Textile Product Design and Development

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Lecture – 19
Water Absorbing Medium

We will discuss absorbing mediums, focusing on two popular products: the towel and the gamchha. Some of you may not be familiar with the gamchha, which is commonly used in rural areas for the same purpose as a towel to wipe the body after bathing. Both products serve a similar function, and design aspects are explained further.

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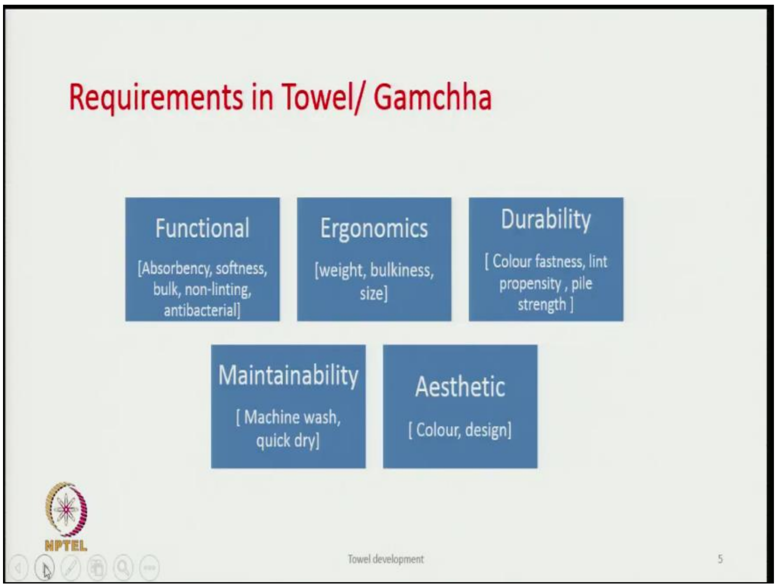

Several key requirements are considered when designing towels and gamchha. First and foremost are the functional aspects, where factors like absorbency, softness, bulkiness, non-linting nature, and, if possible, antibacterial properties are of primary importance. The next critical aspect is ergonomics, where weight and size play a significant role. If a towel is too heavy or too large for the user, then it affects the utility value of the product.

Weight, bulkiness, and size are part of the ergonomics aspect. The next one is durability. Users generally have specific expectations regarding the product's lifespan. The durability of these items depends on several factors, including colour fastness. Another important aspect, especially for towels, is the propensity for lint generation. The strength of the pile is vital for towels, as the pile loops should not be easily pulled out.

These are the key aspects of durability. Colour fastness refers to the fabric's resistance to fading from sunlight, washing, and rubbing, which are all important factors. Another important aspect is maintainability, specifically how easy the fabric is to care for, such as whether it is machine washable. In most urban households, washing machines are common and increasingly rely on them for everyday laundry.

Whether the fabric can be machine-washed or not is an important consideration. Another key factor is how quickly it dries, especially during seasons with heavy rainfall and high humidity. In such conditions, items like towels or gamchha are not dried quickly and take a long time to dry. Quick drying is sometimes extremely important.

Another key aspect is aesthetics, which refers to the overall appearance of the product, where both colour and design play a significant role. This is why gamchha and towels come in various colours and designs, including border patterns and other decorative elements. These five factors are the most important requirements for a towel or gamchha.

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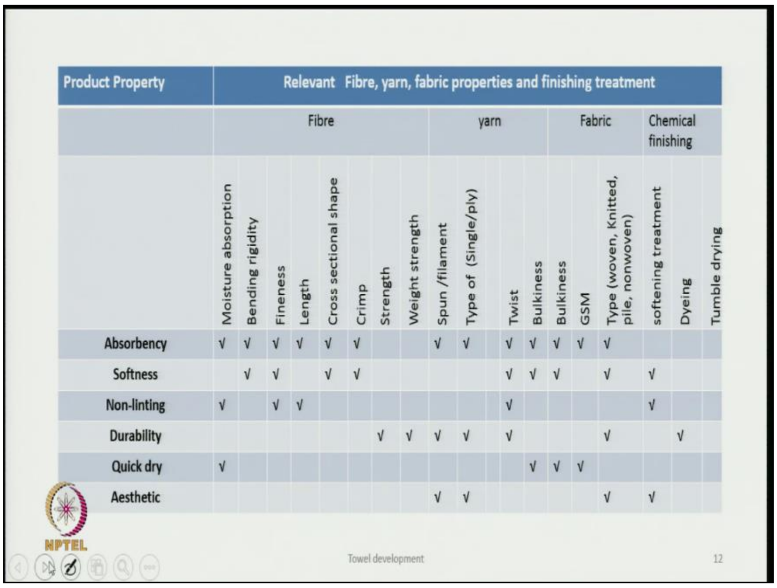

Product Property	Relevant Fibre, yarn, fabric properties and finishing treatment																
	Fibre								yarn				Fabric			Chemical finishing		
	Moisture absorption	Bending rigidity	Fineness	Length	Cross sectional shape	Crimp	Strength	Weight strength	Spun /filament	Type of (Single/ply)	Twist	Bulkiness	Bulkiness	GSM	Type (woven, Knitted, pile, nonwoven)	softening treatment	Dyeing	Tumble drying
Absorbency	√	√	√	√	√	√			√	√	√	√	√	√	√			
Softness		√	√		√	√					√	√	√		√	√		
Non-linting	√		√	√							√					√		
Durability							√	√	√	√	√				√		√	
Quick dry	√											√	√	√				
Aesthetic									√	√					√	√		

Next comes the properties of the fibre, yarn, fabric, and the finishing treatments applied to a product and how these relate to the requirements are listed. The first key requirement is absorbency. When evaluating absorbency, specific fibre properties, yarn characteristics, fabric structure, and chemical finishing treatments are examined. Wherever a tick mark appears, it indicates that the respective property of the fibre, yarn, or fabric is crucial for enhancing absorbency.

In cases where absorbency needs to be improved, identify the relevant parameters that affect absorbency and modify them, if possible, to meet the requirement. When examining fibre properties related to absorbency, the first key factor is moisture absorption, as indicated by a tick mark. Moisture absorption is important for absorbency. The bending rigidity of the fibres is also considered to be important because this property determines how tightly the fibres can be packed into a yarn. If the yarn has many pores, it will absorb more moisture and water, making bending rigidity relevant to absorbency.

Additionally, bending rigidity is significant from a softness perspective. Fineness is also an important factor, as it determines the total surface area of the fibre. The length of the fibres, combined with their fineness, will be important because this decides how many twists can be applied to the yarn. If the fibres are both long and fine, less twist can be applied while still achieving sufficient strength. This results in more pores within the yarn, increasing absorbency.

The cross-sectional shape of the fibres is also important; the more irregular the cross-section, the more porous the yarn structure will be. Crimp is also significant, but strength and weight are not critical factors from an absorbency point of view. Additionally, the type of yarn also influences absorbency, whether it is spun yarn or filament yarn or, single yarn or plied yarn. Plied yarns are generally softer and depending on the twist level in both single and plied yarns can also influence their porosity.

Twist is, therefore, an important parameter. Additionally, the overall bulkiness of the yarn is affected by the twist, as well as the type of fibre and the cross-sectional shape of the fibres used. From the fabric perspective, factors such as bulkiness, areal density, and the type of fabric, whether knitted, woven, pile, or nonwoven, are important. Each fabric form has distinct characteristics, and absorbency will vary accordingly.

Generally, the absorbency depends on the fabric type, as some forms are more porous than others, and therefore, the total amount of liquid that can be absorbed will also be dependent on the form of the fabric. Chemical finishing treatments may not significantly impact absorbency, particularly when using hydrophilic fibres. The next important factor is softness. A towel or gamchha that comes into contact with the skin must be very soft, especially after a bath when the skin is particularly sensitive.

Therefore, rubbing something against soft skin needs the use of soft materials. There may be a chance of abrasive damage to the skin, and therefore, the fabric used has to be soft. Any fabric that comes into contact with the skin should be soft, and in the case of towels or gamchha, this softness is especially important. Factors that influence this softness include the bending rigidity of the fibres, their fineness, cross-sectional shape, and the crimped nature of the fibres. More crimps lead to increased bulkiness, which enhances softness.

The softness also depends on yarn twist, yarn bulkiness, and fabric bulkiness. Some properties are listed here, and applying any softening treatments to the fabric can also influence softness. Similarly, the product properties and the corresponding relevant properties of the fibre, yarn, fabric, and finishing treatments related to each property are listed in the table. Hence, such a table will be helpful for any designer to make quick decisions when a product fails to meet specific requirements.

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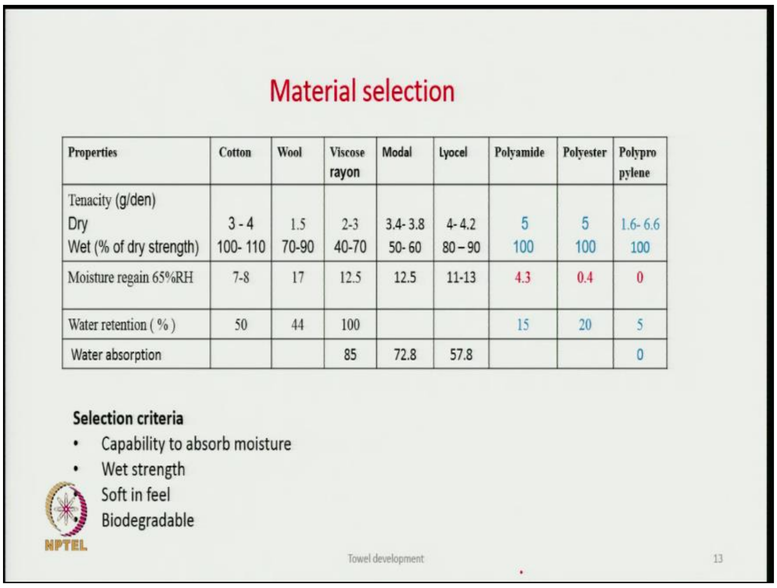

Properties	Cotton	Wool	Viscose rayon	Modal	Lyocel	Polyamide	Polyester	Polypro pylene
Tenacity (g/den) Dry Wet (% of dry strength)	3 - 4 100- 110	1.5 70-90	2-3 40-70	3.4- 3.8 50- 60	4- 4.2 80 – 90	5 100	5 100	1.6- 6.6 100
Moisture regain 65%RH	7-8	17	12.5	12.5	11-13	4.3	0.4	0
Water retention (%)	50	44	100			15	20	5
Water absorption			85	72.8	57.8			0

Next is the material selection. In this slide, a list of fibres, along with their properties, is provided in a table. The selection criteria should be based on the specific requirements for the product. In this case, the ability to absorb moisture is the most important requirement; therefore, any fibres chosen must have good moisture-absorbing capabilities.

The next consideration is the wet strength because once the product becomes wet, strength will be affected, and the durability of the product is critical. Additionally, the fibre should have a soft feel; not all fibres are soft, and some may be quite coarse, so these fibres should be avoided. Another important consideration nowadays is biodegradability. Considering these criteria, there is a prospective list of fibres to determine which one is suitable for the product.

In the list, the tenacity values for various fibres have been provided, deliberately including synthetic fibres as well as natural fibres like cotton and wool, along with manmade fibres such as viscose, modal, and lyocell. Synthetic fibres such as polyamide (nylon), polyester, and polypropylene are also there. Examining properties from the moisture absorption point of view, polypropylene does not absorb any moisture, making it unsuitable for the requirement.

Polyester and polyamide also absorb very little moisture. Therefore, these fibres are not suitable for towels or gamchha. In contrast, fibres with good moisture absorption, such as cotton, wool, viscose, modal, and lyocell, are more appropriate for products like these. Selection criteria also depend on cost, in addition to fibre properties. While all the fibres are moisture regain-wise, they are suitable, but viscose rayon, although it can absorb a high amount of moisture (12.5%), has a very low wet strength.

Wet strength decreases by 40 to 70%. Despite its excellent moisture absorption, viscose rayon is often not preferred because it becomes significantly weaker when wet. The strength of viscose rayon can decrease by up to 50%, which affects the durability and overall shape and size of the product after use, and hence, that is avoided. Modal and lyocell can be suitable alternatives, but they are generally quite expensive, and cost will ultimately factor into the decision.

Although wool has excellent moisture regain, it is rarely used due to its high cost and the presence of scales on the fibres. Moreover, when wet, wool can rub against the skin, potentially causing abrasive damage due to its rough surface and it is very costly. Generally, wool is not preferred, and coarse wool cannot be used. Finer wool is required, which is extremely expensive. Additionally, a significant problem with wool is that when washed, the fibres can interlock, leading to felting, making it less desirable for certain applications.

Therefore, even though it has very high moisture absorption, wool is not commonly used. It's important to note that the surface of the wool is not truly absorbent. Wool can absorb moisture vapour; it is hydrophobic in nature. However, when a drop of water is placed on wool, it tends to roll off rather than spread across the fibre's surface due to the presence of scales, which stop the absorption of liquid drops, but it can absorb moisture vapour.

These are some of the reasons why wool is not suitable for absorbent products. Therefore, cotton and viscose rayon emerge as excellent options; however, viscose rayon has its own issues with wet strength. As a result, cotton is the fibre most commonly used for making towels or gamchha due to its unique combination of properties and affordability, making it accessible to a wide range of consumers. Typically, these two fibres are used and, at times, blended with other fibres to enhance certain characteristics. While this may increase the cost, there is a market where a slight price rise will not significantly impact demand.

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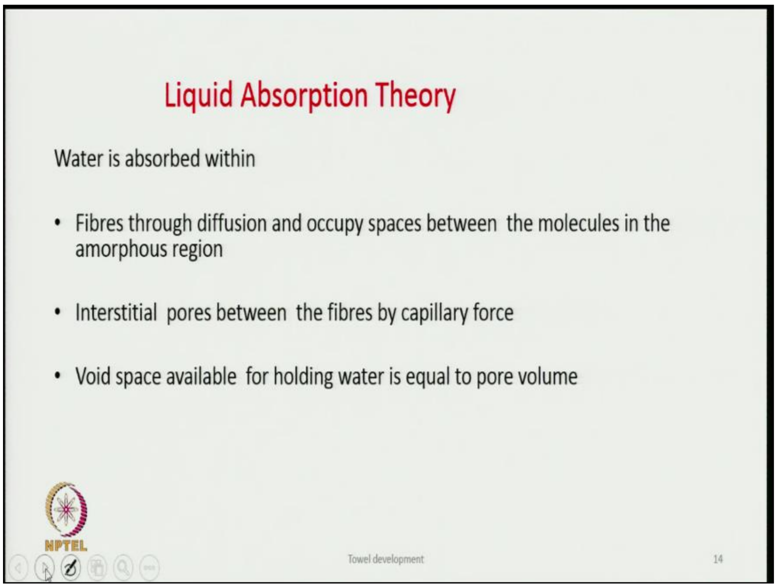

Let us understand the theory of water absorbency since this product is designed to absorb liquid, particularly water. Water is absorbed within the fibres through diffusion. A portion of the water penetrates the fibres, occupying spaces between the molecules in the amorphous regions. Then, interstitial pores between the fibres accumulate with water. Water is held in these spaces by capillary forces, which occupy the interstitial areas between yarns or within fibres. The ability of water to reach these areas is due to these capillary forces.

Additionally, the amount of water that can be held is determined by the pore volume, which refers to the void spaces available for water retention. Some water will also be retained due to the bonds that form between the fibres and the water molecules. These are some important factors to consider, particularly the significance of void space. The amount of water that penetrates the fibre through diffusion is relatively less in comparison to the void space that is available either between fibres within a yarn or between yarns in a fabric. Therefore, void space serves as the primary reservoir for water retention.

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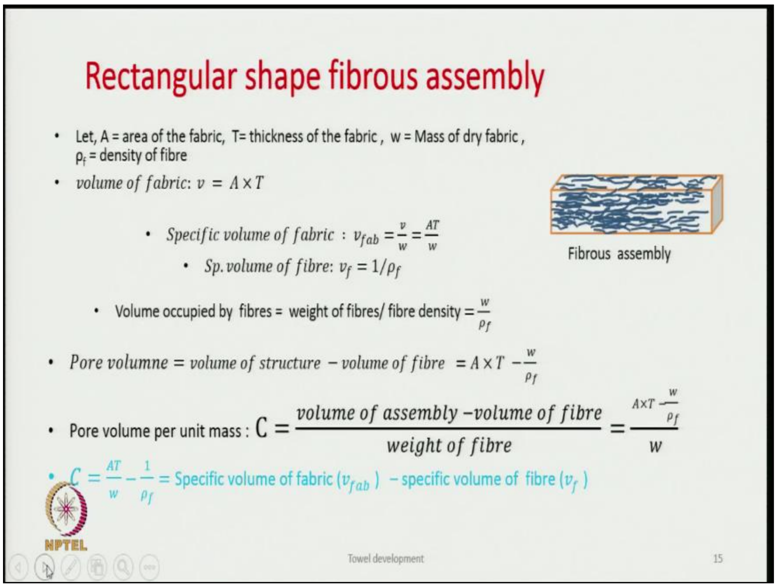

Let us consider a rectangular assembly of fibres, as illustrated in the diagram. If this assembly is considered a rectangular sheet, the available void spaces can be analysed. Let the area of the fabric be 'A', the thickness be 'T', the density of the fibre is 'ρ_y' and the mass of the dry fabric be 'W'. In this case, the volume of the fabric can be expressed as '$A \times T$'. Thus, the specific volume of the fabric is defined as the volume per unit weight, which can be expressed as,

$$\frac{V}{W} = \frac{A \times T}{W}$$

On the other hand, the specific volume of the fibre is given by '$\frac{1}{\rho_f}$' where 'ρ_f' is the density of the fibre. Consequently, the volume occupied by the fibres can be calculated as '$\frac{w}{\rho_f}$' where 'w' represents the weight of the fibres. Within this assembly, the pore volume can be determined by subtracting the volume occupied by the fibres from the total volume of the fabric.

The pore volume within the assembly can be calculated as,

$$A \times T - \frac{w}{\rho_f}$$

To determine the pore volume per unit mass, it can be expressed as,

$$C = \frac{A \times T - \frac{w}{\rho_f}}{W}$$

This equation illustrates that the amount of water that can be absorbed depends on the space available between the fibres.

In the case of a sheet made entirely of fibres, such as a nonwoven fabric, pore volume available per unit mass is the difference between the specific volume of the fabric ($\frac{A \times T}{W}$) and the specific volume of the fibre ($\frac{1}{\rho_f}$). The difference between these two will be the proportion of pore volume available per unit mass.

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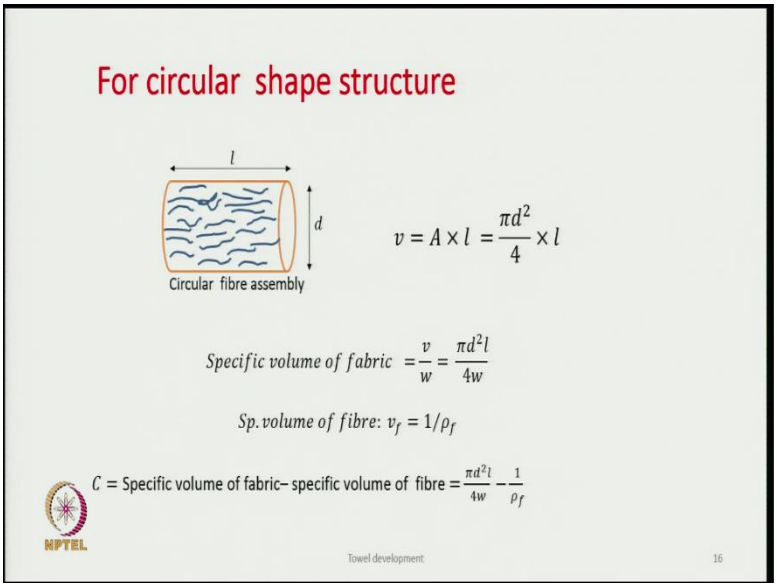

When considering a circular arrangement of fibres, such as yarn, we can model it as a cylindrical structure. The volume of the cylinder can be calculated using the formula

$$v = \frac{\pi d^2}{4} \times l$$

To determine the specific volume of the fabric, it is given by

$$\frac{v}{W} = \frac{\pi d^2 l}{W}$$

The specific volume of the fibre is given by '$\frac{1}{\rho_f}$'. Similarly, the pore volume per unit mass is given by the specific volume of the fabric minus the specific volume of fibre.

This yields a formula

$$C = \frac{\pi d^2 l}{4w} - \frac{1}{\rho_f}$$

In this case, if it is considered to be a yarn, the diameter of the yarn is important; a larger diameter increases porosity. Even a slight change in diameter can disproportionately raise the value of 'C' due to the squared relationship with 'd'. Additionally, the length of the yarn is important; it significantly impacts the value of 'C'. The choice of yarn length and the amount of yarn that can be accommodated in a given area are crucial factors to consider.

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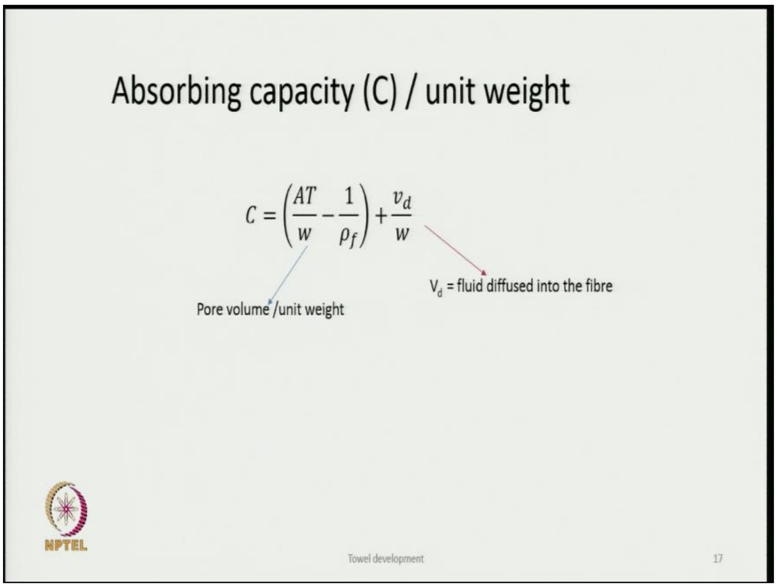

These are the two fundamental formulas related to absorbency. The absorbency capacity, denoted as 'C' which can be expressed as

$$C = \left(\frac{AT}{w} - \frac{1}{\rho_f}\right) + \frac{v_d}{w}$$

where 'A' is the area and 'T' is the thickness, assuming a rectangular sheet. This essentially represents the pore volume per unit weight.

The second term, '$\frac{v_d}{w}$', describes the amount of fluid that can diffuse into the fibre and remain within it through the diffusion process. Both of these aspects are crucial. However, the second term is negligible compared to the first. Therefore, for practical purposes, the primary focus for determining absorbency capacity should be on the first term of this equation.

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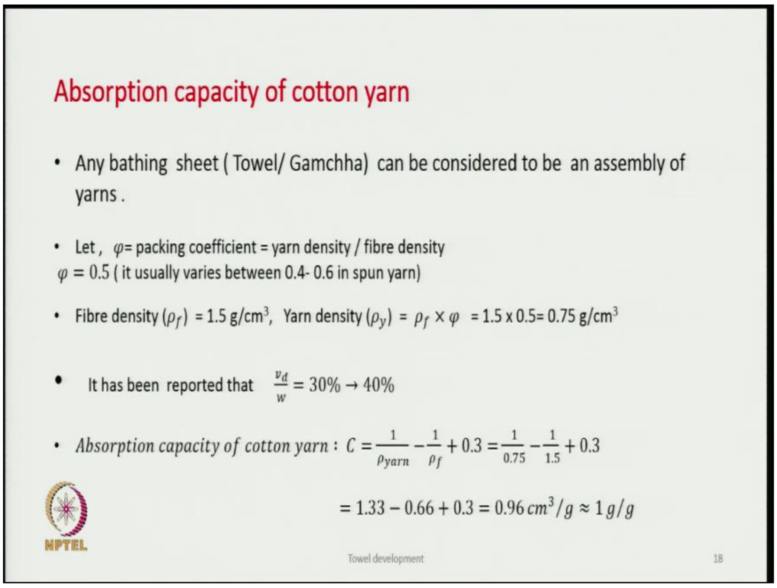

The absorbency capacity of cotton yarn, such as that found in a bathing suit towel or a gamchha, can be viewed as an assembly of yarns. In the case of a gamchha, it forms a two-dimensional sheet consisting of yarns in both the warp and weft directions. For a towel, however, it can be considered a two-and-a-half-dimensional structure due to the presence of a pile. Ultimately, both products are fundamentally composed of yarns.

Yarns are arranged within a specific area, and to maximize the amount of yarn per unit area, the fabric structure changed from a two-dimensional sheet to a two-and-a-half-dimensional, nearly three-dimensional form, as seen in towels. The goal is to increase the yarn density per unit area, which is achieved by incorporating a third dimension, resulting in the creation of a pile. This allows for adding more yarn other than the warp and weft.

Let 'φ' represent the packing coefficient, which is defined as the ratio of yarn density to fibre density. Typically, 'φ' is around 0.5, but it is noted that it usually varies between 0.4 and 0.6 for spun yarns. Understanding this parameter is essential for design research, as it helps inform the design process, particularly when working with spun yarns.

After reviewing various research articles and textbooks, it was found that the packing coefficient for spun cotton yarns with normal twists typically varies between 0.4 and 0.6. For our purposes, we can choose a value of 0.5. Assuming the fibre is cotton, which has a density of 1.5, we can calculate the yarn density by multiplying the fibre density by the packing coefficient to determine the yarn density.

Research articles report that the amount of water diffusing into cotton fibres is around 30 to 40%. This data is critical for understanding how much water can penetrate the cotton fibre. With this information, the absorbency capacity of cotton yarn per gram can be calculated by considering how much water the fibre can absorb. We can calculate the 'C' value as

$$\frac{1}{\rho_y} - \frac{1}{\rho_f} + 0.3$$

which represents the specific volume of the open structure minus the specific volume of the fibre plus the amount of water that diffuses into the fibre.

We can assume this diffusion amount to be around 0.3 to 0.4. In this case, it is considered to be 0.3. The final value obtained is approximately 0.96 cm^3/g, which is close to 1 gram of water absorbed per gram of cotton yarn. This means that a typical cotton yarn will absorb roughly its own weight in water. A cotton yarn with a normal twist has a twist multiplier in the range of around 3.8 to 4.2. this cotton yarn with a normal twist will typically absorb 1 gram of water per gram of yarn, meaning it can absorb 100% of its own weight in water. This is not applicable for highly twisted yarns with a twist multiplier of 6 or 7.

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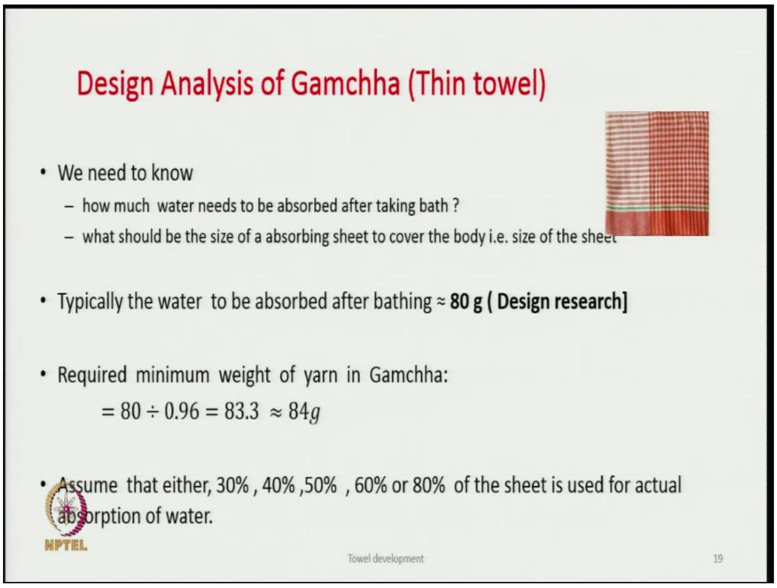

When conducting a design analysis for a gamchha, which is basically a thin towel, it is important to determine how much water needs to be absorbed after a bath. This will help decide the appropriate size of the absorbing sheet needed to cover the body. The size of the gamchha should accommodate the absorption of about 80 grams of water, which is the typical amount of water to be absorbed after bathing. This information is important for designing the gamchha. If this information is available from a reliable source, we can use it for initial estimations. If not, we need to conduct research to determine how much water is typically absorbed from the skin after a bath.

Assuming 80 grams of water needs to be absorbed, the required minimum weight of the gamchha can be calculated by '$\frac{80}{0.96}$' which is approximately 84g. It has been found earlier that the absorption capacity of cotton yarn is 0.96 grams of water per gram of yarn, which is, therefore, close to 83.3 grams, or 84 grams. This means that to absorb 80 grams of water from the skin, a cotton sheet would need to contain at least 84 grams of yarn.

However, the weight of a gamchha is typically higher than this. This raises the question of why our calculated figure might not be practical. The reason this calculated value may not be entirely practical is that the 80 grams we have used is an average value, which can vary depending on the individual. For taller or larger individuals, the amount of water to be absorbed may be closer to 100 grams, while for children, it will be much less. Therefore, the water absorption requirement depends on the size of the person, but for a typical adult, 80 grams is a reasonable estimate.

If someone is very tall and heavy, the water absorption requirement could increase to around 100 grams, while for a thinner person, it may drop to 60 grams. There is always a range, and designers must account for this variability to meet the needs of most people. When a product is brought to market, the manufacturer does not know exactly who the customer will be, but any customer who buys it expects the product to be suitable for their needs. Therefore, for a typical person of standard height and standard health, 80 grams of water absorption may be adequate.

Based on this estimate, the values are calculated accordingly. However, another factor to consider is that when a gamchha is used to absorb water from the skin, not the entire sheet will absorb water. Only the portions that come into direct contact with the skin will absorb moisture, while other parts of the gamchha will remain dry. Let us assume that only 30%, 40%, 50%, or 60% of the gamchha is utilized for actual water absorption while the rest of the area remains unused. This reflects a more practical scenario regarding how the fabric will perform during use.

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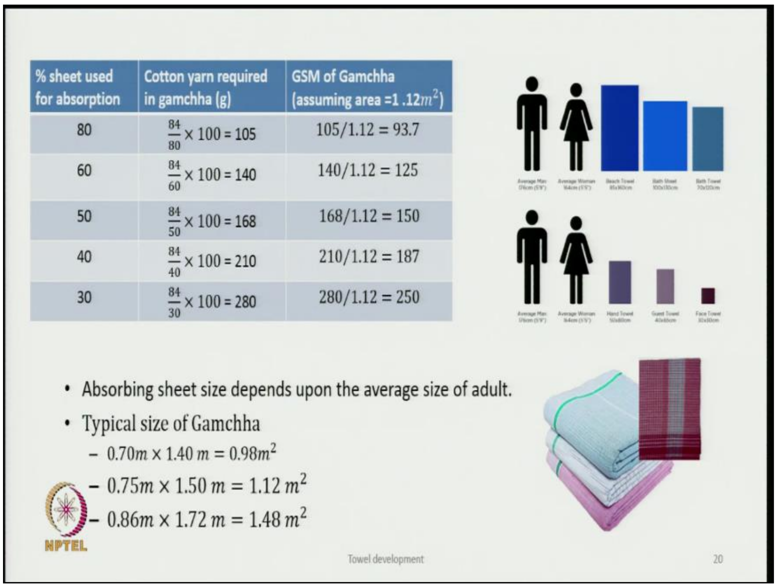

Based on the assumption that a certain percentage of the gamchha will be used for water absorption, the required amount of cotton can be determined. By considering the area of the gamchha, the appropriate grams per square meter (g/m^2) of the fabric calculation can be done. To illustrate this, there is a chart on the right side showing individuals of various sizes.

The typical sizes of gamchha's available commercially can now be easily found on platforms like Amazon or Flipkart, and then specifications can be found. But sometimes the mentioned specifications are inaccurate or wrong. Generally, the quoted sizes vary to accommodate different body types; for example, taller or heavier individuals may require a longer sheet.

Some individuals may require a shorter sheet, such as children who need smaller sizes. Typically, gamchha's range from 0.70 m - 1.40 m, resulting in an area of about 0.98 m^2, though larger sizes are also available. For our calculations, we have chosen a size of 1.12 m^2. Assuming that 30% of the sheet will be utilized for absorption, we estimate that approximately 280 grams of cotton yarn will be required. This means that the total weight of the gamchha needs to be 280 grams.

Hence, the areal density (g/m^2) of the fabric will be calculated as '$\frac{280}{1.12}$' which results in 250 g/m^2. Assuming 30% - 80% of the sheets are used, their corresponding areal density is shown in the last column of the table. This provides a clear understanding of the typical areal density needed to produce a gamchha.

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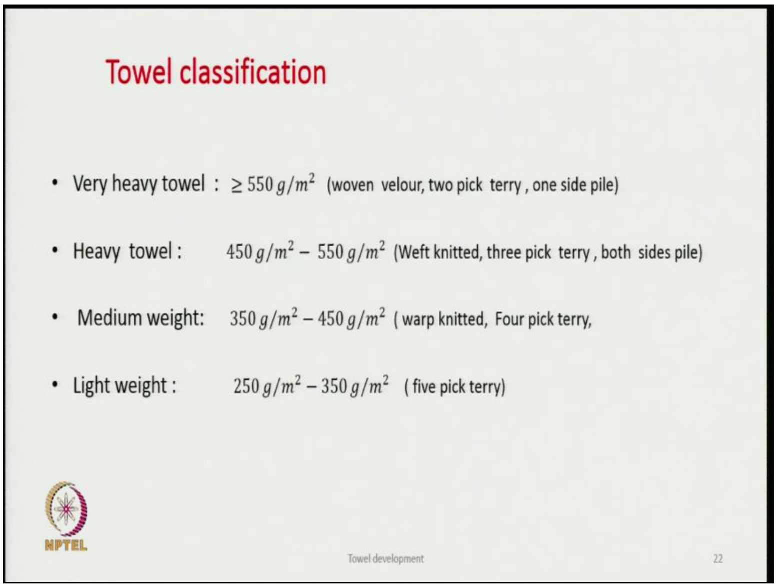

Next is the classification of towels. The towel is slightly different from the gamchha because the form of the fabric is different. There are various types of towels available in the market, ranging from very heavy towels, which weigh around 550 g/m^2, to medium and lightweight varieties. These are the four typical varieties of towels that are available. Similar to the case of the gamchha, that means that although the gamchha contains more yarn than necessary, a portion of the sheet will remain dry during use as it wipes the body.

Therefore, this must be considered when determining the required weight of yarn, which must be appropriately distributed over the entire area. When considering the areal density of the fabric, it is essential to recognize that commercial towels come in various weights, such as lightweight, medium-weight, and heavy-weight. Consumer preferences vary; some individuals prefer heavier towels, while others opt for medium or lightweight options.

For example, older adults often prefer lightweight towels as they may find it difficult to use heavy towels because older adult's strength is reduced. Similarly, children require lightweight towels that are easy for them to handle, while adults may prefer medium or heavy towels. Some individuals even opt for very heavy towels despite their bulkiness, as personal preferences can vary significantly.

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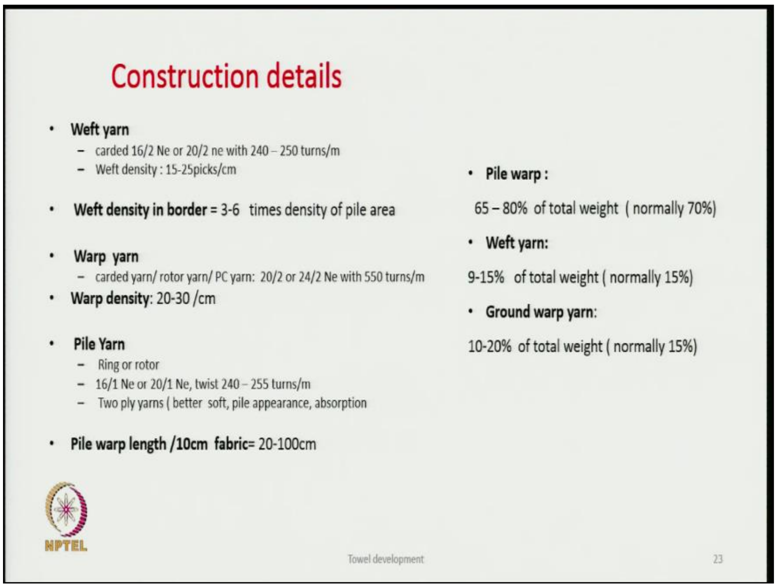

The construction details of the towels are also provided here. Through design research, it is important to understand the commercial practices. Typically, carded yarns are used for the weft, with counts such as 16/2^s Ne or 20/2^s Ne. 16/2 indicates that two 16^s yarns are plied together. Weft densities are also specified, along with the weft density at the border.

Warp yarns typically consist of carded yarn, rotor yarn, and polyester-cotton (PC) blends. Various types of yarns can be utilized, and the corresponding warp densities are also provided. For the pile yarns, ring or rotor yarns are generally used, with typical counts specified. This information includes the pile warp length per 10 cm. These details include the constructional data related to the counts of warp, weft, and pile yarns.

Some data on the twist of the yarn is also provided. It has been observed that the pile warp constitutes 65% to 80% of the total weight of a towel. The towel has a specific structure, including warp and weft yarns, along with pile yarns on both sides of the fabric, with pile yarns contributing approximately 70% of the total weight. The weft yarn's contribution typically ranges from 9% to 15%, with an average consideration of around 15%. Meanwhile, the ground warp yarn contributes between 10% and 20%, with a normality of 15%. This data highlights the typical constructional details and relevant contributions of the three types of yarns used in fabric production.

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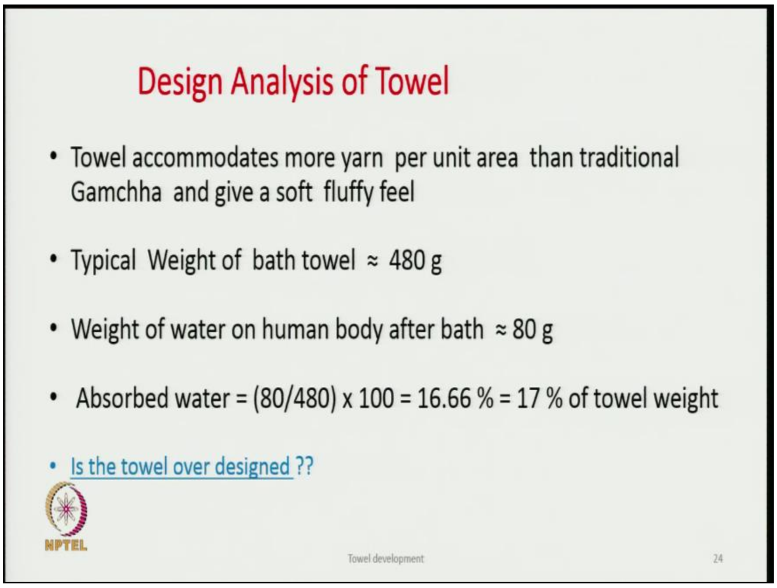

In design analysis, towels accommodate more yarn per unit area than traditional gamchha's and provide a very soft feel. This softness is attributed to the presence of piles, which can easily deform with minimal force. When the towel comes into contact with the skin and is pressed, the deformable piles enhance the overall comfort and softness experienced by the user. The typical weight of a bath towel is around 480 g, while the amount of water absorbed from the human body after a bath is approximately 80 g. This indicates that bath towels are often over-designed, as only 80 g of cotton yarn would be needed to absorb that amount of water.

However, the actual weight of the towel can range from 480 grams to slightly less or more, but it is significantly higher than the required 80 grams. The proportion of absorbed water relative to the towel's total weight is

$$\frac{80}{480} \times 100$$

which is 16.67% or 17% of the total weight. It has been mentioned earlier that cotton yarn can typically absorb water at a rate of one gram per gram of yarn. This raises the question of whether the towel is indeed over-designed. For certain products, design analysis is essential in determining whether a product is over-designed or under-designed.

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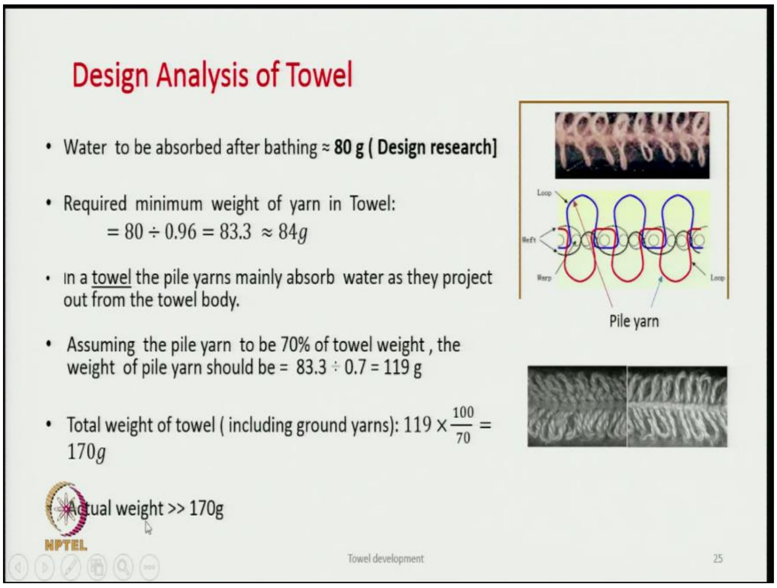

Further analysis shows that the water to be absorbed after bathing is 80 grams. Therefore, the required minimum weight of yarn in a towel can be calculated as '$\frac{80}{0.96}$' which is approximately 84 grams. In towels, it is primarily the pile yarn that absorbs water, as it is the component that comes into direct contact with the skin due to its protruding nature from the towel body. Assuming the pile yarn constitutes 70% of the total weight of the towel. The weight of the pile yarn can be calculated as '$\frac{83.3}{0.7}$', which is 119 grams. Thus, the actual weight of the towel will be '$119 \times \frac{100}{70}$', which is equal to 170 grams. However, the typical weight we observe in the market is significantly higher, often around 480 grams.

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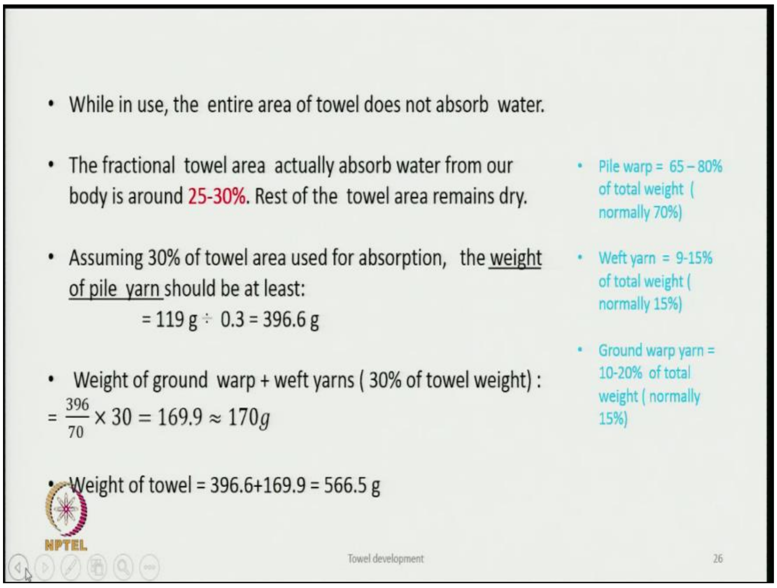

The question arises: is the design effective or not? This argument is relevant when considering that the entire surface area of a towel does not absorb water. One can easily verify this by conducting a simple experiment: after taking a shower, wipe the body with a towel and then check it; you will notice wet patches where only certain areas have absorbed moisture. This indicates that only parts of the towel made contact with your skin, while the rest of the part remained dry.

Typically, a fraction of the towel's surface area, approximately 25 to 30%, absorbs water from our bodies. This can be confirmed through research examining how much of the towel's area is exposed to moisture while wiping the body. Assuming that 30% of the total area is used for absorption, the weight of the pile yarn should be at least '$\frac{119}{0.3}$', which is equal to 396.6 grams, since the remaining pile yarn remains unutilized.

The waste from the pile yarn amounts to 396.6 grams. Additionally, the weight of the ground yarn is necessary because the pile needs to be held together by the interlacing of the warp and weft. The total weight of the ground yarn (warp and weft) is 30%, which is approximately 170 grams, specifically 169.9 grams. Therefore, with the pile yarn weighing 396.6 grams, the total weight of the towel comes to 566.5 grams. This calculation is based on initial assumptions if they remain valid.

Thus, the weight of the towel is estimated to be 566 grams. It is observed that there are towels that are significantly heavier. It has already been mentioned that towels weighing 550 grams and more are also available. These assumptions lead to a value close to 550 grams. Therefore, if we adjust our assumptions, we can get medium-weight or lightweight towels based on the area used for absorbing water. Assuming 30% of the area is used, if we increase that to 40%, the weight will decrease. Assuming a 50% absorption area, the weight will decrease even further.

Ultimately, the size requirement of the towel will depend on the dimensions of the human body, as previously mentioned. Generally, a gents towel is slightly smaller than a ladies. Thus, the area covered, or the size required depends on the dimensions of the person and the weight needed. If you distribute the same weight over a larger surface area, the grams per square meter (g/m^2) value will decrease.

As noted earlier, we assume an areal density of 1.12 g/m^2 for an angocha, and similar measurements can also apply to towels, being sometimes slightly more and sometimes slightly less. Towels can be grouped into various categories, including beach towels, hand towels, and bath towels, each serving different purposes and available in different sizes. We have provided a method to analyse these designs and assess whether they are over-designed through a logical analysis. This approach allows us to better understand the effectiveness of existing towel designs.

From the perspective of how much water needs to be absorbed and the weight of the fibres in a towel, the fibre content often exceeds our actual requirements. However, this additional weight is necessary to ensure complete body coverage, providing sufficient length and width. At the same time, the entire area may not be used for wiping. With this, the discussion on absorbing medium is concluded. Thank you.