Improving the Performance of Terry Fabrics to be used as Pilgrimage Clothes

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Abstract:

Terry fabric is a kind of soft pile fabrics. It is distinguished with uncut or cut loops which must have required usage properties such as higher water absorption, bacterial resistance, high wet strength, ability to dye well, good colorfastness, wash ability, soft hand, and hypoallergenic, low cost, and easy availability. Terry fabric is the most popular fabric for home textiles like bath towels, hand towels, kitchen towels, medical towels. One of the popular applications of terry fabrics is pilgrimage (*IHRAM*) terry cloths. It should have physiological comfort properties; like the breathability, quick absorption and evaporation of sweat, softness, air and water vapor permeability, antibacterial especially in hot weather of *Mecca*. Terry fabrics are produced by three yarn systems: pile warp, ground warp weft yarns. Pile structure mainly affect the functional properties of terry fabrics. The main factors should be considered in the designing of a terry fabric are the fabric materials, type of ground warp yarns, type of pile warp yarns, type of weft yarns, pile length, pile height and pile structure. This research concerns with improving the performance of terry towels used as pilgrimage (Ihram) cloths by measuring the weight (GSM), fabric thickness and air permeability of the fabric. Three parameters were used in executing the research samples to compare them with a common control sample in the market to achieve the research aims. The first factor is using bamboo fibers as pile warp yarns. The second parameter is using different heights of pile (5.5 mm-6.5mm-7.5 mm). The third parameter is using different types of materials as wefts (Cotton-Lyocel-Bamboo). The result of the research showed that decreasing the pile height improves air permeability. In addition, using bamboo yarns as pile warp and picking by using bamboo and Lyocel yarns improves the performance and physiological comfort characteristics of terry towels such as absorption, evaporation, thermal conductivity, anti-microbial and anti-bacterial abilities.

Keywords:

Terry Towels, Bamboo, Lyocel, Tencel, physiological comfort, Pilgrimage (IHRAM) Cloths, air permeability, Anti-Bacterial.

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Introduction

Pile fabric is a form of textile created by weaving or knitting .These fabrics are characterized by a pile, a looped or tufted surface that extends above the ground weave. The pile is formed by pile warp yarn which is running in the direction of the length of the fabric or in the direction of fabric width (weft or filling pile weave). [1]

Pile fabrics are classified to:

- **Warp pile fabrics**: Loop pile (Terry Towels) - Cut loop by wires (Velvet) -Face to Face.
- **Weft pile fabrics**: Plain Velveteen – Corded Velveteen (Corduroys) –Figured Velveteen - Corded Figured Velveteen- Weft plush.
- **Knitted Pile Fabrics:** warp knitted- weft knitted**.**

Terry fabric is a kind of pile fabrics which is a soft, usually cotton fabric with loops which must have required usage properties such as higher water absorption, bacterial resistance, high wet strength, ability to dye well, good colorfastness, wash ability, soft hand, hypoallergenic, low cost, and easy availability compared with other types of textile fabrics as the end uses of terry fabrics require this. Terry fabric is the most popular fabric for home textiles like towels. [2] Terry cloth products are exposed frequently to intensive washing. They also must be resistant to water, alkalis, surfactants, and rubbing. Terry fabrics are produced by three yarn systems: pile warp, ground warp weft yarns. The pile can be formed on one side or on both sides of a terry fabric by pile warp yarns. Pile structure mainly affect the structure and usage properties of terry fabrics. The main parameters to be considered to design a terry fabric are type of ground warp yarns, type of pile warp yarns, type of weft yarns, raw material used, and pile structure [1]. One application of terry fabrics is pilgrimage (IHRAM) terry cloths. It should have required properties like quick Absorption and Evaporation of sweat, Softness, Water vapor Permeability, Antibacterial, Dirt and grease Resistance. [3]

Research Problem

High degrees of temperature in Mecca during the year leads to significant suffering to people during the pilgrimage season. This leads to sweating heavily which is considered an ideal environment for Bacterial growth and thus causes physiological in comfort for them.

Antibacterial treatments should be done during final finishing processes for traditional cotton terry towels to provide these fabrics with antibacterial properties, but the efficiency of this treatments is temporary especially with continuous laundering. So, this requires terry towels which provide physiological comfort and durable antibacterial without chemical treatments by using antibacterial natural materials such as bamboo and Lyocel.

Research Objectives

This research aims to producing terry towels used as pilgrimage (IHRAM) cloths which achieve physiological characteristics for people during pilgrimage as following:

- Improve the ability of water absorption and evaporation.
- Improve the ability of air permeability which improve thermal conductivity.
- Improve the anti-bacterial and anti-microbial properties.

Importance of research

- Improving the physiological characteristics of terry towels used as pilgrimage (IHRAM) cloths.
- Improve anti-bacterial and anti-microbial properties permanently by using anti-bacterial and anti-microbial natural materials.

Research Methodology

The research follows the practical methodology

Theoretical Framework

Description of Terry Towel

Terry fabric is expressed as a textile product which is created with loop pile on one or on both sides forming plain, strips, checks, or other patterns with end hems or fringes and side hems or selvedges. [4]

1.1.1.1 *Yarns Used in Terry Towels*

There are four sets of yarns used in terry towel as indicated in figure (1) as following:

- Ground Warp
- Pile Warp

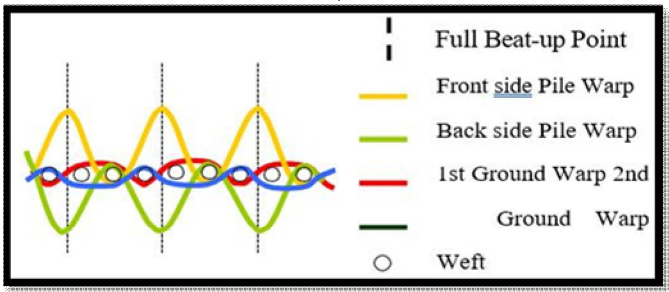


Figure (1) Cross section of weft yarns in a terry towel, showing ground and pile warp end movement

Theory of pile formation in terry towels

Pile loops are achieved by two techniques of beating -up motion of the terry machine as following:

1- **The moving (loose) reed and the constant cloth fell:**

By this technique, pile formation is achieved by a special reed motion and let-off system. This motion is "loose" for number of picks and "fast" for another picks, so it depends on the number of picks per loop.

2- **The constant reed and the moving cloth fell**

In this system, the reed is constant and does not drop back but the cloth fell is moving towards or backward the reed. [5] When the reed is at the front center, the fabric moves towards the reed positively to form the pile by the help of the backrest, terry bar and the temples.

Fibers used in terry towels

The most common fibers used in terry towels are as following:

- ***Natural plant fibers*** like Cotton, Flax, Sea bean, Banana fibers, Sisal, Hemp and Ramie.
- ***Regenerated cellulosic fibers*** like bamboo and Tencel.
- ***Synthetic fibers*** like Microfibers.

Cotton

Cotton remains the world`s favorite natural cellulosic fiber with a huge range of desirable characteristics including appearance, performance, versatility and natural comfort. [6],

Structural Properties

The cross-section of a mature cotton fiber is often described as being kidney bean shaped and the longitudinal section looks to be a twisted ribbon or a collapsed and twisted tube with convolutions.

Polymerization

The degree of polymerization (DP) for primary wall is between 2,000 and 6,000 and their distributions are broader. The “DP” of the cellulose in the secondary wall is about 14,000 and it is nearly 100% cellulose. [7], [8]

Table (1) indicates the chemical composition (%) of cotton fiber

Component	Range
Cellulose	88.0-96.0%
Protein	1.1-1.9%
Pectic Substances	0.7-1.2%
Wax	0.4-1.0%
Total Sugar	0.1-1%
Organic Acids	0.5-1.0%
Pigments	0.5-8.0%
Ash+ Other	0.7-1.6%

Chemical properties

Cotton fibers are resistant to alkalis and are relatively unaffected by normal laundering. Cotton fibers are weakened and destroyed quickly by hot dilute acids or cold concentrated acids.

Water absorbency

Moisture regained of cotton fibers is 8.5% and 10% for mercerized cotton in standard environment and it reaches 25% at 100% humidity.

Biological Properties

Cotton fiber is not an anti-bacterial fiber because it is damaged by *Fungi* and *Bacteria* especially in the presence of heat and moisture. Cotton fibers have a good resistance to moths, beetles and most of insects, but it is attacked by Silverfish insect. [9], [10]

Lyocell

Lyocell fiber is the newest cellulosic fiber and a new brand name is the world of apparel and textiles. Lyocell fiber is a kind of solvent type regenerated cellulose fiber. It is composed of 100% cellulose found in wood pulp and It is produced in a non-chemical manner using NMMO (N-methyl morpholine-N- oxide) solvent. Lyocel fiber is economical in its use of energy and natural resources and is fully biodegradable [11]

Structural Properties

The lyocell fiber structure is a nano-fibrillar cellulose structure, which consists of countless non- swelling crystalline microfibers and very hydrophilic, crystalline nano–fibrils, which are arranged in a very regular manner giving a nanofibrillar- nonporous structure. Lyocell fiber has a close to a circular or an oval cross-section while the longitudinal surface of Tencel fiber is very smooth and cylindrical without any striation. [12]

Polymerization

Lyocell fiber show higher degree of polymerization (600-800 DP), higher crystallinity (up to 60-70%)., longer crystallites with reduced thickness, lower extent of clustering and shorter, higher oriented amorphous regions Compared to the other man-made cellulosic fibers. [13]

Chemical properties

Lyocell fibers have a good resistance to alkalis and are relatively unaffected by normal laundering. Lyocell fibers are weakened and dissolved by hot diluted and cold concentrated acids. [14]

Water absorbency

Lyocell fibers are highly hygroscopic, water absorbing and breathable on the fiber level which provide a cooling atmosphere to the touching skin. Lyocell fibers absorbency is11.5% which is 50% higher than cotton fibers in standard conditions (20°C and 65% relative humidity). [15]

Biological Properties

Lyocell fiber is a perfect retarder of bacterial growth and Gentle to the skin specially for people who suffer from skin diseases. [13]

Bamboo

Bamboo fibers have always been contributing economically to our lives by using their applications in our daily routine. They provide comfortable and eco- friendly products with great UV and bacterial growth resistance. [16]

Structural Properties

Bamboo is a lignocelluloses fiber as its main components are α-cellulose, hemi-cellulose and lignin. The chemical composition average of bamboo is

- **Lignin** (20-30%)
- **Holocellulose** (60-70%) which consists of:
  1. ***Cellulose*** (52-60%) (sugar residues extractives like Galactose, Fructose and Sucrose)
  2. ***Hemi cellulose*** (20-25%) (Pentose-Alcohol-Toluene).
- **Minor components** such as Resins (0.2-0.5%), Proteins (1-1.5%), Tannins (Traces), Ash (1.5-5%), Waxes (0.5-0.7%), Silica (0.7-1%).

Bamboo fiber has an irregular serrated cross-section covered with micro-gaps and holes(voids). The longitudinal section is slender, long, tapered and often forked at the ends. And there are striated cracks distributed along the length of the fiber. [17]

Polymerization

The degree of polymerization (DP) of bamboo is reported to be 50-600 DP and it is 1050 DP for bleached bamboo. Polymerization of bamboo fibers is close to jute fiber and lesser than flax and ramie fibers and much lower than cotton fibers. [18]

Chemical properties

Bamboo fibers are bad anti-alkaline as alkali treatment reduce degree of polymerization and then damaging the fiber with higher concentration of alkalis. Treating bamboo fibers with hot diluted or cold concentrated acids leads to reducing degree of polymerization and tensile strength and then damaging the fiber. [19]

Water absorbency

Bamboo fiber has a greater moisture regain capability (13.3%) than other natural fibers such as cotton (8.5%).

Biological Properties

Bamboo fibers are inherently excellent antimicrobial and antifungal fibers comparing to other natural fibers such as Cotton, Linen, Tencel, Jute and Ramie so it is preferable to make healthier and more hygienic apparels next to the skin from bamboo. [20]

Functional Properties of terry fabrics

Absorbency

The performance of terry fabric is mainly evaluated by its absorbency which refers to the rate at which the fabric absorbs the water (dynamic water absorbency) and the total water retention ability of the fabric (static water absorption). [21] Absorption performance generally depends on the following factors:

- Type of Material.
- Type of yarn (single or plied).
- Yarn count.
- No. of twists per unit.
- Pile height and shape. [22]

Wetting and wicking

Wetting phenomenon takes place at the first moments when fabric comes in touch with water or any liquid. Wicking phenomenon is moving the liquid driven by the capillarity which is responsible for the penetration ability of liquid into fine pores of the fiber.

Wetting and Wicking depend on the following parameters:

- Fiber material
- Type of yarn
- The chemical structure of fiber surface.
- The fiber geometry.
- The surface roughness.
- Orientation of fibers in yarn cross section.
- Porous structure of the fiber and then the yarn. [22], [23]

Air & Water vapor permeability

Air permeability is a measure of passing air through the fabric under a certain pressure. It is a very important factor which affect the terry fabric performance. [24] Water vapor permeability is the rate of water vapor transmission per unit area per unit of vapor pressure differential under test conditions. It is an indicator of the passage of water vapor through the fabric. It is also known as water vapor transmission rate or moisture vapor transmission rate [25]

Air and Water vapor permeability depend on the following parameters:

- Type of fiber and yarn structure. [26]
- No. of twists per unit: Indirect relation.
- Type of fabric structure: Dense and compact structures reduce air and water vapor permeability of the fabric.
- Yarn count: Indirect relation.
- Warp and weft density: Indirect relation.
- Cover factor of the fabric: Indirect relation.
- Pile height and pile length (indirect relation
- Fabric thickness: Indirect relation.

Thermal Insulation and conductivity of terry fabrics

Thermal insulation is termed as thermal conductivity resistance or as the thermal transmittance or warmth keepability rating, which is the ratio of heat loss difference between the uncovered hot surface and covered surface to that of the uncovered hot surface, expressed as a percentage. Thermal conductivity is termed as the fibric ability to conduct heat through it which affects the fabric thermal comfort. The following factors affect thermal insulation and conductivity:

- **Fabric thickness** which has a significant effect on thermal insulation and conductivity. There is a direct relationship between fabric thickness and thermal insulation while there is a reversal relationship between fabric thickness and thermal conductivity.
- **Pile length and height** as Increasing pile length and height increases the thermal insulation and decreases the conductivity due to the greater pile length and height generate more entrapped pockets of air in the fabric.
- **Cover factor of the fabric** by using less close weave structures. The greater cover factor, the greater thermal insulation and the lower conductivity. [27], [28]
- **weight and compressional properties of fabric** as high weight, high resiliency and low compression increase the thermal insulation of the fabric and thus decrease the conductivity.
- **Contact area between the fabric and the**

skin, as there is a reversal relationship between contact area of the fabric to the skin and the thermal insulation of the fabric and thus a direct relationship with the conductivity. Thermal insulation can be increased by increasing the air gap between the body and the fabric, but it begins to decrease beyond the gap of about 7.5-10 mm due to a convection effect.

- **Layers of fabric**, as placing one layer of fabric above another increases the entrapped pockets of air between the layer and thus increase the thermal insulation and decrease the thermal conductivity. [3], [22], [24]
  - **Finishing treatments (indirect relation):**

Softness of terry fabrics

Softness of terry fabric depends on the following factors:

- **Type of material.**
- **Structural and morphological properties of the fibers.**
- **Structure of the yarn**.
- **Loop shape.**
- **Type of finishing treatment like shearing, softening…etc.** [22]**,** [29]

Experimental Work

This study aims to highlights on improving the functional performance of terry fabrics which are used as pilgrimage (IHRAM) clothes (Fabric Weight- Fabric Thickness- Air Permeability) according to the following parameters:

- **Weft Material (Cotton-Bamboo-Tencel).**
- **Pile Height (5.5mm-6.5mm-7.5mm).**
- **Pile Warp Material (Bamboo for 9 samples and cotton for the standard comparative sample).**

According to the previous parameters, 9 terry towel samples were executed in addition to a popular terry towel sample in Egyptian market to be a standard comparative sample.

Specification of the produced samples

Warp specification

- **Material**
  - **For ground warp:** Sudanese cotton is used in the whole 10 samples
  - **For Pile warp**: Bamboo is used for 9 samples and Sudanese cotton for the 10^{th} sample (standard comparative sample).
- **Density/cm:** 24ends/cm (12 ground ends+12 pile ends).
- **Warp Arrangement:** 2 ground ends:2 pile ends
- **Warp count:** 24/2 Ne for both ground and pile warp ends.
- **Pile Height:** 5.5mm for samples (1,2,3 and the 10^{th} standard sample)-6.5mm for samples (4,5,6)-7.5mm for samples (7,8, 9).
- **No. of twists/cm:**
  - **For ground warp:**600 twists/cm
  - **For pile warp:**280 twists/cm
- **Denting:** 2ends/dent

Weft Specification

- **Material**
  - Cotton: for samples (1,4,7& the 10^{th} standard).
  - Bamboo: for samples (2,5,8).
  - Lyocel (standard Tencel): for samples (3,6,9).
- **Density/cm**: 18 picks/cm.
- **Weft count**: 20/1Ne.

1.1.2 Weave Structure

The weave structure technique used to execute the terry towel samples is 3-picks terry technique based on 2/1 warp rib weave as shown in figure (2).

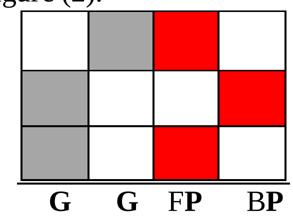


Figure (2) 3-Picks Weave Structure Technique used in the samples

Specification of the machine used in producing the samples.

The research samples were executed at "***C-Tex***" company in ***Shubra Al-Khaimah, Qalyoubyya*** by using an electronic jacquard loom with the specification shown in the following Table (2):

Table (2) Specifications of the machine used for executing samples

Type of loom	Leonardo VAMATEX
Manufacturing Country	Italy
Date of Manufacturing	2003
Reed count	12dent/cm
Denting	2 Ends/Dent
Width of reed	240 Cm
Shedding Device	Jacquard
Model of shedding Device	STAUBLI
Manufacturing Country	France

Jacquard Capacity	2688 Hooks
Design Hooks	960 Hooks
Harness Building Type	Straight
No. of Harness Repeats	3 Repeats each one=80 Cm
Drafting	Grouped
Weft Insertion Device	Rapiers
Capacity of weft selector	8 colors (fingers) and 2 fingers used for the design
Type of Take-up Device	Electronic Positive
Type of Let-off Device	Electronic Positive
Tension of warp	120 for Ground Beam&40 for Pile Beam
Loom Speed	**350 R.P.M**

Laboratory Tests applied to samples under study

Laboratory tests of the executed samples were carried out to check the functional properties of the better terry towel sample to be used as pilgrimage (IHRAM) clothes

1. *Determining Fabric Weight Test.*

This test was carried out by using "***Precisa 1300 c***" balance as shown in Fig (2-2) according to the American Standard Specification of **(ASTM-D-3776-79).** [30] .5 readings were taken from different areas of each sample and the average of each one was calculated.

2. *Determining Fabric Thickness Test.*

This test is carried out by using "***Mituoyo***" thickness digital gage no.7301, produced by "***Turlock Japan company***" as shown in Fig (2-3) according to the American Standard Specification of **(ASTM-D-1777-1996)**. [31] .5 readings were taken from different areas of each sample and the average of each one was calculated.

3. *Determining Fabric Air Permeability Test.*

This test was carried out by using "***MOZIA air permeability tester***" from "**SDL Atlas**" as shown in Fig (2-4) according to the American standard specification of **(ASTM D-737-2012).** [32]. 5 readings were taken from different areas of each sample and the average of each one was calculated.

Results and Discussion

The following data in Table (3) represents the results of the applied tests to the executed samples

Table (3) represents the results of the applied tests to the executed samples

Sample No.	**Study Parameters**			**Applied lab Tests to the samples**		
	Pile Height (mm)	**Pile warp material**	**Weft material**	**Fabric Weight (g/m^2)**	**Fabric Thickness (cm)**	**Air Permeability ($L/M^2/Sec$)**
1	**7.5**	Bamboo	Cotton	**537**	**1.59**	**1020**
2	**7.5**	Bamboo	Bamboo	**506**	**1.58**	**1116**
3	**7.5**	Bamboo	Lyocell	**532**	**1.54**	**1213**
4	**6.5**	Bamboo	Cotton	**459**	**1.47**	**1040**
5	**6.5**	Bamboo	Bamboo	**437**	**1.46**	**1150**
6	**6.5**	Bamboo	Lyocell	**456**	**1.42**	**1242**
7	**5.5**	Bamboo	Cotton	**428**	**1.39**	**1110**
8	**5.5**	Bamboo	Bamboo	**399**	**1.38**	**1166**
9	**5.5**	Bamboo	Lyocell	**421**	**1.33**	**1272**
10(Control sample)	**5.5**	**Cotton**	**Cotton**	**436**	**1.36**	**740**

1. **Fabric Weight of produced samples**

Table (4) and Figure (3) are showing the results of weight test applied to the executed samples using the following parameters:

- **Pile Height.**
- **Weft Material.**
- **Pile Warp Material**.

Table (4) Results of fabric Weight Test (g/m^2)

Sample No.	**Pile Warp**	**Pile Height**	**Weft Material**	**Weight**
1	**Bamboo**	**7.5mm**	**Cotton**	**537**
2			**Bamboo**	**506**

3			Lyocell	532
4		6.5mm	Cotton	459
5			Bamboo	437
6			Lyocell	456
7		5.5mm	Cotton	428
8			Bamboo	399
9			Lyocell	421
10 (Control Sample)	Cotton	5.5mm	Cotton	436

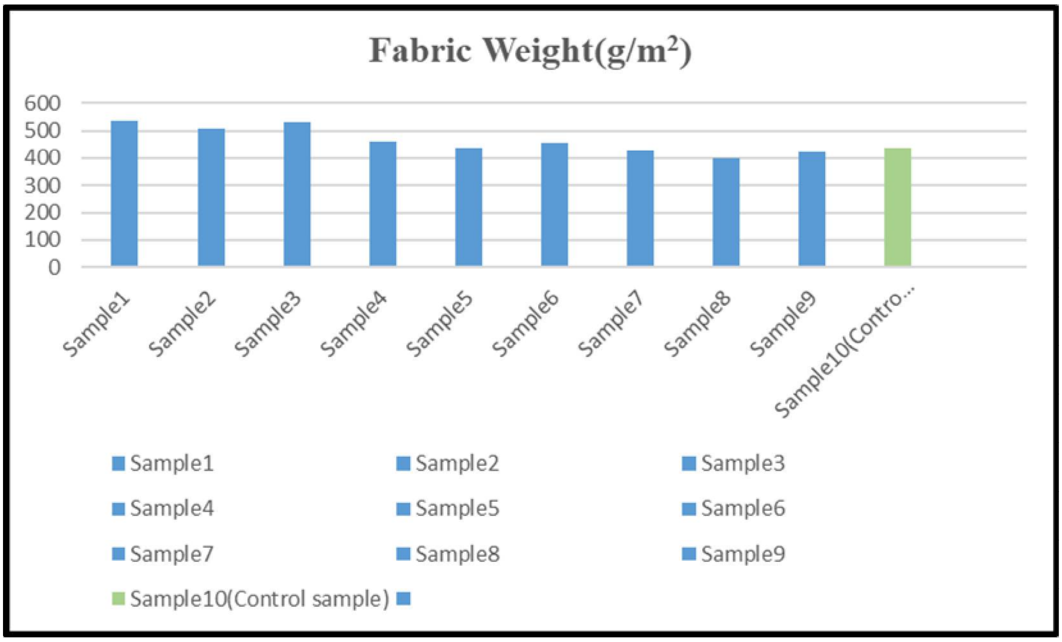


Figure (3) Results of the fabric weight test for the executed samples (g/m2)

According to Table (4), Figure (3), Figure (4), Figure (5), Figure (6), Figure (7) and Figure (8), The fabric weight test results can be concluded as following:

- ***Sample 1*** has recorded the highest fabric weight of 537 g/m^2 by using pile height of 7.5 mm, Cotton material for weft and bamboo material for pile warp.
- The weight of ***sample 1***(537 g/m^2) is higher than the weight of the ***control sample*** (sample10) which has recorded (436 g/m^2) by using pile height of 5.5mm, Cotton material for weft and pile warp.
- ***Sample 8*** has recorded the least fabric weight of 399 g/m^2 by using pile height of 5.5 mm, Bamboo material for weft and bamboo material for pile warp.
- The weight of ***sample 8*** is lower than the weight of the ***control sample*** which is preferable for the physiological comfort of the pilgrims during the rituals of pilgrimage.
- Increasing the fabric weight of the pilgrimage clothes is not accepted due to increasing the fabric weight leads to increasing the time of absorption which is not suitable for high degrees of temperatures and humidity and overcrowding during rituals of pilgrimage. This leads to increasing the temperature of the human body and generating more sweat which make the pilgrims feel discomfort and thus physical stress.

Effect of pile height (mm) on fabric weight (g/m2)

Results presented in Table (4) and Figure (4) show that terry towel samples with pile height **7.5 mm** show higher fabric weight values than terry towel samples with pile height **6.5 mm** and **5.5 mm**. The difference observed was due to the direct proportional relationship between the pile height and the fabric weight. This could be explained that the increase in pile height and thus pile length led to increasing the amount of pile loops therefore the fabric weight increases.

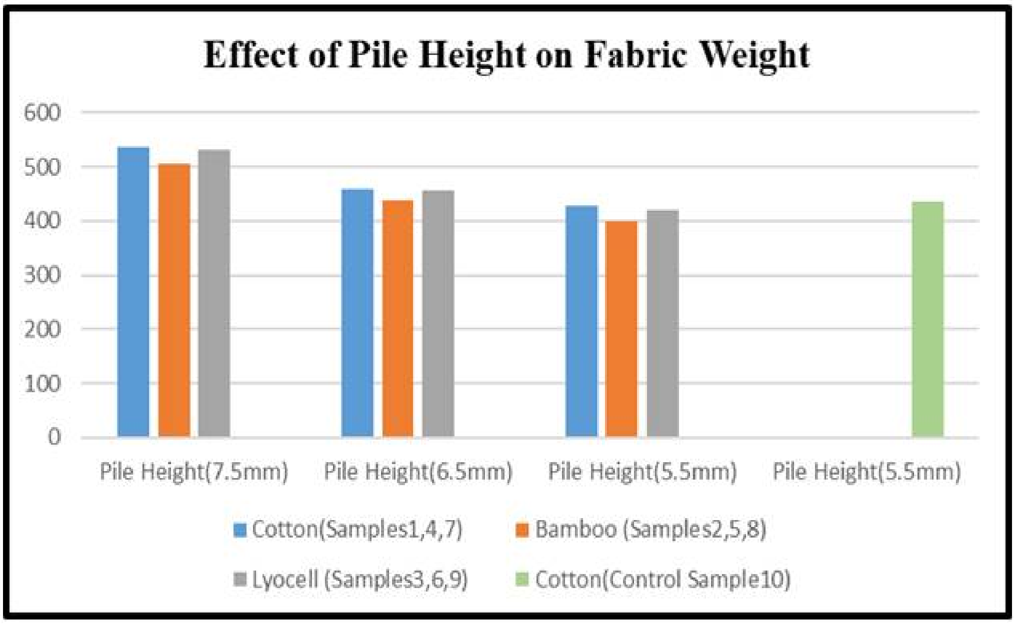


Figure (4) Effect of pile height (mm) on fabric weight(g/m2) for the executed samples

Effect of weft material type on fabric weight (g/m2)

Results presented in Table (4) and Figure (5), Figure (6), Figure (7) show that the executed terry towel samples from cotton weft material recorded higher fabric weight values than the executed terry towel samples from Lyocell and Bamboo materials.

Bamboo samples recorded lower weight than other materials which is considered suitable for pilgrimage clothes.

This may be attributed to the following reasons:

- Fiber specific density is defined as the mass per unit volume and is expressed in grams per cubic centimeters (g/cm^3), so there is a direct proportional relationship between specific density of material and fabric weight.
- Cotton is considered a heavy material with specific density (1.54-1.56 g/cm^3) comparing to Lyocell (1.5-1.52 g/cm^3) and Bamboo (0.6-1.1 g/cm^3) according to Table (5).
- Cotton has more amorphous regions than Lyocell and Bamboo.

Table (5) Specific density of materials

Fiber	**Specific Density (g/cm^3)**
Cotton	1.54-1.56
Lyocell	1.5-1.52
Bamboo	0.6-1.1

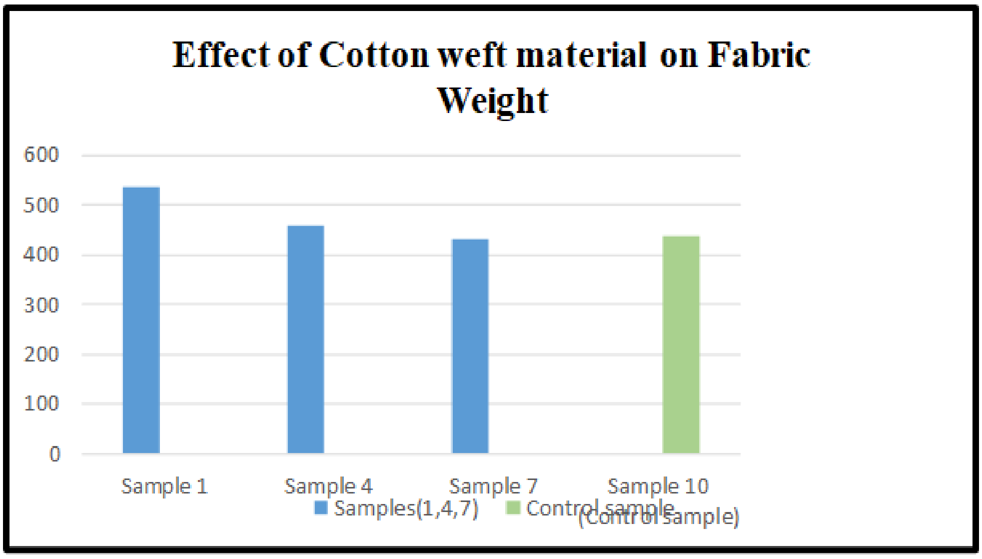


Figure (5) Effect of Cotton weft material on fabric weight(g/m^2) for the executed samples

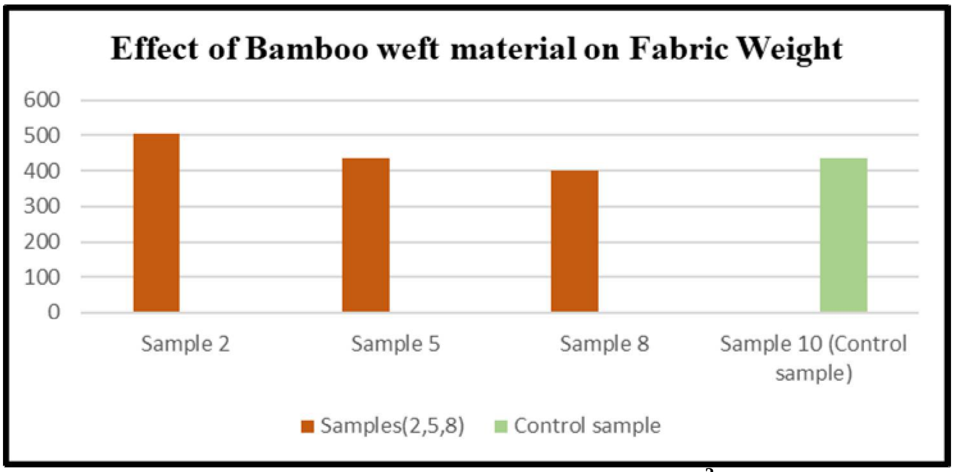


Figure (6) Effect of Bamboo weft material on fabric weight(g/m^2) for the executed samples

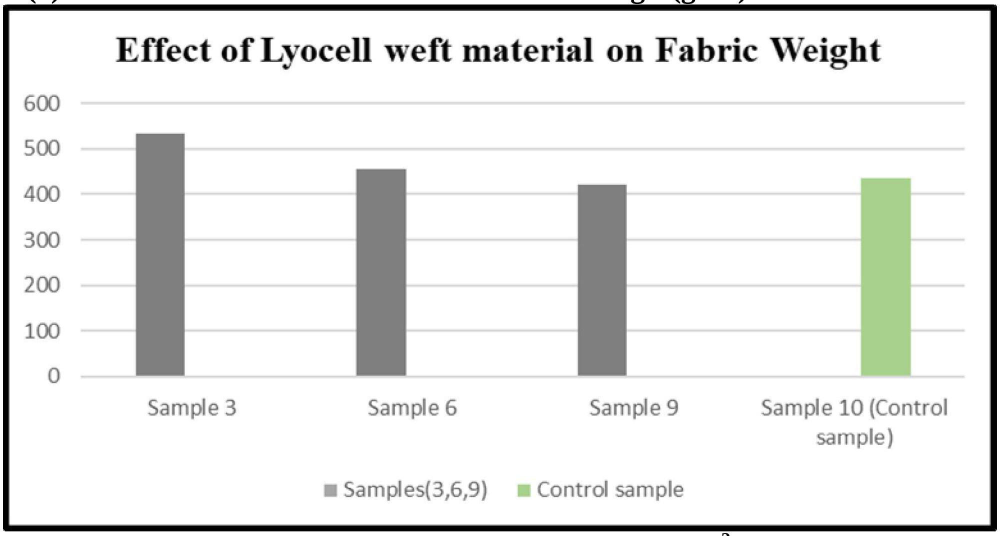


Figure (7) Effect of Lyocell weft material on fabric weight(g/m^2) for the executed samples

Effect of warp pile material type on fabric weight (g/m2)

Results presented in Table (4) and Fig (8) show that the executed terry towel samples (***Samples 7,8&9***) from Bamboo pile warp material recorded lower fabric weight values than the executed terry towel control sample (***sample 10***) from cotton material.

Notice: Samples (7,8,9 &10) have the same pile height (5.5mm).

Low fabric weight may be attributed to the low specific density of bamboo comparing to cotton, according to Table (5). Another reason is that Bamboo fibers have lower amorphous regions than Cotton fibers which leads to lower fabric weight.

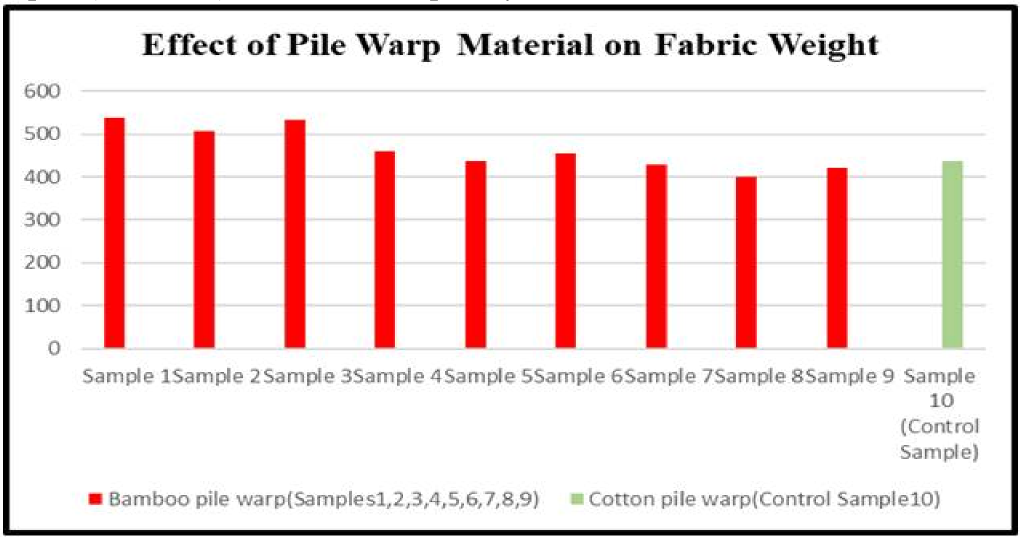


Figure (8) Effect of pile warp material on fabric weight(g/m^2) for the executed samples

2. Fabric Thickness of produced samples

Table (6) and Figure (9) are showing the results of Fabric Thickness test applied to the executed samples using the following parameters:

- **Pile Height.**
- **Weft Material.**
- **Pile Warp Material.**

Table (6) Results of Fabric Thickness Test (Cm)

Sample No.	Pile Warp	Pile Height	Weft Material	Thickness
1	Bamboo	7.5mm	Cotton	1.59
2			Bamboo	1.58
3			Lyocell	1.54
4		6.5mm	Cotton	1.47
5			Bamboo	1.46
6			Lyocell	1.42
7		5.5mm	Cotton	1.39
8			Bamboo	1.38
9			Lyocell	1.33
10 (Control Sample)	Cotton	5.5mm	Cotton	1.36

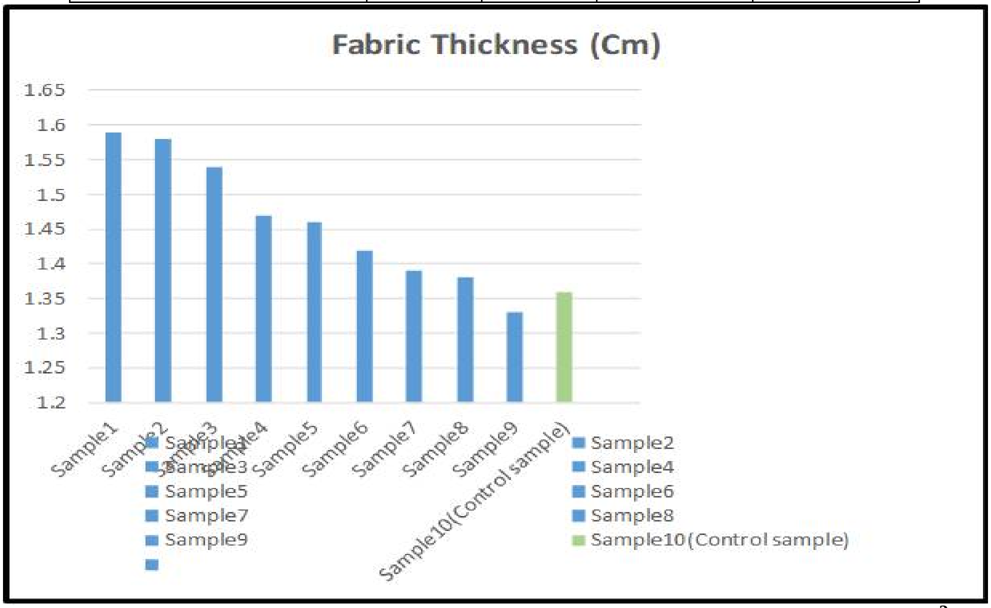


Figure (9) Results of fabric Thickness Test for the executed samples (g/m^2)

According to Table (6), Figure (9), Figure (10), Figure (11), Figure (12), Figure (13) and Figure (14), The fabric thickness test results can be concluded as following:

- ***Sample 1*** has recorded the highest fabric thickness of 1.59 Cm by using pile height of 7.5 mm, Cotton material for weft and bamboo material for pile warp.
- The Thickness of ***sample 1*** (1.59 Cm) is higher than the thickness of the ***control sample*** (sample10) which has recorded (1.36 Cm) by using pile height of 5.5mm, Cotton material for weft and pile warp.
- ***Sample 9*** has recorded the least fabric thickness of 1.33 Cm by using pile height of 5.5 mm, Lyocell material for weft and bamboo material for pile warp.
- The thickness of ***sample 9*** is lower than the thickness of the ***control sample***, so low thickness is preferable for the physiological comfort of the pilgrims during the rituals of pilgrimage.
- Decreasing the thickness of the pilgrimage terry towels is accepted because it leads to decreasing the time of absorption, decreasing the thermal insulation and thus increasing the thermal conductivity which are suitable for high degrees of temperatures and humidity and overcrowding during rituals of pilgrimage. This leads to decreasing the temperature of the human body and generating less sweat which make the pilgrims feel comfort, cool and thus decreasing physical stress.

Effect of pile height (mm) on fabric weight (g/m2)

Results presented in Table (6) and Figure (10) show that terry towel samples with pile height **7.5 mm** show higher fabric thickness values than terry towel samples with pile height **6.5 mm** and **5.5 mm**.

The difference observed was due to the direct proportional relationship between the pile height and the fabric thickness.

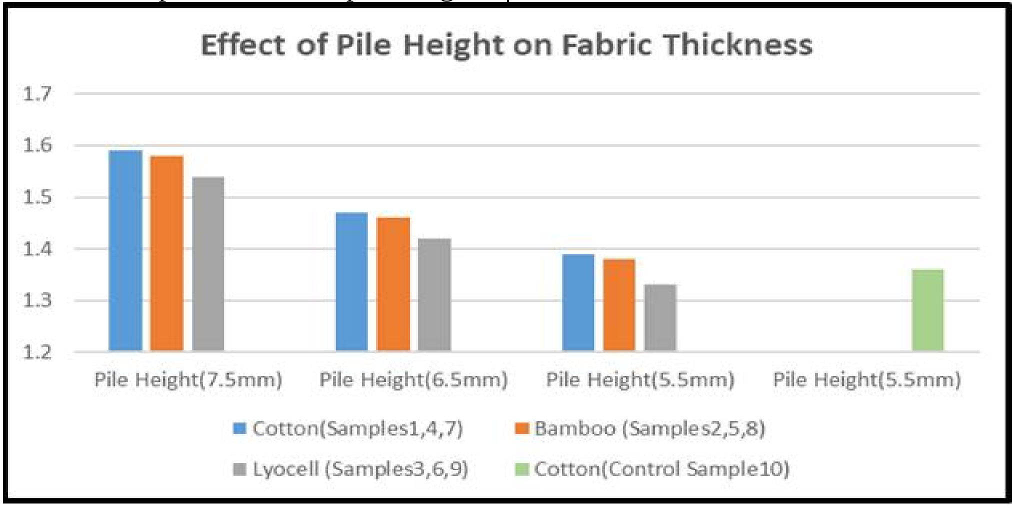


Figure (10) Effect of pile height (mm) on fabric thickness (Cm) for the executed samples

Effect of weft material type on fabric thickness (Cm)

Results presented in Table (6) and Figure (11), Figure (12), Figure (13) show that the executed terry towel samples from cotton weft material recorded higher fabric thickness values than the executed terry towel samples from Bamboo and Lyocell materials, but this difference is not effective. The effect of terry towel weft materials (Cotton-Bamboo-Lyocell) on fabric thickness is statistically not significant.

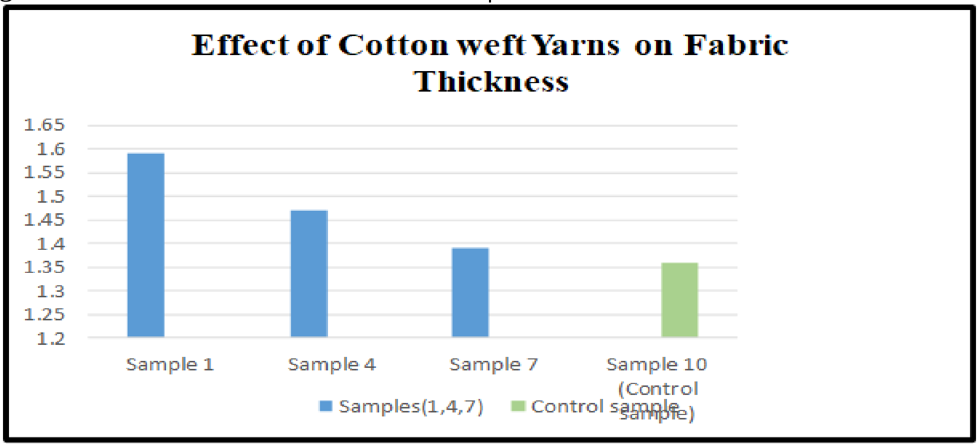


Figure (11) Effect of Cotton weft material on fabric thickness (Cm) for the executed samples

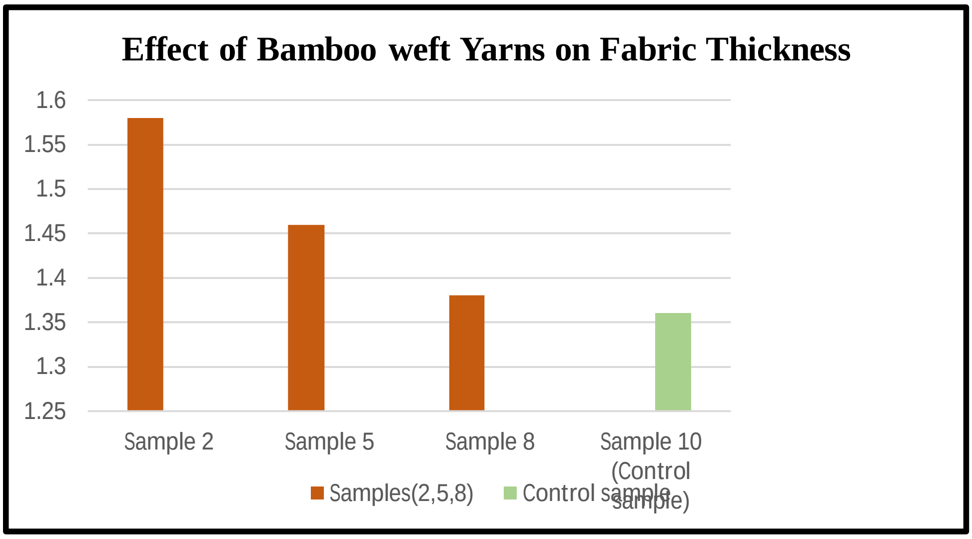


Figure (12) Effect of Bamboo weft material on fabric thickness (Cm) for the executed samples

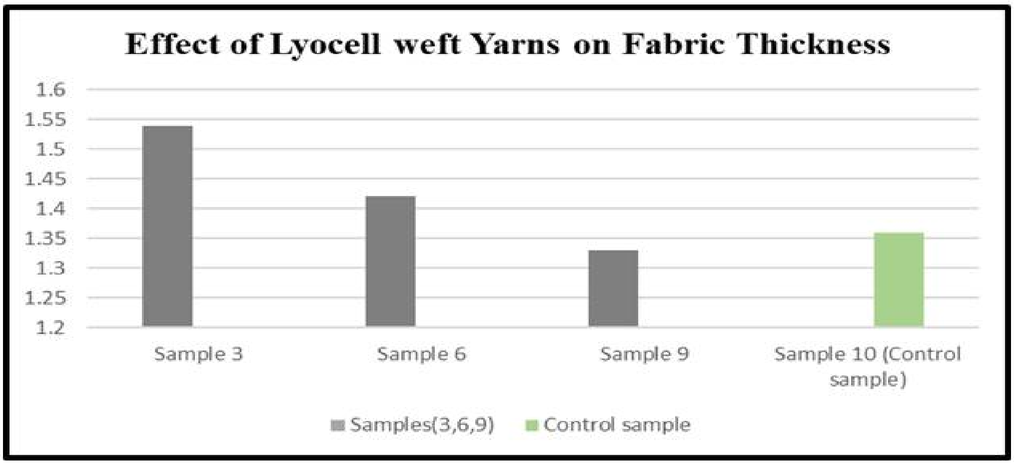


Figure (13) Effect of Lyocell weft material on fabric thickness (Cm) for the executed samples

Effect of warp pile material type on fabric thickness (Cm)

Results presented in Table (6) and Figure (14) show that the executed terry towel sample 9 from Bamboo pile warp material recorded lower fabric thickness values than the executed terry towel control sample (***sample 10***) from cotton material but this difference is not effective.

Notice: Samples (7,8,9 &10) have the same pile height (5.5mm).

The effect of terry towel pile warp materials (Bamboo or Cotton) on fabric thickness is statistically not significant.

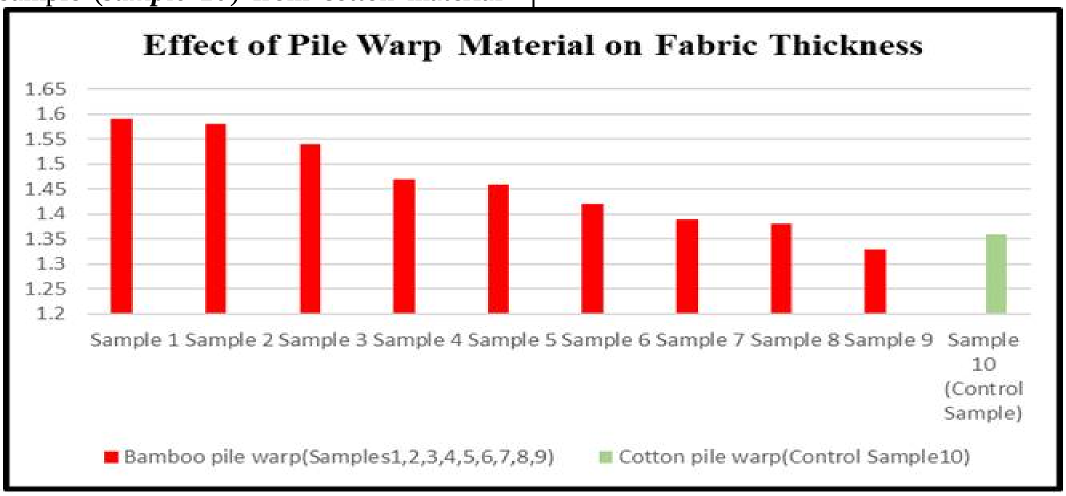


Figure (14) Effect of pile warp material on fabric thickness (Cm) for the executed samples

Air Permeability of produced samples

Table (7) and Figure (15) are showing the results of Air Permeability test applied to the executed samples using the following parameters:

- **Pile Height.**
- **Weft Material.**
- **Pile Warp Material.**

Table (

7) Results of fabric Air Permeability Test (L/m^2/Sec)

Sample No.	Pile Warp	Pile Height	Weft Material	Air Permeability
1	Bamboo	7.5mm	Cotton	1020
2			Bamboo	1116
3			Lyocell	1213
4		6.5mm	Cotton	1040
5			Bamboo	1150
6			Lyocell	1242
7		5.5mm	Cotton	1110
8			Bamboo	1166
9			Lyocell	1272
10(Control Sample)	Cotton	5.5mm	Cotton	740

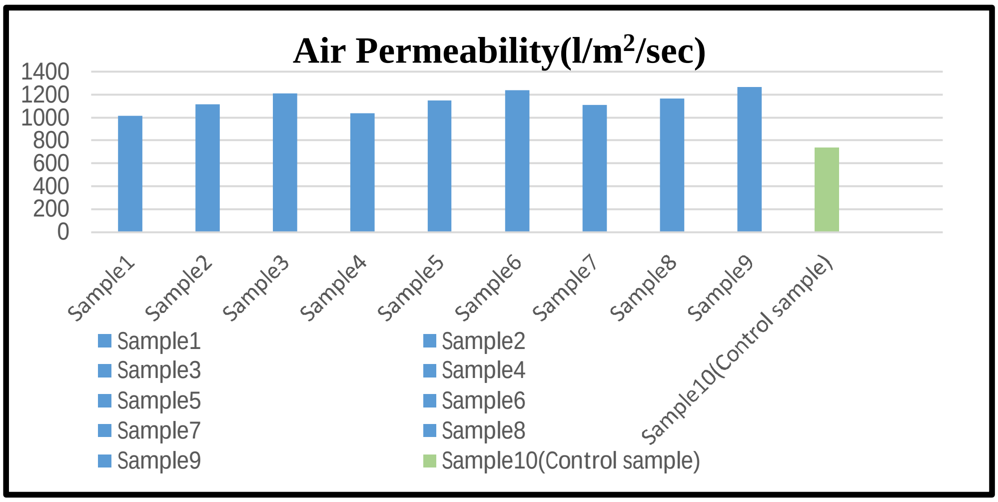


Figure (15) Results of fabric air permeability Test for the executed samples (L/m²/Sec)

According to Table (7), Figure (15), Figure (16), Figure (17), Figure (18), Figure (19) and Figure (20), The fabric air permeability test results can be concluded as following:

- ***Sample 9*** has recorded the highest air permeability of **1272 (L/m²/Sec)** by using pile height of **5.5 mm**, Lyocell material for weft and Bamboo material for pile warp.
- Air permeability of ***sample 9*** (**1272 L/m²/Sec**) is higher than the air permeability of the ***control sample*** (sample10) which has recorded (**740 L/m²/Sec**) by using pile height of **5.5mm** and Cotton material for weft and pile warp.
- ***Sample 1*** has recorded the least air permeability of **1020 (L/m²/Sec)** by using pile height of **7.5 mm**, Cotton material for weft and Bamboo material for pile warp.
- Air permeability of ***sample 1*** is higher than air permeability of the ***control sample*** (sample 10) which has recorded (**740 L/m²/Sec**) by using pile height of **5.5mm** and Cotton material for weft and pile warp.
- High air permeability is preferable for the physiological comfort of the pilgrims during the rituals of pilgrimage as it leads to decreasing the time of absorption, decreasing the thermal insulation and thus increasing the thermal conductivity which are suitable for high degrees of temperatures and humidity and overcrowding during rituals of pilgrimage. This leads to decreasing the temperature of the human body and generating less sweat which make the pilgrims feel comfort, cool and thus decreasing physical stress.

Effect of pile height (mm) on fabric air permeability (L/m2/Sec)

Results presented in Table (7) and Figure (16) show that terry towel samples with pile height **5.5 mm** show higher air permeability values than terry towel samples with pile height **6.5 mm** and **7.5 mm**. The difference observed was due to the inverse proportional relationship between the pile height and the air permeability. This refers to broad structure, low cover factor and also the volume that the air can pass through in the lower pile samples is greater than in the higher pile samples.

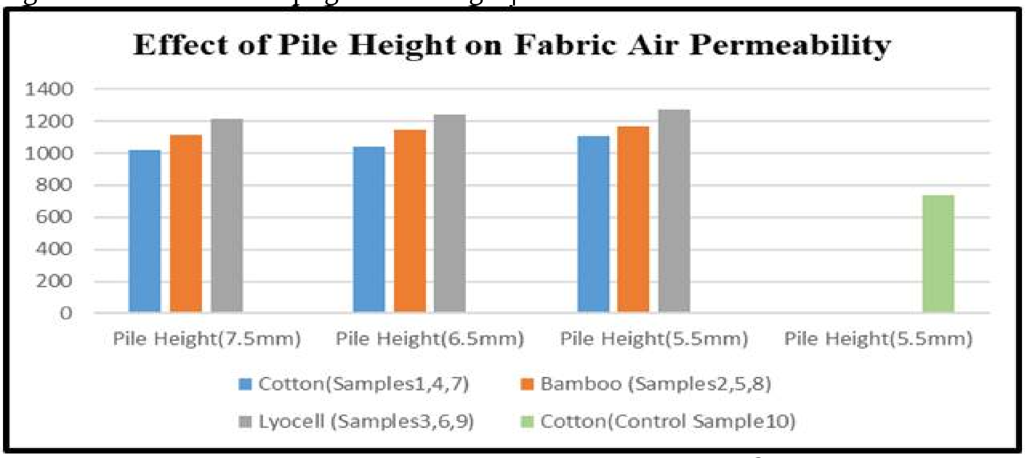


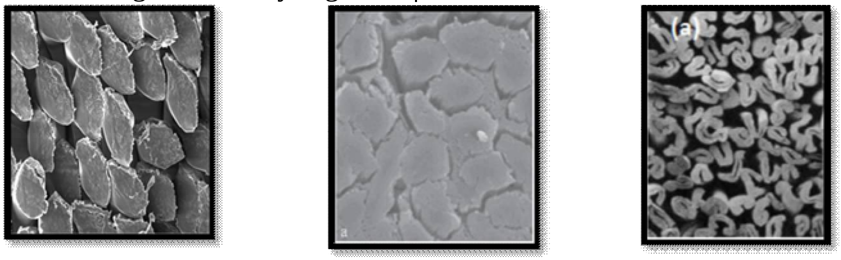
Figure (16) Effect of pile height (mm) on fabric air permeability (L/m²/Sec) for the executed samples

Effect of weft material type on fabric air permeability (L/m2/Sec)

Results presented in Table (7) and Figure (18), Figure (19), Figure (20) show that the executed terry towel samples from Lyocell weft material recorded higher fabric air permeability values than the executed terry towel samples from Bamboo and Cotton materials, so using lyocell enhance air permeability which is considered suitable for pilgrimage clothes. Cotton samples recorded lower air permeability than other materials

This may be attributed to the following reasons:

- Lyocell (Tencel) fibers have unique nano-fibril structure and very smooth surface which has a network of pores and voids comparing to Bamboo and Cotton according to Figure (17). The nano-fibrils are arranged in a very regular manner forming capillaries between the fibrils which are considered ideal passages for air flow and hence hinder the high air permeability.
- Lyocell fibers have finer diameters than Bamboo and Cotton which increases the number of fibers with higher cohesion and more voids in cross section of Lyocell fiber, so it leads to better passage of air through the fabric and thus higher air permeability than Bamboo and Cotton.



Lyocell (Tencel) **Bamboo** **Cotton**

Figure (17) Cross section of Lyocel, Bamboo and Cotton

- Air permeability of Bamboo is higher than cotton because Bamboo fibers have irregular serrated cross-sections covered with micro-gaps and holes (voids) and also there are striated cracks distributed along the length of the fiber which enhance air flow higher than cotton fibers.
- Bamboo fibers have finer diameters than cotton fibers which increases number of fibers in the cross section of bamboo fiber and then allow air flow and then increase air permeability.

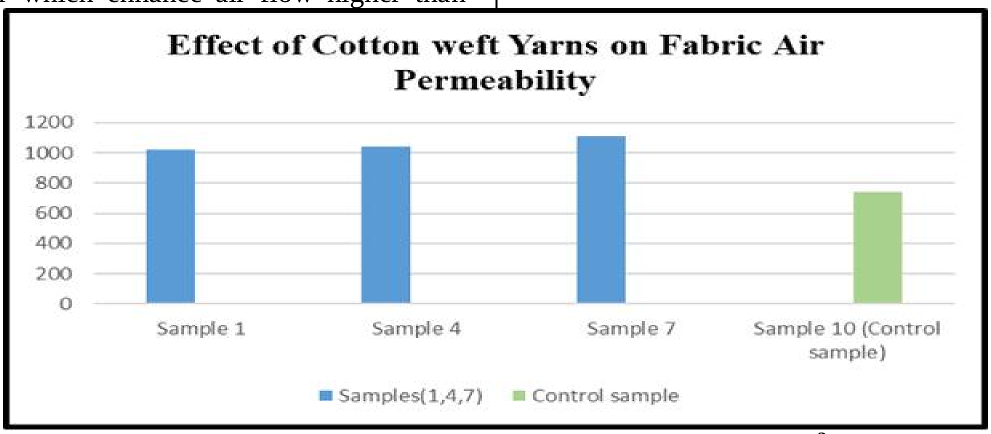


Figure (18) Effect of Cotton weft material on fabric air permeability (L/m^2/Sec) for the executed samples

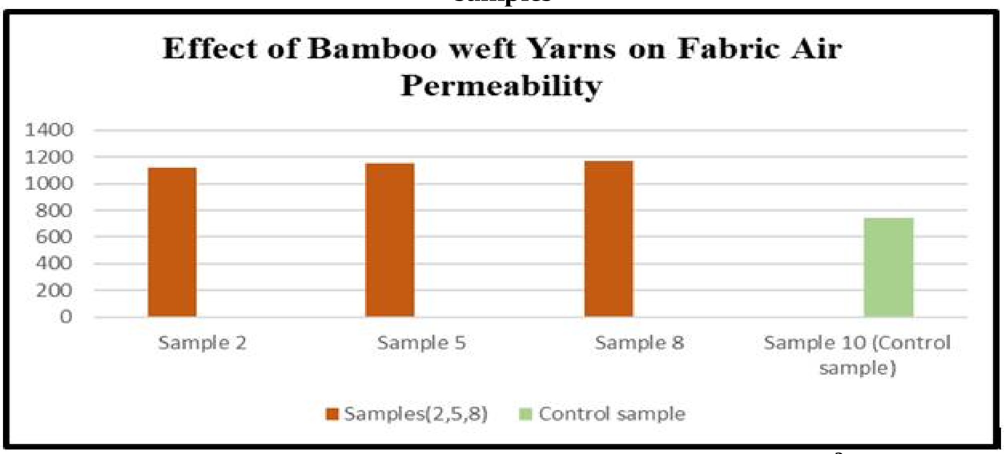


Figure (19) Effect of Bamboo weft material on fabric air permeability (L/m^2/Sec) for the executed samples

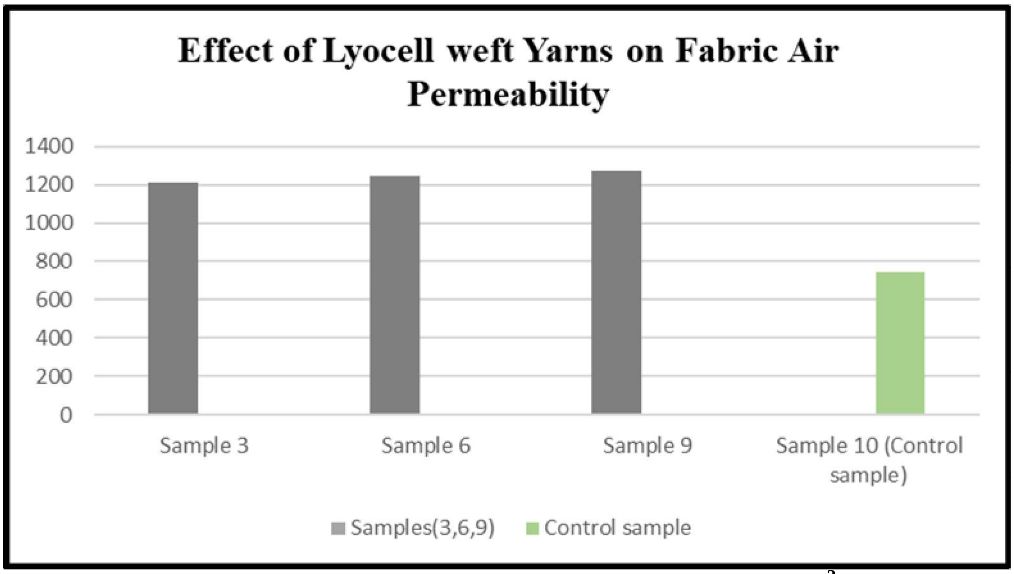


Figure (20) Effect of Lyocel weft material on fabric air permeability (L/m^2/Sec) for the executed samples

Effect of pile warp material type on fabric air permeability (L/m2/Sec)

Results presented in Table (7) and Figure (21) show that the executed terry towel samples from Bamboo pile warp material recorded higher fabric air permeability values than the executed terry towel control sample (***sample 10***) from cotton material.

High air permeability may be attributed to:

- Air permeability of Bamboo is higher than cotton because Bamboo fibers have irregular serrated cross-sections covered with micro-gaps and holes (voids) and also there are striated cracks distributed along the length of the fiber which enhance air flow higher than cotton fibers.
- Bamboo fibers have finer diameters than cotton fibers which increases number of fibers in the cross section of bamboo fiber and then allow air flow and then increase air permeability.

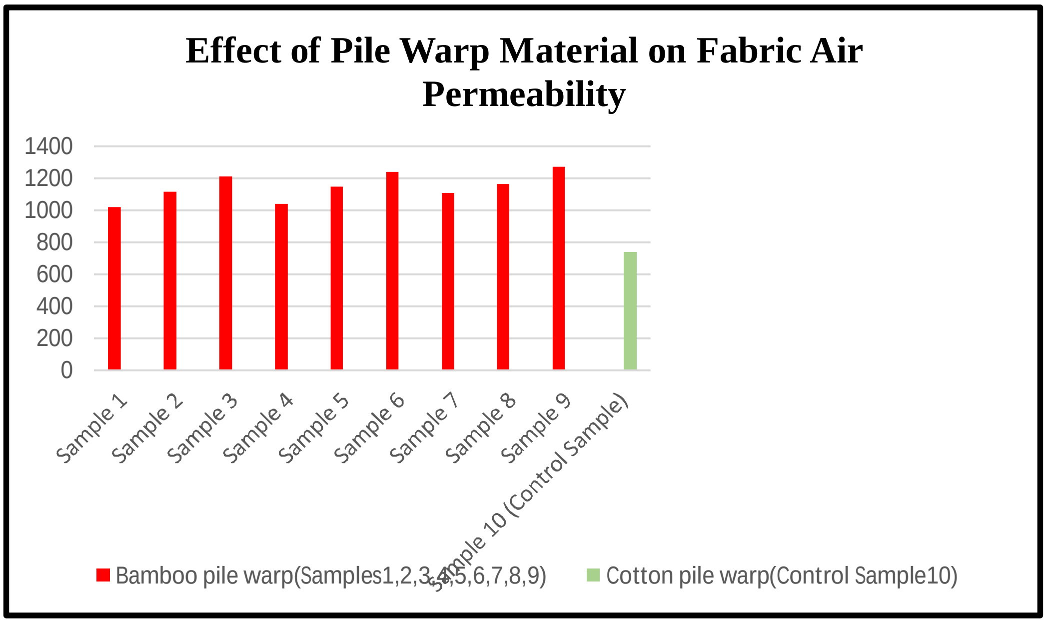


Figure (21) Effect of pile warp material on fabric air permeability (L/m^2/Sec) for the executed samples.

Conclusions

According to the previous figures, tables, relationships and graphs concerning improving the functional properties of pilgrimage (IHRAM) terry towels such as weight, thickness, air permeability, some conclusions were achieved that could improve the functional properties and performance of pilgrimage terry towels as following:

1. Results showed that pile height and material of pile warp are the main parameters which affect the performance of terry towels more than the weft material.

2. There is a direct proportional relationship between pile height and fabric weight, fabric thickness.
3. There is an inverse proportional relationship between pile height and air permeability.
4. Lyocell recorded the greatest results of air permeability compared to Bamboo and Cotton when they are used as wefts.
5. Cotton recorded the greatest results of weight, thickness.
6. Bamboo pile warp material recorded the greatest results of fabric air permeability than Cotton pile warp.
7. Cotton warp material recorded the highest results of weight, fabric thickness than Bamboo pile warp.
8. There is no significant difference in fabric thickness between Cotton, Bamboo and Lyocel.
9. Sample 9 achieved the best performance by using pile height of 5.5mm,bamboo for pile warp and lyocell for weft followed by Sample 8,Sample 6, sample 7,Sample 5, Sample 4, Sample 3, Sample2 compared to the control sample (Sample 10), while sample 1 achieved the least performance.

References

1. O. E. Halawa, Production Technology of Jacquard Fabrics, Cairo: Sign, 2010.
2. K. Moslov, "Enzymatic scouring and bleaching of cotton terry fabrics," Journal of Nature Fibers, vol. 15, no. 5, pp. 740-751, 2018.
3. A. E. F. Lamiaa and M. Nagda, "Possibility of Implementing some "Ehram" Terry Fabrics for men to Improve its Functional Perfoemance," Alexandria Journal of Agricultural Research, vol. 60, no. 2, pp. 181-221, 2015.
4. Aminul Islam Mishuk,Mohammad Shahidul Kader,Azim Mst,Sarmin Khatun, "Terry Towel Iin BANGLADESH," European Scientific Journal, vol. 11, no. 3, pp. 260-271, 2015.
5. Adanur, Handbook of Weaving, Lancaster,USA: Technomic publisher.Co.Inc, 2001.
6. Menachem Lewin,Jack Preston, "Handbook of fiber science and technology; Volume III, High technology fibers," Polymer Degradation and Stability, vol. 57, no. 1, p. 109, 1997.
7. Phillip J. Wakelyn, Alfred D. French, Cotton Fiber Chemistry and Technology, M. LEWIN, Ed., USA: CRC Press © Taylor & Francis Group, 2007.
8. H.L.Needles, Textile Fiber,Dyes,Finishes and Processes, New Jersy, USA: Noyes Publicatios, 1986.
9. P. j. Wakelyn, Cotton, in Encyclopedia of Polymer Science and Technology, New York: John Wiley &Sons, 2004.
10. SomayeAkbariA, AsayeshS., KhaliliazarM., RazipourN.Esmaeeli, "Chemical and physical characteristic of modified cotton and linen fabrics with amine-terminated dendritic polymer," in Handbook of Natural Fibres (Second Edition), Tehran,Iran, The Textile Institute Book Series, 2020, pp. 451-467.
11. Lewin, Pearce, Handbook of Fiber Chemistry, New York: Marcel Dekker Inc, 1998.
12. Schuster, K. C., Aldred, P., Villa, M., Baron, M., Loidl, R., Biganska, "Characterising the emerging lyocell fibres structures by ultra small angle neutron," Lenzinger Berichte, vol. 82, pp. 107-117, 2003.
13. M. Abou-Rous, Characterisation of the wet-state pore structure of lyocell and other man-made-PHD Thesis, Dornbirn: University of Innsbruck,, 2006.
14. Široký, J., Blackburn, R. S., & Bechtold, T.,, "Influence of fabric structure on NaOH release from woven lyocell type material," Textile Research Journal, vol. 81, no. 16, pp. 1627-1637, 2011.
15. Široká, B., Noisternig, M., Griesser, U. J., & Bechtold, a. T., "Characterization of cellulosic fibers and fabrics by sorption/desorption.," Carbohydrate Research, vol. 343, no. 12, pp. 2194-2199, 2008.
16. Abhijit Majumdar, Sanchi Arora, "Bamboo fibres in textile applications," in Bamboos in India, Dehradun, India, National Forest Research Institute, pp. 285-304.
17. Liu, D.; Song, J.; Anderson, D.P.; Chang, P.R.; Hua, Y., "Bamboo fiber and its reinforced composites: Structure and properties," Cellulose, vol. 19, no. 5, pp. 1449-1480, 2012.
18. Erdumlu, N. , Ozipek, B, "Investigation of Regenerated Bamboo Fibers and Yarn Characteristics," Fibers and Textiles in Eastern Europe, vol. 16, no. 4, pp. 43-47, 2008.
19. Kaur, V.; Chattopadhyay, D.P.; Kaur, S, "Study on extraction of bamboo fibers from raw bamboo fibers bundles using different retting," Textiles and Light Industrial Science and Technology, vol. 2, no. 4, pp. 174-179, 2013.
20. Lipp-Symonowicz, B.; Sztajnowski, S.;

Wojciechowska, D., "New commercial fibres called 'bamboo fibres' their structure and properties. ,," Fibres and Textiles in Eastern Europe, vol. 19, no. 1, pp. 18-23, 2011.
21. Salvinija Petrulyte, Renata Baltakyte, "Static Water Absorption in Fabrics of Different Pile Height," FIBRES & TEXTILES in Eastern Europe, vol. 17, no. 3, pp. 60-65, 2009.
22. O. A. Gamil, Improving Functional Performance of Cotton Terry Fabrics(Towels) by Using Microfibers, Giza, Egypt: Faculty of Applied Arts,Helwan University, 2017.
23. Renata Baltakyte, Salvinija Petrulyte, "Investigation into the Wetting Phenomenon of Terry Fabrics," Fibres and Textiles in Eastern Europe, vol. 16, no. 4, pp. 62-66, 2008.
24. M. M. Qotb, "Improvement of the properties of multi-layered fabrics used in the production of mattresses to achieve the best functional performance," International Design Journal, vol. 7, no. 4, pp. 293-299, 2017.
25. D. Gungor, "The comfort Properties of Terry Towels Made of Cotton and Polyproplyne Yarns," Journal of Engineered Fibers and Fabrics, vol. 8, no. 2, pp. 5-7, 2013.
26. Renata Baltakytė, Salvinija Petrulytė, "Experimental Analysis of Air Permeability of Terry Fabrics with Hemp and Linen Pile," Materials Science, vol. 14, no. 3, pp. 3-7, 2008.
27. J.P. Fohr, D. Couton, G. Treguier, "Dynamic Heat and Water Transfer Through Layered Fabrics," Textile Research Journal, vol. 72, no. 1, pp. 1-12, 2002.
28. Rasha Abd El-Hady, Rawya Abd El-Baky, "The Influence of Pile Weft Knitted Structures On The Functional Properties Of Winter Outerwear Fabrics," Journal of American Science, vol. 11, no. 9, pp. 101-108, 2015.
29. Hossein Barani, Shahram Peyvandi, "Enhanced Deep Coloring of Micro Polyester Fabric," Materials Science, vol. 16, no. 2, pp. 138-143, 2010.
30. ASTM-D-3776-79, "Standard Test Method for Weight".
31. ASTM-D-1777-1996, "Standard Test Method fot Mesuring Thickness of Textile Material".
32. ASTM D-737-2012, "Standard Test Method for Mesuring Air Permeability of Textile".