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Thermal comfort properties of modified yarn path in cotton fabrics

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Effect of the modified yarn path in ring spinning on the thermal comfort behavior of the cotton woven fabric has been investigated. The modified ring yarn is produced by changing the path of the yarn in the ring spinning process. The finding shows that it has a clear impact on the fabric geometrical properties and thermal comfort properties when path of the yarn is changed in ring spinning as left and right diagonal path. It is also observed that the air permeability of the fabric decreases with the right diagonal yarn path and thermal resistance of the fabric increases with the right diagonal yarn path. The fabric woven from the left diagonal yarn path shows higher water vapour permeability.

Keywords: Air permeability, Cotton, Thermal comfort, Thermal resistance, Water vapor permeability

1 Introduction

The understanding of the concept of moisture and heat transport through the fabric is a major concern for scientific researchers, designers, developers, and manufacturing industries. Plenty of research papers deal with this area of thermal comfort. The garment should act as a barrier tovapour and heat transport between the skin and the environment[1].Transportation of water into the fabric is controlled by different mechanisms like evaporation, sorption, desorption, diffusion and condensation. Conduction, convection, and radiation can be considered for heat transfer exchange through textile materials[2].

Heat and moisture transfers affect the comfort of the garment. The comfort can be stated as a state of psychological, physiological and physical interaction between the environment and human. It depends on the activity of the wearer, clothing type, and the environment of climate like temperature, humidity and velocity of the wind. There are some clothing properties which influence the thermal comfort properties such as the fabric design with its weave structure, the composition of fibres, the porosity of the fabric.

Thermal comfort is defined as the psychological expression of satisfaction with the surroundings of the thermal environment. Normal body temperature is about 37ºC. This temperature is maintained by the balancing amounts of heat developed in the body with the amount transferred to the environment. Heat losses need to be balanced in order to maintain the stable body temperature. The heat balance can be written as

$$M\text{-}W = C + C_k + R + E_{res} + E_{sk}$$

where M is the metabolic rate; W, the external work; C, the heat loss by the convection process; C_k, the heat loss by the conduction process; R, the heat loss by radiation to the environment; $E_{res,}$ the heat loss due to respiration activity and E_{sk}, the heat loss by evaporation from the skin of a human.

The air permeability is a very essential property in textile materials. It mainly depends on the weight of the fabric and the thickness. The fabric porosity will be affected by the type of weave structure. Therefore, the amount of entrapped air will vary according to the weave structure of the fabric. Woven fabrics which are tighter in construction with a high yarn count are warmer because their air permeability is low and thus avoid convective heat loss. Flexible fabrics have more air permeability and permit more warm air to pass through, away from the body. Heat transfer can be defined as the rate of energy that passes from a medium with higher temperature to a medium with low temperature. Heat transfer will remain in process till the two media attain the same temperature and maintain the equilibrium. This energy transformation rate depends on the difference of the temperature and the degree of heat resistance between the two media.

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Heat can be transferred in fabrics in many possible ways, like conduction through fibres and air, fibre to fibre radiation and convection of the air within the fabric structure.

The yarn structure also affects the thermal insulation behaviour of fabrics. A spun yarn has a capacity to hold more trapped air as air packet than a flat filament yarn, so that the fabric will have more thermal insulation. The woven fabric comfort properties produced from the ring-rotor and friction spun yarns has been analysed and the thermal conductivity of fabrics is reducing when the bulkiness of the fabric is increases[3,4]. This is due to very bulky structure of the weft which acts as an insulating medium. It holds the air in the bulky fibrous assembly spaces and does not allow the heat of inner layer to transmit to the outer layer.

Holcombe and Hoschke[5] have analyzed the dry heat transfer properties of innerwear fabrics. They have studied the relationship between thermal resistance and thickness of textile fabrics corresponding to the structures. And they found the linear relationship between thermal resistance and thickness of the fabric. Marolleau[6] reported the influences of weight of thickness & porosity of the fabric, air permeability and moisture regain on the thermal comfort and moisture management behaviour of the fabric. The influences of pick density, a cover factor of the fabric and bulk density on the value of q-max. In this research, pick density found to be a linear relationship with q-max, whereas bulk density and cover factor are having a negative correlation with q-max value. The fabric with lower pick density gives higher heat transfer and air permeability[7].

Water vapour permeability is defined as the ability to transport vapour from the body. Water vapour permeability of the fabric allows the wearer to obtain thermal equilibrium and provide cool beyond evaporation and sweat production. The water vapour passes through the fabric to the outer layer of the fabric then transported to the air[8]. Human perspiration can occur in two different ways, viz vapour form and liquid form. Vapour can transport through the spaces between yarns in the fabrics and the spaces between the fibres in the yarn. The fibres, yarn count, texture, thickness and density of the fabric influence the fabric permeability. The texture, weft tightness, overall tightness, density and thickness of the fabric have significant influence on the fabric permeability. The breathable performance increases with the lighter fabric as it has more pores. So, it is very significant to select the optimum structure parameters in fabrics for effective clothing comfort.

Das[9] observed that the substitution of the polyester in place of cotton and viscose in the fabrics blend decreases the rate of water transport of the fabrics for the long duration. It is also noted that the fabrics made up of polyester-cotton yarns are having higher water vapour transport than the fabrics made up of polyester-viscose for the long duration. But, the fabrics made up of polyester-viscose exhibits greater water vapour permeability than fabrics made up of polyester-cotton. Midha and Suresh Kumar[10] have studied the comfort properties of denim fabrics with different count of yarn, polyester and core-spun lycra fabrics. Influence of enzyme washing and repeated laundering on moisture management, air permeability and drying rate has also been analyzed. It was found that the unwashed denim fabrics made up of cotton weft yarn have higher air and water vapour permeabilities than polyester and lycra cotton weft yarns.

The yarn spinning from the modified yarn path will improve the physical properties of the yarn[11-14]. Though there is a conflict between the above authors, the resultant yarn shows enhanced tensile strength, hairiness and imperfections due to an improvedyarn structure. There is a significant difference between the various yarn structure and the physical & comfort properties of the fabric woven from those yarns[15]. It is identified that the type of fibre, properties of yarn, structure of fabric and surface treatments of fabric are the prime parameters influencing the thermo-physiological comfort. Therefore, the fabric produced from these yarns also may provide better thermal comfort properties. Hence, in this study the effect of modified yarn path in ring spinning on the cotton woven fabric properties has been investigated.

2 Materials and Methods

2.1 Cotton Fibre

Commercially available MCU 5 cotton fibres were purchased from the industry resources. The technical parameters of the cotton fibres are given in Table 1.

2.2 Production of Yarn

Single yarns of 60 Ne (9.54 tex) were spun by the ring spinning. Yarns were produced from straight, left diagonal and right diagonal paths. The conventional ring spinning yarn path was assumed as the straight path. Left diagonal path of the yarn was obtained by altering the path towards left side of the spindle to the adjacent spindle. Right diagonal path of the yarn was

Table — 1 Details of fibre properties of cotton fibre

Characteristics	Cotton	CV%
Fibre length, mm	32	2.28
Fibre length uniformity ratio, %	74.8	1.59
Tenacity, g/tex	22	1.12
Specific density, g/cm^3	1.51	0.48
Elongation, %	6.6	0.35
Moisture regain, %	7.4	1.37
Trash content, %	0.21	0.41
Maturity ratio, %	82.03	0.58

Table 2 — Fabric plain weave construction details

Sample ID	Warp yarn	Weft yarn
S-L	Straight Path	Straight path
S-R	Straight path	Right diagonal path
S-L	Straight path	Left diagonal path
R-R	Right diagonal path	Right diagonal path
R-L	Right diagonal path	Left diagonal path
R-S	Right diagonal path	Straight path
L-L	Left diagonal path	Left diagonal path
L-S	Left diagonal path	Straight path
L-R	Left diagonal path	Right diagonal path

obtained by changing the path towards right side of the spindle to the adjacent spindle[16].

2.3 Fabric Production

Plain weave fabrics were woven with various combinations of warp and weft from the straight, left diagonal path and right diagonal path of yarns. Table 2 indicates the detailed combination of fabric sample.

2.4 Fabric Processing

The produced fabric samples, scoured with 1.5% NaOH, 1% Na_2CO_3, and 1g/L wetting agent, were kept at 90 ºC for 60 min, by maintaining *p*H at 10.5-11. Also, fabric samples were scoured and bleached with hydrogen peroxide. The M: L ratio of 1:10 was maintained throughout the process. The concentrations of hydrogen peroxide (1.5%), wetting agent (0.5 %), caustic soda (1.2%), stabilizer (sodium silicate) (0.2%) and lubricant oil (0.3%) were used for bleaching. The treatment was carried out at 90º C for 45 minutes.

2.5 Testing of Yarn

Yarn breaking strength and extension were estimated on a Zwick universal testing instrument. The gauge length was 500 mm with the extension rate of 150 mm/min. An unevenness tester was used to determine the yarn unevenness using a testing speed of 100 m/min. Yarn hairiness was measured using Zweigle hairiness tester speed of 50 m/min and at a pre-tension of 5 g. The S3 hairiness measurement was done using this instrument for the length of 10000 m yarn. All the tests were performed under the standard atmospheric temperature of 20º C ± 2º C and RH of 65 ± 2 %.

2.6 Fabric Parameters

The fabric thickness was evaluated by SDL fabric digital thickness tester under ISO 5084 standard. The fabric ends per inch and picks per inch were determined by ASTM D3775. The areal density (GSM) of fabric sample was determined by ASTM D3776 standard.

2.7 Air Permeability

Fabric air permeability was determined based on TS 391 EN ISO 9237 using model FX3300 tester. Ten samples were evaluated for air permeability property of the cotton fabric. All the tests were performed under the standard atmospheric temperature of 20º C ± 2º C and RH of 65 ± 2 %.

2.8 Water Vapour Permeability

Permetest instrument has been used to determine the water vapor permeability of the cotton fabric. The instrument has been working on simulated skin model principle as per ISO 11092. The instrument works based on the principle of heat flux sensing. The temperature of the measuring head was maintained at 24°C for isothermal conditions. When water flows into the measuring head, there will be some loss of heat. This instrument determines the heat loss from the measuring head because of the water evaporation in bare state and in covered state by the fabric. A parallel air flow with a velocity of 1.5 - 3.0 m/s is observed in a slightly curved porous measuring wet surface. The fabric specimen is placed at a distance of 1 - 1.5 mm from the wet area of diameter 80 mm and maintained by high thermal conductivity. The flow of heat is developed by evaporation of water from the surface of the fabric and is determined by a heat flow sensor which is mounted into the porous layer. This instrument can determine the water vapor permeability of the fabric in the idle state isothermal condition. The measuring head temperature is kept at 24°C for isothermal conditions. The heat provided to balance the temperature of the measuring head to a 24°C, from where the supplied water gets evaporated, is determined. The heat provided to maintain a constant temperature with and without the fabric specimen placed on the hot plate is calculated. Further the water vapour permeability is determined by the ratio of latter to that of former. An average of 10 tests for each sample was taken into account.

2.9 Thermal Resistance

Thermal resistance was measured by the Alambeta tester (Sensora instruments). The instrument works on the principle of heat flux sensing. This instrument is used to measure various thermal properties like thermal absorptive, thermal conductivity and thermal resistance. It consists of two measuring plates namely hot top measuring plate at 32°C and ambient bottom measuring plate at 22°C. When the top plate touches the fabric, the amount of heat transferred from a hot surface to cold surface is detected for the measured thermal resistance.

2.10 Data Analysis

The quantitative data of objective measurements were analyzed by the SAS System (version 8 for Windows). Two-way ANOVA was used to find the significance of differences between modified yarn path in ring spinning and yarn properties, thermal comfort properties of woven fabric. Any differences were considered to be significant if P value is less than 0.05.

3 Results and Discussion

3.1 Effect of Diagonal Path on Yarn Properties

The improvement in yarn properties, achieved by left diagonal path, is due to the modification in spinning triangle and tension of the fibre in the spinning triangle. The hairiness of the Z twist yarn is produced by the fibres that are located on the left side of the spinning triangle[12]. Additionally, for 'Z' twist yarn, the fibres located on the left side of the spinning triangle are found uncontrolled in nature instead of the right side of the spinning triangle. Hence, it creates the hairiness of the yarn when it follows the right diagonal path of yarn. Also, the yarn spun by the left diagonal yarn path shows better evenness and tensile properties, followed by the straight and right diagonal path of yarns as shown in Table 3.

Table 3 — Diagonal path yarn properties

Parameters	Straight	Left diagonal	Right diagonal
U%	11.32	11.19	11.99
Thin (-50%)	20.50	10.10	20.70
Thick (+50%)	91.00	43.60	92.10
Neps (+ 200%)	210.00	121.30	230.90
Hairiness (S3)	481.0	291.0	497.6
Breaking force, cN	145.20	181.8	143.20
Elongation, %	3.98	4.21	3.91
RKM	15.12	18.24	14.92
Packing density, %	0.79	0.81	0.78

3.2 Geometrical Properties

The geometrical properties of the all the fabric samples woven by the yarn produced from modified yarn path are shown in Table 4. It has been clearly identified that the warp density (EPI) and weft density (PPI) remain almost same for all the fabric samples, irrespective of the types of yarn. This gives a neutral platform to all the fabric samples to determine its physical properties with respect to the types of the yarn. This is clearly observed from table 4 that the areal density (GSM) and thickness of the fabric increase with the combination of right diagonal path yarns followed by the straight and left diagonal path yarns. This is because of the fact that the yarn made with right diagonal path is bulky in structure as compared to straight and left diagonal path yarns. Also the fibres are not well packed in the right diagonal path, thus giving bulkier structure. However, the fibres in the left diagonal path are under control and hence, the yarns show well packed structure in the left diagonal path. So, the areal density and thickness of the fabric are reduced with the content of left diagonal path yarn in the fabric. The porosity of the fabric increases with the increase in the content of left diagonal path yarn in the fabric. This is mainly due to the high inter-yarn spaces between the warp and the weft yarns in the fabric, as the left diagonal path yarns are well packed in the structure. In contrast, the porosity of the fabric is decreased with the increase in the content of right diagonal path yarn in the fabric. This is mainly due to the low inter-yarn spaces between the warp and the weft yarns in the fabric, as the right diagonal path yarns are bulkier in structure as compared to left diagonal path yarns.

Table 4 — Geometrical parameters of fabric

Parameters	Fabric sample								
	S-S	S-R	S-L	R-R	R-L	R-S	L-L	L-S	L-R
EPI	70	71	71	70	71	70	71	70	71
PPI	91	90	91	90	91	90	90	91	91
GSM, g/ m^2	80	83	78	86	82	84	75	77	81
Thickness, cm	0.0255	0.0256	0.0252	0.026	0.0255	0.0258	0.0251	0.0254	0.0256
Porosity, %	79.76	79.08	80.03	78.66	79.25	78.99	80.72	80.44	79.59

3.3 Variance Statistics for Effect of Modified Yarn Path on Geometrical Parameters of Fabric

ANOVA testing was conducted to analyse the statistical importance of modified yarn paths on geometrical properties of the fabric produced from the modified yarn path. Analysis of variance (ANOVA) was performed using the SAS System (version 8 for Windows) (alpha level of 0.05) to evaluate any changes in geometrical properties of the fabric due to the modified yarn path in ring spinning. The variables are considered as significant if the probability (p) value is less than 0.05. The results of Two-way ANOVA are given in Table 5, for the geometrical properties of the fabric and the modified yarn path.

Table 5 shows that the *p* value of geometrical properties of the fabricis< 0.05, except for the warp density and weft density of the fabric. This clearly shows that there is a significant difference in the modified yarn path effects on the geometrical properties of the fabric at 95% confidence level, except for the warp and weft density of the fabric. So it can be concluded that the path of yarn significantly (95% confidential level) affects the GSM, thickness and porosity of the fabrics but does not affect (non-significant at 95% confidence level) the warp density (EPI) and weft density (PPI) of the fabric.

It is clear that all established variables are significant except for the warp density (EPI) and weft density (EPI) of the fabric. These data clearly show the reliability of our experimental design.

3.4 Air Permeability

The effect of modified yarn path on air permeability of the fabrics is shown in Fig. 1. It is clearly evident from the figure that the fabric made with the left diagonal yarn path shows the higher air permeability as compared to the fabric made with the right diagonal yarn path. This is due to higher thickness of the fabric produced from the right diagonal yarn path, restrict by the passage of air. Also, the yarn hairiness also plays a major role in air permeability. As the fabric made with right diagonal yarn path has more hairiness, it hinders the passage of air through the fabric.

The areal density and thickness of fabrics increase with the fabric woven with a left diagonal yarn path. The results show that the fabric thickness has a considerable impact on the air permeability of the cotton fabrics. Thus, the fabric woven with right diagonal yarn path has a lower air permeability. The fabric woven with left diagonal yarn path has

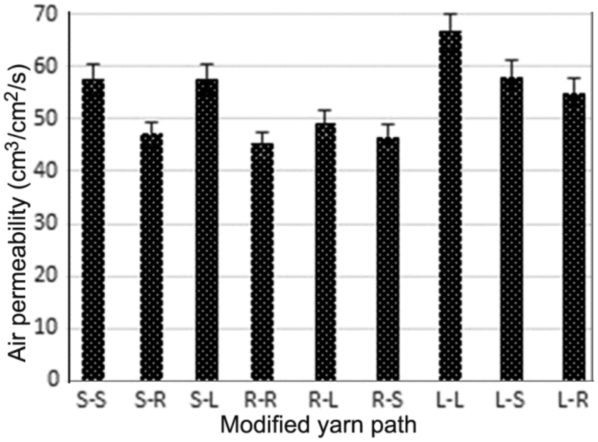

Fig. 1 — Effect of modified yarn path on air permeability of the fabric

Table 5 — Two-way ANOVA effects on geometrical properties of the fabric and modified yarn path

Response	Source of variation	SS	df	MS	F	*p*-Value	F-Crit
Warp density	Yarn Path	22.22	8	2.77	0.71	0.67	2.05
	Error	314	81	3.87			
	Total	336.22	89				
Weft density	Yarn Path	22.22	8	2.77	0.66	0.72	2.05
	Error	338	81	4.17			
	Total	360.22	89				
GSM, g/ m^2	Yarn Path	1000	8	125	31.25	9.82E-22	2.05
	Error	324	81	4			
	Total	1324	89				
Thickness, cm	Yarn Path	6.69E-06	8	8.36E-07	11.31	1.28E-10	2.05
	Error	5.98E-06	81	7.39E-08			
	Total	1.27E-05	89				
Porosity, %	Yarn Path	37.28889	8	4.66	5.54	1.35E-05	2.05
	Error	68.1	81	0.84			
	Total	105.38	89				

higher porosity due to lesser yarn hairiness and being thinner in nature. Thus, it provides more space for the air to pass through the fabric. Hence, the fabric made with left diagonal yarn path gives higher air permeability as compared to the fabric woven with right diagonal yarn path. It is also observed that the fabric woven with straight path exhibits higher air permeability with the combination left diagonal yarn path.

3.5 Water Vapour Permeability

The influence of modified yarn path on the water vapour permeability of the fabric is shown in Fig. 2. It is clearly evident from the figure that the fabric made with the left diagonal yarn path exhibits higher water vapor permeability than the fabric woven with right diagonal yarn path. This is due to the lesser yarn hairiness and lesser fabric thickness in the left diagonal yarn path. The fabric made up of left diagonal yarn path has higher inter-yarn space and more porosity due to the thinner nature of yarn and less hairiness. This gives more air spaces in the fabric made with left diagonal yarn path to transport water vapour to the environment. Thus,the fabric woven with left diagonal yarn path gives the higher water vapour permeability than the fabric made with right diagonal yarn path. Further, the fabric woven with straight yarn path exhibits higher water vapour permeability when combining with left diagonal yarn path.

The effect of modified yarn path in ring spinning on the thermal resistance of the fabric is shown in Fig. 3. The results show that the fabric woven with right diagonal yarn path exhibits higher thermal resistance than the fabric woven with the left diagonal yarn path. This is due to the higher yarn hairiness, bulky and lesser yarn packing coefficient of the right diagonal yarn path. The bulky nature of the right diagonal yarn path creates more air packs and it will act as a good thermal insulation of the fabric. Also the fabric made up of right diagonal yarn path has higher thickness and less porosity, that will increase the thermal resistance of the fabric. Thus, the fabric made with the right diagonal yarn path has higher thermal resistance than the fabric made with the left diagonal yarn path. Further, the fabric made with straight path also gives higher thermal resistance when combined with the right diagonal yarn path.

3.6 Variance Statistics for Comfort Properties of the Fabric

ANOVA testing is conducted to analyse the statistical importance of modified yarn path on the thermal comfort properties of the fabric produced from the modified yarn path. Analysis of variance (ANOVA) is performed using the SAS System (version 8 for Windows) (alpha level of 0.05) to evaluate any changes in thermal comfort properties of the fabric due to modified yarn path in ring spinning. The variables are considered as significant if the probability (p) value is less than 0.05. The results of One-way ANOVA are given in Table 6 for the moisture management properties of the fabric and the path of the yarn in ring spinning.

Table 6 shows that the *p*-value for moisture management properties of the fabric is < 0.05. This clearly indicates that there is significant difference in the modified yarn path effects on the thermal comfort properties of the fabric at 95% confidence level. So, it can be concluded that the path of yarn significantly (95% confidential level) affects the air permeability, water vapour permeability and thermal resistance of the fabrics.

It is clear that all established variables are significant. These data clearly show the reliability of our experimental design.

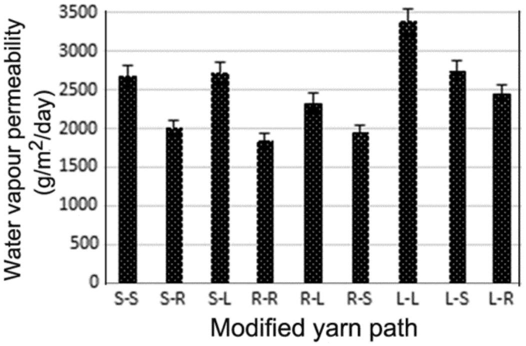

Fig. 2 — Effect of modified yarn path on water vapour permeability of the fabric3.6 Thermal Resistance

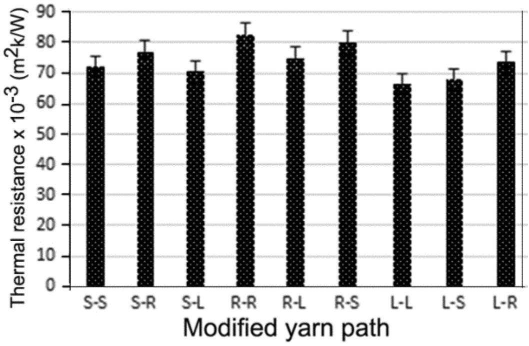

Fig. 3 — Effect of modified yarn path on thermal resistance of the fabric

Table 6 — One-way ANOVA on thermal comfort properties of the fabric and modified yarn path

Response	Source of variation	SS	df	MS	F	*p*-value	F-Crit
Air permeability	Yarn Path	4303.04	8	537.88	1446.25	5.06E-84	2.05
	Error	30.125	81	0.37			
	Total	4333.16	89				
Water vapour permeability	Yarn Path	19211420	8	2401428	406.08	5.15E-62	2.05
	Error	479000	81	5913.58			
	Total	19690420	89				
Thermal resistance	Yarn Path	2255.75	8	281.96	823.78	3.19E-74	2.05
	Error	27.72	81	0.34			
	Total	2283.48	89				

4 Conclusion

The fabric produced from the left diagonal yarn path shows the higher air permeability but the fabric produced from the right diagonal path shows the lower air permeability. The fabric woven from the left diagonal yarn path shows higher water vapour permeability but the fabric woven from the right diagonal path shows lower the water vapour permeability. In thermal resistance property, fabric woven from the left diagonal yarn path has a greater advantage than the right diagonal yarn path. The modified yarn in ring spinning has a considerable effect on the thermal comfort properties of the fabric in terms of air permeability, water vapour permeability and thermal resistance. Hence, it is observed that the fabric woven with left diagonal path yarn has better performance in air permeability and water vapour permeability of the fabrics. Also the fabric woven with right diagonal yarn path has better performance in the thermal resistance of the fabric.

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