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Performance of Terry Towel - A Critical Review
Part I: Water Absorbency

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ABSTRACT

There is nothing wrong in saying that water absorbency is a synonym for terry fabric as it may not existed without this property. So, this paper intended to collect, critically analyze, rearrange and present the scattered information scientifically and to provide a single source of all information. In this paper, a critical review of the evolved theories and mechanisms of water absorption in terry fabric has been presented along with the key factors to improve the water absorption. Randomly scattered information throughout the current as well as last century, has been collected, analyzed and concluded judicially. Critical analysis of all the information helps to understand and choose the most realistic theory and mechanism of water absorption of terry fabric which will be helpful in designing the most absorbent terry fabric. An attempt has also been made to conclude findings of the researches that have been directed towards understanding the effect of washing, dyeing and finishing treatment on water absorbency of terry fabric. Both dynamic and static water absorbency along with the initial time lag immerses to be the equally important attributes of the water absorbency performance of terry fabrics. High loop shape factor is the key to improve the absorbency behavior of the terry fabric. This article provides a collective source of information to understand the philosophy of absorbency and the ways to develop highly absorbent terry fabric. This is the first review article providing a comprehensive source of information regarding all aspect of water absorbency behavior. Study of cross-section images of different fabric is the original work of the authors for supporting the concluding theory, mechanism and results.

Keywords: Capillary action, dynamic water absorption, static water absorption, loop geometry, terry fabric

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1. INTRODUCTION

The performance of terry fabric is mainly assessed by its absorbency that refers to both the rate at which the fabric absorbs the water i.e. dynamic water absorbency; and the total water retention ability of the fabric i.e. static water absorption. Systematic research on water absorbency of terry fabric started in the first half of the 20thcentury (Stevenson and Lindsay, 1926; Larose, 1942; Holland, 1943) with the conceptual development of absorbency, the theory of absorption and suitable method of water absorption (Jackson and Roper, 1949; Buras *et al.*, 1950). Research in the beginning of the second half of 20th century is focused on the absorbency performance of terry fabric after certain wet processing treatment and home laundering (Murphy and Macormac, 1958; Aycock, 1972).Later some research has been done to see the effect of different yarn on water absorbency characteristics along with the investigation of best suited test method (Lord, 1974; Cary and Sproles, 1979; Swani*et al.*, 1984). More extensive work have been done in the end of the 20thcentury utilizing capillary theory, surface tension, wetting, wicking, pore size and its distribution etc.(Akira *et al.*, 1990; Bozgeyik, 1991; Hsiesh and Yu, 1992; Hsiesh, 1995; Kissa, 1996; Jacques and Schramm, 1997; Nostadt, Zyschka, 1997; Crow, 1998; Kadolph, 1998). Static and dynamic water absorption has been studied in relation with fabric construction and yarn properties. Now in 21st century, numerous developments have been made towards increasing absorbency of terry fabric (Meeren *et al.*, 2002; Izabela and Snycerski, 2004; Yamamoto *et al.*, 2005; Karahan and Eren, 2006; Nyoni and Brook, 2006; Karahan, 2007; Petrulyte and Balatakyte, 2008; Petrulyte and Balatakyte, 2009a; Petrulyte and Balatakyte, 2009b; Petrulyte and Nasleniene, 2010; Behera and Singh, 2012; Sekerden, 2012; Singh and Behera, 2013). Zero twist yarn, low twist, wrap yarn etc. have entered in the terry fabric as pile yarn with the primary aim to increase the absorbency and got success. Still the hunt is on for the ways to improve the absorbency of terry fabric. Recent research is focused on the loop geometry and its effect on water absorbency (Singh and Behera, 2012).

Wetting and wicking are quite distinct from each other (Kissa, 1996). Wetting in completely dependent on properties of fiber surface and wetting liquid while wicking is dependent on the arrangement of fiber and yarn into the fabric. Wetting characteristic of fibrous materials are important to their chemical processing and functional performance. Liquid must wet the fiber surface before being transported through the inter fiber pores by means of capillary action /capillary force. Absorbency characteristic of fiber assemblies depends on the geometry of fiber assemblies, especially surface roughness as well as pore size distribution (Buras*et al.*, 1950; Nyoni and Brook, 2006). The amount of water absorbed or the static water absorption by the terry fabric is important for its end use. However, it does not give any idea as how quickly a terry fabric absorbs the water, or how water absorption changes with time. This aspect of water absorbency is particularly known as rate of water absorption or dynamic water absorption which is also important from the practical point of view. So the terry fabrics must be evaluated in terms of static and dynamic water absorption. Optimum absorbency performance can be achieved by controlling the pore sizes and their distribution (Hsiesh, 1995).

2. THEORY OF WATER ABSORPTION

The three primary phenomenon - time lag, the dynamic absorption and the static absorption must be explained by would be successful theory of absorption mechanism (Buras *et al.*, 1950). The initial period during which no significant volume of liquid is absorbed is termed as time lag. The weight of water absorbed by unit weight of oven dry weight of the fabric per unit time is the dynamic water absorption while the maximum weight of water absorbed by unit weight of oven dry weight of the fabric is static water absorption. The dynamic water absorption can be defined as the ratio of absorptive forces to the resistance of fabric wetting.

$$w_{dy} = \frac{a}{r} \qquad (1)$$

The resistance, r, is the resistance to wetting centered in the initial contact areas. Number of contact pints between fabric and wet plate affects this resistance. Smoother fabric surface offer less resistance than surfaces having loops e.g. terry fabric. The absorptive forces, a, can be determined by extension of the tangents to the curves relating maximum rate of flow and head to interception with the zero flow axis. All capillaries and channels contribute to the ultimate absorption whereas smaller ones are effective in initial phase of absorption, in which the maximum rate is observed.

$$\frac{w_t}{w_{st}} = 1 - e^{-tI/w_{st}} \tag{2}$$

Equation (2) can represent the general absorption curve (Buras *et al.*, 1950).

Where w_t = amount absorbed at time t, w_{st} = static water absorption, I = initial flow rate. Static water absorption (w_{st}) is the weight ratio of the absorbed water over the oven dry weight of the fabric. Static water absorption can be calculated as:

$$W_{st}(\%) = \frac{w_w - w_d}{w_d} * 100 \tag{3}$$

Where W_{st} is static water absorbency, w_w is wet weight of fabric and w_d is dry weight of fabric. In spite of extremely complex pore structure, combination of several fabric attributes can qualify the overall fabric porosity. Porosity is a function of void space in a porous medium.

$$porocity(p) = 1 - \frac{fibrevolume}{fabricvolume} = 1 - \frac{\rho_{fa}}{\rho_{fi}} \tag{4}$$

So, the static water absorption as a function of porosity (p), water density (ρ_w) and fiber density (ρ_{fi}) can be given as (Hsieh, 1995).

$$w_{st} = \frac{\rho_w}{\rho_{fi}}\left[\frac{p}{1-p}\right] \tag{5}$$

The proposed mechanism (Hsieh, 1995) of water absorption depends on pore size, pore size distribution, pore connectivity, and total pore volume. Inside a capillary, the liquid is taken up by the net positive force (Δf) across the liquid-solid interface (Hsieh, 1995):

$$\Delta f = f - h\rho_w g \tag{6}$$

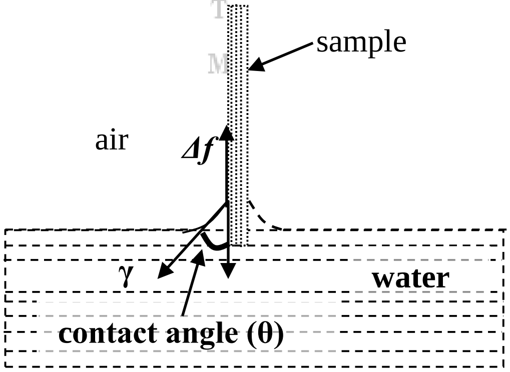

Figure 1.Capillary action

Where ρ_w is water density (g/cm^3), g is gravitational acceleration (cm/s^2), and h is height of liquid rise (cm). The internal wetting force (f_w) in the capillary area (πr^2) is known as the capillary force (*f*), which is given by the Laplace equation (De Gennes, 1985; Miller, 1985):

$$f = \frac{f_w}{\pi r^2} = \frac{2\gamma cos\theta}{r} \tag{7}$$

Where γ is liquid surface tension (dyne/cm), *r* is inner radius of capillary (cm),θ is liquid-solid contact angle. When weight of the liquid ($h\rho_w g$) is lower than the capillary pressure (*f*), the liquid is taken up by the positive force. At equilibrium point where weight of liquid column inside capillary is equal to the capillary pressure, the net driving force becomes zero and the liquid stops going above the equilibrium water column height inside the capillary.

Hegen-Poiseuille's law of laminar flow (Yoo and Barker, 2004) can explain the volumetric liquid flow through textile structure

$$\frac{dV}{dt} = \frac{\pi r^4}{8\eta h}\Delta f \tag{8}$$

$$\frac{dV}{dt} = \frac{4\pi r^4}{8\eta h}\left[\frac{2\gamma cos\theta}{r} - h\rho_w g\right] \tag{9}$$

Linear flow rate (*dh/dt*) in equilibrium is based on Hagen-Poiseuille's equation considering $dV=dh\ \pi r^2$ (Washburn, 1921).

$$\frac{dh}{dt} = \frac{r\gamma cos\theta}{4\eta h} \tag{10}$$

Under the influence of gravity of the risen liquid, linear flow rate changes to:

$$\frac{dh}{dt} = \frac{r\gamma cos\theta}{4\eta h} - \frac{r^2\rho_w g}{8\eta} \tag{11}$$

After integration and simplification, Lucas-Washburn equation can be written as Equation and is known as Lucas-Washburn kinetics.

$$h = m\sqrt{t} \tag{12}$$

Where m= rate constant and$t = \sqrt{\left(\frac{r\gamma cos\theta}{2\eta}\right)}$. Further research (Laughlin and Davis, 1961) modified the relationship (Equation 12) as the time exponent is less than 0.5 and *C* is a constant.

$$h = Ct^m \tag{13}$$

Actually, the water column rises until the surface tension is equal to the weight of the water column whereas the equation (11) suggest that it should rise continuously with time. The researchers (Fisher, 1979; Jeje, 1979; Joos*et al.*, 1990; Zhuang*et al.*, 2002) have not considered all factors i.e. change of contact angle with increase of water level, effect of gravity and moment of inertia, which is the basis of controversy over the Washburn equation. Despite the limitations mentioned above, Lucas-Washburn theory effectively addresses the liquid behavior during absorption (Hodgson and Berg, 1988). Several researchers (Good and Lin, 1976; Marmur and Cohen, 1997; Nyoni and Brook, 2006) tried to accommodate the effect of gravity into the Lucas-Washburn theory. Landau's theory (Zohng*et al.*, 2001), special form of Hagen-Poiseuille's law for laminar viscose flow, gives the rate of liquid rise considering gravity and the angle of capillary to the vertical.

$$\frac{dh}{dt} = \frac{r\gamma cos\theta}{4\eta h} - \frac{r^2\zeta g cos\beta}{8\mu} \qquad (14)$$

Where ζ =liquid density, μ is liquid viscosity, β = angle of the capillary to the vertical and h = liquid rise along the tube axis. The changes of the contact angle was experimentally investigated by researchers (Joos*et al.*, 1990) and proved that it is variable and reduces with as the liquid rises.

$$cos\theta_d = \cos\theta_0 - 2(1+\cos\theta_0)\left(\frac{\eta v}{\sigma}\right)^{\frac{1}{2}} \qquad (15)$$

Where θ_d= dynamic contact angle, θ_0= static advancing contact angle, η = viscosity, v = velocity and σ = surface tension of the liquid. A study (Marmur and Cohen, 1997) on the kinetics of the vertical liquid penetration into a capillary, considering the effect of gravity, gave the equation for liquid rise (h) with time (t) as

$$At = -Bh - \ln(1 - Bh) \qquad (16)$$

Where $A = \frac{\rho^2 g^2 r^3}{16\sigma\mu cos\theta}$, and $B = \frac{\rho g r}{2\sigma cos\theta}$

Using two dimensional Ising's model and the Monte Carlo simulations, researchers (Zohng*et al.*, 2001) described the wetting process and concluded that travelling rate of liquid is inversely proportional to the packing density and the liquid column width is inversely proportional to the height due to balance of surface tension and gravity. The study (Nyoni and Brook, 2006) of wicking mechanism of textured twisted and untwisted vertical yarn under variable tension found that wicking height is inversely proportional to twist but directly proportional to the tension. The study also concludes that the heterogeneity of pore size, shape and orientation affects the penetration and retention of liquid leading to saturated, unsaturated and dry zones in the yarns. The study (Saeed, 2006) of liquid uptake by various knitted structure with different yarns further developed the theoretical model for liquid uptake considering gravity.

$$w_{dy} = \frac{\rho_l}{\rho_y}\left(\frac{p}{1-p}\right)Ax\left[1 - exp\left(-\frac{2\gamma r\cos\theta_0}{8\eta h}t\right)\right] \qquad (17)$$

Where A= fabric area, x= fabric weight, p= fabric porosity, ρ_l = liquid density and ρ_y= yarn density.

Time lag depends on the fabric-liquid contact angle. Contact angle depends on the surface roughness of the fabric surface and surface tension of the water (Hsieh and Yu, 1992). Higher fabric surface roughness and low liquid surface tension reduces the contact angle thus promotes wetting. If the contact pressure of the cloth against the porous plate is low, initially the fabric is wetted only at elevated points of the fabric like cross over points of warp and weft (in plain fabric) and at some portion of the loop (in terry fabric) as shown in Figure 2.These elevated point of the fabric surface which comes in contact with the water containing surface like porous plate.

At the cross over points, the inter fiber spaces were filled rapidly as the water is drawn into the fiber bundle. Dynamic water absorption is low due to the small volume of these spaces. The continuous inter fiber absorption wets the walls of inter yarn spaces and further capillary action fill these spaces. This is the point of significant flow and maximum dynamic water absorption. These actions happen at the same time i.e. in certain portion of the sample inter yarn absorption are in progress while in other portion this action is still waiting for the completion of the inter fiber action. Inter yarn wall surface progressively gets more and more wet due to more amount of water drawn into the cloth causing the rapid increase in the volume effect.

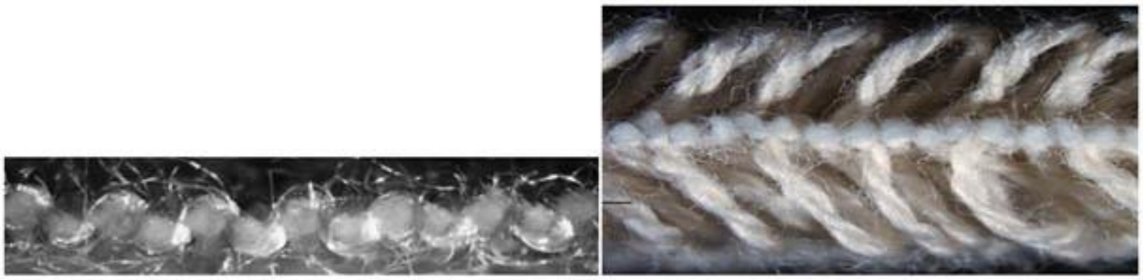

Figure 2. Cross-sectional views of terry and plain fabrics
(a) Plain Fabric (b) Terry fabric

3. FABRIC VARIABLES AFFECTING ABSORBENCY PERFORMANCE OF TERRY FABRICS

Now, it is clear that the terry fabric is quite different from normal plain fabric and so are its absorbency characteristics. It is important to identify the key fabric variable so that one can alter it to produce highly absorbent fabric.

3.1 Fabric variables affecting dynamic water absorption

A time dependent water absorption property of terry fabric is known as the dynamic water absorption or the rate of water absorption. It is one of the most important properties of terry fabric which tells that how quickly a fabric can absorb water. Dynamic water absorption can be measured by various methods like porous plate method; Bureau Veritas Consumer Products service BV S1008 etc. Research (Karahan, 2007) shows that fabric and yarn parameters are important for dynamic water absorption. Around 65 % of water is absorbed during the first 30 second of contact and rest 35% take another 270 sec to absorb so the complete absorption curve can be approximated with logarithmic curve. Yarn type has the most significant effect on dynamic water absorption properties of terry fabric. Ring spun single ply yarn has the quicker water absorption than ring spun double ply yarn which itself has quicker water absorption than rotor spun single ply yarn. Double ply rotor spun yarn has lowest dynamic water absorption. Looking at the cross-section view of terry fabric produced using rotor and ring spun pile yarn (Figure 3), these results seems more realistic than those of Swani *et al.* It is clearly visible from the Figure 3 that the terry loop produced from ring spun yarn are straighter, well oriented than from rotor spun yarn; consequently producing less tortuous capillaries which explains higher dynamic water absorption. The reason behind the different loop structure is the fact that the higher twist level and shorter fiber used for the production of rotor yarn.

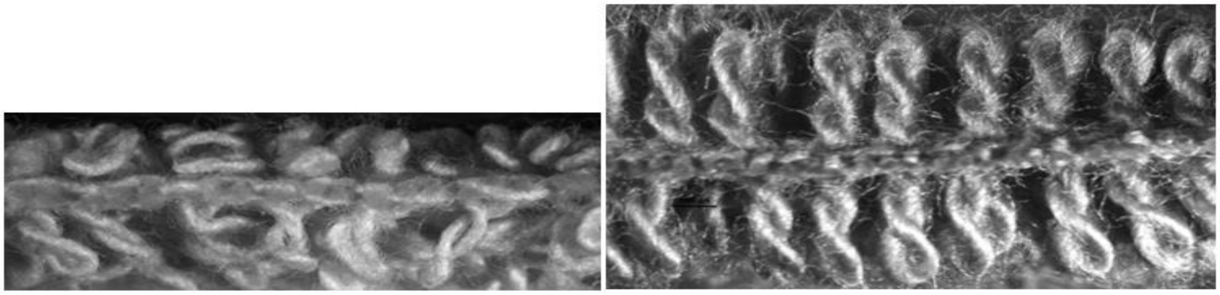

Figure 3. Cross-section view of terry fabric made of rotor and ring pile yarn
(a) Rotor pile terry fabric (b) Ring pile terry fabric

Warp density, weft density and pile height have only a small effect on the percentage of the water absorption speed of terry fabrics, which is not worth considering when designing them (Karahan, 2007). This result seems contradictory to the latest findings by the researchers (Behera and Singh, 2012). In which, it has been illustrated that the dynamic water absorption increases with loop density and loop length. Fabric cross-section image (Figure 4) clearly shows that how fabric and loop geometry changes with change in loop density and loop length. Loop become straighter with increase in loop density and loop shape factor increases with increase in loop length. Both these reasons improve the dynamic water absorbency.

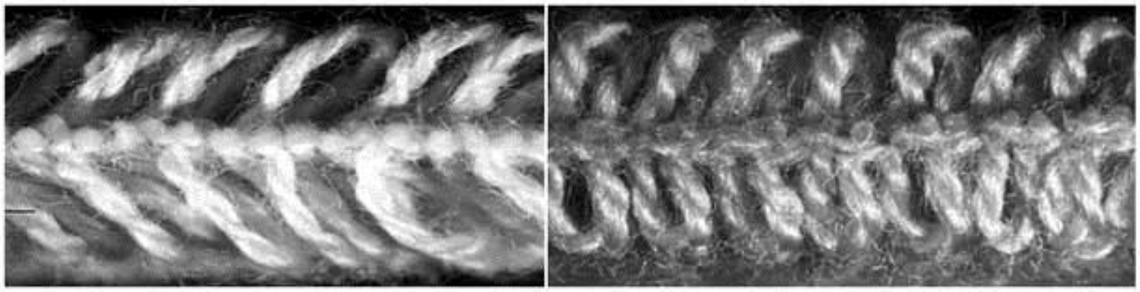

Figure 4. Cross-section of terry fabric having different loop length and loop density
(a) High loop length but low loop density (b) Low loop length but high loop density

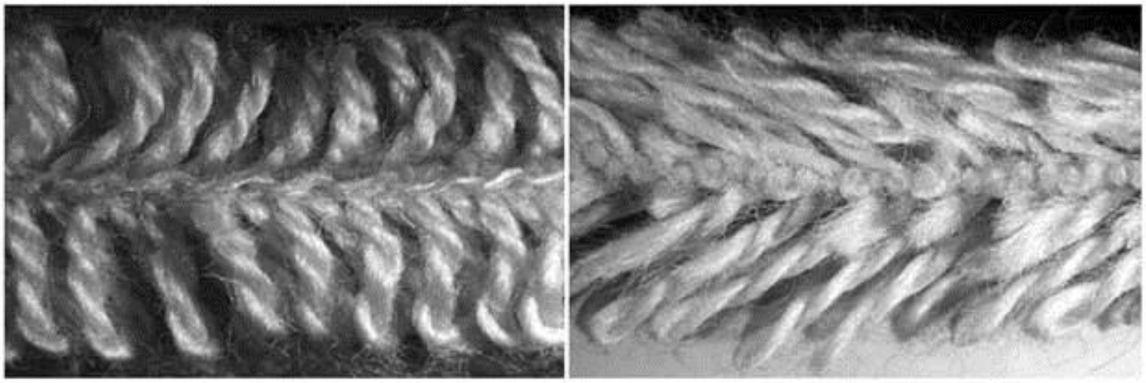

Figure 5. Cross-section of fabric made up of double-ply and single-ply
(a) Double ply yarn fabric (b) Single ply yarn fabric

Looking into the structural details of the terry fabric, it can be found that loop density is directly proportional to the warp and weft density and loop length is directly proportional to the pile height. It has also been found that fabrics produced from pile yarn having high staple length, low twist, combed and porous yarn gives high dynamic water absorbency. Terry loop having high loop shape factor also gives high dynamic water absorbency. Researchers (Petrulyte *et al.*, 2008) measured the dynamic water absorption using image processing technique and studied the effect of pile height and different process variables on it. Their method measures the rate of change of wet spot area. Principally they have measured the rate of water flow in a horizontal plane. Since the presence of loops on surface of terry fabric make it different from two dimensional fabrics. It becomes nearly 3D or more precisely 2.5D fabric. So it becomes important to consider the water flow in all possible direction and their method seems not doing the right thing. Their conclusion regarding the effect of pile height differs from that of Behera and Singh's. However another research (Yamamoto *et al.*, 2005) supports the finding of Behera and Singh i.e. dynamic water absorption of water increases with increase in pick density and pile length. They also compared the absorption phenomenon in plain and terry fabric. They found that dynamic water absorption is almost constant with increase in weft density and fabric areal density for plain fabric. Cross-section view of the terry fabrics (see Figure 4) clearly shows the structural changes due to pick density and pile height.

In a study (Kim et el., 2003) studied the absorbency behavior of pile fabrics and found that pile yarn having dense and even splits have more micro-pores so they can absorb much liquid at high speed. Separated microfibers form dense voids with each filament so that effective capillary pressure can be created. So the water absorption properties of pile knit rely heavily on the splitting of the multi-filaments and also on the uniform distribution of the split microfibers. It seems that the capillary size and their distribution are the key factors to govern the dynamic absorption of water. The studies conducted on the absorbency of terry fabric (Behera and Singh, 2012) tells the effect of pile yarn count, pile yarn twist, fiber quality, combed yarn and yarn structure. These entire factors affect the capillary size and their distribution. High dynamic water absorption has been found with fabric made of pile yarn having finer count, low twist, high staple length, combed yarn and porous yarn. Finer yarn usually produced from high staple length fibers using low twist which helps to form long continuous and less tortuous capillaries causing high dynamic water absorption. Combing process removes the short fiber from the raw material improving its staple length hence producing the above condition. Porous yarn is produced by mixing poly vinyl alcohol fibers with cotton fiber before spinning. After weaving the fabric goes into wet processing where the poly vinyl fiber is washed out at 100° C leaving behind a void space thus producing large number of capillaries. Loop density can be increased by increasing weft density and warp density. In both the cases, ground of the fabric becomes compact thus reducing the capillaries the increasing their tortuosity which will reduced the dynamic water absorption of the ground fabric. But the higher number of loops per unit area increases the overall capillary population in the loops consequently increasing the dynamic water absorption of the terry fabric. Loop shape factor is a measure of the circularity of the loops. The portion of the loop in contact with water increases with increasing circularity of the loops. Thus exposing more and more number of capillaries into the contact of the water and increasing the dynamic water absorption of the terry fabric. Terry loops produced from finer yarn will have the higher loop shape factor and hence the higher dynamic water absorption which is clearly visible from the Figure 6.

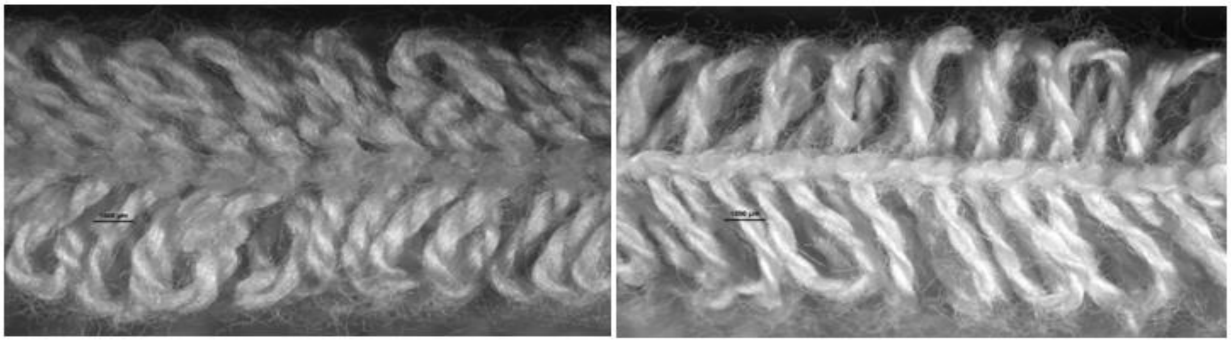

Figure 6. Cross-section of fabric having loops of different shape factor
(a) Loops of lower shape factor (b) Loops of higher shape factor

3.2 Fabric variables affecting static water absorption

The weight ratio of amount of water absorbed to the dry weight of the terry fabric is known as the static water absorption properties. It tells the maximum amount of water that can be absorbed by the terry fabric. Dynamic water absorption can be measured by various methods like porous plate method; Bureau Veritas Consumer Products service BV S1008 etc.

In a systematic research (Yamamoto *et al.*, 2005) studied the effect of weft density, fabric areal density and mean pile length on the absorbency of terry fabrics. They found that static water absorption increases with increasing weft density, fabric areal density and mean pile length. But increasing weft density and fabric areal density for plain fabric does not change the static water absorption. This can be explained by the fact that the increasing the said parameters makes the fabric more compact and reduced the capillary size and air space inside the fabric. Thinner capillary promotes the dynamic water absorption but on the other hand reduced the static water absorption. In another research (Karahan and Eren, 2006), the effect of warp density, weft density, pile height and pile yarn type had been studied and found that ring spun yarn gives more static water absorbency than rotor spun yarn. Double ply yarn gives more static water absorption than single ply due to the fact that double ply yarn can produce terry loop with higher shape factor which is clearly visible from the fabric cross section shown in Figure 5 and 7. These results are very well supported by the latest research (Behera and Singh, 2012). Karahan and Eren (2006) also found that an increase in warp and/or weft density reduces the static water absorption which is contradicted by both Yamamoto *et al.*, (2005) and Behera and Singh (2012). Yamamoto *et al.* and Behera and Singh found that higher warp and weft densities give higher static water absorption. In another research (Bozgeyik, 1991) had found that the water absorption increased with increase in fabric areal density and pile height. The reasons in support to these results were given in the previous section. Double ply yarn gives more static water absorption than single ply yarn. This is due to the fact that the double ply yarn is more voluminous as compared to its equivalent single ply yarn along with higher loop shape factor (see Figure 7).

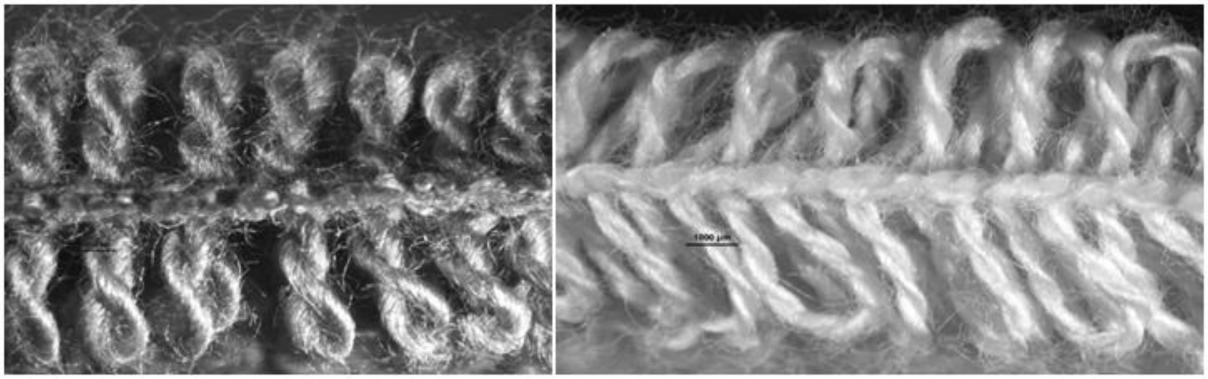

Figure 7. Cross-section of terry fabrics produced from single ply and double ply yarn
(a) Terry fabric from single ply yarn (b) Terry fabric from doubly ply yarn

In another research (Petrulyte and Baltakyte, 2009) investigated the effect of pile height on the static water absorption. They had found that fabric with high pile height gives more static water absorption. This result is also supported by another research (Petrulyte and Nasleniene, 2010). The studies conducted on the absorbency of terry fabric (Behera and Singh, 2012) tells the effect of pile yarn count, pile yarn twist, fiber quality, combed yarn and yarn structure. These entire factors affect the capillary size and their distribution.

High static water absorption has been found with fabric made of pile yarn having finer count, low twist, high staple length, combed yarn and porous yarn. Finer yarn usually produced from high staple length fibers using low twist which helps to form long continuous and less tortuous capillaries leading to bulky structure causing high static water absorption. Combing process removes the short fiber from the raw material improving its staple length hence producing the above condition.

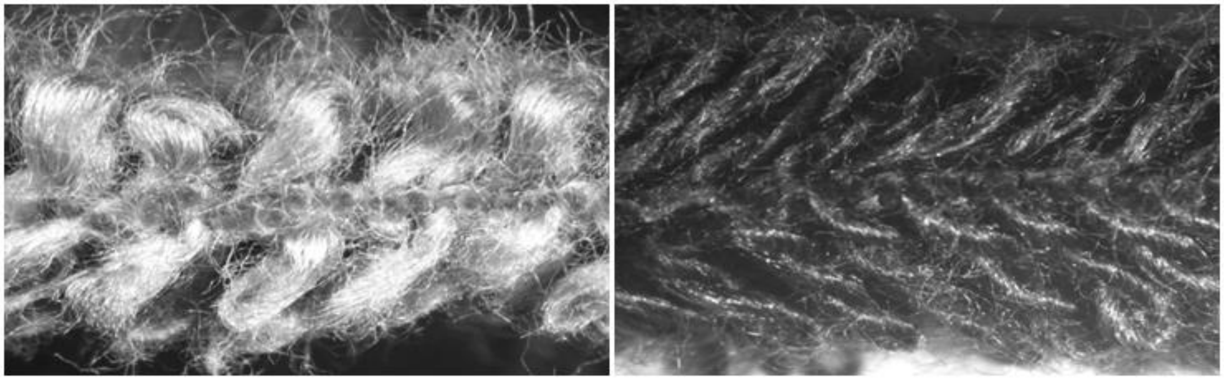

Figure 8. Cross-section of fabric with zero twisted and long staple bamboo fiber yarn
(a) Zero twisted pile yarn (b) Long staple bamboo fiber yarn

Porous yarn is produced by mixing poly vinyl alcohol fibers with cotton fiber before spinning. After weaving the fabric goes into wet processing where the poly vinyl fiber is washed out at 100° C leaving behind a void space thus producing large number of capillaries leading to bulky structure. Loop density can be increased by increasing weft density and warp density. In both the cases, ground of the fabric becomes compact thus reducing the capillaries the increasing their tortuosity which will reduced the static water absorption of the ground fabric. But the higher number of loops per unit area increases the overall capillary population in the loops consequently increasing the static water absorption of the terry fabric. Loop shape factor is a measure of the circularity of the loops. The portion of the loop in contact with water increases with increasing circularity of the loops. Thus exposing more and more number of capillaries into the contact of the water and increasing the static water absorption of the terry fabric. Figure 8 shows the fabric cross section produced from zero twisted and low twisted high stable cotton. It is clearly visible here that the loops are not in proper shape neither their shape factor can be defined but the surface is really more fluffy and bulky which explains the high dynamic water absorption but low static water absorption of such fabrics.

4. PROCESSING FACTORS AFFECTING ABSORBENCY PERFORMANCE OF TOWEL

Apart from the raw material and fabric construction related factor, there are other factors that affect the performance of terry fabric. Considerable amount of research had been directed towards this area. Starting from an important research (Murphy and Macormac, 1958) in which the effect of home laundering and fabric areal density has been studied. They found that the maximum dynamic absorption increased with the number of washing cycles until the finish was completely removed, showed no significant change with additional washing cycles indicating that fabric surface is the important factor in dynamic water absorption. The areal density does not have any effect on dynamic water absorption. Static water absorption increases consistently with number of washing cycles and with increasing fabric areal density. Measuring static absorption in per gram of fabric indicate the importance of fabric construction as the absorption per gram of fabric is higher for fabrics of lower areal density. The results of effect of washing cycles were also supported by earlier research (Bura et el., 1950). Fabric conditioner has no effect on physical characteristics such as porosity and pore size, and so on the static water absorption of terry fabric.

Another research (Aycock, 1972) shows that the absorbency and aesthetic characteristics are affected more by the type of softeners than the number of laundering. Latest research (Meeren *et al.*, 2002) shows that the types of conditioners play important role in dynamic water absorption. Cationic fatty acid based surfactants are the main ingredients of the fabric conditioners and they cover the fibers with a fatty acid coating (Jaques *et al.*, 1997). This mechanism may make the treated fabric surface more hydrophobic leading into the reduction of water uptake. Pronounce effect of fabric conditioners on dynamic water absorption due to change in wettability (contact angle with water) of cotton had been recorded. Liposomal fabric conditioner reduced the dynamic water absorption up to a great extent whereas isotropic formulation had no significant effect. Some of the enzymes like Cellulase, when applied alone on cotton, produce detectable improvements in static and dynamic water absorption (Hartzell and Hsieh, 1998).

Another research (Nostadt and Zyschka, 1997) in support to this result explains the suitability of hydrophilic softeners. Static water absorption of fabric increases with number of washing cycles (Izabela and Snycerski, 2004). Another research (Belkis and Erdem, 2006) says that softener type affects the degree of hydrophility. Fabric dyed samples has more hydrophility than yarn dyed samples. Washing cycles improve the static and dynamic water absorption. Hydrophility of uncut pile towel was found higher than those of cut pile towel. Dynamic water absorption is high for washed fabric than grey and macerated fabrics (Petrulyte and Balatakyte, 2008). Static water absorption depends on the king and intensity of the finishing (Petrulyte and Nasleniene, 2010; Petrulyte and Balatakyte, 2009) applied to the fabric. Washing with detergent and water alone improves the static water absorption. Macerating also improves it a little but using softeners reduce it. Tumbling process improves both the static and dynamic water absorption. All these results can be explained by the fact that washing and tumbling opens up the structure and makes it voluminous thus increasing static water absorption. Recently, more extensive research (Singh and Behera, 2013) has been done and found no considerable change in the dynamic water absorption has been observed after repeated wash of the samples until 4th wash after which it decreased. Static water absorption increases with increasing number of wash until 8th wash after which it decreased.

5. CONCLUSIONS

Producing highly absorbent terry fabric is the ultimate goal of the textile technologist in the industry which can be achieved by using longer, finer and hydrophilic fiber to produce soft, bulky, low twisted fine ring spun pile yarn; further producing terry fabric having high loop density, optimum loop length, high thread density and loop shape factor. Macerating, tumbling, hydrophilic softeners and washing are the post production treatment for further improvement in absorbency. The crucial outcome of the latest research regarding the absorbency of the terry fabric is the loop shape factor which is the main factor behind the super absorbency of terry fabric. Fiber and yarn characteristics, fabric constructional parameters and wet processing treatments affects the loop shape factor which consequently affects the water absorbency performance of terry fabric. Therefore, all efforts should be made to increase the loop shape factor to get excellent water absorbency performance. Since the aesthetic characteristics of terry fabric have also gained their importance in recent years, it may be interesting to see how these factors affect them which are discussed in next part of this paper.

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