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Thermal Comfort Properties of Bamboo/Silk Fabrics

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Abstract
The thermal resistance of fabrics containing silk showed a higher value in comparison with lyocell-rich blends. The water vapour permeability, absorbency and wickability of lyocell and lyocell-rich blends were found to be superior as compared to 100% silk fabrics. With respect to aesthetic comfort properties, the drape of the lyocell rich fabrics was good in comparison with 100% silk fabrics.

Key words: *bamboo, comfort, knitted fabrics, thermal comfort, silk.*

Introduction

The evolution of the textile industry has been ongoing for years. The industry dominates the world economy in terms of large inventions in the area of fibre science, technology and desired applications [1]. Also, the development of the textile industry has been influenced by continuous development in the lifestyle of the consumer. Hence, the textile industry is continuously looking for novel approaches to develop conceptual textile systems. Moreover, these technological developments will help to create textile materials with new environmental responsiveness and advanced functionalities [2]. In this research, the thermal comfort properties of silk/bamboo blended fabrics and the application of selected functional finishes were analysed. Silk fibre has always been identified with royalty due to its lustrous appearance and peach-like softness [3]. Silk fibre also has properties of good moisture absorption, dry tactile hand, high strength, draping qualities and lively suppleness. Silk is also a solid fibre with a simple physical structure. It is this physical nature of silk that makes it difficult to replace with some other fibres. However, silk fibre has some properties which will not be obtained from other fibre. As silk fibre is costly, it is difficult to manufacture products from these fibres in the textile industry. The blending of fibres is the combination of the positive attributes of each of the components, and it minimises the weakness properties and balances the cost of the textile material to be economical. It also gives the fabric different aesthetic properties through the combination of different fibres, it enables fabric to be put to different, new uses, thus creating a path for product development [4]. Silk fabrics are remembered for their various unique properties like versatility, beauty, comfort and wearability. They also have the property of absorbing moisture. However, the cost of silk fibre is high, but the demand for silk fabric in the market is very high [5]. In many countries, bamboo is one of the most cultivated plants. Also, bamboo fibre is one of the cheapest fibres and hence has gained in popularity in the manufacturing of different varieties of textile materials in recent years. Moreover, it has a high moisture absorption capacity, brightness and softness. Also, the thermal comfort and UV protective properties of bamboo fibres have imitated a lot research in the field of textile materials [6].

The moisture management properties of knitted fabrics woven from regenerated bamboo with various cover factors was investigated. It was concluded that the wetting time increased with an increase in the cover factor of the fabrics, whereas the maximum wetted radius, rate of absorption, spreading speed and overall moisture management capacity decreased as the cover factor of the fabric increased [7]. The characteristics of knitted fabrics made from natural fibres like cotton, wool and regenerated fibres such as new generated synthetic fibres, for instance cool max polyester and bamboo, were also studied. It was concluded that variation in the physical structure of fibres will have in effect on the properties of the fabric, such as air permeability and water vapour permeability [8]. Hence, by considering the characteristics of bamboo and silk fibres, research was carried out on the influence of blended silk and bamboo fibres in different ratios to derive the thermal comfort characteristics of this effect.

Materials and methods

Commercially available mulberry silk cut filaments and bamboo fibres were purchased from the market. Details of fibre properties are given in ***Table 1***.

Production of yarn

Sliver blending was carried out at a spinning mill with a series of blended yarns of silk/bamboo with blend proportions of 75:25, 50:50 and 25:75 for the purposes of this research. Apart from this, 100% bamboo yarn and 100% spun silk yarn were also used for this research. This process of blending was undertaken in the line of Lakshmi machine process to manufacture 9.84 tex yarn. The evenness of the yarn was determined using an unevenness tester at a testing speed of 100 m/min.

Fabric production

Woven fabric was produced from blended yarns with a plain weave. The thickness of the fabric was determined by an SDL fabric digital thickness tester according to the ISO 5084 standard. The density of the fabric was calculated according to the

ASTM D3775 standard. The weight of the (areal density) of the fabric sample was evaluated according to the ASTM D3776 standard.

Fabric porosity was determined by the following technique,

$$\text{Fabric porosity (\%)} = 1 - \frac{\rho_{fab}}{\rho_{fab}} \quad (1)$$

Where, *ρ_{fab} is the fabric bulk density,*
ρ_{fib} is the fibre density.

Thermal comfort properties

The air permeability of the fabric samples was calculated from the rate of air flow between the two surfaces of the fabric and the air permeability was obtained by a TEXTTEST FX3300 at a pressure of 100 Pa, following the ASTM D737-2004 method. The water vapour permeability of the samples was studied with permetest equipment according to ISO 11092. This experiment setup works based on the principle of sensing heat flux. The measuring head temperature was maintained at room temperature for isothermal conditions. Some amount of heat will be lost when water flows into the measuring head. This heat loss can be measured with the measuring head based on the evaporation of water from the fabric surface. The thermal conductivity and thermal resistance of the fabric was determined by an Alambeta instrument according to ISO 11092. This instrument consists of two plates, namely hot and cold. The fabric sample was kept between these two plates. When the hot plate touches the fabric sample with a pressure of 200 Pa, the heat flow from the hot surface to the cold surface was detected by the heat flux sensor. This estimated value can be utilised to determine the thermal resistance behaviour of the fabric from the following equation.

$$\text{Thermal resistance (R)} = \text{fabric thickness (h)/thermal conductivity } (\lambda), \ m^2K/W \quad (2)$$

The fabric wicking property was determined based on the AATCC 197:2018 method, shown in ***Figure 1***. Samples were cut 25 mm x 200 mm along the warp and weft directions. The specimens were clamped vertically towards the tank containing distilled water so that the bottom of the fabric was immersed 20 mm in the distilled water. The immersed fabric was clamped with a weight of 3 grams to provide pre-tension in the fabric. The wicking height was measured at uniform intervals of 5 min. All the experiments were carried out at a relative humidity of 65 ± 2% and standard atmospheric temperature of 20 °C ± 2 °C.

Statistical analysis

Statistical analysis was determined using one-way analysis of variance (ANOVA) to test the significance of the effect of the blend ratio on the silk/bamboo blended fabrics. The variables and experiment are statistically significant if the value of P is equal to or less than 0.05.

Results and discussion

Physical properties of silk/bamboo blended yarns

Table 2 represents the yarn properties of all blend proportions. It is observed that the yarn made with silk has lower imperfection, but this increases with the addition of bamboo fibre. The unevenness % of the fabric also increases with the content of bamboo fibre, which is due to the imperfection caused by the addition of bamboo fibres. And owing to this the thick places, thin places and neps/km are also higher in the yarn made with bam-

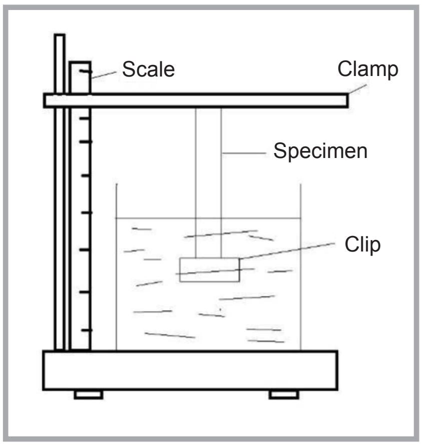

Figure 1. *Fabric vertical wicking setup.*

Table 1. *Properties of silk and bamboo fibres.*

Characteristics	Silk	CV%	Bamboo	CV%
Fibre length, mm	40	2.81	36	0.33
Fibre denier	1.1	1.15	1.38	1.56
Tenacity, g/d	3.9	1.23	3.49	1.91
Specific density, g/cm^3	1.34	0.81	1.32	1.11
Elongation, %	18	2.53	20.9	1.06
Moisture regain, %	11	1.73	11.1	1.03

Table 2. *Physical properties of silk/bamboo blended yarns.*

Properties	Bamboo/Silk (100:0)	Bamboo/Silk (70:30)	Bamboo/Silk (50:50)	Bamboo/Silk (30:70)	Bamboo/Silk (0:100)
Count, tex	9.99	9.94	9.88	9.83	9.79
CV%	1.15	1.43	1.06	1.54	1.33
Rkm, g/tex	18.8	19.2	19.4	19.1	20.1
U%	18.8	18.1	17.5	17.2	16.5
Thin places – 50%, km	13	12	10	9	8
Thick places + 50%, km	58	38	33	28	23
Neps + 200%, km	118	87	72	64	61
Total imperfections, km	182	159	124	102	92

Table 3. *Properties of silk/bamboo blended fabrics.*

Sample identification code	Material	Fabric weight, g/m^2	Ends, cm	Picks, cm	Fabric thickness, cm	Fabric porosity, %
B 100	Bamboo/Silk (100:0)	180	30	25	0.066	79.34
B/S 70:30	Bamboo/Silk (30:70)	177	30	25	0.064	79.27
B/S 50:50	Bamboo/Silk (50:50)	175	30	25	0.063	79.11
B/S 30:70	Bamboo/Silk (70:30)	172	30	25	0.062	79.08
S 100	Bamboo/Silk (100:0)	170	30	25	0.060	78.86

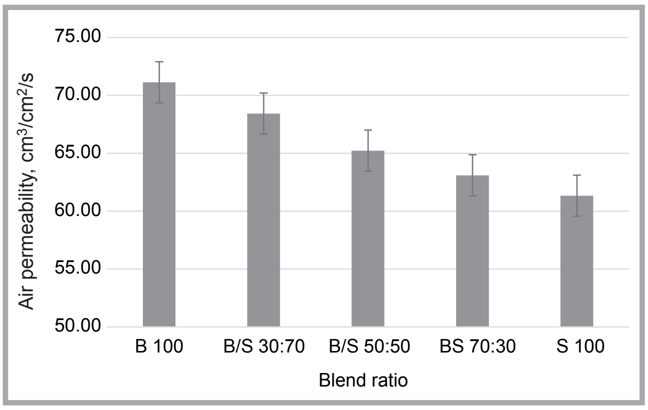

Figure 2. *Air permeability of silk/bamboo blended fabrics.*

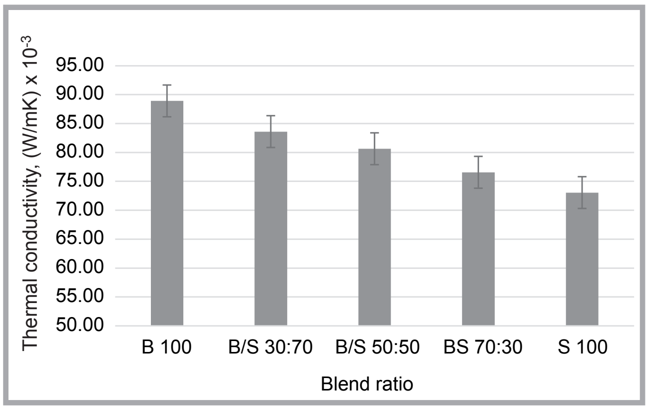

Figure 3. *Thermal conductivity of silk/bamboo blended fabrics.*

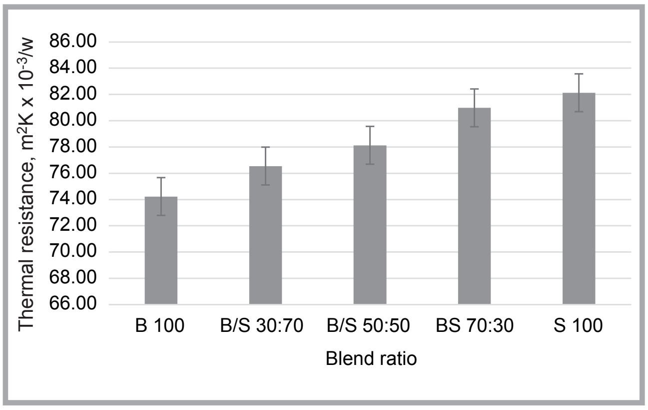

Figure 4. *Thermal resistance of silk/bamboo blended fabrics.*

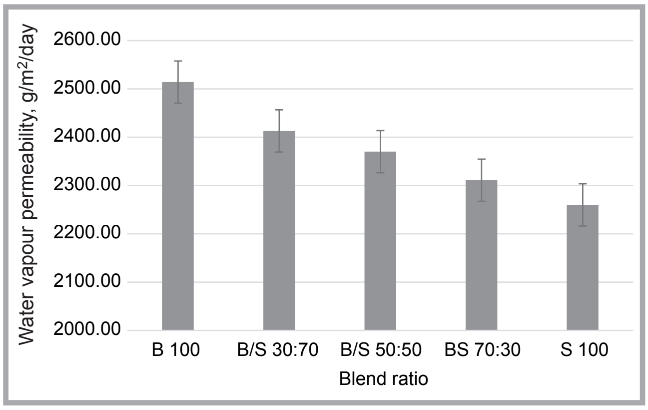

Figure 5. *Water vapour permeability of silk/bamboo blended fabrics.*

boo fibres. These irregularities increased along with the content of bamboo fibres due to the floating fibres in the drafting zone, and it is very difficult to control the bamboo fibres in the drafting zone in order for them to integrate [9]. The tenacity of the fabric is reduced with a content of bamboo fibres, which is due to their low tenacity and weak cohesion [10].

Geometrical properties of the fabric

Table 3 represents properties of the fabric samples with a sample identification code. It is identified that the warp and weft density remain the same for all the fabrics. The GSM of the fabric increased with the content of bamboo fibres, which is due to the irregularities and bulky structure of the bamboo fibre content. The porosity of the fabric also increased with the content of bamboo fibre because of more inter yarn space therein. This is due to the uncontrolled nature of bamboo fibres in the spinning draft.

Air permeability

Air permeability is one of the major properties that will affect the wearer's comfort behaviour. In ***Figure 2*** *CAL* indicates the air permeability properties for various blend ratios of bamboo/silk blended fabrics. It is found that 100% bamboo fabric has higher air permeability behaviour than fabric made from 100% silk. The air permeability decreases with an increase in the content of silk fibre, which is due to silk having a very high adhesivity and cohesivity; thus fabric made from this yarn and fabric construction is also compact [11]. The porosity of the fabric also has a significant impact on its air permeability [12]. As fabric made from bamboo yarns has more porosity, its air permeability also increases with tan increase in the content of bamboo fibres.

Thermal conductivity

Thermal conductivity is a significant factor for analysing the comfort properties of fabrics. ***Figure 3*** shows the thermal conductivity properties of fabrics made with the various compositions of silk/bamboo blended fabrics. The fabric made with bamboo has the highest thermal conductivity, while the lowest is shown by the fabric made with silk fabric. This is due to the fabric made with bamboo fibre having higher inter yarn space and more porosity, and as a result possesses higher air permeability.

Thermal resistance

Figure 4 shows the thermal resistance of the fabrics made from the blends of silk/bamboo. It is found that the thermal resistance is high for the fabric with a content of silk and lowest for that with a content of lyocell. Thermal resistance behaviour is considered as one of the significant thermal insulation characteristics of the fabrics. The porosity of the fabric will affect its thermal resistance [13]. As the fabric made with the silk fabric has lesser porosity, its thermal resistance is higher. Thermal resistance decreased with an increase in air permeability for silk/bamboo blended fabrics. The heat and vapour transfer properties of the fabric will increase with an increase in the air permeability of the fabric. Hence, a more open structure fabric will have lower thermal resistance and higher air permeability in comparison to lesser air permeable fabric [14].

Water vapour permeability

Figure 5 shows the water vapour permeability of all silk/bamboo blended fabrics. It is found that the water vapour permeability increased with the content of bamboo fibres and decreased with an increase in the content of silk fibres. The fabric made with bamboo fibre has higher inter yarn space and more porosity of yarn and fabric. This leads to greater air gaps in the fabric made with bamboo fibre, which helps to pass water vapour to the environment from the fabric surface. Thus, the fabric water vapour permeability of the fabric increased with an increase in the content of bamboo fibre.

Wickability

Wickability is a major parameter in evaluating the comfort characteristics of fabrics. The quick drying behaviour of fabrics is based on their wickability level [15-18]. ***Figure 6*** shows the wickability of silk/bamboo blended fabrics of various ratios. It is found that as the content of bamboo increases, the wickability characteristics of the fabric also increase. This due to the high porous nature when increasing the content of bamboo fibre, which will raise the possibility of water passing to the surface of the yarn and fabric.

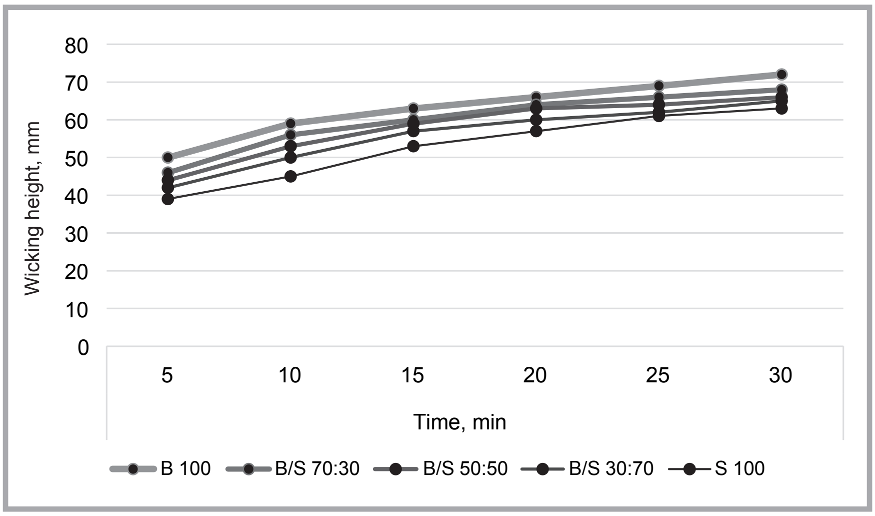

Figure 6. *Wickability of silk/bamboo blended fabrics.*

Data analysis: variance statistics for comfort properties of the fabric

The statistical significance of the various blend proportions of silk/bamboo fibres for the thermal comfort properties of the fabric was studied with ANOVA s. Analysis of variance (ANOVA) was carried out by the SAS System (version 8 for Windows) (alpha level of 0.05) to determine significant variations in thermal comfort properties of the fabric due to the various blend proportions of silk/bamboo blended fibres. The variables are considered as a significant impact on the thermal comfort properties if the probability (p) value is less than or equal to 0.05. ***Table 4*** shows the outcome of One-way ANOVA for the thermal comfort characteristics of the fabric and the blend ratios of silk/bamboo blended fibres.

Table 4. *One-way ANOVA for thermal comfort characteristics of the fabric and blend ratios of silk/bamboo blended fibres.*

Response	SV	SS	df	MS	F	*p*-Value	F-Crit
Air permeability	Blend ratio	284.96	4	71.24	111.97	2.15×10^{-13}	2.86
	Error	12.72	20	0.63			
	Total	297.68	24				
Water vapour permeability	Blend ratio	191925	4	47981.26	225.36	2.5×10^{-3}	2.86
	Error	4258	20	212.9			
	Total	196183	24				
Thermal resistance	Blend ratio	252.76	4	63.19	149.25	1.37×10^{-14}	2.86
	Error	8.46	20	0.42			
	Total	261.22	24				
Wicking	Blend ratio	274.20	4	68.55	72.24	1.3×10^{-11}	2.86
	Error	18.97	20	0.94			
	Total	293.17	24				

Table 5. *Summary of ANOVA statistical results for the thermal comfort characteristics of the fabric**. ***Note:*** **At 95% confidence limit; "s" means statistically significant at 95% confidence level, and "ns" means statistically non-significant at 95% confidence level.*

Factor	Air permeability	Water vapour permeability	Thermal resistance	Wicking
Blend ratio	Significant	Significant	Significant	Significant

From ***Table 4***, it is identified that the *p* value for thermal comfort characteristics of the fabric is less than 0.05. From this it is clearly determined that there is a significant change in the blend ratio of silk/bamboo fibres for the thermal comfort characteristics of the fabric at a 95% confidence level. Thus, it can be determined that the effect of the path of the blend ratio of silk/bamboo fibres has an influence on the air permeability, thermal resistance and water vapour permeability of the fabric.

Table 5 shows tabulated results of the ANOVA analysis. As per ***Table 4*** and ***Table 5***, it is evident that all exhibited variables are significant for the thermal comfort characteristics of the fabric.

Conclusions

The air permeability of the fabric increased with the content of bamboo fibre and decreased that of silk fibres. Moreover, the water vapour permeability of the fabric increased with the content of bamboo fibre and decreased with that of silk fibre. Furthermore, the thermal resistance of the fabric increased with the content of silk fibres and decreased with that of bamboo fibres. In addition, the wicking property of the fabric increased with the content of bamboo fibres and decreased with that of silk fibres. The proportion of the blend ratio of silk/bamboo fibres has a significant effect on the thermal comfort characteristics of the fabric in terms of air permeability, thermal resistance. water vapour permeability and wicking. Thus, it is concluded that the fabric has better performance in air permeability and water vapour permeability with the increasing content of bamboo fibres. Also, the fabric has better performance in thermal resistance with the increasing content of silk fibres.

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