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Comfort Behavior of Unconventional Natural Fiber Based Union Fabrics

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Abstract

To fulfill the sustainability need of today's comfort conscious consumers, an attempt has been made in this research study to explore the possibilities of producing high-quality apparel fabrics using unconventional fiber fabrics and their union fabrics. Unconventional natural fibers such as banana, hemp, linen and ramie and also their union fabrics with cotton were used. Union fabrics have different fiber content in warp and weft directions. A comparative study was made on the comfort behavior of these fabrics to evaluate their comfort performance. The properties of these fabrics were evaluated and compared under air permeability, moisture management, thermal properties, low-stress mechanical properties, etc. Unconventional fiber fabrics showed better results in many cases and thus were comparable with 100% cotton fabrics.

Keywords

Comfort, Low-Stress Mechanical Properties, Fabric Hand, Union fabric, Air Permeability

1. Introduction

With the advancement in our time, people have placed a great emphasis on environment-friendly materials and processes. This trend results in an encouragement to use and develop fibers that can be obtained or manufactured from renewable sources like natural fibers as a substitute for conventional synthetic fibers that are based on petroleum. Even cotton fiber is now considered as non-eco-friendly fiber as it requires large quantity of chemicals, pesticides along with water. Unconventional natural fibers such as hemp, ramie, flax, sisal, kenaf, etc. can be used as an alternate to cotton and other synthetic fibers. These alternative fibers include banana fiber obtained from pseudo-stem of banana plant, pineapple fibers obtained from leaves, sugarcane fibers obtained from the sugarcane stalks, etc. and some other bast fibers obtained with almost no use of pesticides and chemicals include hemp, ramie, flax, sisal, kenaf, etc. [1]. These fibers are present in abundance all over India but still neglected everywhere. These fibers have potential to become useful textile fibers. Along with abundant availability, these fibers possess characteristics like elegance in aesthetic appeal, comfort in wear and many other utility performances as peruse in different applications including clothing.

Woven designed fabrics with eco-friendly fiber are more in demand. Nowadays consumers are fashion and health-conscious so that they switch towards the eco-friendly fabrics [2]. One of the most important aspects of clothing and apparels is comfort. Clothing comfort is mainly associated with three common aspects such as psychological, tactile and thermal [3]. Psychological comfort is mainly related to the aesthetics of the clothing and fashion trends prevailing in a particular society and has no dependence on fabric's properties quantitatively. Tactile comfort majorly depends upon the interaction between the fabric and skin during wear [4]. It deals with the mechanical properties and surface characteristics of fabric. However, thermal comfort is a measure of fabric's ability to maintain wearer's skin temperature and deals with fabric's transmission behaviors, namely thermal insulation or conductivity, water vapor or liquid water transmission and air permeability [5] [6].

In this research, efforts are being made to explore the possibilities of producing high-quality apparel fabric from unconventional natural fibers under industrial production environment. A comparative study was made on the low-stress mechanical properties, fabric hand and thermal comfort of banana, hemp, linen and ramie fabrics and their respective union fabrics with cotton [7] [8]. Union fabrics are the fabrics where the fiber content is different in the warp and weft direction.

2. Materials and Methods

2.1. Materials

For this research, the four unconventional fibers namely banana, hemp, linen and ramie are used. Cotton is used as reference fiber for comparison of respective fabric properties. Yarn samples of 30 Ne were developed from the above mentioned five fibers under industrial production conditions and accordingly used for fabric development.

2.2. Methods

2.2.1. Fabric Sample Development

The nine grey fabric samples were prepared in a weaving mill under controlled manufacturing conditions using construction parameters as given in **Table 1**. The construction parameters were taken to maintain fabric areal density at 145 ± 10 g/m^2 taking into account the manufacturing constraints in the mill.

Table 1. Constructional parameters of fabric samples.

Code	Fabric sample	Warp type	Weft type	Weave	Weight (g/m^2)	Thickness (mm)
C	100% Cotton	100% Cotton	100% Cotton	Plain	143	0.24
B	100% Banana	100% Banana	100% Banana	Plain	145	0.26
H	100% Hemp	100% Hemp	100% Hemp	Plain	136	0.21
L	100% Linen	100% Linen	100% Linen	Plain	141	0.26
R	100% Ramie	100% Ramie	100% Ramie	Plain	138	0.22
CB	Cotton-Banana Union Fabric	100% Cotton	100% Banana	Plain	147	0.25
CH	Cotton-Hemp Union Fabric	100% Cotton	100% Hemp	Plain	139	0.20
CL	Cotton-Linen Union Fabric	100% Cotton	100% Linen	Plain	151	0.24
CR	Cotton-Ramie Union Fabric	100% Cotton	100% Ramie	Plain	144	0.22

2.2.2. Chemical Processing of Fabrics

The chemical pretreatment of all the fabrics was carried out in industry maintaining standard parameter used in commercial production of cotton fabric. The sequence of chemical processes is as follows:

Desizing → Scouring → Bleaching → Neutralization → Stentering → Calendering → Folding

2.2.3. Evaluation of Yarn Properties

Yarn diameter was measured using projection microscope at 50 random places along the length of the yarn. The average of the reading is reported as yarn diameter. Yarn count was measured by weighing known length of yarn on an electronic balance.

2.2.4. Evaluation of Fabric Constructional Parameters

All the fabric samples were measured for physical properties such as thread density, fabric mass per unit area and thickness. Fabric thread density was calculated by counting number of yarns per cm in warp as well as weft directions using a pick glass. Mass per unit area of the fabric samples was evaluated as per IS 1964-2001 method. A circular sample of 11.3 cm diameter was cut using a paramount round cutter and then weighted on electronic balance to calculate gram per meter square (g/m^2) of gram. Fabric thickness was measured on thickness tester under 20 gf/cm^2 pressure and the average of 5 readings was taken.

2.2.5. Evaluation of Fabric Air Permeability

Air permeability of all the fabric samples was measured on Textest FX 3300 air permeability tester according to standard BS 5636. The instrument measures the volume of air passing through the fabric per unit area per unit time. The 100 Pa air pressure was maintained, and the test area was 5.08 cm^2.

2.2.6. Evaluation of Fabric Thermal Insulation Property

The thermal insulation was evaluated on Thermolabo thermal tester. The Kawabata evaluation system (KES FB7-II) was used to measure the heat flow resistance or thermal insulation value. The sample of 20 cm × 20 cm dimension with a test area of 10 cm × 10 cm was used. The testing was done using Dry contact method with air velocity of 30 cm/s.

2.2.7. Evaluation of Fabric Relative Moisture Vapor Permeability

The moisture vapor diffusion rate through the fabric is determined using LABTHINK MVTR tester that works according to the simple dish method, similar to ASTM E96-80. The test sample is placed over a water dish having 33 cm^2 area and 7.5 cm diameter. The test conditions were maintained at 80% humidity and 38˚C temp inside the instrument. Dry air is circulated at an interval of 10 min. A vibration-free turntable platform that can accommodate eight dishes rotates at uniform speed. All dishes are exposed to the same average ambient condition during the test. The rate of moisture vapor loss (MVTR) is calculated in units' $g/m^2/24$ hr. A higher MVTR value advocates a greater passage of moisture vapor through the material.

2.2.8. Evaluation of Fabric Moisture Management

The multi-dimensions liquid moisture transport properties come under moisture management properties of the fabrics and are evaluated on M290 MMT (Moisture Management Tester) SDL Atlas Inc. (Rock Hill, SC) made in accordance with AATCC Test Method 195-2009 (Liquid Moisture Management Properties of Textile Fabrics). Five specimens of size 8 × 8 cm were tested for each sample. Moisture management parameters like absorption rate, one way transport capacity (or OWTC), spreading speed and overall moisture management capacity (OMMC) were analyzed and reported in this study.

2.2.9. Evaluation of Fabric Low stress Mechanical Properties and Fabric Hand

The Kawabata Evaluation System was used to measure fabric low stress mechanical properties at standard conditions prescribed for apparel fabric. KES system consists of four different modules for different testing e.g. KES-FB1 for tensile and shear tests, KES-FB2 for bending tests, KES-FB3 for compression properties testing and KES-FB4 for testing surface properties. Total 16 parameters describing fabric mechanical properties were evaluated from the instrumental outputs. The "primary hand values" contributing to specific comfort aspects of the fabric and then "total hand value" were calculated by the software using Kawabata equation [9].

3. Results and Discussion

3.1. Yarn Properties

From the results shown in **Table 2**, it is evident that banana yarn is the thickest of all yarns while ramie and linen yarns have smaller diameter for similar linear density. This is mainly due to low density and bulky structure of light weight banana fibers compared to all other natural fibers used in this work.

Table 2. Yarn properties.

Fiber Type	Yarn Diameter (mm)	Yarn Fineness (Ne)
Banana	0.21	27
Hemp	0.20	28
Linen	0.16	28
Ramie	0.15	29
Cotton	0.17	30

3.2. Air Permeability Behavior of Fabrics

The air permeability of different unconventional fiber fabrics and their respective union fabrics with cotton were studied to ascertain their physiological comfort. The outcomes of the test are listed in **Table 3**. The results show that pure linen fabrics permit more air to pass through them, compared with pure cotton and all union fabrics. The trend is followed by hemp, ramie and then banana. The reason for higher permeability in case of pure fabrics of unconventional natural fiber fabrics can be attributed to less hairiness in these yarns due to longer fiber length than cotton. These fibers are smoother, circular and coarser than cotton fibers also favor an easy passage to air through the yarn. Also the larger diameter of banana yarn gives high cover of the fabric which prevents transmission of air through the banana fabric [10].

3.3. Thermal Insulation Property of Fabrics

For comfort body heat should be transmitted away from the body to the outer side of the clothing. This dry heat transmission occurs through conduction, convection and radiation. The mechanism of heat transmission through a fabric depends on its constituent fiber type, fiber arrangement, fabric bulk density, thickness, and the compressibility of the fabric structure [11]. Cellulosic fiber fabrics are well known for their excellent thermal conductivity. Here, an attempt has been made to compare the thermal behavior of various cellulosic fabrics including union as well as pure fabrics with 100% cotton. The results for comparative analysis of thermal insulation value (TIV) are listed in **Table 3**. From the results it can be seen that fabric samples containing cotton indicate thermal insulation values on higher side as compared to pure fabrics of unconventional fibers presumably due to the structure of cotton fiber. Cotton fiber contains hollow lumen and twists causing more air entrapping in yarn. Whereas, the fibers of hemp, linen and ramie are smooth, straight and contain almost no lumen [12].

3.4. Water Vapor Permeability of Fabrics

Moisture and water vapor transmission plays a very important role in governing the physiological comfort of apparel fabrics. This is related to the moisture vapor transmission through the fabric. This decides the extent of comfort the wearer feels in a sweating or similar condition. The results of moisture vapor transmission

Table 3. Results of fabric properties.

Sample code	Weight (g/m²)	Air Permeability (cm³/cm²/s)	MVTR (g/m²/day)	TIV (%)
C	143	8.85	5128.20	3.27
B	153	52.78	6414.25	2.03
CB	150	11.74	6223.70	4.80
H	136	64.95	6566.97	1.61
CH	137	10.11	6393.15	4.61
L	141	91.34	6295.70	1.67
CL	149	12.02	5728.81	3.97
R	135	56.48	6827.34	1.61
CR	137	10.21	6430.97	4.91

rate (MVTR) are listed in **Table 3**. The findings reveal that all the pure fabrics of unconventional fibers and their respective union fabrics have increased volumes of moisture vapor transmission as compared to the reference cotton sample. This behavior can be attributed to the hygroscopic nature of the fibers used. Also the fiber properties like diameter, rigidness and cross-section play an essential role in deciding the extent of openness of structure that will be responsible for better moisture vapor transmission. The higher values of MVTR indicates that these fabrics can transfer liquid moisture (sensible sweating) very easily and quickly from next-to-skin (inner side) to the outer surface.

3.5. Fabric Moisture Management Properties

The findings compiled in **Table 4** reveal that all the pure fabrics of unconventional fibers and their respective union fabrics have increased values of Accumulative one-way transport index (OWTC) as compared to the reference cotton sample. Generally fabrics which possess high OWTC values indicate that the liquid (sweat) can be quickly transferred from the inner surface next to the skin to the outside surface. Also it will be spread quickly over the fabric bottom surface with a large wetted area. This large area spread of liquid help its quick evaporation into the environment. This behavior can be attributed to the hygroscopic nature of the fibers used. Also the fiber properties like diameter, rigidness and cross-section play a major role in deciding. Hemp fabrics show a relatively higher OMTC values and bottom spreading speed. This indicates that hemp fabrics can manage liquid moisture very efficiently. The sweat will quickly transmit to the outer side of such clothing and so will be evaporated by larger spreading in no time. The bottom water radius is also higher than top in fabrics containing hemp. The fabrics containing linen falls in the next position after hemp in such type of overall moisture management.

3.6. Low Stress Mechanical Properties and Fabric Hand

The 16 parameters related to low stress mechanical properties of the fabrics measured on Kawabata Evaluation Systems [13] are reported in **Table 5** and **Table 6** with their standard notations.

Table 4. Results of moisture management properties.

Sample Code	Wetting Time		Absorption Rate		Max water Radius		Spreading speed		Accumulative one-way transport index	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
	(Sec)	(Sec)	(%/sec)	(%/sec)	(mm)	(mm)	(mm/sec)	(mm/sec)	(%)	
C	2.70	2.66	75.06	94.27	30	30	6.44	6.25	394.26	0.9588
B	2.68	2.64	56.53	89.36	25	25	5.79	5.64	471.52	0.9667
H	3.20	3.26	13.36	78.80	20	25	2.31	5.46	995.37	0.9412
L	2.40	2.32	40.47	91.67	30	30	5.89	6.74	561.66	0.9395
R	2.24	2.08	24.23	65.95	27.5	27.5	5.77	5.68	758.45	0.9054
CB	3.08	2.96	48.90	88.32	25	25	4.82	5.09	559.94	0.9676
CH	2.96	2.20	40.27	94.68	27.5	30	6.48	6.98	676.00	0.9852
CL	5.29	5.77	30.01	96.55	15	27.5	2.41	4.55	1085.88	0.9321
CR	3.76	3.72	49.04	73.61	20	30	2.80	4.07	889.24	0.9132

Table 5. KES test results of tensile, bending and shear properties.

Sample	LT	WT	RT	B	2HB	G	2HG	$2HG_5$
		gf·cm/cm^2	%	gf·cm^2/cm	gf·cm/cm	gf/cm/degree	gf/cm	gf/cm
C	0.9965	0.1200	75.365	0.1626	0.5161	4.195	6.150	14.835
B	1.0290	0.5250	44.170	0.0949	0.0921	1.515	2.980	6.810
CB	1.0705	0.1100	85.090	0.1794	0.1101	3.145	5.110	13.305
H	0.9150	0.1250	107.475	0.3285	0.1858	1.445	0.655	9.470
CH	1.0410	0.2350	52.965	0.0789	0.0810	3.315	6.570	11.485
L	0.8165	0.1800	74.480	0.3738	0.1427	0.610	0.610	2.630
CL	1.0095	0.1000	85.110	0.1960	0.1399	4.775	9.015	16.435
R	1.0825	0.0950	107.120	0.1858	0.2299	2.620	3.750	14.780
CR	1.0095	0.1000	85.110	0.1960	0.1399	4.775	9.015	16.435

It may be observed that the bending and shear hysteresis of cotton and cotton rich union fabrics are significantly higher than other fabrics. The tensile resiliency values of hemp and ramie fabrics are also significantly higher than other fabrics. Tensile linearity of all cellulosic fibers is almost similar; the same is also observed in case of low stress compressibility. This actually falls in the logic that at low stress levels both tensile and compression results behave alike. From surface properties point of view, banana and linen fabrics exhibit significantly higher geometrical roughness (SMD) due to higher hairiness and surface roughness of these two yarns.

The THV of the fabric samples is estimated with the help of various primary hand values using the Kawabata-Niwa equations by KES system and the results are displayed in **Figure 1**. It may be observed that the linen fabric gives the

Table 6. KES test results of surface and compression properties.

Sample	LC	WC	RC	MIU	MMD	SMD	T	W
		gf·cm/cm^2	%			micron	mm	mg/cm^2
C	1.078	0.037	32.080	0.177	0.0068	2.40	0.184	13.900
B	1.138	0.037	52.700	0.160	0.0081	6.86	0.279	15.300
CB	0.990	0.037	31.910	0.163	0.0155	4.59	0.208	15.100
H	0.999	0.036	59.770	0.160	0.0149	3.44	0.219	13.600
CH	1.138	0.052	36.280	0.157	0.0082	4.36	0.249	14.700
L	0.994	0.036	36.830	0.145	0.0120	8.92	0.238	14.100
CL	1.081	0.029	33.210	0.153	0.0084	3.55	0.347	14.400
R	0.891	0.030	28.940	0.160	0.0152	4.00	0.191	13.800
CR	1.081	0.029	33.210	0.153	0.0084	3.55	0.347	14.400

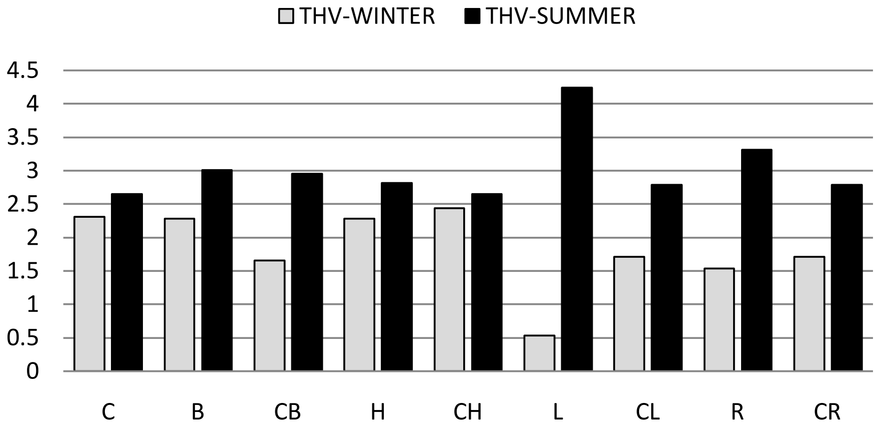

Figure 1. Total hand values (THV) of different fabric samples.

highest THV for summer and lowest THV for winter applications. This behavior is reflected in its constituent low stress mechanical properties where it found that both bending and shear hysteresis are significantly lower than other fabrics. The results also depict that almost all the fabric samples exhibit higher THV for summer applications as compared to winter due to obvious reason of their suitability as a cellulosic fiber predominantly meant for tropical and sub-tropical climate. The values of summer THV of all pure unconventional fiber based fabrics and their respective union fabrics are either comparable or better than 100% cotton. This trend strongly advocates the possibility of unconventional fiber fabrics to be used as an apparel fabric for summers.

4. Conclusions

- The unconventional fiber fabrics allow more air to pass through as compared to 100% cotton fabric of similar areal density.
- The unconventional fiber fabrics and their union fabrics also give higher moisture vapor and heat transmission.

- The hemp fabrics pure as well as union shows better moisture management property compared to other fabrics.
- From thermal comfort point of view, pure unconventional fiber fabrics and their union fabrics with cotton give better performance value than 100% cotton fabric. Therefore, these fabrics can be considered more suitable for summer clothing applications.

THV of all pure unconventional fiber based fabrics and their respective union fabrics are either comparable or better than 100% cotton.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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