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Thermoregulatory characteristics of bamboo / lyocell union fabrics

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Heat transfer properties of different woven fabric structures made from regenerated bamboo and lyocell yarns woven in different proportions have been studied. Five union fabrics have been produced using bamboo and lyocell yarns of 30s count in the proportion of 100:0, 75:25, 50:50, 25:75 and 0:100. Three types of woven structures, viz plain, 2/2 twill and 1/3 twill weaves are produced from each combination and then analyzed for their heat transfer properties. The thermal conductivity of the 100% bamboo woven fabric and the thermal insulation value of 100% lyocell woven fabric are found to be higher as compared to all other blends. The results are discussed with 95% significant level with multivariate ANOVA test results.

Keywords: Bamboo fibre, Lyocell fibre, Thermal conductivity, Thermal diffusion, Thermal insulation, Union fabric, Woven fabric

1 Introduction

Thermal wear comfort is mainly related to the sensation involving temperature and moisture. This factor responds mainly with the thermal receptors in the skin and relates to the transfer properties of clothing such as heat transfer, moisture transfer and air permeability[1]. The thermal properties of woven fabrics through heat transfer[2-5] have been studied and it is reported that the thermal insulation values of the woven fabrics depend on the fabric structure, thickness, aerial density and porosity of fabric.

Different textile fibres vary little in their thermal transmittance behaviour. The behaviour of the fibre is mainly influenced by chemical make-up by altering the overall insulation capacity of a fabric than by the physical structure and this affects the thermal comfort of the user or wearer. Fridrych *et al*.[6] presented a comparative analysis of thermal insulation properties such as thermal conductivity, absorption and thermal resistance of fabrics made of cotton and lyocell. Hoge and Fonseca[8] studied the thermal conductivity of a multilayer sample of innerwear material made of wool/cotton blends and reported the fibre blend ratio contribution to the thermal behaviour. Other researchers[5,6,9-12] also reported that the insulation and thermal properties of textile materials are mainly related to the fabric properties. Kawabata and Rengasamy [2] reported that the thermal insulation, air permeability and fabric thickness mainly depend on fabric geometrical parameters.

In this study, fabrics made of bamboo and lyocell yarns (ecofriendly cellulosic) have been produced and analyzed for their heat transfer properties. Parameswaran and Liese[12] highlighted that bamboo fibre is characterized by its good hygroscopicity, permeability, soft feel, anti-bacterial and deodorizing nature. Since the cross-section of bamboo fibre is filled with various micro-gaps and micro-holes, it has much better moisture absorption, ventilation and an excellent wicking ability that pulls moisture away from the skin so that it can evaporate. Bamboo owns a unique antibacterial and bacteriostatic bio-agent named "bamboo kun" which gives the inherent antimicrobial property to the bamboo fibre[13,14]. Similarly lyocell is a new age fibre which unites the advantages of many different fibres. From the experimental results, researchers concluded that lyocell can effectively be used for the development of high performance sportswear, provided the fabric is carefully designed to maximize the contribution of the lyocell to its performance.

Although considerable research work has been carried out to study the viability of bamboo and lyocell fibres for clothing application, very little published work is available on the use of bamboo/lyocell union fabrics. In this research work, an attempt has been made to analyse the thermal behaviour of plain and twill weave structures of bamboo/lyocell union fabrics with different blend

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proportions. This study will be of immense help to the researchers who are analysing the comfort characteristics of woven fabrics for various seasonal dress wears.

2 Materials and Methods

In this research work, an attempt has been made to analyse the suitability of the bamboo yarn combined with lyocell yarn for effective use in apparel and medical textiles. The bamboo and lyocell yarns are tested for their physical characteristics such as tenacity, breaking force and elongation (Table 1).

Union fabrics were produced by incorporating lyocell in different proportions with bamboo, as mentioned below:

(i) 100% bamboo and 100% lyocell fabrics are produced by weaving the respective yarn in both warp as well as weft directions.

(ii) 75% bamboo and 25% lyocell blended union fabric is produced by using bamboo yarn in warp direction and both lyocell combined with bamboo yarn in weft direction.

(iii) 50% bamboo and 50% lyocell blended union fabric is produced by using bamboo yarn in warp and lyocell yarn in weft direction.

(iv) 25% bamboo and 75% lyocell blended union fabric is produced by using bamboo yarn and lyocell yarn in warp and lyocell yarn alone in weft direction.

2.1 Test Methods

All the fabrics produced from above combinations were tested for their properties, such as fabric strength, elongation, thermal conductivity, thermal insulation, thermal diffusion, water vapor permeability[15] and air permeability by standard testing methods. The air permeability of the fabric was measured in $cm^3/cm^2/s$ using air permeometer at an air pressure of 100 Pa using ASTM D737 test standard[16].

Table 1—Bamboo and lyocell yarns properties

Parameter	Bamboo yarn	Lyocell yarn
Nominal count, Ne	30	30
Actual count, Ne	29.6	29.8
Single yarn strength, g	361.3	491.45
CV% of yarn strength	7.4	7.2
Elongation, %	14.17	7.01
CV% of elongation-to-break	2.41	2.24
Twist per inch (TPI)	20.24	19.87

Thermal Conductivity

Thermal conductivity (K) is an intensive property of the material that indicates its ability to conduct heat. It is defined[17] as the quantity of heat (Q), transmitted through a thickness (L), in a direction normal to a surface of area (A) due to temperature difference (ΔT), under steady state conditions and when heat transfer is dependent only on the temperature gradient. Thermal conductivity can be expressed by the following equation;

$$K = Q \times L/(A \times \Delta T) \quad \ldots (1)$$

where K is the thermal conductivity; Q, the heat flow rate; L, the thickness; A, the area and ΔT, the temperature difference.

The measurements were made for both face side and back side of the fabric (in contact with hot plate) of each sample. For each side, five measurements were taken and the average values of the measured parameters were calculated.

The thermal resistance expresses the difference in temperature across a unit area of material of unit thickness when a unit of heat energy flows through it in a unit time. The thermal conductivity of knitted fabrics was calculated by substituting the thermal resistance value and the fabric thickness in the following equation:

$$\lambda = \frac{h}{r} \text{ K m}^{-1}\text{W}^{-1} \quad \ldots (2)$$

where r is the thermal resistance; h, the sample thickness; and λ, the thermal conductivity. Thermal conductivity was measured using Lee's Disc.

Thermal Insulation

Thermal insulation[18] property of the fabric refers to its ability to resist the transmission of heat by all modes. The effectiveness of a fabric in maintaining the normal temperature of the body under equilibrium conditions is based on its thermal insulation characteristics. The most important thermal property in most of the apparels is the insulation against heat flow and it is measured by thermal resistance unit K m^2W^{-1}. Thermal insulation is defined as the ratio between the temperature difference in the two faces and the heat flux. The magnitude of the heat flux at a point is inversely proportional to the thermal resistance of the material. It implies that the higher the resistance the lower will be the heat loss. The relationship between sample thickness and thermal insulation is expressed in terms of thermal insulating values (TIV), as showm below:

$$TIV = \left[\frac{1 - hc}{hb} \right] \times 100 \qquad \ldots (3)$$

where hc is the heat loss from covered hot body; and hb, the heat loss from the uncovered body.

Thermal Diffusion

Thermal diffusion[18] is an ability related to the heat flow through the air in the fabric structure. The thermal diffusion of the textile materials signifies the transient thermal characteristics of textiles. The thermal diffusion of knitted fabrics has been calculated by substituting the thermal conductivity parameters in the following equation:

$$a = \frac{\lambda}{\rho.c} \ \mathrm{m^2\ s^{-1}} \qquad \ldots (4)$$

where a is the thermal diffusion; λ, the thermal conductivity; ρ, thermal density; and c, the specific heat capacity.

Fabric Packing Factor and Porosity

To ascertain the ratio of fibre to fabric volume, packing factor was calculated[19]. Fabric packing factor of all the woven fabrics were calculated using the following equations;

$$C_f = \frac{d}{Sg} \qquad \ldots (5)$$

$$d = \frac{Fw}{t} \qquad \ldots (6)$$

$$Fo = 1 - C_f \qquad \ldots (7)$$

where C_f is the fabric packing factor; d, the fabric density; Sg, the fibre specific gravity; d, the fabric density; Fw, the fabric weight per unit area; t, the thickness; Fo, the fabric porosity; and C_f, the fabric packing factor. Fibre specific gravity values of 1.38 and 1.52 were considered for regenerated bamboo[20] fibre and lyocell[21] fibres respectively.

2.2 Multivariable ANOVA Analysis

Statistical analysis of test results of thermal characteristics such as thermal conductivity, insulation and thermal diffusion of regenerated bamboo and lyocell blended fabrics along with their fabric characteristics was carried out by using MS Excel software 2003.

3 Results and Discussion

The developed woven fabric made out of regenrated bamboo and lycocell blended yarns were made with five proportions namely 100% bamboo, 75 bamboo / 25 lyocell, 50 bamboo / 50 lyocell, 25 bamboo / 75 lyocell and 100% lyocell. The physical and thermal properties of the developed plain , 2/2 twill and 1/3 twill fabrics are given in Tables 2-4.

3.1 Thermal Insulation

The thermal insulation characteristics of the woven fabrics made out of regenerated bamboo and lyocell blended yarns with five blend proportions and three different structures such as plain, 2/2 twill and 1/3 twill weaves were analyzed and are shown in Fig. 1. It is observed that the thermal insulation values of the twill woven fabrics are higher than those of the plain woven fabrics. This is because of higher thickness and higher porosity of the twill fabrics. Thermal insulation increases as the thickness and cover factor of the fabric increase[22]. The correlation between the thermal insulation properties of fabric and the cover factor is weaker than that between thermal properties and structural factors[22]. The amount of air entrapped inside the fabric structure is comparatively higher in the case of twill fabrics. The thermal insulation value of the woven fabric samples also depend on the lyocell fibre content in the union fabric and it increases with increase in lyocell content. This may be attributed to the lower thermal conductivity of the lyocell fibre[23]. These findings are supported by Frydrych *et al.*[24].

3.2 Thermal Conductivity

The thermal conductivity of the woven fabrics made out of regenerated bamboo and lyocell blended yarns with five blend proportions and three different structures are shown in Fig. 2. It reveals that the thermal conductivity values of the twill woven fabrics are higher than those of the plain woven fabrics due to the increased float length of the twill woven fabric. These results are in contradiction with those reported by Matusiak and Sikorski[22] .

The highest thermal conductivity is noted for plain fabrics. The second highest thermal conductivity is found for the 2/2 (2) twill and twill 3/1 weave fabrics with respect to cotton. Hence, the thermal conductivity of the fabric seems to have a direct correlation with the content of the bamboo fibre (Fig. 3). These results are supported by Prakash *et al.*[25]. They have mentioned that bamboo blended fabrics can be expected to display higher thermal conductivity than the fabrics made from equivalent cotton yarns. This is because of the fact that the bamboo yarns reduce more hairiness index than the equivalent cotton yarns. Besides, the porosity of the bamboo blended fabrics is generally lower than that of cotton fabrics [26].

3.2.1 Effect of Fabric Packing Factor, Blend Proportion and Fabric Structures on Thermal Insulation

Table 5 shows the ANOVA statistical analysis. The thermal insulation values of the woven fabrics has significant difference with respect to blend proportion, F value is found to be 16.54 in comparison with F_{crit} (6.94) with a degree of freedom of 8 and at 5% significance level. The thermal insulation values of the fabric also has significant difference with respect to packing factors of woven fabrics at 5% significant level as the F value is 89.66 which is greater than F_{crit} value of 6.94. Similarly, the thermal insulation values of the woven fabrics has significant difference with respect to weave structures which is found to have higher thermal insulation behaviour as lyocell content increases in all the woven structures. This can be attributed to the higher packing density and lower thermal conductivity of the lyocell fibres in fabric than the bamboo fibres. The fabric structures such as plain and twill structures also influence the thermal insulation characteristics of the regenerated bamboo/lyocell woven fabrics, as the F value is 61.49 which is greater than F_{crit} of 6.94 with degree of freedom 8. It is basically due to fabric cover factor and fabric thickness.

3.2.2 Effect of Fabric Packing Factor, Blend Proportion and Fabric Structures on Thermal Diffusion

The thermal diffusion behaviour of the plain and twill woven fabrics made out of regenerated bamboo/lyocell blended fibres has been studied (Fig. 4) and the multivariable ANOVA statistical tool is used to analyze the significance of blend proportions, fabric packing factor and woven structures on the thermal diffusion behavior of the fabrics. The ANOVA result shows that with respect to fibre proportions, packing factors and fabric structures, there is a significant difference in thermal diffusion as F_o is less than F_{cr} at $F_{2,8}$=19.097 ($p<0.05$) . It may be due to the better integrity and packing density of lyocell fibres when compared to

Table 2—Physical and thermal properties of plain woven fabrics samples (S1-S5) made out of bamboo and lyocell yarns [30s Ne yarn count]

Property	S1	S2	S3	S4	S5
Physical properties					
Warp threads / inch	98	98	92	94	98
Weft threads / inch	88	94	90	88	94
Fabric cover factor, Tk	23.69	24.24	23.37	23.38	24.24
Warp cover factor, k1	17.89	17.89	16.79	17.16	17.89
Weft cover factor, k2	16.07	16.43	16.43	16.07	17.16
Fabric weight, GSM Calculated	127.54	152.75	143.68	140.85	147.65
Measured	123.69	148.86	141.1	141.11	148
Fabric density, kg/m^3	354.45	346.17	313.56	344.17	352.38
Fabric thickness, mm	0.42	0.43	0.45	0.41	0.42
Warp tensile strength, kgs	60.18	61.29	60.85	59.74	60.5
Weft tensile strength, kgs	23.8	25.4	24.6	23.7	60.82
Warp elongation-to-break, %	19.9	19.8	20.2	16.3	17.9
Weft elongation-to-break, %	22.7	22.6	20.4	21.2	18.67
Fabric packing factor	0.269	0.253	0.222	0.237	0.235
Fabric porosity	0.731	0.746	0.777	0.763	0.765
Thermal properties					
Thermal conductivity, K m^{-1}W^{-1}	0.047	0.039	0.025	0.021	0.017
Thermal insulation, K m^{2}W^{-1}	8.936	11.026	17.200	19.524	24.706
Thermal diffusion, m^2 s^{-1}	0.00127	0.00087	0.00059	0.00050	0.00038
Air permeability, cm^3/cm^2.min	54.15	63.87	62.28	66.74	69.19
Water vapour permeability, g m^{-2}/day	1685.36	1774.07	1862.77	1962.77	2523.8

S1 —100% bamboo, S2—75 bamboo / 25 lyocell, S3—50 bamboo / 50 lyocell,m S4—25 bamboo / 75 lyocell and S5—100% lyocell plain woven fabrics.

Table 3—Physical and Thermal properties of 2/2 Twill woven fabrics samples (S6-S10) made out of bamboo and lyocell yarns [30s Ne yarn count]

Property	S6	S7	S8	S9	S10
Physical properties					
Warp threads / inch	98	92	100	98	94
Weft threads / inch	80	92	92	84	88
Fabric cover factor, Tk	23.16	23.51	24.1	23.43	23.38
Warp cover factor, k1	17.89	16.76	18.26	17.89	17.16
Weft cover factor, k2	14.6	16.79	16.79	15.34	16.07
Fabric weight, GSM Calculated	142.84	152.40	147.62	143.25	145.98
Measured	141.12	148.86	148.87	141.11	147.00
Air permeability, $cm^3/cm^2.min$	65.55	63.87	99.64	113.23	115.03
Fabric density, kg/m^3	271.38	275.67	291.9	300.23	358.54
Fabric thickness, mm	0.52	0.54	0.51	0.47	0.41
Warp tensile strength, kgs	60.41	63.06	64.82	62.17	73.02
Weft tensile strength, kgs	24.6	26.4	24.7	25.6	59.96
Warp elongation-to-break, %	24.1	20.45	19.9	22.5	18.2
Weft elongation-to-break, %	22.7	23.2	24.3	23.1	19.58
Fabric packing factor	0.205	0.202	0.207	0.206	0.235
Fabric porosity	0.794	0.798	0.793	0.794	0.765
Thermal properties					
Thermal conductivity, $K\ m^{-1}W^{-1}$	0.083	0.076	0.058	0.030	0.024
Thermal insulation, $K\ m^2W^{-1}$	6.265	7.105	9.310	16.000	17.083
Thermal diffusion, $m^2\ s^{-1}$	0.001795	0.001299	0.000672	0.001961	0.0005442
Air permeability, $cm^3/cm^2.min$	63.87	65.55	77.84	99.64	124.55
Water vapour permeability, $g\ m^{-2}/day$	1874.07	1951.47	2440.18	2951.47	4967.3

S6 — 100% bamboo, S7—75 bamboo / 25 lyocell, S8—50 bamboo / 50 lyocell, S9—25 bamboo / 75 lyocell and S10—100% lyocell 2/2 twill woven fabrics.

Table 4—Physical and Thermal properties of 1/3 Twill woven fabrics sample (S11-S15) made out of bamboo and lyocell yarns [30s Ne yarn count]

Properties	S11	S12	S13	S14	S15
Physical properties					
Warp threads / inch	98	98	92	94	98
Weft threads / inch	90	94	88	80	84
Fabric cover factor, Tk	23.82	24.24	23.22	22.81	23.43
Warp cover factor, k1	17.89	17.89	16.79	17.16	17.89
Weft cover factor, k2	16.43	17.19	16.07	14.6	15.34
Fabric weight, GSM Calculated	150.24	146.85	143.24	143.27	151.84
Measured	147.32	148.86	141.56	142.91	150.00
Air permeability, $cm^3/cm^2.min$	92.6	80.35	118.23	146.53	148.38
Fabric density, kg/m^3	288.86	286.27	267.09	264.65	375
Fabric thickness, mm	0.51	0.52	0.53	0.54	0.4
Warp tensile strength, kgs	63.71	62.39	63.71	63.05	67.26
Weft tensile strength, kgs	24.3	24.3	25.6	26.2	60.24
Warp elongation-to-break, %	20.45	20.1	20.3	22.1	19.8
Weft elongation-to-break, %	22.9	21.3	20.9	24.2	20.92
Fabric packing factor	0.219	0.21	0.189	0.182	0.25
Fabric porosity	0.781	0.79	0.811	0.818	0.75
Thermal properties					
Thermal conductivity, $K\ m^{-1}W^{-1}$	0.096	0.083	0.072	0.038	0.032
Thermal insulation, $K\ m^2W^{-1}$	5.313	6.506	7.639	13.947	15.938
Thermal diffusion, $m^2\ s^{-1}$	0.001878	0.001612	0.002261	0.000886	0.0007111
Air permeability, $cm^3/cm^2.min$	80.35	92.26	113.23	138.38	146.53
Water vapour permeability, $g\ m^{-2}/day$	2040.18	2862.77	3040.18	4128.88	6564

S11 — 100% bamboo, S12—75 bamboo / 25 lyocell, S13—50 bamboo / 50 lyocell, S14—25 bamboo / 75 lyocell and S15—100% lyocell 1/3 twill woven fabrics.

bamboo fibres. Also significant differences are noticed in case of plain and twill weave structures of the fabrics (Table 5). It is due to the fabric thickness, fabric porosity and aerial density of the bamboo/lyocell yarn woven fabrics. Mainly the air permeability and fabric tightness factor play an important role in the thermal diffusion of the woven fabrics.

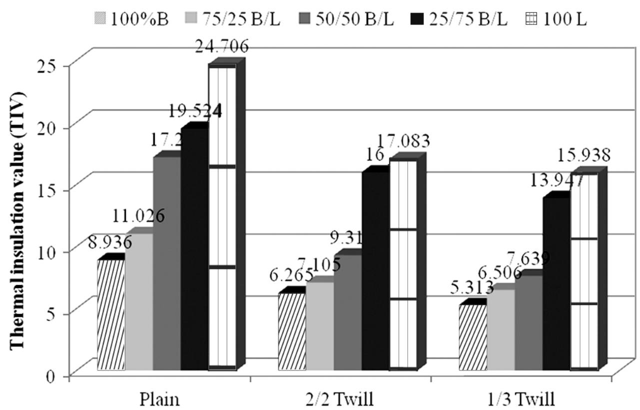

Fig. 1—Thermal insulation values (TIV) of regenerated bamboo and lyocell blended woven fabrics

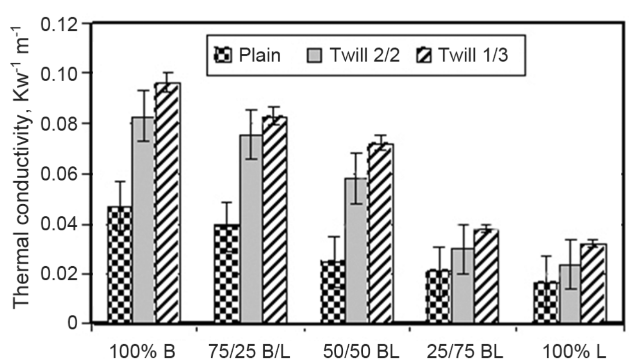

Fig. 2—Thermal conductivity of regenerated bamboo and lyocell blended woven fabrics

3.3 Effect of Fabric Properties on Thermal Conductivity

3.3.1 Fabric Thickness

The relationship between the thermal conductivity of woven fabrics against its fabric thickness is shown in Fig. 5. It indicates that the thermal conductivity values follow a decreasing trend when the fabric thickness of woven fabric increases in all the cases.

It is also noticed from Fig. 2 that the thermal conductivity of bamboo/lyocell blended plain woven fabrics shows lower thermal conductivity when compared to 2/2 twill and 1/3 twill woven fabrics. It implies that the twill woven fabrics have better thermal insulation behaviour than plain woven fabrics. The reason for the above trend may be due to the compactness of the yarn interlacement in woven structure which is obtained through effective packing factor and lower fabric porosity of the fabrics.

3.3.2 Fabric Packing Factor and Porosity

The thermal conductivity values of various woven fabrics made out of bamboo/lyocell blended yarns are

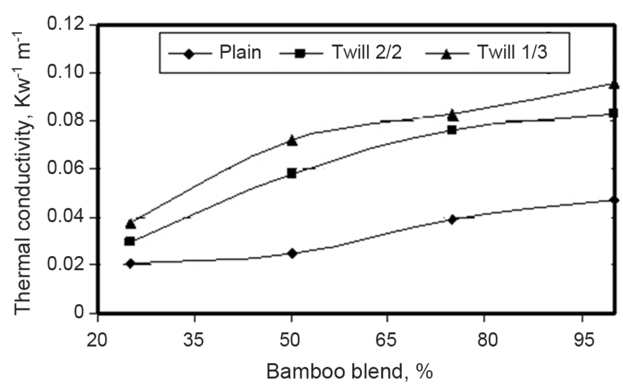

Fig. 3—Relationship between bamboo blend (%) and thermal conductivity of woven fabrics

Table 5—ANOVA multivariable data analysis

Variance analysis	Degree of freedom (df)	Sum of square value (SS)	Mean square value (MS)	F_{actual}	$F_{critical}$	P_{value}
Thermal conductivity behavior						
Between woven structures	8	101.13	50.466	146.81	6.944	0.00168
Between packing factor	8	25.785	12.448	11.848	6.994	0.01907
Between blend ratio	8	17.821	8.9606	9.8813	6.944	0.037
Thermal insulation behavior						
Between woven structures	8	11.088	5.544	61.49	6.944	1.06E-05
Between packing factor	8	9.779	4.889	89.66	6.944	0.0004
Between blend ratio	8	1.804	0.902	16.54	6.944	0.0116
Thermal diffusion behavior						
Between woven structures	8	0.0016	8.29E-05	34.84	6.944	0.0018
Between packing factor	8	0.014	0.0069	41.52	6.944	0.0013
Between blend ratio	8	0.0024	0.0012	19.097	6.944	0.0325

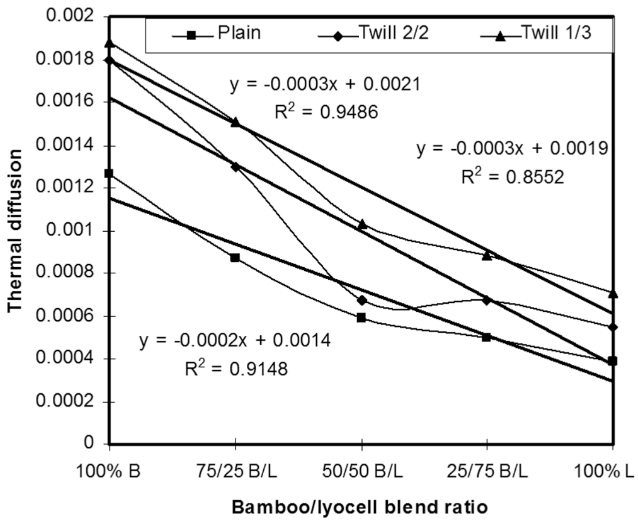

Fig. 4—Thermal diffusion behavior of regenerated bamboo and lyocell blended woven fabrics

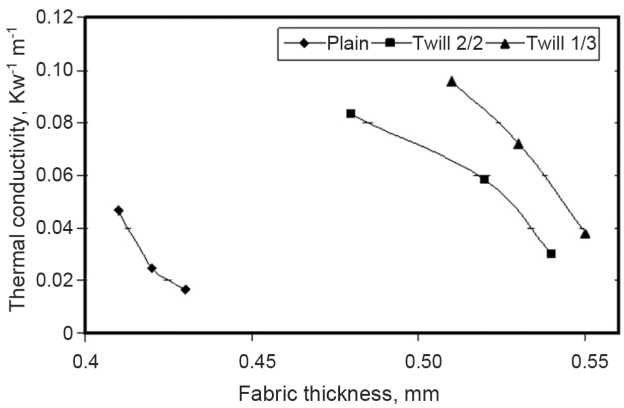

Fig. 5—Relationship between fabric thickness and thermal conductivity of woven fabrics

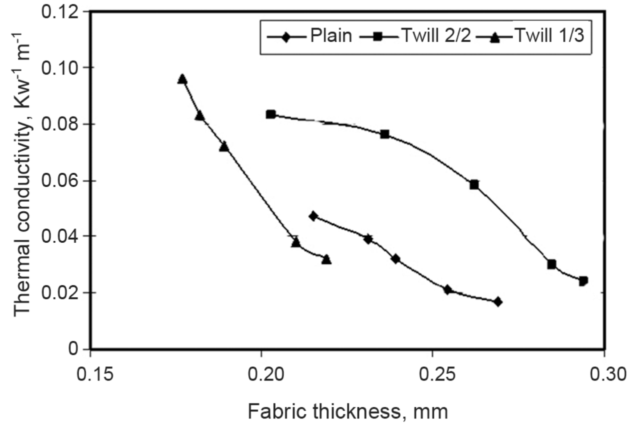

Fig. 6—Relationship between fabric packing factor and thermal conductivity of woven fabrics

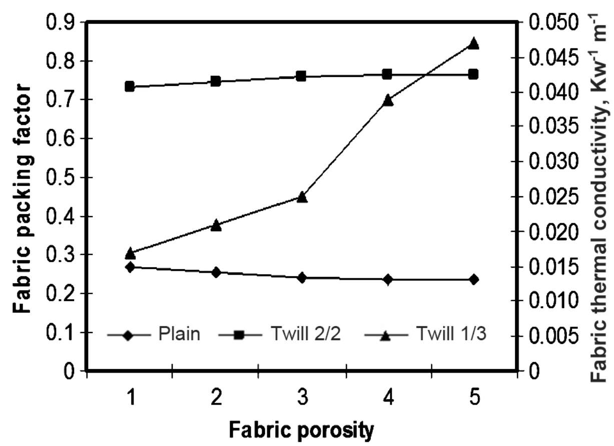

Fig. 7—Relationship between fabric porosity and packing factor *vs* thermal conductivity of woven fabrics

analyzed against the packing factor of the fabrics (Fig. 6). It is observed that the thermal conductivity of the woven fabrics increases when the fabric packing factor of the woven fabrics decreases. In other words, the thermal insulation of the woven fabrics increases when the packing factor of the woven fabrics increases.

The relationship between the fabric porosity and the thermal conductivity of plain and twill woven fabrics is shown in Fig. 7. It is noticed that the thermal conductivity values shows an increasing trend when the fabric porosity of the woven fabrics increases or in other words, thermal insulation values decrease with increasing fabric porosity values of the woven fabrics. The fabric packing factor and porosity behaviour of the woven fabrics are analysed using multivariable ANOVA tool (Table 5). It is found that there is significant difference observed in between the woven structures of plain and twill fabrics due to their fabric properties such as fabric thickness, aerial density, and fabric cover factor. Also it is noticed that there is significant difference in between bamboo/lyocell blend proportions of the woven fabrics, F_o value is found to be less than F_{cr} at $F_{2,8}$=9.8813> $F_{2,8}$=6.944 ($p<0.05$).

4 Conclusion

The thermal behaviour of plain and twill woven fabrics made out of bamboo/lyocell union fabrics with different blend proportions have been discussed. It is found that the thermal insulation of 1/3 twill is higher when compared to plain and 2/2 twill weave structures, the reason may be attributed to higher fabric density, packing factor and higher yarn floating in twill weave structures. The bamboo/lyocell union fabric is found to have higher thermal conductivity when there is an increase in the content of the bamboo fibre in the fabric. The thermal diffusion rate increases when the fabric packing density is lower and fabric porosity is higher. The thermal insulation behaviour of woven fabric increases when the lyocell fibre proportion increases in the blended fabric because of the lower thermal conductivity and finer structure of lyocell fibre, which leads to higher lyocell fibre density when compared to the bamboo fibre. This thermal behaviour of the bamboo/lyocell blended woven fabric will pave the way for a new era in creating a market segment for development of new products with respect to clothing for winter/summer seasons.

References

1 Bhat Prabhakar & Bhonde H U, *Asian Text J*, 15(11) (2006) 73.
2 Kawabata S & Rengasamy R S, *Indian J Fibre Text Res*, 27 (2002) 217.
3 Reagan M Barbara & Villasi Ludwig, *Text Res J*, 52 (11) (1982) 703.
4 Werden E Jane, Fahnestock M K & Galbraith L Ruck, *Text Res J*, 29 (8) (1959) 640.
5 Tyagi G K & Sharma D, *Indian J Fibre Text Res,* 30 (2005) 363.
6 Frydrych I, Dziworska G & Bilska J, *Fibres Text Eastern Eur*, 39 (2002) 40.
7 Harold J Hoge & George F Fonseca, *Text Res J,* 34 (5) (1964) 401.
8 Nuray Ucar & Turgut Yilmaz, *Fibres Text Eastern Eur*, 12 (3) (2004) 34.
9 Malgorzata Matusiak, *Fibres Text Eastern Eur*, 14 (5) (2006) 59.
10 Jirrsak O, Gok T, Ozipek B & Ning Pan, *Text Res J*, 68 (1) (1998) 47.
11 Senthilkumar P, Kantharaj M & Vigneswaran C, *J Text Assoc,* 71(4) (2010) 188.
12 Parameswaran N & Liese W, *Wood Sci Technol*, 10 (4) (1976) 231.
13 Erdumlu N & Ozipek B. *Fibres Text Eastern Eur*, 16(4) (2008) 43.
14 Xi L, Qin D, An X & Wang G, *Bioresources,* 8(4) (2013) 6501.
15 *Specification for water vapour permeable apparel fabrics, BS 7209* (BSI Group, London, UK), 1990.
16 *Standard Test Method for Air Permability of Textile Fabrics, ASTM D737* (ASTM international, USA), 1996.
17 Farnworth B, *Text Res J,* 53 (1983) 717.
18 Ramachandran T, Manonmani G, Vigneswaran C, *Indian J Fibre Text Res*, 35 (2010) 250.
19 Sabit Adanur, *Wellington Sears Handbook of Industrial Textiles* (Technomic Publishing Company Inc. Pennsylvania, USA), 1995, 626.
20 Narayanamurti D & Mohan D, *The use of bamboo and reeds in building construction* (Department of Economic and Social Affairs. United Nations, New York), 1972.
21 http://www.kongfi.com/cp_2.htm. (accessed on 10 August 2014).
22 Matusiak M & Sikorski K, *Fibres Text Eastern Eur*, 19(5) (2011) 46.
23 Schuster K C, Firgo H, Haussmann F & Männer J, *Lenzinger Berichte*, 83 (2004) 111.
24 Frydrych I, Dziworska G & Bilska J, *Fibres Text Eastern Eur*, (2002) 40.
25 Prakash C. Ramakrishnan G & Koushik C V, *Fibres Text Eastern Eur*, 19 (2012) 38.
26 Prakash C, Ramakrishnan G & Koushik C V, *Afr J Basic Appl Sci*, 4 (2) (2012) 60.