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Moisture management properties of cellulose single jersey fabrics

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Modified cellulose (tencel, modal and bamboo) lycra plated single jersey knitted fabrics have been developed with two different loop lengths (2.7mm and 3.4mm) and with different lycra plating (without plating, half plating and full plating), along with the cotton fabrics of same variables. The test results of moisture management properties prove that the overall moisture management capability (OMMC) values of 3.4mm tencel fabric without lycra have the highest value and exhibit an excellent grade in the moisture management test (MMT) chart. This is attributed to the low wetting time, higher bottom absorption rate, higher value of maximum wetted radius and spreading speed and accumulative one-way transport index (AOTI) value. It is also found that the value of OMMC decreases with the increase in elastane content and increases with the increase in loop length. Further, it is also observed that all the developed fabrics fall under the category of good to excellent grades in MMT indices.

Keywords: Comfort, Knitted fabrics, Loop length, Moisture management, Plating, Single jersey fabric, Cellulosic fabric, Tencel

1 Introduction

The close-to-skin garments must have two crucial properties, viz evaporation of perspiration from the skin surface and moisture transmission to the atmosphere to keep the wearer comfortable. The transportation of sweat or heat from the human skin to the outside environment decides the comfort level of any fabric.

The unnecessary loss of body heat results in a moist feeling, which is avoided by the moisture management property of the textile material by letting the fabric, in contact with the skin, almost dry[1]. The moisture management property of the clothing is determined by the wetting and wicking properties. The water vapour and the liquid are transmitted through the textiles by simple diffusion through inter-yarn spaces, capillary transfer through fibre bundles and diffusion through individual fibres[2].

The single jersey cotton knitted fabrics have become part of our everyday clothing which cannot be avoidable. The comfort, light weight and skin-friendly nature of the cotton knitted fabrics have brought this importance for their use in close-to-skin garments. Though cotton fabrics have all the advantages, the problem of sustainability of the cotton materials has directed the researchers to move towards alternative fibres with the same features as cotton textiles. This has aroused the use of modified cellulosic fibres in the clothing and apparel sectors. Further, the use of elastomeric yarns in the single jersey knitted fabrics also has increased in order to improve the dimensional stability and ease in the body movements of the wearer[3-6]. Knitted fabrics produced from non-elastomeric yarns like cotton do not recover when subjected to deformation, resulting in poor dimensional stability in knitted fabrics, especially in the case of single jersey knit fabrics. The introduction of elastane yarns in single jersey knitted fabrics has improved its dimensional properties along with its elasticity[7]. The use of elastane has not only improved the fabrics dimensional stability but also better fit and shape retention to the garments[8]. The elastane can be introduced in knitted fabrics as core-spun yarns with natural and synthetic fibres or as additional yarns in circular knitting machines. The former method has an adverse effect on the thermal comfort properties of the fabrics compared to the later[9]. Khalil *et al.*[10] findings stated that the use of core-spun yarn and dual core spun(DCS) yarns in the

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fabrics has increased the thermal absorptivity and decreased water vapour permeability. The use of core-spun and dual core-spun yarn has also affected the OMMC values of the fabric, resulting in discomfort compared to the plated fabrics. It has also affected the THV of the fabric by 34%. Hence, the plating is the best option for the knitted fabrics for insertion of elastane to achieve dimensional stability with superior comfort and hand values. The use of plated knitted fabrics has become unavoidable in today's comfort world. The plated knit fabrics are used in lingerie, hosiery, leisurewear, sportswear and so on for their superior comfort and moisture management characteristics[11]. Many researchers have discussed that the raw materials and the fabric's structural properties influence the moisture management properties of the fabrics. In this study, the effect of fibre characteristics, loop length variation and elastane plating on the cellulose single jersey knitted fabrics has been analyzed.

2 Materials and Methods

2.1 Materials

Tencel, modal, bamboo and cotton staple fibres of cellulosic origin were selected for this work. The fibres were individually ring spun into 30^{s}Ne yarn. Table 1 displays yarn characteristics. Lycra filament (20 denier), having the specifications: 412% elongation,12.7cNT break, 3.3- 4.3 cN TP 200, 0.44-0.7cN TM 200 and 13.5- 21.5 % relaxation, was used.

The single jersey plated knitted fabrics were produced using a weft knitting machine with a positive lycra feeder. The fabrics were produced with two different loop length values (2.7 mm and 3.4 mm) with and without lycra plating. The developed lycra knitted samples were subjected to heat setting treatment in order to improve the dimensional stability of the samples. The fabrics were subjected to a temperature of 190°C at a speed of 20 m/ min for 10 min. The samples were conditioned at a standard atmospheric temperature of 21ºC ±1 and relative humidity of 65% ± 2 for 48 h prior to testing.

Table 1 — Yarn parameters

Parameter	Tencel	Modal	Bamboo	Cotton
Yarn diameter, mm	0.29	0.185	0.155	0.286
Unevenness, %	9	9.13	9.18	7.2
Thick /km (+50%)	4.3	6	4.3	4
Thin /km (-50%)	3	0	2	2
Hairiness index	5.82	5.9	5.3	7
Neps/km	16	16	16.5	12
Tenacity, cN/tex	15.13	24.96	16.13	15.5
Elongation, %	8.92	10.72	14	6.15
Twists per inch	15.21	15	19.16	17.02

2.2 Methods

2.2.1 Moisture Management Properties

The controlled movement of water vapor and liquid water (perspiration) from the surface of the skin to the atmosphere through the textile substrate is defined as moisture management. The dynamic liquid transport properties of textiles were measured by moisture management tester (MMT) an instrument developed by SDL Atlas, by analyzing:

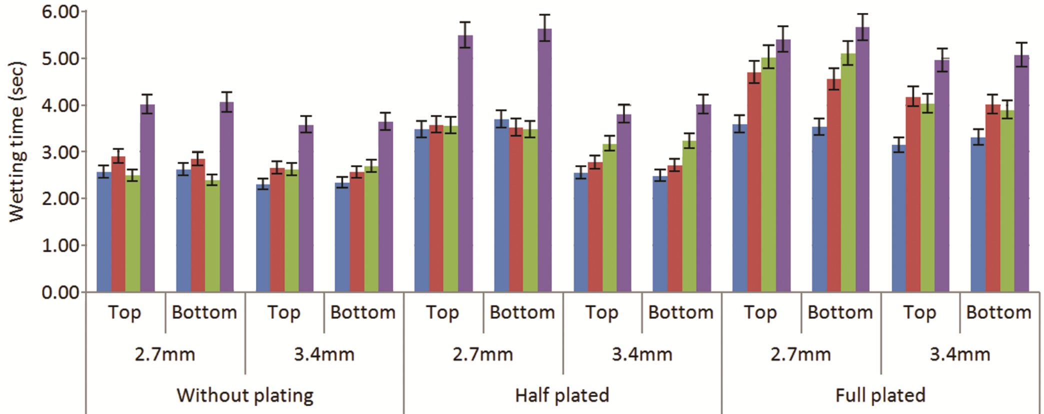
- Absorption rate –Moisture absorbing time of the fabric's inner and outer surfaces.
- One-way transport capability –Liquid moisture one-way transfer from the fabric's inner surface to the outer surface.
- Spreading/drying rate – Speed of liquid moisture spreading on the fabric's inner and outer surfaces.

In MMT, a fabric specimen was placed between two horizontal (upper and lower) electrical sensors, each with seven concentric pins, to assess the liquid moisture management properties of textiles. A preset amount of test solution was dropped onto the middle of the upward-facing test specimen surface to enable the detection of electrical conductivity variations. The test solution is free to move in three directions. Changes in the electrical resistance of the specimen were monitored and recorded throughout this test. Fabric liquid moisture content variations were calculated using electrical resistance to quantify the dynamic liquid moisture transport behaviour of the specimen. The summary of the measured results was used to grade any fabric's liquid moisture management qualities using specified indices by AATCC Test Method 195-2009.

3 Results and Discussion

3.1 Wetting Time

Wetting time (WT) is the time required for both the top and bottom surfaces of a fabric to start getting wet. Figure 1 shows that the fabrics composed of cotton fibres have higher wetting time for both top and bottom surfaces. This may be attributed to the hydrophilic nature of the cotton fibre, which tends to absorb more water molecules within the structure, and letting it out very slow. Hence, the wetting time for the bottom surface is higher than that for the top surface. Previous research has indicated that thinner fabrics exhibit faster wetting as compared to thicker



	Without plating 2.7mm Top	Without plating 2.7mm Bottom	Without plating 3.4mm Top	Without plating 3.4mm Bottom	Half plated 2.7mm Top	Half plated 2.7mm Bottom	Half plated 3.4mm Top	Half plated 3.4mm Bottom	Full plated 2.7mm Top	Full plated 2.7mm Bottom	Full plated 3.4mm Top	Full plated 3.4mm Bottom
Tencel	2.57	2.62	2.31	2.34	3.48	3.69	2.55	2.49	3.59	3.53	3.15	3.31
Modal	2.90	2.85	2.66	2.56	3.58	3.52	2.77	2.71	4.70	4.55	4.17	4.01
Bamboo	2.49	2.40	2.62	2.70	3.56	3.48	3.17	3.23	5.02	5.09	4.02	3.89
Cotton	4.01	4.06	3.58	3.64	5.48	5.64	3.80	4.02	5.39	5.65	4.95	5.07

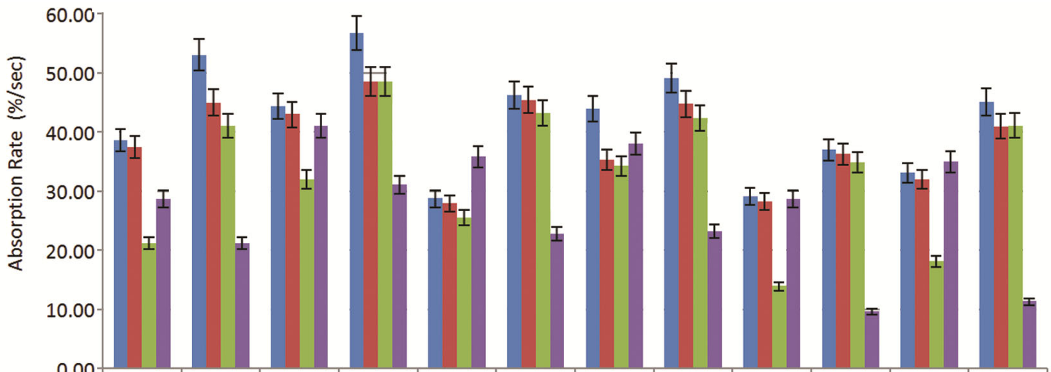
Fig. 1 — Effects of fibre, plating and loop length on wetting time

Table 2 — Dimensional properties of cellulose single jersey knitted fabrics

Yarn	Structure	Loop length mm	WPI	CPI	Stitch density	Thickness, mm	Areal density g/m^2 (CPI × WPI)
Tencel	Without plating	2.7	31	32	1705	0.47	137.3
		3.4	31	55	992	0.38	99.4
	Half plated	2.7	34	44	2046	0.50	165.7
		3.4	33	62	1496	0.48	142.8
	Full plated	2.7	39	50	2516	0.62	202.0
		3.4	37	68	1950	0.55	182.6
Modal	Without plating	2.7	34	55	1870	0.45	141.8
		3.4	33	45	1485	0.41	119.2
	Half plated	2.7	37	43	2419	0.54	198.1
		3.4	41	59	1998	0.51	152.9
	Full plated	2.7	45	74	3330	0.85	277.3
		3.4	45	61	2745	0.69	260.8
Bamboo	Without plating	2.7	33	36	1998	0.45	161.3
		3.4	37	54	1188	0.40	115.9
	Half plated	2.7	37	54	2840	0.62	224.5
		3.4	40	71	1591	0.57	196.1
	Full plated	2.7	42	68	3416	0.84	310.3
		3.4	41	76	2856	0.63	246.4
Cotton	Without plating	2.7	40	43	1729	0.59	169.4
		3.4	32	34	1090	0.47	134.6
	Half plated	2.7	43	63	2717	0.82	278.2
		3.4	34	50	1713	0.65	220.9
	Full plated	2.7	45	66	2972	1.02	361.9
		3.4	36	52	1874	0.81	278.1

fabrics[12]. From Table 2, it is observed that the thickness of cotton fabrics is high as compared to other modified cellulose fabrics; tencel having the lowest thickness.

While comparing the wetting time between the higher and lower loop length fabrics, it is observed that the wetting time is high for fabrics with higher loop lengths than for those with lower loop lengths. This result is in agreement with the findings of Oner *et al.*[13], stating that the decrease in fabric tightness leads to increased porosity of the fabric, resulting in increased air and liquid moisture transfer. This reduces the wetting time of



	Without plating				Half plated				Full plated			
	2.7mm		3.4mm		2.7mm		3.4mm		2.7mm		3.4mm	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Tencel	38.62	53.02	44.37	56.74	28.76	46.22	43.93	49.11	29.15	36.98	33.06	45.12
Modal	37.42	45.00	43.00	48.51	27.87	45.43	35.31	44.77	28.25	36.23	32.04	40.97
Bamboo	21.22	41.08	31.98	48.52	25.56	43.21	34.22	42.36	13.91	34.87	18.13	41.11
Cotton	28.65	21.22	41.08	31.04	35.81	22.78	38.05	23.17	28.65	9.60	34.96	11.33

Fig. 2 — Effects of fibre, plating and loop length on absorption rate

the loosely knitted fabrics. Additionally, the insertion of elastane in single jersey knitted fabrics leads to an increase in the wetting time. The value of wetting time increases with the increase of elastane content. Furthermore, the wetting time values are higher for full plated fabrics followed by half plated and then fabrics without elastane. This can be explained by the research findings of Manshahia and Das[14], which suggests that the increase in elastane content results in the fabric compactness, leading to less transfer of water from the top to bottom surface of the test samples.

3.2 Absorption Rate

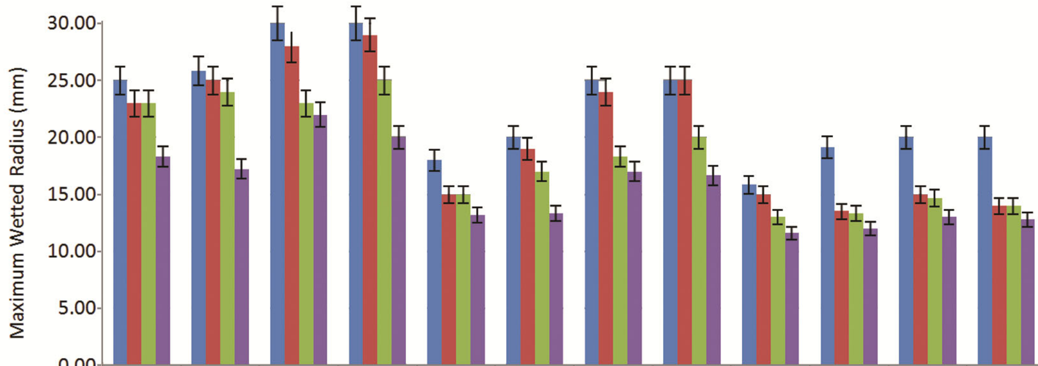
The average moisture absorption ability of the top and bottom surfaces in the pump time is known as the Absorption Rate (AR). Figure 2 reveals that the bottom absorption rate is higher for the fabrics made of tencel fibres followed by modal and bamboo fabrics, when compared to cotton fabrics. This result is in line with the findings of several researchers, conforming that the presence of free hydroxyl groups in cotton fibre hold the absorbed moisture well in tact within the structure, and thus resulting in the poor surface transfer giving way to the low bottom absorption rate[13]. In case of the modified cellulosic fibres, the presence of free hydroxyl groups is very less comparatively and moreover the fibril structure in these fibres especially in tencelhelps in the quick transport of the liquid moisture, resulting in high values of bottom absorption rate[15].

On comparing the absorption rate values between the loose and the tight fabric structure, it is found that the absorption rate decreases with increased in fabric tightness. This means that the absorption rate values are higher for high loop length fabrics (3.4 mm) and relatively lower for low loop length fabrics (2.7mm) due to the difference in the fabric porosity. The effect of plating follows a similar trend, showcasing higher absorption rate values for fabrics without elastane. The absorption values decrease with increased elastane content.

3.3 Maximum Wetted Radius

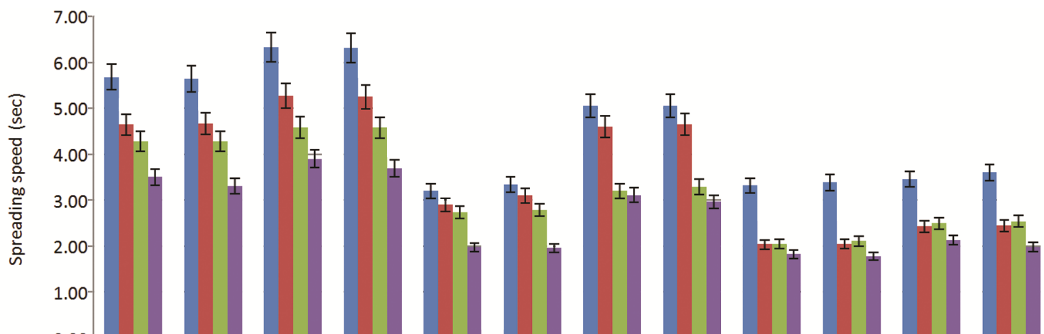
Figure 3 indicates that the maximum wetted radius (MWR) values are higher for tencel fabrics and lower for cotton fabrics. This finding aligns with the work conducted by Özkan and Meric[16], who concluded that an increase in MWR value leads to a decrease in the drying time of the fabrics. This higher MWR value for tencel fabrics may be due to the fibrillar structure, which increases the liquid spreading. On the other hand, the higher MWR value for the cotton fabrics is due to its hydrophilic nature which tend to absorb the liquid and slows down liquid spreading.

The loop length variation in the fabric structure affect the MWR values. As depicted in Fig. 3, MWR values increase as the loop length increases. When the loop length of the fabrics increases, the fabric tightness decreases with an increase in the fabric porosity. This increase in porosity facilitates quick



	Without plating				Half plated				Full plated			
	2.7mm		3.4mm		2.7mm		3.4mm		2.7mm		3.4mm	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Tencel	25.00	25.83	30.00	30.00	18.00	20.00	25.00	25.00	15.83	19.17	20.00	20.00
Modal	23.00	25.00	28.00	29.00	15.00	19.00	24.00	25.00	15.00	13.52	15.00	14.00
Bamboo	23.00	24.00	23.00	25.00	15.00	17.00	18.33	20.00	13.00	13.33	14.67	14.00
Cotton	18.33	17.22	22.00	20.00	13.20	13.33	17.00	16.67	11.61	12.00	13.00	12.78

Fig. 3 — Effects of fibre, plating and loop length on maximum wetted radius



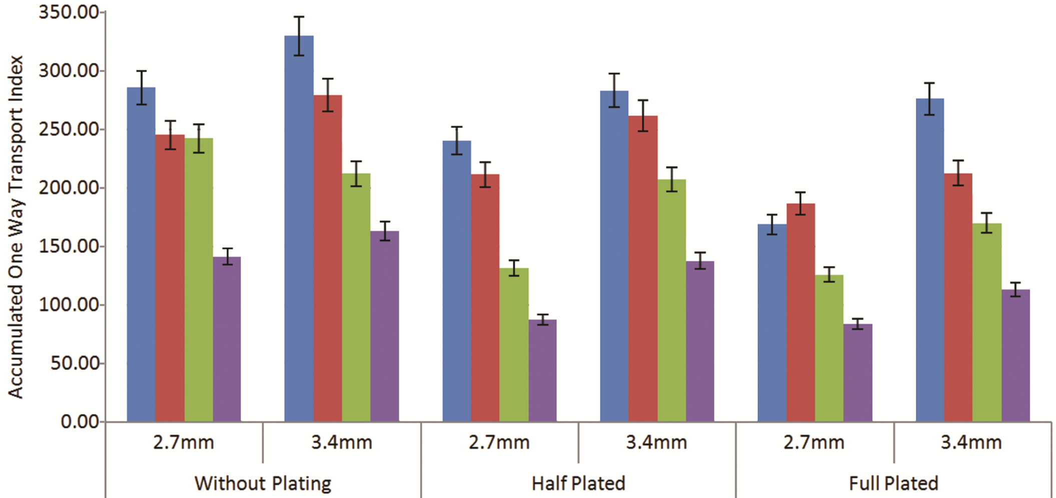
	Without plating				Half plated				Full plated			
	2.7mm		3.4mm		2.7mm		3.4mm		2.7mm		3.4mm	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Tencel	5.68	5.64	6.32	6.31	3.21	3.34	5.05	5.06	3.32	3.39	3.46	3.61
Modal	4.64	4.67	5.27	5.25	2.90	3.10	4.60	4.65	2.04	2.05	2.43	2.44
Bamboo	4.28	4.29	4.58	4.58	2.74	2.79	3.20	3.29	2.05	2.12	2.49	2.54
Cotton	3.50	3.31	3.90	3.70	1.98	1.96	3.11	2.97	1.82	1.78	2.13	1.99

Fig. 4 — Effects of fibre, plating and loop length on spreading speed

drying of the fabric, thereby increasing the MWR values. The insertion of elastane yarn in the fabric structure decreases the MWR values. From the Fig. 3, it is evident that the MWR values decrease with an increase in elastane content. This indicates that the fabrics without elastane show higher MWR value, while half plated followed by the full plated fabrics show lower value. The reason may be attributed to the increase in elastane content which increases the tightness of the fabric and shows poor liquid moisture transfer.

3.4 Spreading Speed

The spreading speed (SS) is determined as the accumulative liquid spreading speed from the centre to the maximum wetted radius. Figure 4 indicates that the spreading speed values are higher for fabrics with higher absorption rate values. The tencel fabrics show high SS values in all cases, while cotton fabrics show low bottom SS values. These results can be attributed to the fibre structure as stated by many researchers[17-18] that the hydrophilic nature of cotton fibres and the nano-fibrillar structure of tencel along with



	Without Plating 2.7mm	Without Plating 3.4mm	Half Plated 2.7mm	Half Plated 3.4mm	Full Plated 2.7mm	Full Plated 3.4mm
Tencel	285.78	329.94	240.30	283.19	168.78	276.12
Modal	245.24	279.21	211.48	261.57	186.61	212.64
Bamboo	242.46	212.28	131.66	207.16	125.85	169.98
Cotton	141.15	163.07	87.55	137.75	83.68	113.03

Fig. 5 — Effects of fibre, plating and loop length on accumulative one way transport index

hydrophilicity, contribute to those contrasting results, despite both fibres being of cellulosic origin.

The spreading speed values for the tight fabrics are low as compared to the loose structure fabrics. This may be due to the increased porosity of the loose structure fabrics. Many studies have demonstrated that an increase in loop length reduces fabric tightness and increases fabric porosity. Among the plated structures, it is observed that the fabrics without elastane have more SS values and these values decrease with an increase in elastane content. Figure 4 clearly illustrates that the spreading speed values are low for full plated fabrics but the values are higher for half plated fabrics followed by fabrics without elastane.

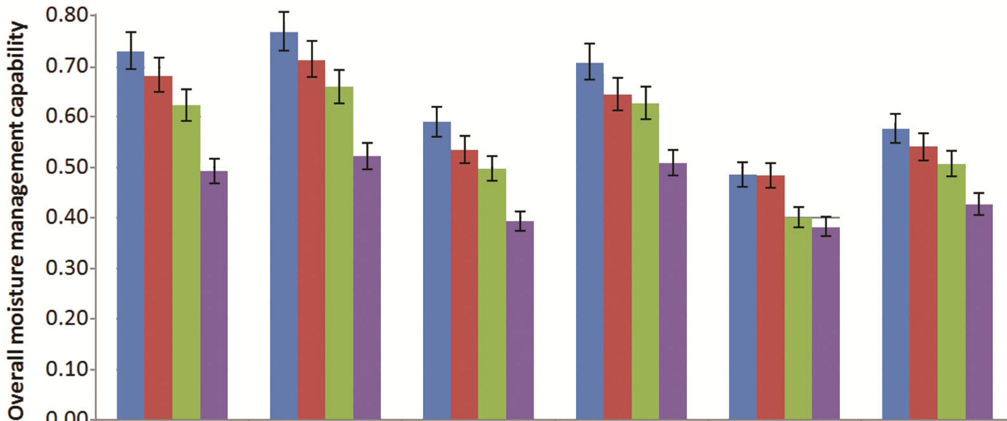
3.5 Accumulative One Way Transport Index

The difference of accumulative moisture content between the two surfaces of a fabric is termed as accumulative one way transport index (AOTI)[19]. Figure 5 depicts that the AOTI values are higher for tencel fabrics followed by modal and bamboo fabrics. On the other hand, AOTI values are lower for the cotton knitted fabrics. Research findings also support the notion that the higher AOTI values indicate the faster transfer of liquid moisture from skin to the outer surface, while negative and low AOTI values suggest that the fabrics absorbs moisture faster but dry out at slower rate[20]. The low AOTI values in cotton fabrics may be attributed to their hydrophilic nature, which tends to hold more liquid moisture in its structure and then release it at a slower rate[21].

The AOTI values for higher loop length fabrics (3.4 mm) are more when compared to the fabrics of lower loop length (2.7 mm). The reason may be related to the fabric porosity in the loose fabrics which are also reported by several researchers globally[19]. Regarding the effect of plating, it is noted that the AOTI values are higher for fabrics without elastane and they decrease with an increase in elastane content. The reason is similar to that for loop length.

3.6 Overall Moisture Management Capability

The index stating the overall capacity of the fabric to manage the liquid moisture transport is termed as overall moisture management capability (OMMC). Figure 6 shows OMMC values of the tested fabrics, suggesting that the fabrics made of tencel fibres have higher OMMC values as compared to the other fabrics, while the value is low for cotton fabrics. Though the OMMC values of other modified cellulose fabrics are lower as compared to the tencel fabrics, the MMT grades range from good (0.4-0.6) to very good (0.6-0.8). The cotton fabric grades range from fair (0.2-0.4) to good (0.4-0.6). The lower value of cotton fabrics may be due to the moisture accumulation on the top surface[22].



	Without Plating		Half Plated		Full Plated	
	2.7mm	3.4mm	2.7mm	3.4mm	2.7mm	3.4mm
Tencel	0.73	0.77	0.59	0.71	0.48	0.58
Modal	0.68	0.71	0.53	0.64	0.48	0.54
Bamboo	0.62	0.66	0.50	0.63	0.40	0.51
Cotton	0.49	0.52	0.39	0.51	0.38	0.43

Fig. 6 — Effects of fibre, plating and loop length on overall moisture management capability

When compared with the varied loop lengths, it is found that the OMMC values are high for higher loop length fabrics (3.4mm) as compared to the lower loop length fabrics (2.7 mm). This can be explained by the fact that the tight fabric structures hinder the liquid moisture transfer, resulting in the reduced OMMC values as compared to loose structure fabrics. Similarly, on comparing plated fabrics, it is found that the OMMC values decrease with an increase in elastane content. The elastic knitted fabrics exhibit tightness in the structure, which reduces the liquid moisture transport.

4 Conclusion

The moisture management properties of the knitted fabrics are affected by various factors, such as fibre constituent, lycra plating and variation in loop length of the fabric. The values of both top and bottom wetting time is higher for cotton fabrics, due to their hydrophilic nature. The wetting time for the modified cellulose fabrics is less, indicating their quicker wetting properties. Fabrics with loose structures have lower wetting time as compared to the tight fabrics. Full plated fabrics exhibit higher wetting time than the fabrics without lycra. The values of absorption rate show the reverse trend to wetting time. The value of bottom absorption rate is higher for tencel fabrics, with loop length of 3.4 mm and without lycra, indicating faster absorption of fabric. MWR values are higher for 2.7 mm tencel fabrics without lycra, while they are lower for 3.4 mm full plated cotton fabrics. This indicates that the tencel fabrics exhibit quick drying property and the process of drying slows down as the lycra content increases. The fabric of 2.7 mm loop length shows higher MWR values when compared to 3.4 mm loop length fabric. Spreading speed follows the same trend as in absorption rate and MWR. The AOTI values are highest for 3.4 mm tencel fabric without lycra and the lowest for cotton samples. AOTI values decrease with an increase in elastane content. AOTI values are higher for loose fabrics and lower for the tight fabrics. Finally the 3.4 mm tencel fabric without lycra exhibits the highest OMMC values & categorised as Very Good in the OMMC grades. The 2.7mm full plated cotton fabric has lower OMMC value (Fair grade). Overall, OMMC values of all the tested fabrics range from Good to Very Good making them suitable for close-to-skin garments. The material selection and construction may depend on the end-use application of the garment.

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