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Development of biodegradable tri-blended fabrics with improved moisture management properties using cotton/polylactic-acid/bamboo-viscose fibres

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The influence of fibre blend composition on the moisture management properties of tri-blended cotton-rich knit fabrics with biodegradability has been studied. The cotton, polylactic acid and bamboo-viscose fibres are blended to produce yarns of 14.7 tex (40s Ne) with four different blend proportions, namely 60/20/20, 50/30/20, 50/20/30 and 40/30/30. The yarns are then knitted into a single jersey structure of 130-135 gsm, followed by its scouring, bleaching and relaxation treatments. The relaxed fabrics are then evaluated for dynamic moisture transport properties using the SDL Atlas moisture management tester. The moisture management test results indicate that blending polylactic acid fibres with cotton and bamboo-viscose fibres improves the blended fabric's moisture management properties. The overall moisture management capability value is found to be better for cotton/polylactic-acid/bamboo-viscose blended fabric in the proportion of 50/30/20.

Keywords: Bamboo-viscose fibre, Biodegradable fabrics, Cotton, Moisture management properties, Polylactic acid, Tri-blended fabric

1 Introduction

Climate change has already had observable effects on the environment. It also affects the apparel wearer who feels more discomfort in hot and humid conditions. An essential property of fabric/apparel that decides the thermophysiological comfort of the wearer is the ability of a fabric to transport moisture. A fabric with good moisture management properties denotes that the fabric can transport both the moisture vapour and liquid moisture away from the body and keep the wearer in a comfortable state. Cotton fibre is known for its comfort properties in the dry state. The cotton fibre has a good moisture absorbency, and because of this property, cotton retains the moisture within the structure. The ability of cotton fibres to absorb moisture exceptionally well can often be a negative attribute in performance of apparel. In applications like sports, body sweat must be transmitted from the skin to the atmosphere as quickly as possible. In cotton, humidity remains in the fabric and is not transported to the surface for evaporation; cooling cannot occur. The body warms up, and even more sweat is produced, resulting in discomfort. This behaviour of cotton material is one of the main reasons for cotton fabrics not finding their market share in technical applications like sports apparel. Blending is a well-known method to bring together different materials' positive attributes and minimise the adverse effects. The moisture characteristic of cotton fabric can be improved through blending with synthetic fibre components[1]. By blending synthetic fibres with cotton in a cotton-rich blend, it is possible to improve the moisture management performance of the end product.

Several researchers have studied the moisture management properties of knitted fabrics concerning their structures & fibre profile[2-7], the effect of finishing[8, 9] and effects of blends[10]. Cil *et al*.[11] studied the comfort-related properties of fabrics from cotton, acrylic and cotton–acrylic blends. They found that both longitudinal and transfer wicking abilities and drying rates of the fabrics increase with the increase in the acrylic fibre ratio within the composition. Baltušnikaitė *et al*[12]. investigated the moisture transport properties of knitted materials. They have suggested that the fabrics constructed from cellulose & polyester and pure polyester in the outer layer could be used as fast-absorbing and quick-drying fabrics. Guruprasad *et al*.[13] investigated the moisture and thermal properties of knitted fabric by a binary blend of cotton / PLA and reported that cotton / PLA fibres with a blend ratio of 65:35 shown good overall moisture management properties. From the previous

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studies, it is clear that the proper selection and blending of fibres is essential to achieve improved moisture management properties in the fabric. In this work, an attempt has been made to develop a biodegradable tri-blend fabric made of cotton/PLA/bamboo-viscose with improved moisture management properties. It will help to understand the influence of fibres blend ratio in fabric moisture management properties.

2 Materials and Methods

2.1 Raw Materials

The cotton (MCU-5 variety), polylactic-acid (PLA) and bamboo-viscose fibres were sourced from a local spinning industry manufacturing blended yarns. The properties of cotton, PLA and bamboo-viscose fibres are given in Table 1.

2.1.1 Yarn Preparation

The staple length and fineness are the two most essential fibre properties that need to be matched for the satisfactory processing of blends. The cotton fibres were processed up to the stage of combing, and then combed cotton was taken back to the blow room for mixing with PLA and bamboo-viscose fibres. The cotton, PLA and bamboo-viscose fibres were mixed in four different proportions, namely 60/20/20, 50/30/20, 50/20/30 and40/30/30 (CO/PLA/BV). The blended fibres were then spun into yarns using a compact ring spinning system to a nominal count of 14.76 tex (40s Ne) with a twist factor of 36.4 (3.8 TM). Also, 100% cotton, 100% PLA and 100% bamboo-viscose yarns were spun to the same count to enable comparison between the yarns.

Table 1 — Properties of cotton, PLA and bamboo-viscose fibres

Fibre property	Cotton (CO)	Polylactic acid (PLA)	Bamboo-viscose (BV)
Length, mm (2.5% span length)	30	38	38
Fineness, den	1.2 (3.4mic)	1.4	1.2
Tenacity, g/tex	25 (bulk)	32	23
Elongation, %	6.7	25	21

2.2 Methods

2.2.1 Knitting and Processing

The yarns were then knitted into fabrics using a KNITMAC 16-inch diameter, 24-gauge single jersey knitting machine equipped with 27 numbers of positive storage feeders to a GSM of 110. The plain knitted fabrics were scoured and bleached by adopting a single-stage scouring and bleaching process. The 100% PLA and 100% bamboo-viscose fabrics were given a gentle scouring treatment to remove added impurities during mechanical processing. The fabrics were then subjected to dry and wet relaxation treatments before conditioning and testing.

2.2.2 Moisture Management Properties

The cotton, PLA, bamboo-viscose liquid moisture transport capabilities and its tertiary blended knitted fabrics were tested using SDL Atlas moisture management tester (MMT). The MMT instrument was designed to measure liquid moisture transport behaviour in multiple directions. Different indices were measured by the instrument, such as wetting time (WT), absorption rate (AR), maximum wetted radius (MWR), spreading speed (SS), accumulative one-way transport capacity (R), and overall moisture management capability (OMMC). The testing of samples was carried out according to the AATCC Test method 195-2017. For testing each sample, six specimens of size 8×8 cm were used. Table 2 gives the details of the grading of moisture management indices.

Table 2 —Grading scales of moisture management indices (AATCC-TM195-2017)

Index	Position	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Wetting time, s	Top	≥120	20 – 119	5 – 19	3 – 5	< 3
	Bottom	≥120	20 – 119	5 – 19	3 – 5	< 3
Absorption rate, %/	Top	0 – 9	20 – 29	30 – 49	50 – 100	> 100
	Bottom	0 – 9	20 – 29	30 – 49	50 – 100	> 100
Max wetted radius, mm	Top	0 – 7	8 – 12	13 – 17	18 – 22	> 22
	Bottom	0 – 7	8 – 12	13 – 17	18 – 22	> 22
Spreading speed, mm	Top	0.0 – 0.9	1.0 – 1.9	2.0 – 2.9	3.0 – 4.0	> 4.0
	Bottom	0.0 – 0.9	1.0 – 1.9	2.0 – 2.9	3.0 – 4.0	> 4.0
One-way transport capability (R)	-	<-50	-50 – 99	100 – 199	200 – 400	> 400
Overall moisture management capability (OMMC)	-	0.00 – 0.19	0.20 – 0.39	0.40 – 0.59	0.60 – 0.80	> 0.80

3 Results and Discussion

3.1 Fabric Properties

The count of different yarns produced and the fabric construction particulars and the properties of knitted fabrics are given in Table 3. The GSM of the blended fabrics is taken in the range of 130-135.

The bursting strength of 100% cotton fabric is higher than 100% PLA and 100% bamboo-viscose fabrics. A similar trend is observed in the blended fabrics as well with 60% cotton blended fabric, showing higher strength than the other blended fabrics. However, it is observed that there is no significant variation in bursting strength among the other fabrics with different blend proportions**.** The bursting strength values obtained are in acceptable range for the knit fabrics. It needs to be emphasized here that bursting strength of fabric is measured as a general fabric property and it has no relation to the moisture management properties of the fabrics.

3.2 Moisture Management Properties

3.2.1 Effect on Wetting Time

The results of the moisture management properties of tertiary blended fabrics grading are given in Table 4. From Fig. 1, it is observed that the wetting time for the top (WT_t) and bottom (WT_b) surface of the fabric changes with the blend ratio. The cotton and bamboo viscose are hydrophilic in nature, whereas PLA is hydrophobic in nature. On blending of fibres, it is observed that wettability has improved. The presence of bamboo-viscose fibre in the blending components enhances the wettability of the fabric. Similar observations on the effect of bamboo-viscose fibres on wettability are also made by other resaercher[14-16].

3.2.2 Effect on Absorption Rate

The absorption rate is the average moisture absorption ability (%/s) of the top and bottom surfaces of the fabric in the pump time (20 s). From Fig. 2, it can be seen that the absorption rates are dependent on

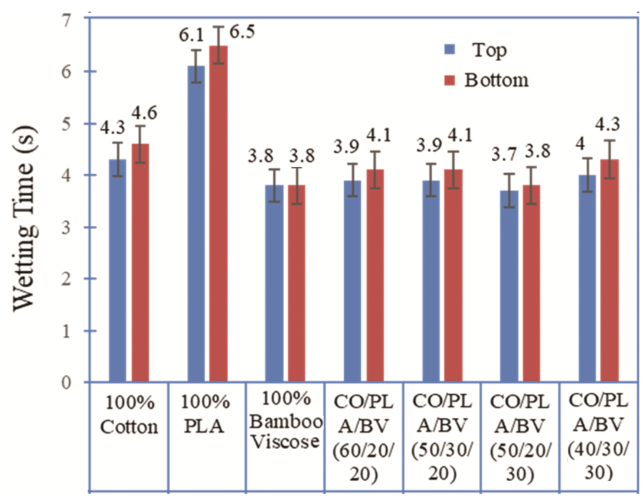

Fig. 1 — Effect of blend ratio on wetting time

Table 3 —Construction particulars and fabric properties of knitted fabrics

Parameter	100% Cotton (CO)	100% PLA	100% Bamboo-viscose (BV)	CO/PLA/BV 60/20/20	50/30/20	50/20/30	40/30/30
Yarn count, tex	15.02	14.54	14.65	14.82	14.72	14.87	14.96
Wales/cm ×courses/cm	18×22	17×22	17×23	17×22	18×22	18×22	17×23
Stitch length, mm	2.46	2.46	2.47	2.46	2.47	2.47	2.47
Fabric weight, g/m^2	135	133	130	132	131	130	133
Thickness, mm	0.95	0.90	0.82	0.87	0.84	0.80	0.76
Bursting strength, kg/cm^2	8.2	6.3	6.2	6.2	5.2	5.3	5.5

Table 4 — Moisture management grading of tertiary blended fabrics

Testing parameters	100% Cotton (CO)	100% PLA	100% Bamboo (BV)	CO/PLA/BV 60/20/20	50/30/20	50/20/30	40/30/30
Wetting time top, s	4	3	4	4	4	4	4
Wetting time bottom, s	4	3	4	4	4	4	4
Top absorption rate, %/s	2	2	2	2	2	2	2
Bottom absorption rate, %/s	2	3	3	3	3	3	3
Top max wetted radius, mm	4	5	4	4	5	4	5
Bottom max wetted radius, mm	4	5	4	4	5	4	5
Top spreading speed, mm/s	4	5	4	4	5	5	5
Bottom spreading speed, mm/s	4	5	4	4	5	5	5
Accumulative one-way transport index, %	2	3	2	2	2	2	2
OMMC	2	3	3	3	3	3	3

the blend ratios and increases with bamboo-viscose and PLA contents in the blend. The results clearly show that the absorption values of the top surface for all fabrics are much lower than that of the bottom surface. It implies that the liquid (sweat) diffuses from the next-to-skin surface to the opposite side and accumulates on the bottom surface of the fabric. The 100% cotton fabric has lower absorption rates than 100% bamboo-viscose and 100% PLA. It may be due to the cotton fibre with its flat & kidney-shaped cross-section and ribbon-like appearance, producing very irregular capillaries within a yarn and changes in the geometry of the cotton fibres due to swelling.This leads to slowing down of the transfer of liquid from inner to the outer side of the fabric.

3.2.3 Effect on Maximum Wetted Radius

The maximum wetted radius of fabrics is shown in Fig. 3. It can be observed that the 100% bamboo-viscose fabric has a low MWR as compared to cotton and PLA. This may be due to the tendency of viscose material to absorb and retain moisture. The maximum wetted radius value is higher for the fabrics made from 100% PLA and its blended proportion of 30% in the tertiary blended fabrics, which is found to be higher than those of 100% cotton, 100% bamboo-viscose and other blend proportions. Because of the hydrophobic character of PLA fibre, the liquid is not absorbed but only spread across the fabric's surface. PLA also has a uniform cross-sectional area. It will have a higher perimeter so that the capillaries formed by these fibres will provide a higher perimeter for the liquid to wet[5].

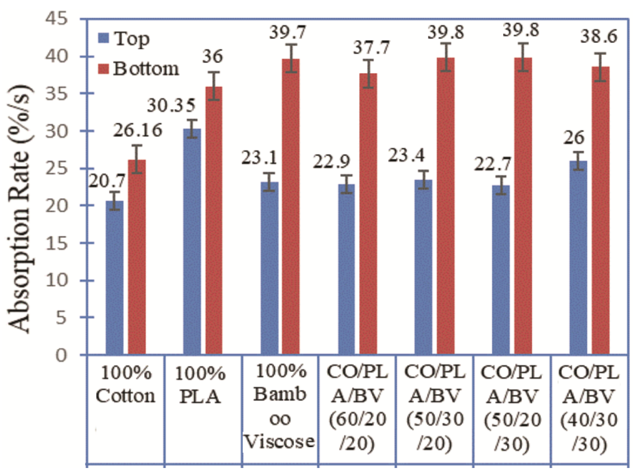

Fig. 2 —Effect of blend ratio on absorption rate

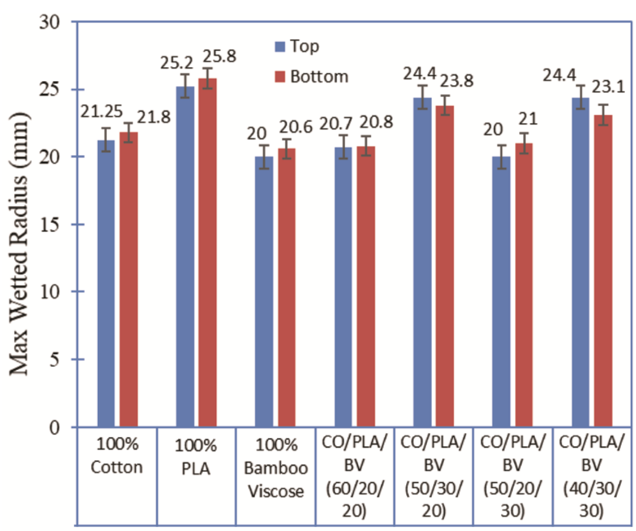

Fig. 3 —Effect of blend ratio on maximum wetted radius

3.2.4 Effect on Spreading Speed

Spreading speed is the rate at which moisture travels from the centre to the maximum wetted radius. The effect of blend ratio on fabric's spreading speed is shown in Fig. 4. It is observed that the cotton and bamboo-viscose have low spreading speed as compared to PLA fibre. This is mainly due to the hydrophilic nature of fibre and has a high affinity to water; when water molecules reach the capillary, it forms a bond with an absorbing group of fibre molecules, which inhibits the capillary flow[9]. In comparison, PLA is hydrophobic fibre and has lower water absorption capacity, which helps the quick capillary flow of liquid through inter-fibre or inter-yarn spaces in a fabric. In the tri-blended fabric, as the proportion of PLA fibre increases, the wetting radius as well as spreading speed of the fabric improve. The fabric with 30% blend proportions of PLA shows a higher spreading speed.

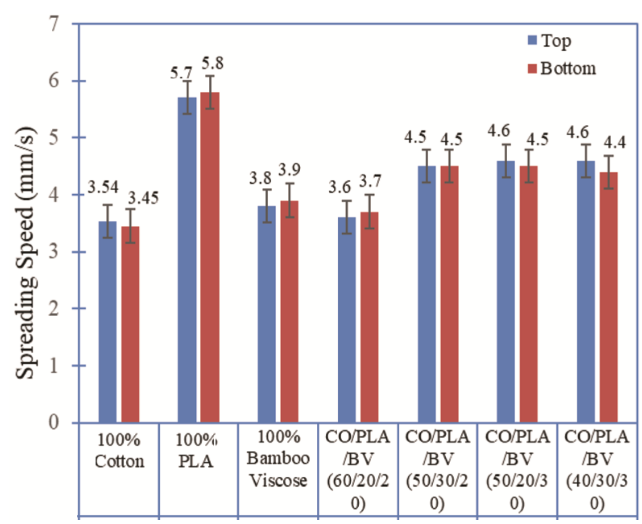

Fig. 4 —Effect of blend ratio on spreading speed

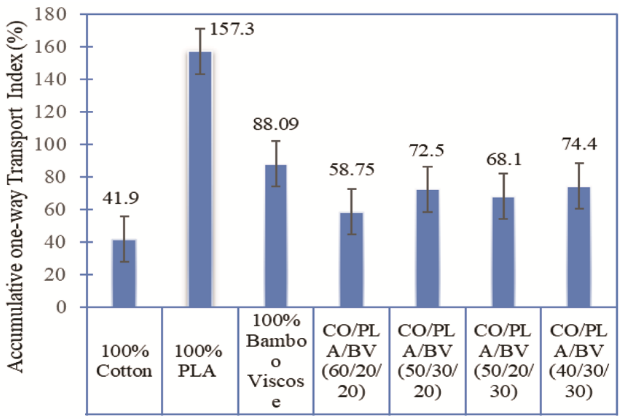

Fig. 5 —Effect of blend ratio on accumulative one-way transport index

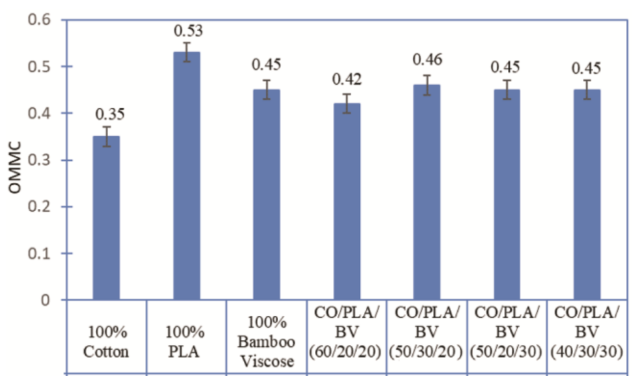

Fig. 6 —Effect of blend ratio on overall moisture management capacity (OMMC)

3.2.5Effect on AOTI & OMMC

The effect of blend ratio on fabric's accumulative one-way transport index (AOTI) and overall moisture management capacity (OMMC) are shown in Figs 5 and 6 respectively. The data reveals that PLA fabric has the highest liquid moisture management capacity (OMMC = 0.53) and one-way transfer capacity (OWTC = 157), indicating that the liquid sweat can be easily transferred from next to the skin to the outer surface. In the case of tertiary blend fabrics, increasing the proportion of PLA thus helps in improving the moisture transport from the top surface to the bottom surface. The OMMC values are found to be higher for the tri-blended fabrics than the 100% cotton fabric. However, with a tertiary blend of 60/20/20 (cotton/PLA/bamboo-viscose), only a marginal improvement in OMMC is observed. The moisture absorption rate on the bottom, maximum spreading speed on the bottom side, and one-way transport ability influence the OMMC of the fabric, which shows higher values for 50/30/20 and 40/30/30 proportions of cotton/PLA/bamboo-viscose than 100% cotton and 60/20/20 blended fabric. The better moisture management property mainly seems to emerge from the PLA component of the blend that helps in the faster transportation of liquid moisture.

4 Conclusion

The moisture management properties of tri-blended knitted fabrics are studied in this work. The results show that an increase in PLA fibre content in the blend improves the maximum wetted radius, spreading speed, one-way transport capability (R), and OMMC value. The presence of PLA ensures a dry feel by a quick transfer of liquid and spreading it over a larger area for rapid evaporation to the environment and improves the OMMC. When the bamboo-viscose content increases in the blend, it enhances the fabric's wetting time and absorption rate. Overall, the moisture management properties are better for cotton-rich tri-blend fabrics in the ratios of 40/30/30 and 50/30/20. Also, the developed fabrics are 100% biodegradable containing 70% cellulosic with 30% PLA blends.

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