Investigation of Comfort Properties of Bed Sheet Fabrics Using Different Weft Materials and Weave Structures

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Abstract:
Bed sheet is one of the most important items of interior furnishings, these bed sheet fabrics need to ensure the comfort level of the human and needs to be manufactured with a high comfort property. Recently, the requirements in terms of comfort properties are widely linked to the use of new cellulosic fibers. Therefore, this research aims to investigate the relationship between different weft materials, weave structures and the comfort properties of produced bed sheet fabrics.
For this objective, six bed sheet samples were produced varying in weave structure (basket 2/2 & Piqué) and three different weft materials (bamboo, Tencel & viscose pcm). Comfort properties, porosity, horizontal wicking rate, stiffness and air permeability of all the fabric samples were determined. Our finding showed that there is a direct relationship between horizontal wicking rate and packing factor of produced fabrics, while the fabric porosity affects on the rate of air volume flowing through fabric, the fabric stiffness was influenced by the areal density of produced fabrics. The best sample performance evaluated by radar chart is sample (S6) manufactured with Bamboo material for wefts & Piqué weave structure, with the quality factor percentage reached to (82.4%)

Keywords:
Bed Sheet,
Comfort,
Regenerated fibers,
wicking,
Porosity,
Packing factor

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INTRODUCTION

Bed sheet is a material used to cover the bed, which should be soft with warm handle and easy-care properties. Most of the bed sheets are made from cotton and polyester/cotton blended yarns. Depending on the end use, price, mechanical and functional properties, the fiber choice is made from natural fiber, regenerated cellulosic fibers and synthetic fibers. [1, 2]

Recently, the demand of cotton fiber has been increased but its low production rate cannot fulfill the world requirements. The increase in cotton demand has augmented the production of regenerated cellulosic fibers. [3]

Textile fibers production has grown to nearly 110 million metric tonnes in 2018, with major categories being synthetics (65%), cotton & other natural fibers (29%), regenerated cellulosic (6%) [4]. And the global production of textile fiber is expected to reach 145 million mt in 2030.

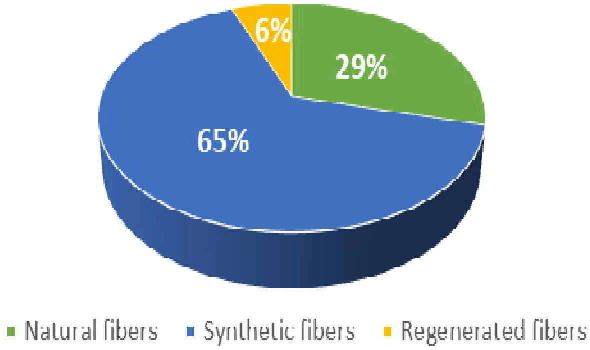


Fig. (1) Global fibers production in 2018 (million metric tonnes) [4]

Regenerated fibers, such as bamboo, Tencel and viscose fibers are the most important fibers regarding to its properties [3]

Bamboo fiber is generated from bamboo pulp. it is famous as the natural, green and eco-friendly textile material. [5] it is characterized by its good hygroscopicity, excellent permeability, soft feel, easiness to straighten and dye, and splendid color effect of pigmentation. [2] it is also having a natural anti-bacterial property due to a bioagent which resists the growth of bacteria on the fiber. This is normally carried through the final product allowing it also to resist the growth of the bacteria that causes odor even after many times of washing. This eliminates the need for anti-microbial chemical treatments which cause allergic reactions. [6]

Tencel fiber is one of the most important developments in regenerated cellulosic fiber.[5] The generic name for Tencel is ‘‘Lyocell’’. 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. [7] It is characterized by good breathability, moisture absorption, smooth fiber surface, low wet cling tendency by maintaining dry and cool microclimate on the skin. [2]

Viscose is a type of rayon fiber that is made from natural sources such as wood and agricultural products that are regenerated as cellulose fiber. viscose possesses higher moisture absorbency as compared to cotton. Breathability, softness, comfort, and ease in dyeing with glowing colors are the other favorable properties of viscose fibers. [8]

Healthy humans have to sleep for at least 4 to 6 hours during the daily cycle. Comfort of sleeping is very important component of our life, and its level depends on design of the bed, climatic conditions in the bedroom, and the comfort properties of cushions and bedsheets.[9]

The comfort properties of a textile material are generally represented by thermal resistance, stiffness , air permeability and fabric moisture management "Moisture management is the controlled movement of liquid (perspiration) from the skin surface to the environment through the fabric " as shown in figure (2) [10,11, 12].

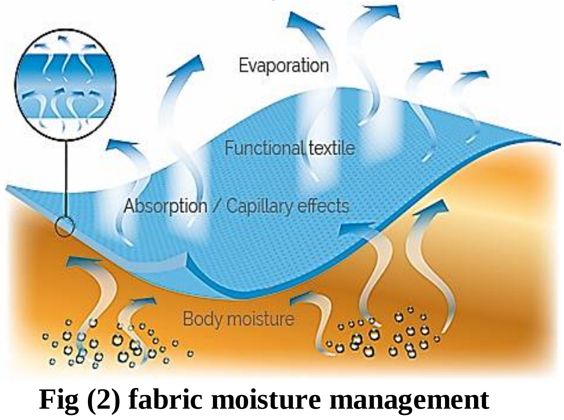


Fig (2) fabric moisture management

Wetting and wicking take place before perspiration evaporates from the skin through the fabric into the atmosphere [12]. wicking is the ability to sustain capillary flow” whereas wettability describes the initial behavior of a fabric, yarn or fiber when brought in contact with water. [13]

Wicking rate affected by packing factor where packing factor indicates the degree of porosity of the produced fabrics. (porosity is the amount of open spaces in the unit volume of fabric). The packing factor and porosity of a fabric calculated by the following equations: [14]

** Packing factor = (*fabric density* / *fiber density*) equation (1)

** Fabric density = (*fabric weight* "g/cm^2" / *fabric thickness* " cm") equation (2)

** Fabric porosity = (1- *packing factor*) equation (3)

The main objective of this study work was to produce bed sheet fabrics with better comfort properties by utilizing the excellent characteristics of Bamboo, Tencel and viscose PCM fibers. For this aim, we focus to evaluate air permeability, stiffness and moisture transport behavior of these woven bed sheet fabrics.

2. Materials and Methods:

The current work is concerned with studying the effect of different weft materials and weave structures on the properties of produced bed sheets as; air permeability, horizontal wicking and fabric stiffness to achieve optimum comfort properties for bed sheet fabrics.

2.1. Specification of the dobby machine & produced fabrics To investigate the effect of the study parameters on the horizontal wicking rate, air permeability, and stiffness properties six samples were produced, using dobby weaving machine with the specifications as shown in table (1). For all samples the warp densities were 36 ends/cm and the warp material was 100% cotton, with linear density of 50/2 Ne . Whilst, the weft density was 24 picks/ cm and the weft materials were (Viscose pcm, Bamboo, Tencel) with linear density ranged from (36/1 Ne, 24/1 Ne & 20/1 Ne) respectively, as shown in the table (2)

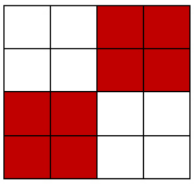
Viscose PCM has been manufactured by Outlast company. where, Microencapsulated PCMs have been incorporated into the spinning dope of viscose fiber to make one of the smart material [15] .Where, phase change materials (PCMs) are latent heat storage materials that can absorb, store and release large amounts of energy, in the form of latent heat, over a narrowly defined temperature range, also known as the phase change range, while that material changes phase or state (from solid to liquid or liquid to solid) [16].

Table (1) Specifications of the dobby machine used in producing samples

No.	Item	Specification
1	Weft insertion device	Rapier
2	Name of Loom	itema- R9500
3	Date of Manufacturing	2014
4	Speed of the machine	280 picks / min.
5	Width of warp without selvedge	163 cm
6	Reed used (dents per cm)	12 dents / cm
7	Denting	3 ends / dent

Table (1) specifications of produced bed sheet samples

Sample No.	Fabric structure	Warp material	Warp count (Ne)	Ends/cm	Weft materials	Weft count (Ne)	Picks/cm	Weight (g/m^2)	Thickness (mm)
S1	Basket 2/2	100% Cotton	50/2	36	Viscose, PCMs	36/1	21	119.5	0.33
S2					Tencel	20/1		153.8	0.40
S3					Bamboo	24/1		139.5	0.36
S4	Piqué				Viscose, PCMs	36/1		114.5	0.34
S5					Tencel	20/1		159.2	0.42
S6					Bamboo	24/1		139.5	0.36



Basket 2/2, Structure (A)

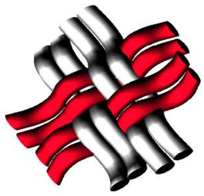
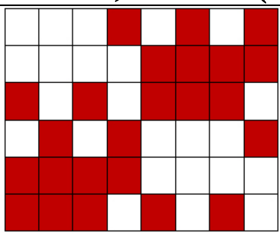


Illustration of the 3D-simulation for structure (A)



Piqué, Structure (B)

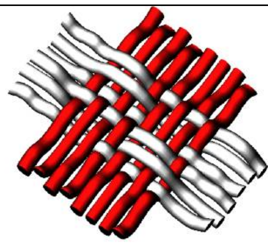
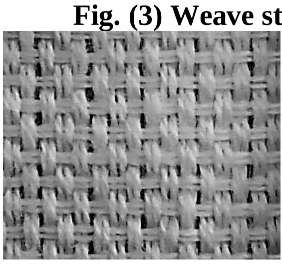


Illustration of the 3D-simulation for structure (B)

Fig. (3) Weave structures of produced samples

(A)



(B)

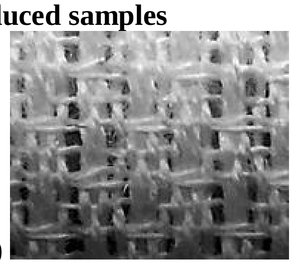


Fig. (4) the roughness of produced bed sheet fabrics (A) Basket 2/2 & (B) Piqué

*** Note:** The methodology of using this weave structure for produced bed sheet fabric was based on this fact: the weave structure which has a high surface roughness lead to decreases the fabric sliding and increasing the fabric friction. This owing to the gap between the weft yarns increased as the weave changed from basket 2/2 to Piqué as shown in figures (3&4), giving very high and low peaks on the fabric surface, which in turn increased surface roughness [17].

2.2. Laboratory Testing

Many different tests were carried out on produced bed sheet fabrics to improve the functional properties.

2.2.3. Horizontal wicking rate Test

This test was carried out on produced bed sheet samples according to (AATCC 198 (2012)) [18]

2.2.4. Air permeability Test

This test was carried out on produced fabrics according to (ASTM D737 – 04 (2012)) [19]

2.2.5. Stiffness Test

This test was carried out on samples according to (ASTM D4032-08) [20]

3. Result and Discussion:

This part is concerned with studying the effect of the research variables on the produced samples properties. The following table (2) shows the results of tests applied to the produced bed sheet fabrics.

Table (2) Bed sheet fabrics testing results

	Variable Parameter		Results					
Sample Number	**Weave Structure**	**Weft materials**	**Porosity**	**Packing Factor**	**Horizontal Wicking Rate (mm /sec.)**	**Air Permeability ($cm^3/cm^2/s$)**	**Stiffness (Gf)**
S1	Basket 2/2	Viscose, PCMs	0.76	0.24	6.47	110	75.5
S2		Tencel	0.74	0.26	6.9	82.2	149.3
S3		Bamboo	0.57	0.43	7.78	97	101.3
S4	Piqué	Viscose, PCMs	0.78	0.22	3.68	150	76.5
S5		Tencel	0.75	0.25	4.78	101.1	171.3
S6		Bamboo	0.58	0.42	7.3	112	108

3-1: Horizontal wicking rate:

Table (2) and figure (5) shows the results of horizontal wicking rate test carried out on the produced bed sheet samples using the research parameters as following; three different weft materials & two different weave structures.

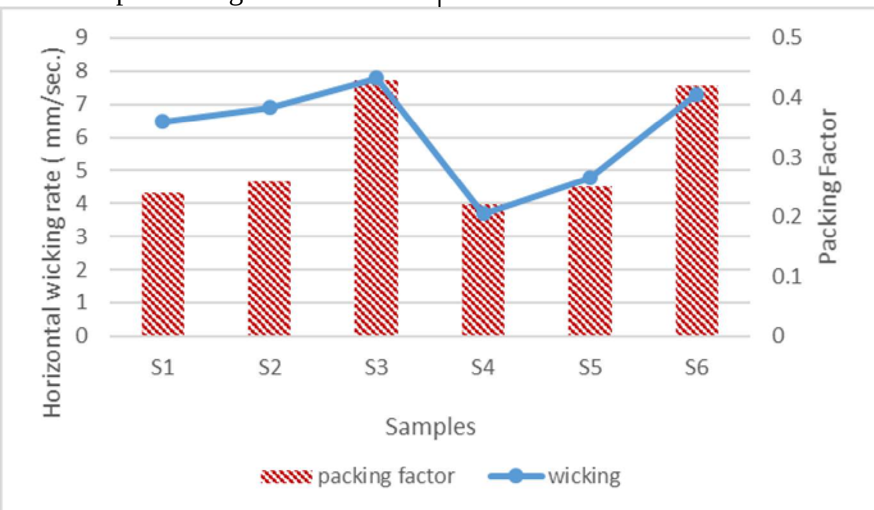


Fig. (5) Relationship between horizontal wicking rate & packing factor

3-1-1: Influence of weft materials on horizontal wicking rate:

As illustrated in Figure (5), it can be seen that the Bamboo has recorded the highest rates of horizonal wicking followed by Tencel and Viscose respectively. This can be attributed to the role of the fiber density of bamboo yarn (0.9 g/cm^3) which leads to increases the volume of yarn and increases the packing factor of produced bed sheet fabrics. So, as a result yarns inside the fabrics become as a routing point to diffuse the water which causes the higher horizontal wicking rates

[8].

3-1-2: Influence of weave structure on horizontal wicking rate:

From figures (5&6) and table (2) it can be observed that, the horizonal wicking rate of Piqué weave lowest than the basket 2/2 weave. This is due to increases the float length in the Piqué weave as shown in the figure (3) which leads to a decrease in routing points in this samples compared to samples with weave structure basket 2/2. So, as the result the horizonal wicking rate decreases.

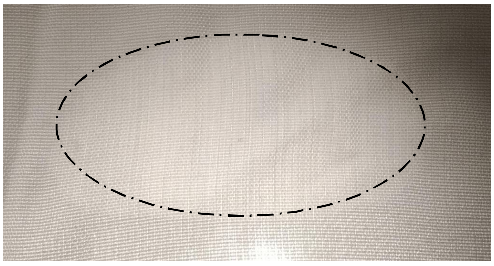
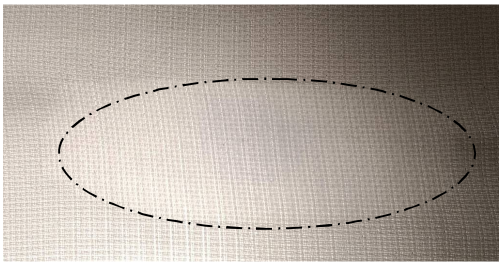
(A) 
(B) 

Fig. (6) Illustration of the water diffusion on the surface of: (A) sample 3- basket 2/2 , (B) sample 6- Piqué
(Black ellipse indicates wicking area)

3-1-3: Influence of packing factor of produced fabrics on horizontal wicking rate:

By comparing results of packing factor of produced bed sheet fabrics and the horizontal wicking rate, as tabulated in Table (2) there is a direct relationship between packing factor and wicking rate in the horizontal direction. This is owing to increase the routing points as mentioned before.

3-2: Air permeability:

Table (2) and figure (7) shows the results of air permeability test carried out on the produced bed sheet samples using parameters mentioned before.

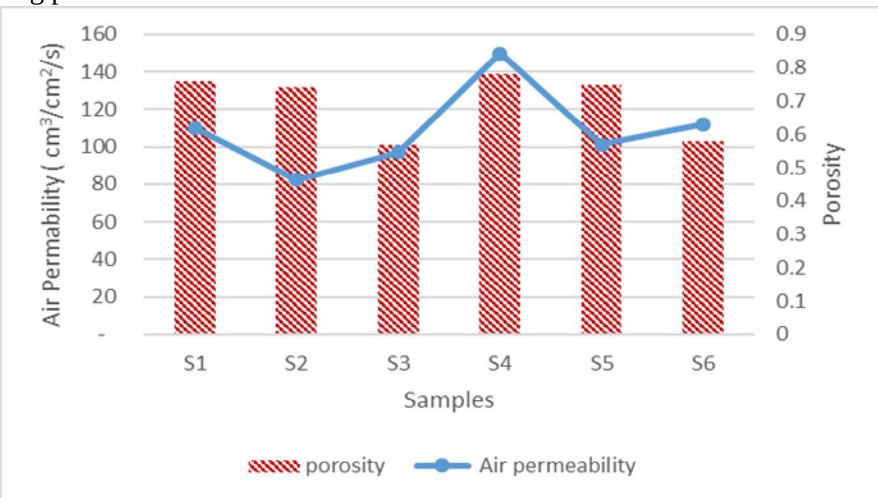


Fig. (7) Relationship between air permeability & porosity

3-2-1: Influence of weft materials on air permeability:

It can be noticed from figure (7) that the Viscose yarn has recorded the highest rates of air permeability followed by Tencel and Bamboo respectively. This can be attributed to the liner density of Viscose is (36/1 Ne) that lead to decreases the yarn diameter which leads to an increase in the fabric spaces between yarns. So as the result the fabric becomes more porosity and hence the air permeability increased [12]. Whilst the Tencel has nano-fibril structure as shown in figure (8) which forming capillaries between the fibres that allow the air to pass through the fabric effectively comparing to Bamboo [7]. .

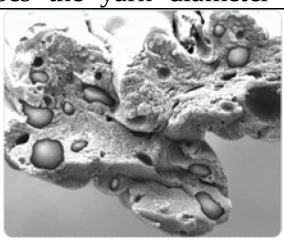
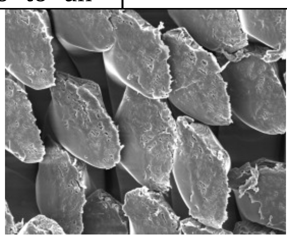
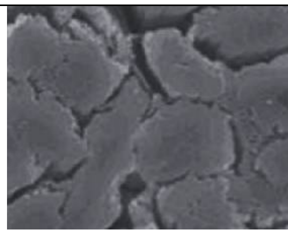
(A) 
(B) 
(C) 

Fig. (8) SEM of different weft materials used in this paper, (A) Viscose, pcm – (B) Tencel – (C) Bamboo

3-2-2: Influence of weave structure on air permeability:

It can be observed from figure (8) that Piqué weave has scored the highest rate of fabric air permeability followed by basket 2/2. This is owing to increases the float length in Piqué weave structure leads to a decrease the number of intersections per unit area in the produced fabrics which leads to increases the porosity of fabrics. Consequently, this results in increases the air permeability

3-2-3: Influence of porosity of produced fabrics on air permeability:

From table (2) and figure (8) it is clear that there is a direct relationship between porosity and air permeability of produced fabrics. This is due to increase the free spaces between warp and weft which leads to increase the rate of air permeability.

3-3: Fabric Stiffness:

Table (2) and figure (9) shows the results of stiffness test carried out on the produced samples using parameters mentioned before.

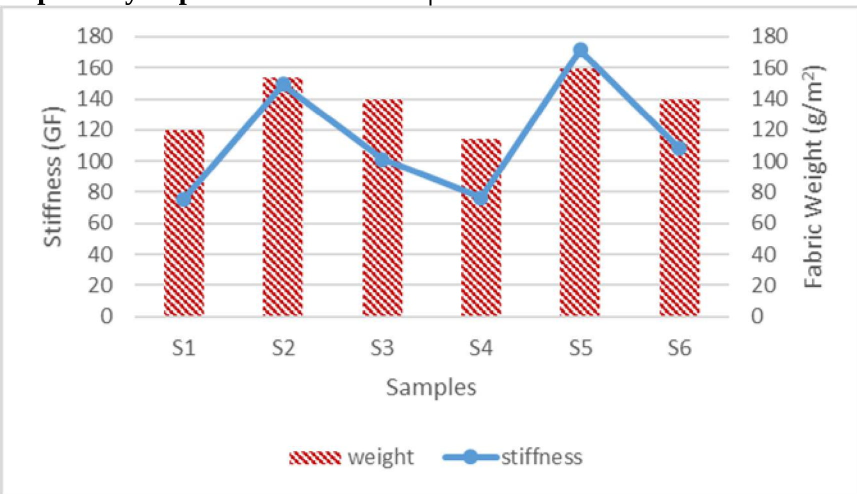


Fig. (9) Relationship between stiffness & fabric weight

3-3-1: Influence of weft materials on fabric stiffness:

From Figure (9), it could be seen the values of fabric stiffness for produced bed sheet fabrics with respect to weft materials type. It is observed that the Viscose improves the bending characteristic of the final produced fabric followed by Bamboo and Tencel respectively. The possible reason of this is that, Viscose fabrics exhibit better fabric feel and drape compared with Bamboo and Tencel owing to the fibre shape and appearance of Viscose. Addition to Viscose yarn linear density is a higher than Bamboo and Tencel, that leads to decreases the diameter of viscose yarn and the produced fabric from this fibre tends to be lighter, so as the result the usage Viscose fibre leads to decrease in bending resistance.

3-3-2: Influence of weave structure on fabric stiffness:

From this figure (9) it is also shown that the stiffness of produced fabrics woven from Piqué weaves is higher than those woven fabrics from basket 2/2 structures. This is due to increase in the intersections in picks (1, 3,4, 6) in Piqué weave structure as shown in 3D simulation figure (3), which lead to increase the friction between yarns and increase the fabric coherence leading to increase the fabric stiffness.

3-3-3: Influence of areal density of produced fabrics on stiffness:

From figure (9) it can be observed that, there is direct correlation between fabric weight per unit area and stiffness of produced fabrics. This is because of that fact the lighter fabric tends to be lower its bending rigidity [21]

3-4: Quality factor

The averages Results measurements of the sample's tests were converted to comparison relative values (without units) ranges from (0% – 100%) called quality factor, where the greatest comparative value is the best with all the properties. The following equation was used to calculate the relative comparison value (quality factor) for all the properties except the stiffness property.

$$\mathbf{Q\,F_{+} = (X / X_{max}) \times 100}$$

Where: Q.F (quality factor), X (reading for each sample), X_{Max} (the highest reading)

The following equation was used to calculate the relative comparison value (quality factor) for the stiffness property.

$$\mathbf{Q\,F_{-} = (X_{min} / X) \times 100}$$

Where: Q.F (quality factor), X_{Min} (the least reading), X (reading for each sample) [22].

To calculate the total area of each sample which is equivalent to the performance for each fabric the following equation was used:

= ½ (sin 360/8) x ((A x B) + (B x C) + (C x D) + (D x E) + (E x A)) [23]

Where: (A, B, C, D, E) refer to evaluated properties as shown in table (3)

Table (3): Illustrate the Relative Value Equivalent to the Samples Tests Results (%)

No.	Horizontal wicking (A)	Air permeability (B)	Weight (C)	Stiffness (D)	Thickness (E)	Total area	Samples grade
S1	83.2	73	75.1	100.0	77.4	15,809	3
S2	88.7	55	96.6	50.6	94.0	13,365	5
S3	100.0	65	87.6	74.5	85.7	15,971	2
S4	47.3	100	71.9	98.7	81.0	14,649	4
S5	61.4	67	100.0	44.1	100.0	12,274	6
S6	93.8	75	87.6	69.9	85.7	16,012	1

*** Note:** the above properties have been arranged according to its importance.

3-2-4-1: Quality evaluation of bed sheet fabrics with basket 2/2:

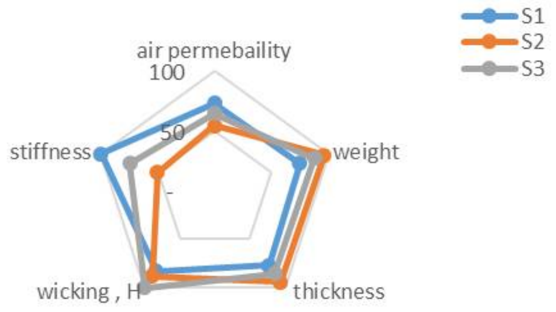


Fig (10) illustrated radar chart for the produced samples with structure (Basket 2/2)

From figure (10) it can be concluded that, the best sample performance evaluated by radar chart is sample (S3) manufactured with Bamboo material for wefts. Whilst the lowest sample according to radar chart is sample (S2) which produced by using Tencel yarn for weft.

3-2-4-2: Quality evaluation of bed sheet fabrics with Piqué:

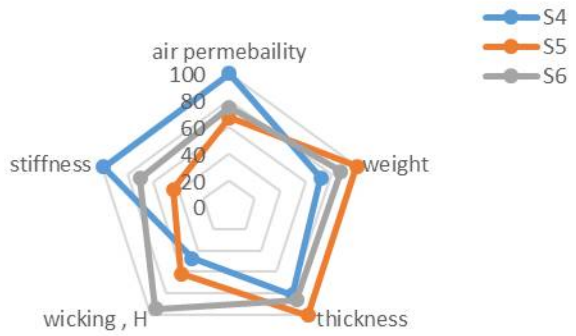


Fig (11) illustrated radar chart for the produced samples with structure (Piqué)

From figure (11) it can be noticed that, the best sample performance evaluated by radar chart is sample (S6) manufactured with Bamboo material for wefts. Whilst the lowest sample according to radar chart is sample (S5) which produced by using Tencel yarn for weft.

4. CONCLUSIONS

The main objective of this paper was manufacturing a bed linen woven fabric and investigate the effect of research parameters (three weft materials & two weave structures) on the comfort properties. From the results and statistical analysis concerned with the comfort properties of produced bed sheet fabrics evidently showed that:

- For horizontal wicking property, Bamboo has recorded the highest rates of wicking followed by Tencel and Viscose respectively. Whilst weave structure (basket 2/2) has recorded highest rates of horizontal wicking compared to Piqué weave. From experimental work we demonstrated that there is a direct relationship between packing factor and wicking rate in the horizontal direction.

- Viscose, PCM has recorded the highest rates of air permeability followed by Tencel and bamboo respectively. Whilst weave structure (Piqué weave) has recorded highest rates of air flow through the produced bed sheet fabrics compared to (basket 2/2). There is a direct relationship between fabrics porosity and air permeability.
- For fabric stiffness property, Viscose decreased the bending resistance followed by Bamboo and Tencel respectively. Whilst weave structure (basket 2/2) has recorded lowest rates of fabric stiffness compared to Piqué weave. From experimental we conclude that there is a direct relationship between fabric weight per unit area and stiffness of produced fabrics.
- From radar chart it can be concluded that, the best sample performance with structure basket 2/2 is sample (S3) manufactured with Bamboo material for wefts. Whilst the best sample performance with structure Piqué is sample (S6) manufactured with Bamboo material for wefts.

5. RECOMMENDATION

I recommend studying the effect of blend ratio between viscose fibers incorporated with PCM microcapsules and regenerated fibers on the thermal properties of produced bed sheet fabrics.

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