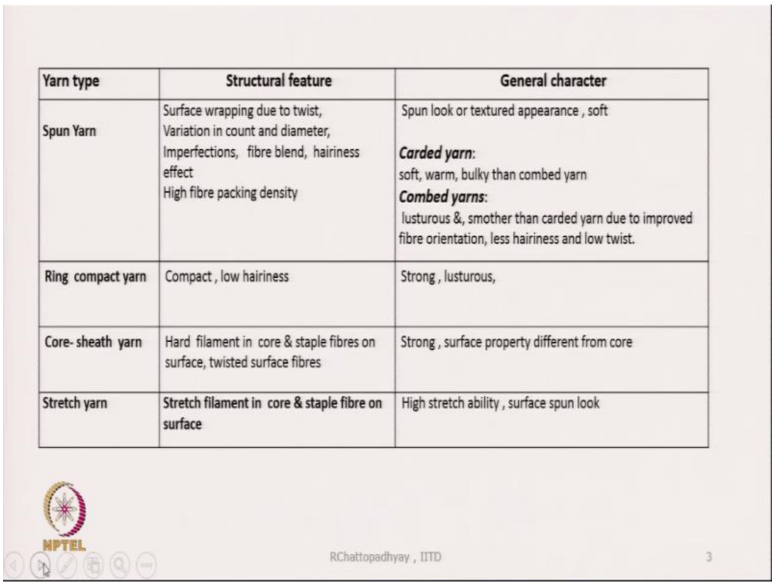

Yarn type	Structural feature	General character
Spun Yarn	Surface wrapping due to twist, Variation in count and diameter, Imperfections, fibre blend, hairiness effect High fibre packing density	Spun look or textured appearance , soft ***Carded yarn***: soft, warm, bulky than combed yarn ***Combed yarns***: lusturous &, smother than carded yarn due to improved fibre orientation, less hairiness and low twist.
Ring compact yarn	Compact , low hairiness	Strong , lusturous,
Core- sheath yarn	Hard filament in core & staple fibres on surface, twisted surface fibres	Strong , surface property different from core
Stretch yarn	**Stretch filament in core & staple fibre on surface**	High stretch ability , surface spun look

Yarn types and their basic structural characteristics are represented in the table. What are the basic structural characteristics of these yarns? Generally, spun yarns have visible surface wrapping or fibres due to the twist. These yarns often exhibit variations in count and diameter. They always have some imperfections. Additionally, spun yarns have hairiness; typically, a high fibre packing density is also expected.

These are the structural features of spun yarns, and the general character, as a result, gives a spun look or a textured appearance. The spun yarns are generally soft. Within spun yarns, there are two varieties based on the manufacturing process: carded and combed. Carded yarns are soft and warm because of their bulkier nature and have higher porosity than combed yarns. Combed yarns are generally lustrous, smoother, and less hairy due to the removal of short fibres and a low twist.

Compact yarns have a very compact structure, meaning the yarn diameter is lower or thinner for the same count. These yarns are strong and lustrous because their tightly packed structure reduces surface hairiness. Similarly, structural features and general characteristics are stated in the table for other types of yarns. These features help the designers to find out the characteristics that can be expected from the final product.

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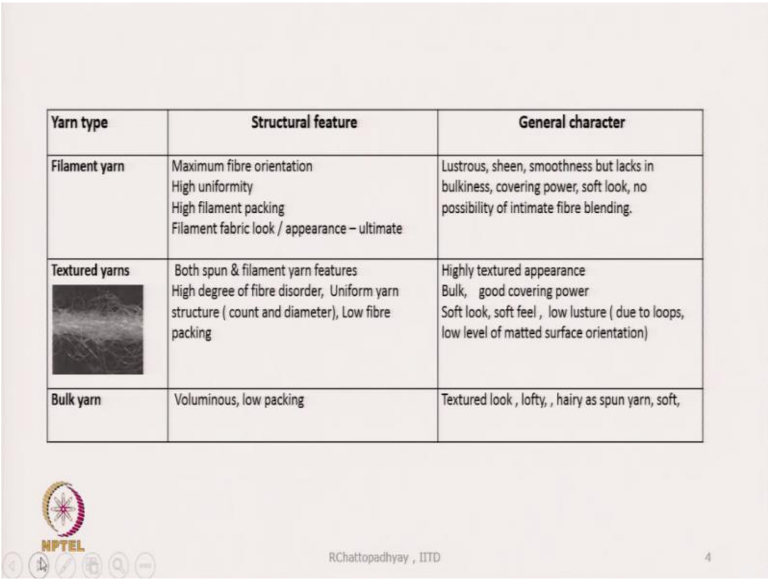

Yarn type	Structural feature	General character
Filament yarn	Maximum fibre orientation High uniformity High filament packing Filament fabric look / appearance – ultimate	Lustrous, sheen, smoothness but lacks in bulkiness, covering power, soft look, no possibility of intimate fibre blending.
Textured yarns	Both spun & filament yarn features High degree of fibre disorder, Uniform yarn structure (count and diameter), Low fibre packing	Highly textured appearance Bulk, good covering power Soft look, soft feel , low lusture (due to loops, low level of matted surface orientation)
Bulk yarn	Voluminous, low packing	Textured look , lofty, , hairy as spun yarn, soft,

Filament yarns have high fibre orientation due to the absence of staple fibres, resulting in a uniform texture and high packing density, which varies with the twist level. They are characterized by their lustrous sheen and smoothness but tend to lack bulkiness and covering power. Filament yarns are ideal for fabrics that need to be highly lustrous and free from surface hairs. If achieving an intimate blend of two different types of fibres is important, filament yarns may not be ideal. This is because blending filaments from different filament yarns can be challenging and may not yield the best results.

Textured yarns typically exhibit a high degree of fibre disorder, as depicted in the image, but they maintain a uniform structure with lower fibre packing density. So it provides a textured appearance. In contrast, filament yarns are highly lustrous due to an extensive light reflection from the fibre, yarn, and fabric surface. It enhances the shine and smoothness of the filament yarns.

To avoid a highly lustrous appearance in such applications, textured yarns are beneficial because their disoriented surface fibres scatter light, giving a spun look. It has better covering power because of its bulkier nature in comparison to 100% filament yarns. Additionally, bulk yarns, known for their voluminous structure, are ideal for products where fabric bulkiness is desirable.

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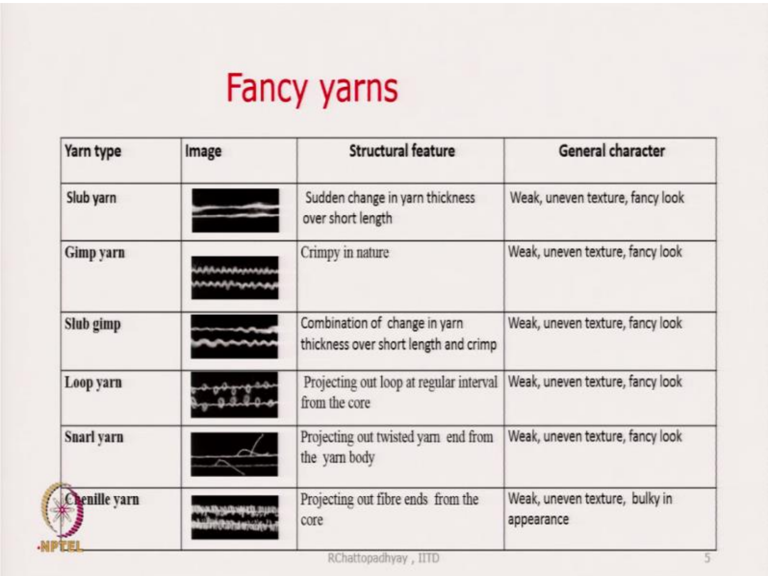

The next discussion is on the fancy yarns. There are many types of fancy yarns produced by the industry, including slub yarns, gimp yarns, slub gimp, loop yarns, snarl yarns, and chenille yarns. Each type has distinct structural features and characteristics. Fancy yarns are primarily used to enhance the aesthetic aspect of fabrics and garments. So, many other types of fancy yarns are available other than those stated in the slide.

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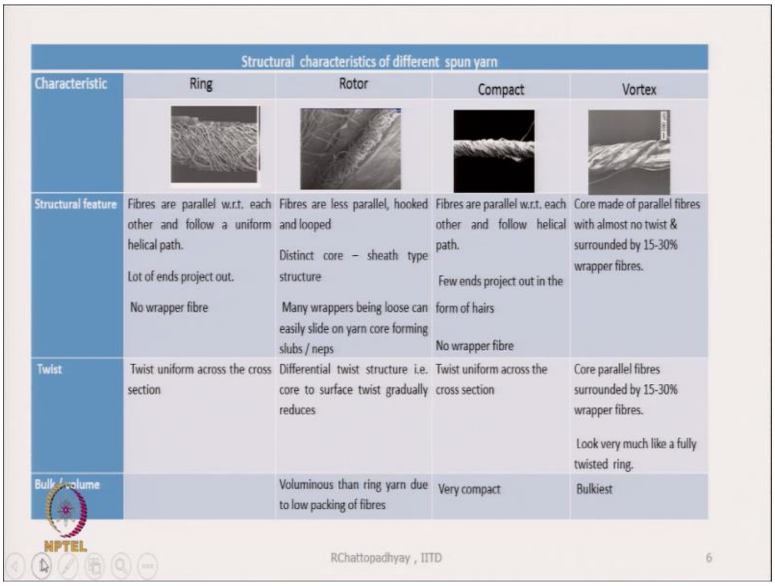

The table provides detailed structural characteristics of different spun yarns, accompanied by images that illustrate their appearances. These images give an idea about the expected fabric outcomes when using these yarns. Commercially, products made from various types of spun yarn, such as ring yarn, rotor yarn, compact yarn, and vortex yarn, are available. Understanding the structural characteristics of yarn is crucial for selecting the most appropriate yarn for a specific product. This comparative chart is designed to evaluate and choose the right yarn by highlighting various attributes and how they affect the final fabric. By analysing these characteristics, one can make informed decisions to achieve the desired properties in a product.

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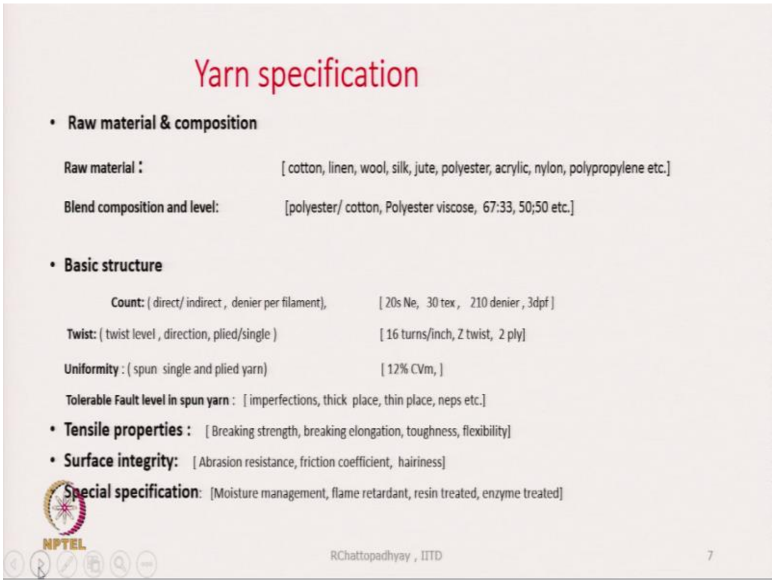

The other thing is the yarn specification. A designer must know the specifications of yarns from some manufacturers or vendors. The first consideration is the raw material and their compositions. The raw material could be cotton, linen, or wool. It also could be a blend composition such as polyester-cotton or polyester-viscose. Specification of blend composition must be mentioned.

Blends can vary from binary blends with two components to tertiary blends with three components and even more complex blends involving four or more components. Manufacturers can provide yarns with these diverse blend combinations to meet specific performance and aesthetic requirements.

The yarn count also must be specified, which indicates its fineness. The level of twists required should also be detailed, as twists can play an important role in deciding the yarn's character and, consequently, the fabric's character. Additionally, the uniformity level of the yarn should be specified. The tolerable level of faults in yarn must be specified, such as imperfections, thick places, and thin places.

In spun yarns, achieving a completely fault-free yarn is challenging. Technology is such that to minimize the number of faults, completely fault-free yarn is not able to be produced. The other important aspect is the tensile property, i.e., breaking strength, breaking elongation, and toughness. Surface integrity is the abrasion resistance, frictional coefficient or hairiness.

Other special specifications could be moisture management, flame retardant, resin treatment, or enzyme treatment. There are many factors involved in determining yarn specifications. When purchasing yarn from a vendor, specifying these factors, including the actual values, ensures the type of yarn needed for the project.

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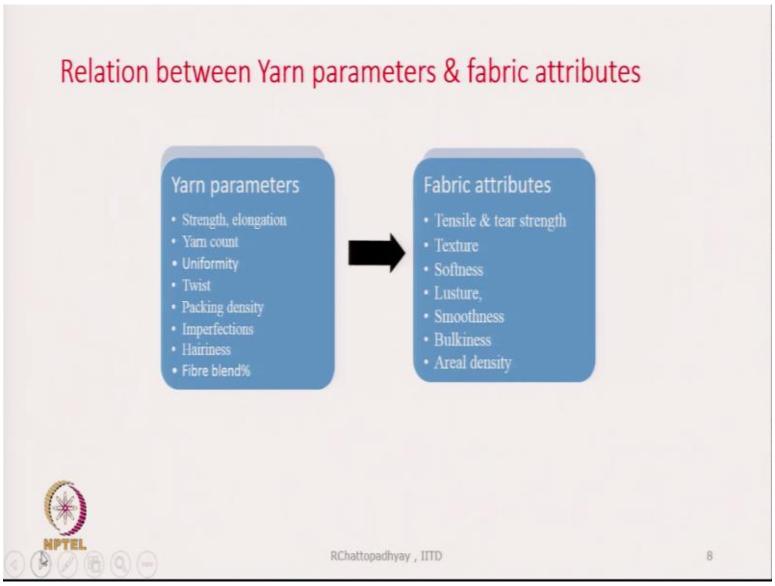

The most important thing is the relation between yarn parameters and fabric attributes. Since fabrics are made from yarn, it is natural that the properties of the yarn influence the properties of the fabric. Yarn characteristics such as strength, elongation, yarn count, uniformity, twist, packing density, imperfections, hairiness, and fibre blend percentage are all key parameters that directly impact the final fabric's performance and appearance.

The fabric attributes affected by yarn properties include tensile or tear strength, texture, softness, lustre, smoothness, bulkiness, and areal density. The yarn parameters directly influence many fabric attributes. Therefore, to achieve specific fabric properties, it is essential to understand which yarn parameters influence those attributes. Twist is one of the yarn parameters which affects fabric attributes. The twist is needed, especially in spun yarns, though the filament yarns are also twisted. Twist is a fundamental structural parameter of a yarn.

The twist insertion aims to improve coherence between the fibres, whether in filament or spun yarn. In staple fibre yarns, twisting is crucial in improving coherence and strength. This is particularly important because, without twists, the fibres in staple yarn tend to slip from each other under tensile load, resulting in weak yarn.

Therefore, the twist is essential to enhance fibre cohesion and increase the overall strength of the yarn. In contrast, filament yarns are inherently strong, even without twist, due to the continuous nature of the fibres. In filament yarns, the fibres are continuous, unlike in staple fibre yarns, where the yarn is made up of discrete fibres. A twist is introduced to hold these individual fibres together. The other important aspects that are affected by twisting are the abrasion resistance and fatigue behaviour of the yarns.

Most textile products are abraded against external surfaces, against itself or even against the human body. Since abrasion is a common occurrence for textile products, a twist is introduced into the yarn to enhance its abrasion resistance. The other aspect is fatigue resistance. Yarns often experience cyclic extensions, leading to fatigue, which eventually causes them to fail. Twist plays an important role in improving fatigue resistance.

Additionally, a twist affects the flexural rigidity of yarn; by adding a twist, the compactness of the yarn increases, which in turn enhances its bending rigidity. Therefore, a sufficient amount of twist is essential if a compact yarn is desired. Hence, twist significantly impacts numerous yarn properties, and it can completely change the character of the yarn, which in turn affects the fabric's overall attributes.

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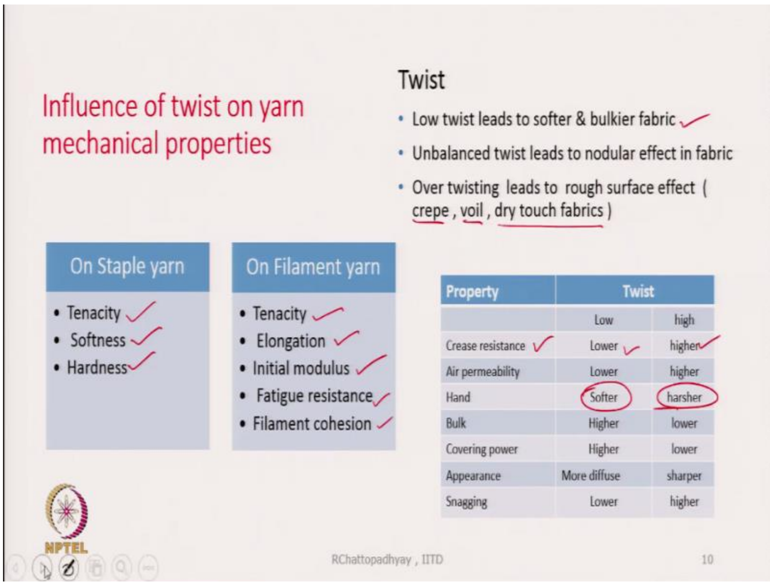

Next is the influence of twisting on the mechanical properties of yarns. For staple yarns, the amount of twist will initially increase tenacity, but excessive twist can reduce the yarn strength. The twist-tenacity curves explain this behaviour. Twist also influences the softness of yarn. An increase in twist produces harder yarn, which is the opposite of softer yarn. Twist affects several key properties of yarns.

For staple yarns, it influences softness, hardness, and tenacity. In filament yarns, twist impacts tenacity, elongation, modulus, fatigue resistance, and filament cohesion. Generally, low twist results in a softer and bulkier yarn, leading to a softer and bulkier fabric. Conversely, an unbalanced twist can cause a nodular effect in the fabric.

If the twist is not balanced, it negatively affects the appearance of the fabric. An unbalanced twist may lead to snarling tendencies in ply yarns or excessive roughness in the surface of over-twisted yarns. In certain cases, excessive twisting of the yarn can impart desirable characteristics to the fabric, such as those seen in crepe fabrics, voile, and dry-touch cotton fabrics, which are popular.

The table at the bottom of this slide illustrates how the twist in the yarn influences various properties of the fabric. Crease resistance is an example of how twist affects fabric properties. A lower twist generally results in lower crease resistance, while a higher twist improves crease resistance. Similarly, twist influences air permeability, hand value, bulkiness, covering power, appearance, and snagging.

For hand value, if the twist is low, the fabric feel is softer and more comfortable. In contrast, high twists result in a harsher feel, making the fabric more desirable for specific applications like crepe and voile fabrics. Despite their harsher texture, these fabrics are preferred for their unique appearance and other properties, such as stretchability, which are enhanced by higher twist levels. So, we expect varieties of properties in a fabric, and we want certain properties to be predominant in certain types of products. Therefore, even though in some respects the property may suffer, in some other respects, the property is something which is desirable.

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This slide provides insight into the levels of twists used in different types of yarns. The twist is quantified by the twist factor, which determines the inclination angle of the fibres within the yarn. Measuring this angle directly can be challenging and cumbersome, often requiring a microscope, a glass slide to fix the yarn, and careful measurement procedures. The twist factor is a numerical value that correlates directly with the inclination angle of the fibres on the surface of the yarn.

The higher the twist factor, the greater the inclination of the fibres with respect to the yarn axis. For knitting yarn, the twist factor typically ranges from 3 to 3.5. These values correspond to twist factors when the yarn count is expressed in the Ne, i.e., the English count system, which is widely used in the spun yarn industry, particularly in cotton spinning. So, for knitting yarn, the twist factor is typically between 3 and 3.5, while for weft yarns, it ranges from 3.5 to 4, and for warp yarns, it is between 4 and 4.5, or even up to 5 in some cases.

Crepe yarns generally have twist factors from 5.0 to 5.5, and for voile yarns, the twist factor exceeds 5.5. This wide range of twist factors results in different yarn characteristics. A lower twist factor leads to softer yarn, but it also makes the yarn weaker. For knitting yarns, very high yarn strength is not required because the stress during the knitting process is much lower compared to the stress on yarns during weaving on a loom. This allows for using yarns with less twist in knitting operations.

Additionally, knitted products are generally designed to be soft, and a lower twist means the yarn will be softer, resulting in a softer fabric. For example, intimate garments are often made from knitted fabrics with low-twist yarns to achieve softness.

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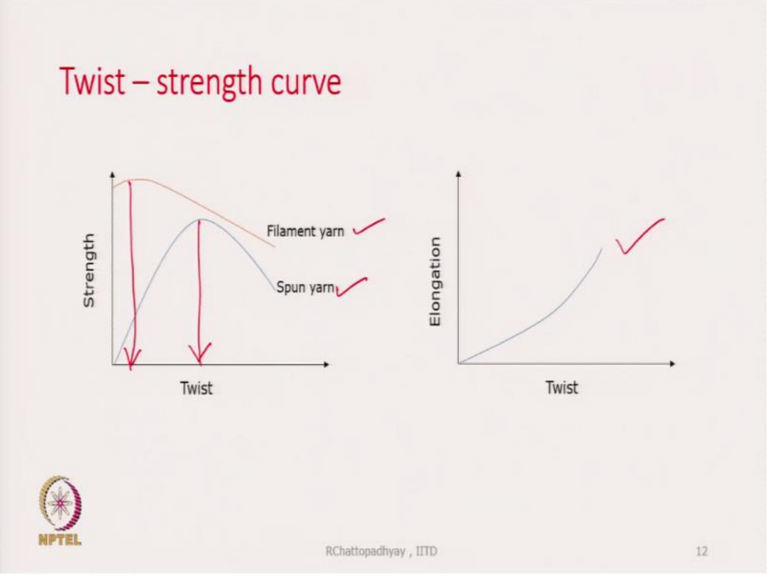

Next, we move to the twist-strength curve. As mentioned earlier, twist plays a crucial role in determining the strength of yarn, particularly for spun yarn. In the twist-strength curve for spun yarn, it is observed that the strength initially increases with twist, reaches an optimum level, and then starts to decrease. This forms a characteristic curve where there is an optimal twist level that maximizes strength. For filament yarns, the strength initially rises a little with the introduction of a twist, but it steadily decreases as the twist increases.

Initially, as we increase the twist in the spun yarn, the yarn strength rises because the cohesion between the fibres improves. However, beyond a certain point, the obliquity effect comes into play. This refers to the fibres becoming more inclined or slanted with respect to the yarn axis. As a result, the fibre strength realization in the yarn decreases, which overtakes the benefits of increased cohesion, causing the yarn strength to start declining beyond the optimum twist level.

A small amount of twist is applied for filament yarn, and the yarn reaches its maximum strength relatively quickly. Beyond this point, adding more twists leads to a gradual reduction in strength. The general trend in the elongation versus twist plot is that as the twist increases, the elongation also increases. This is particularly common in spun yarns.

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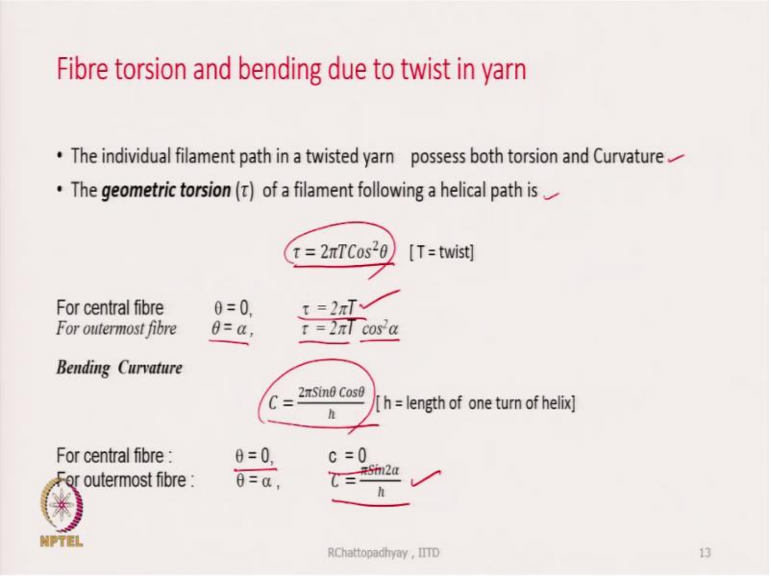

The other aspect is the fibre torsion and bending due to twisting in the yarn. In a twisted yarn, each fibre or filament follows a spiral path, which leads to both torsional and bending stress. The fibres are forced into this spiral structure as the twist is applied, causing them to bend and experience a certain degree of torsion along their own axes. In spun yarns, made from cotton, linen, wool, or even polyester blends, this torsion and curvature do not significantly affect the yarn's performance.

However, it has some influence in the case of yarns made from high-tenacity fibres. The torsion of a filament following a helical path is shown by the equation, '$\tau = 2\pi T\, cos^2\, \theta$' where '$\theta$' is the inclination angle, and 'T' is the level of twist. For a central fibre, where '$\theta = 0$' i.e., there is no twist. So, the torsion value is '$\tau = 2\pi T$', which means that for a central fibre with no inclination, the torsion is directly proportional to the twist level. For the outermost fibre, '$\theta = \alpha$' and torsion value is '$\tau = 2\pi T\, cos^2\, \alpha$', which means that the fibres at the core of the yarn are subjected to maximum torsional stress, while the outermost fibres experience less torsion.

The bending curvature of the fibre is given by '$c = \frac{2\pi \sin\theta \cos\theta}{h}$' where '$h$' is the length of one turn of the helix. For the central fibre, '$\theta = 0$' and therefore, bending curvature '$c = 0$'. The central fibre follows a straight path along the yarn axis and experiences no bending. But for the outermost fibre in the yarn surface, bending curvature is '$c = \frac{\pi \sin 2\alpha}{h}$'. If the torsion is maximum for the central fibre, the fibres that are weak to torsional stresses, like glass fibre, are damaged.

Technical yarns are often made from high-performance fibres such as glass, carbon, or high-density polyethene (HDPE) fibres. These fibres are known for their exceptional strength but tend to exhibit weaknesses in their shear strength. When a yarn made from these fibres is twisted excessively, the central filaments are subjected to high torsion stresses. If the level of torsion surpasses the critical value, some damage occurs to the filaments.

Yarns made from high-tenacity fibres are typically given only a small amount of twist, just enough to hold the fibres together and prevent them from spreading out. When too much twist is applied, the fibres are forced to follow a bending path and are subjected to torsional stresses, which can negatively impact their properties.

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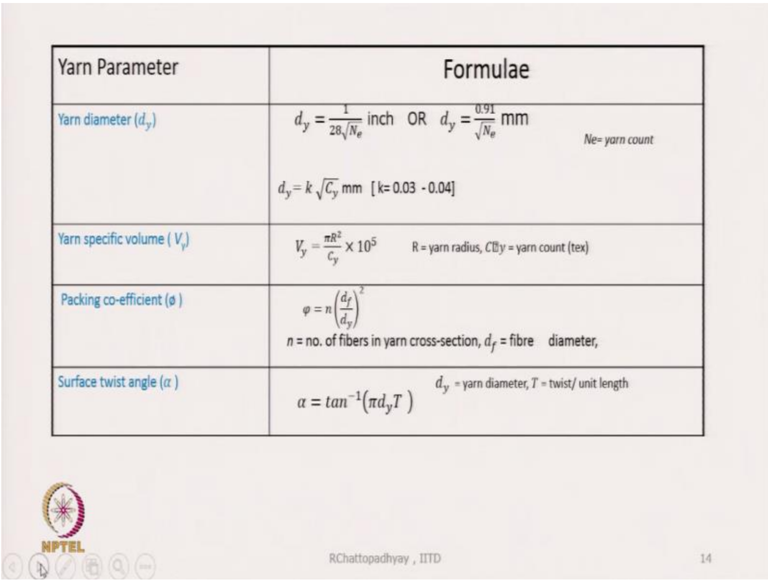

Yarn Parameter	Formulae
Yarn diameter (d_y)	$d_y = \frac{1}{28\sqrt{N_e}}$ inch OR $d_y = \frac{0.91}{\sqrt{N_e}}$ mm *Ne= yarn count* $d_y = k\sqrt{C_y}$ mm [k= 0.03 - 0.04]
Yarn specific volume (V_y)	$V_y = \frac{\pi R^2}{C_y} \times 10^5$ R = yarn radius, Cy = yarn count (tex)
Packing co-efficient (ø)	$\varphi = n\left(\frac{d_f}{d_y}\right)^2$ n = no. of fibers in yarn cross-section, d_f = fibre diameter,
Surface twist angle (α)	$\alpha = tan^{-1}(\pi d_y T)$ d_y = yarn diameter, T = twist/ unit length

In this slide, several important formulas are presented which are familiar. However, for a designer, readily available formulas are crucial for performing calculations as needed during the design process. These formulas include yarn diameter, yarn-specific volume, packing coefficient, and surface twist angle. Each of these parameters plays a key role in understanding and predicting the behaviour of yarns.

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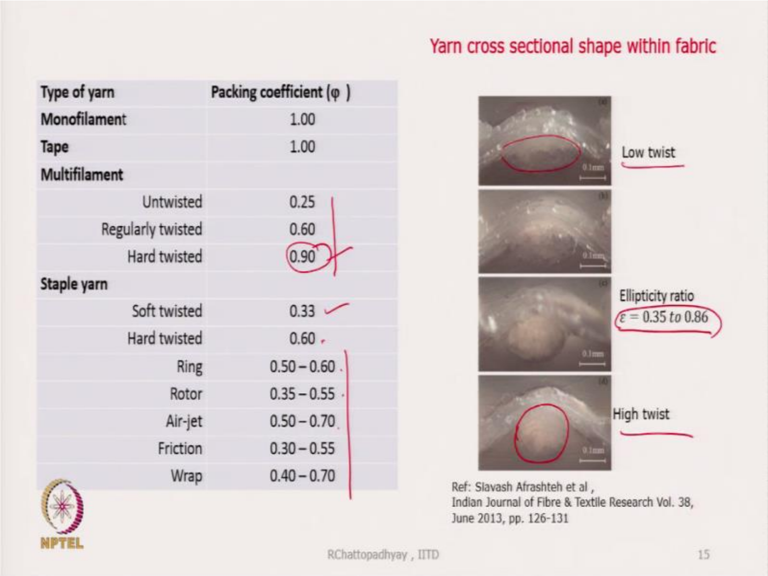

The cross-sectional shapes of yarns within fabrics are shown here, along with a table on the left-hand side displaying the packing coefficient of yarns. This is significant because the way fibres are packed within a yarn can impact both the properties of the yarn and the fabric. In multifilament yarns, the packing coefficient varies based on the level of twist. For untwisted or yarns with a minimal twist, the packing coefficient is around 0.25.

Regularly twisted yarns have a packing coefficient of around 0.60. Hard twisted yarns can reach a packing coefficient of 0.9, which is the maximum expected packing when the fibres are circular in shape. Soft twisted yarns may have a packing coefficient of around 0.33 for staple fibre yarn. Hard twists bring the coefficient up to around 0.60. The packing coefficient essentially indicates the proportion of space occupied by the fibres in a yarn.

In other words, the volume of fibres occupied in the given volume of yarn. This is the packing coefficient of yarn. This concept can also be extended to fabric, i.e., the volume occupied by the fibres in a given volume of fabric. The rest of the volume is filled by void space. On the right-hand side, images depict the deformation of yarns within the fabric under varying levels of twist. Four images are presented: one for low twist, one for high twist, and two for intermediate twist levels. These images are specific to filament yarns. In the low-twist image, it is observed that the cross-sectional shape of the yarn appears more elliptical.

As the twist increases, the yarn shape becomes almost circular as shown in the high-twist image. The degree of deformation that a yarn experiences within a fabric is influenced by the amount of twist inserted into the yarn. This deformation is measured by a parameter known as ellipticity. The ellipticity ratio typically ranges from 0.35 to 0.86, as stated in various research studies on filament yarns within fabrics. This deformation occurs due to the forces acting at the points of interlacement where yarns press against each other. As a result of these forces, yarns, which are circular in cross-section, become deformed and take an elliptical shape.

The degree of deformation depends on the level of packing in the yarn, which is influenced by the amount of twist inserted into the yarn. Since the thickness is a function of the yarn deformation, it becomes clear that the packing coefficient of the yarn is vital. Thus, twist is a key factor in fabric design, affecting both structural and mechanical properties.

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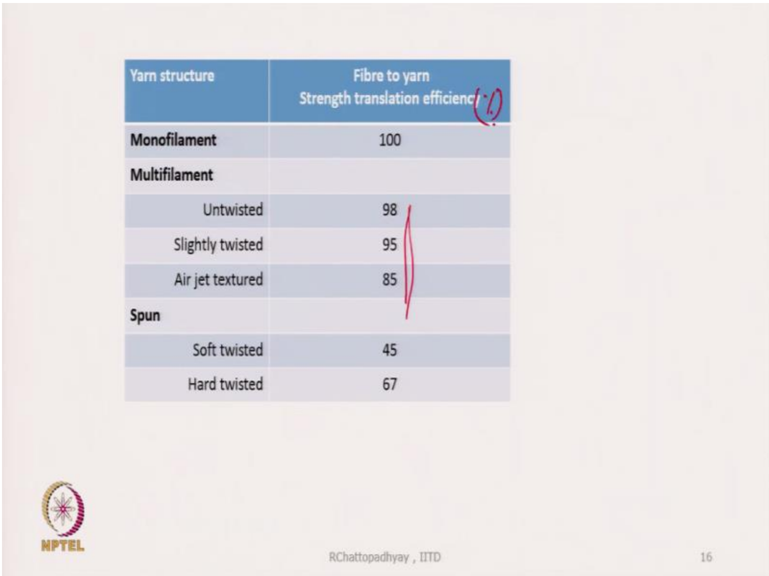

Yarn structure	Fibre to yarn Strength translation efficiency (%)
Monofilament	100
Multifilament	
Untwisted	98
Slightly twisted	95
Air jet textured	85
Spun	
Soft twisted	45
Hard twisted	67

The strength translation efficiency from fibre to yarn is an important aspect, as it indicates how much of the inherent strength of the fibres is translated to the final yarn. For multi-filament yarns, the efficiency is quite high due to the continuous nature of the fibres. For example, untwisted yarns can retain about 98% of the fibre strength, and slightly twisted yarns about 95%.

Air-jet textured yarns exhibit a lower efficiency at around 85%. However, for spun yarns, the strength translation is generally lower. Soft twisted yarns retain about 45% of the fibre strength, while hard twisted yarns manage to retain around 67%. So, this gives an idea about the strength of fibre that can be expected to be translated into the yarn.

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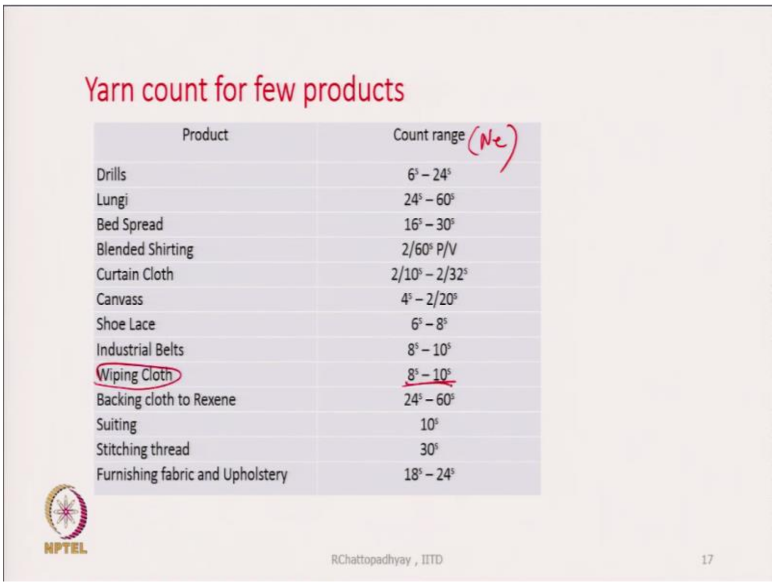

Generally, yarn counts used for different types of products are different. Some products and the corresponding count range used to produce them are stated in this particular table. Lungi, bedspread, blended shirting, curtain cloth, shoelace, and different types of product names are here on the left-hand side. The count is typically measured in Ne (English count system). The right-hand side in the table indicates the range of counts which are used to produce them. This is useful from the point of view of designing a particular type of cloth or a particular type of product.

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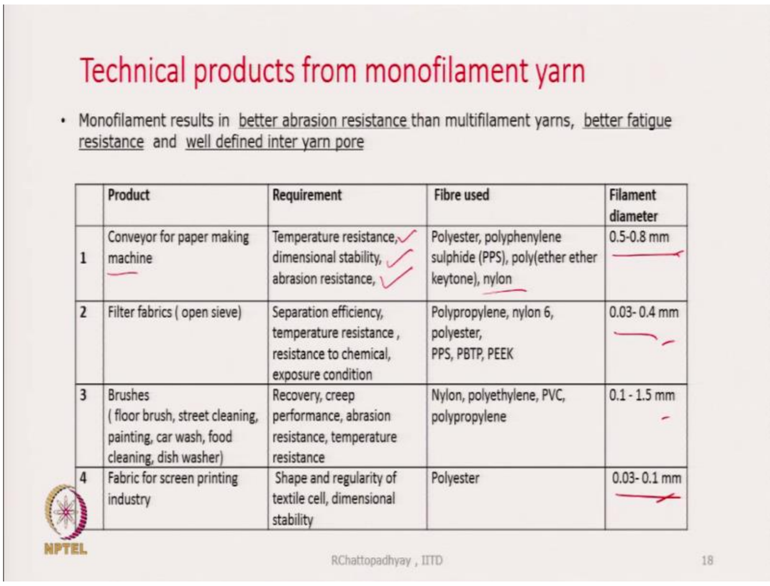

Next are the technical products that come from monofilament yarn. Monofilaments consist of a single continuous filament. Monofilaments result in better abrasion resistance than multifilament yarn, better fatigue resistance, and a well-defined inter-yarn pore when it is in fabric form. Some examples of products that utilize monofilament yarns are listed, along with the types of fibres used and their typical filament diameters. For conveyor belts used in paper-making machines, the fibres employed need to meet specific requirements, including temperature resistance, dimensional stability, and high abrasion resistance. These technical products and fibres used are polyester, polypropylene sulphide, polyphenylene sulphide, polyether ether ketone, and nylon. Technical requirements, fibres used and filament fineness in terms of diameter are stated.

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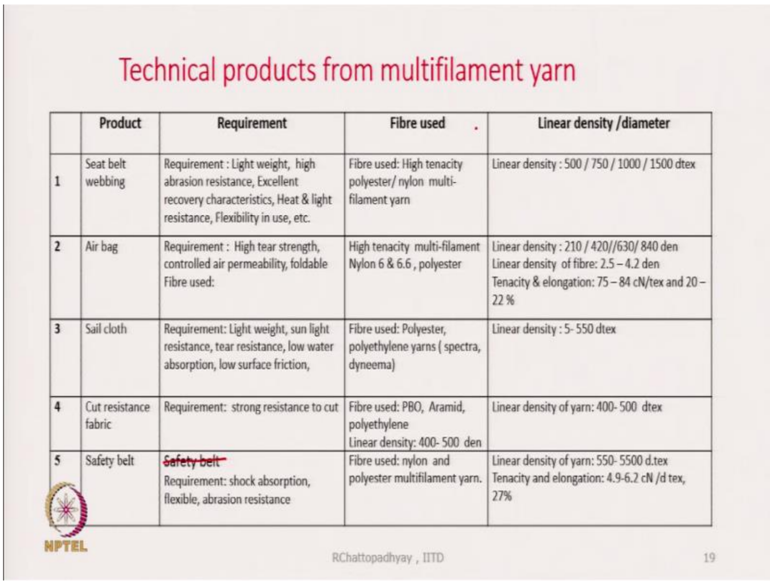

Technical products from multifilament yarn

	Product	Requirement	Fibre used	Linear density /diameter
1	Seat belt webbing	Requirement : Light weight, high abrasion resistance, Excellent recovery characteristics, Heat & light resistance, Flexibility in use, etc.	Fibre used: High tenacity polyester/ nylon multi-filament yarn	Linear density : 500 / 750 / 1000 / 1500 dtex
2	Air bag	Requirement : High tear strength, controlled air permeability, foldable Fibre used:	High tenacity multi-filament Nylon 6 & 6.6 , polyester	Linear density : 210 / 420//630/ 840 den Linear density of fibre: 2.5 – 4.2 den Tenacity & elongation: 75 – 84 cN/tex and 20 – 22 %
3	Sail cloth	Requirement: Light weight, sun light resistance, tear resistance, low water absorption, low surface friction,	Fibre used: Polyester, polyethylene yarns (spectra, dyneema)	Linear density : 5- 550 dtex
4	Cut resistance fabric	Requirement: strong resistance to cut	Fibre used: PBO, Aramid, polyethylene Linear density: 400- 500 den	Linear density of yarn: 400- 500 dtex
5	Safety belt	~~Safety belt~~ Requirement: shock absorption, flexible, abrasion resistance	Fibre used: nylon and polyester multifilament yarn.	Linear density of yarn: 550- 5500 d.tex Tenacity and elongation: 4.9-6.2 cN /d tex, 27%

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Similarly, multifilament yarns are used in various technical products. Some typical technical products like seat belts, airbags, sailcloth, cut resistance fabric, safety belts, and their requirements and linear densities are all stated. In this lecture, the different types of yarns used, their general characteristics, and their influence on the properties of the fabric are discussed. One of the most important yarn parameters is the twist and the role of twist in deciding different properties of the fabric. This kind of information is important because it helps the designer choose the right type of yarn. Thank you.