Effect of Fiber Content on Comfort Properties of Cotton/Spandex, Rayon/Spandex, and Polyester/Spandex Single Jersey Knitted Fabrics

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Abstract

Comfort influences consumers' buying decision regarding textile and apparel product. In this study, comfort related properties of three different single jersey knit fabrics were tested. All fabrics had 5% spandex as a common factor. Spandex was blended with cotton, rayon and polyester. Three comfort related attributes studied for the investigation were stretch and recovery, air permeability and horizontal wicking. Presence of spandex in knitted structure expected to enhance stretch and recovery hence flexibility and comfort in garments. Therefore, the purpose of this study was to determine the influence of cotton, rayon and polyester on selected comfort properties of textile materials. ANOVA and t-test were used to test the hypotheses. Findings revealed significant differences among three types of knits. Results can be used by textile and apparel professionals, retailer, and consumers alike. Research can be extended to include additional structural and performance variables.

Keywords — *Knit, Single Jersey, Cotton, Rayon, Polyester, Spandex, Comfort, Air Permeability, Stretch and Recovery, Count, Wicking, Thickness, Fabric Weight.*

I. INTRODUCTION

Cotton is known for its exceptional comfort properties and contributes 40% of total fiber consumption worldwide. However, easy care is not a function of 100% cotton. Blending cotton with different fibers such as polyester, rayon, and acrylic can enhance its durability and ease of care. Even though moisture absorbency of cotton makes it good conductor of heat and electricity, it makes the sweat to leave the fabric quickly. Combining it with fiber contents that have better wicking helps with moisture management in cotton. Different blends like cotton–polyester, cotton–acrylic, and cotton–nylon knitted fabrics in terms of their moisture characteristics and noticed a remarkable increment in water vapor transmission of cotton–synthetic blend ([1]- [3]). Stretch in cotton can be incorporated by knit construction and blending with spandex. Polyester and rayon (viscose) are also commonly used fabrics in apparel that can have enhanced stretch through knit structure and addition of spandex.

Comfort can be function of several structural and performance attributes [2]. Structural attributes could include fiber content and fabric construction. Spandex is an elastomeric fiber and adds comfort through its stretching ability ([4], [5]). Knits offer higher stretch than woven materials. Knit with spandex can provide added comfort for the wearer. Performance attributes such as air permeability, stretch and recovery, and wicking ability in textiles add comfort by letting the air to pass through easily, stretching the garment with reasonable recovery during body movements, and spreading the water in the surrounding areas and reduce clamminess. Therefore, the purpose of the reported study was to determine the impact of fiber content and fabric thickness on air permeability, stretch and recovery, and wicking.

II. LITERATURE REVIEW

Previous research conducted in the area of investigation includes seven categories. The seven categories are fiber content, fabric construction, fabric thickness, comfort, air permeability, stretch and recovery, and wicking.

Rayon is manufactured textile that is obtained from the regenerated cellulose derived from different cellulosic sources as plants and linters. Researchers stated that Rayon was the first manmade fiber with many properties similar to cotton and silk [4]. However, it swells and loses strength when wet. Although rayon has several advantages such as luster and low cost, it can baffle the consumer due to the diverse terms (i.e. wood silk, artificial silk) used to define the product. Rayon is also known as viscose fiber.

Spandex is a synthetic fiber also known as Lycra or Elastane. It is famous for its exclusive elasticity and higher strength than the natural rubber. Several scholars found that inclusion of spandex to the single jersey knitted fabric resulted in increased stitch density, fabric thickness, and fabric weight ([3], [6], [7]). A limited research focused on comfort properties of knitted materials blended with newly manufactured fibers like spandex. Most of the prior studies examined changes in dimensional and physical characteristics of the knitted fabrics only. With presence of spandex, fabric stretched in the knitting zone during manufacturing. Knitted fabric with spandex yarns usually results in a tight structure because after taking-off from knitting machine fabric become relaxed and yarn squeezed, which changes loop shape, stitch length and loop geometry. Researchers reported that knitted fabric with spandex yarn stretches more than one without it [8]. This added stretch makes the fabric to be more resilient and resistant to snagging, fiber fatigue and pin holing. Consequently, fabric becomes more useful for multiple purposes. A study found that mixing Spandex with natural or regenerated fibers in fabrics used for children's clothing helps with boosting the body comfort from enhanced movement adaptation [9].

The utilization of knitted fabric in the clothing industry is increasing at a constant rate due to several advantages of the knitted structure [10]. Researchers stated that the American consumers' desire for knit fabrics has grown steadily since the 1970 [11]. Knitted fabrics are famous for many significant attributes such as clothing comfort, soft hand, conformity of fit with body structure, flexibility, lightweight, easy production techniques, easy care, low cost, and wide product range ([6], [7], [12]- [14]).

The term "comfort" is defined as "the absence of unpleasantness or discomfort" or "a neutral state compared to the more active state" ([15], [16]). Researchers reported comfort as the most important attribute that influences consumers' purchase decision regarding textile products [17]. Comfort is of three kinds: sensorial (tactile) comfort, psychological comfort and thermo-physiological comfort ([16], [18]-[20]). Another study reported that thermo-physiological comfort sensations are divided into major three groups: thermal and moisture sensations, tactile sensations and pressure sensations [8]. Clothing attributes like air permeability, heat transfer, moisture management ([16], [21]) and wetness [22] determined thermo-physiological comfort.

Air permeability is one of the most crucial, directly responsible attributes of textile materials that regulates clothing comfort. Researchers defined air permeability as the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material [23]. It is generally expressed in SI units as cm3 /s/cm2 and in inch-pound units as ft3 /min/ft2. In summer, a material with higher air permeability is preferred because the heat and sweat transfer from human body to the atmosphere depends on it ([23], [24]). Air permeable fabric is hygienic since it let the dampness pass out of human body let fresh air in ([23], [25]). Researchers found that the extract of extra perspiration from the body increases the level of comfort. Therefore, higher air permeability means better comfort in warm and humid weather [16].

Thickness is the distance between two surfaces of the fabric and it is generally express in millimeters (mm) or inches. Regardless fiber type researchers found negative relationship between thickness and air permeability ([23], [26]). Other researchers found inverse relation of air permeability to water vapor permeability and porosity of the knitted fabrics ([23], [27]).

Fabric weight is the mass per unit area (meter^2) of fabric in metric system and it is expressed in gram/m^2. Fabric weight (GSM= gram per square meter) precisely depends on the knitted structure and stitch length [10]. The researchers also asserted that finished products always have higher values than the unfinished textiles. They also observed that single jersey knitted structure ranked lowest in finished GSM and width among all knitted structures they considered whereas Double Lacoste ranked top for same attributes.

Wicking is the natural transportation of liquid by capillary force through the pores of fabric surface and results of continuous wetting of textile surface through the capillary system [28]. Researchers stated that high wicking rate of the textile materials can move sweat very quickly from human skin and transmit it to the outer surface of the fabric that results in higher level of comfort to the wearer due to dissipating cooling [29]. Study argued that wicking only occurs when the fabric is wet and the process continues as long as capillary action between wet yams or fibers exists [30]. Wetting and wicking behaviors of textile influence the moisture and thermal comfort.

Researcher defined stretch and recovery as "The ability of a stretch fabric to recover after stretching depends on the tension in the component yarns and on the friction and interlocking forces between yarns and fibres or filaments within the fabric" [31] .The stretch and recovery properties of the knitted fabric are responsible for the pressure generated by garments. Knitted structures have some inclusive [32]. Stretch and recovery properties of knitted fabric has an impact in body comfort and fit. Stretchability and elasticity of knitted fabric allow users to move freely with minimal resistance [33].

As evidenced by the preceding information, even though previous researchers examined some aspects of the proposed relationships in the reported study, they did not investigate them within the context of fiber content and thickness exclusively. Spandex is used extensively in today's apparel with several different fiber contents. Therefore, it was deemed important to examine spandex blends. The reviewed literature did not provide information on proposed relationships for fiber content. Therefore, four null hypotheses were developed as follows.

H1: Fiber content will not impact stretch.
H2: Fiber content will not impact recovery.
H3: Fiber content will not impact air permeability.
H4: Fiber content will not impact the wicking rate.

Studies reported that fabric thickness has an impact on air permeability ([23], [26]), wicking [34], stretch and recovery [35]. Therefore, four alternate hypotheses were developed.

H5: Fabric thickness will impact air permeability.
H6: Fabric thickness will impact stretch.
H7: Fabric thickness will impact recovery.
H8: Fabric thickness will impact wicking.

EXPERIMENTAL

A. Materials

The single jersey materials used in the study were purchased from local market. The fiber compositions of three blended specimens were 95/5 cotton/spandex, 95/5 rayon/spandex and 95/5. The average fabric counts of cotton/spandex, rayon/spandex, and polyester/spandex were 39 x 73 = 112, 51x 52 = 103, and 36 x 59 = 95 respectively. The specimens were conditioned in the environmental chamber as suggested by ASTM D1776. The standard atmospheric conditions were 21+/-1ºC and 65%+/-2% of relative humidity. Specimens were preconditioned for 12 hours before the measurements were taken. In Table I, II and III, the measurements of each fabric specimen are given. The specimens were named C for cotton/spandex, R for rayon/spandex, and P for polyester/spandex.

B. Methods

The reported study followed testing standards by American Society for Testing and Materials (ASTM) and The American Association of Textile Chemists and Colorists (AATCC).

1) Fabric Count:

Fabric count was tested as directed in ASTM specification D3887-2004 that defines it as number of wales and courses per inch on the face of the fabric. Counting started with wales and, then the same operation was repeated for the course. This whole procedure repeated 5 times from 5 random places for each specimen and confirmed that places are not closer than 5 cm or less.

2) Stretch and Recovery:

Stretch and recovery (between wales) were tested by the industrial method. Five 10” x 10” specimens were cut and marked inner 5” of each specimen to hold from the middle thus specimens can be stretched as hard as possible. The industrial scale was used, stretch %, original stretched length, and recovery after 5 minutes were recorded. Finally, % recovery was calculated by using formulas.

3) Fabric Thickness:

Thickness was measured in accordance with ASTM D1777-2015 for preconditioned specimens. Digital Thickness Gauge was used for measure 5 thickness of each specimen from 5 different places.

4) Air Permeability:

According to ASTM-D737 2016 standard, air permeability was determined by using Textest Air Permeability Digital Tester. Five measures were taken from five different places of every specimen. Horizontal

5) Horizontal Wicking:

Wicking was determined according to AATCC 198-2013 standard. Five 8” x 8” specimens were cut, dispense 10 ml distilled water on every specimen and weight for 5 minutes. The measured spread of water lengthwise and widthwise in millimeters, calculated wicking rates (mm^2/sec) by using the standard formula.

Collected data were analyzed by statistical means, t-test analysis, and Analysis of Variance (ANOVA). All the calculations were carried out using Statistical Package for the Social Sciences (SPSS) software.

III. RESULT AND DISCUSSION

The structural properties of investigated fabrics are described in Table I. Properties are included wales per inch (WPI), course per inch (CPI), fabric count and thickens. The mean values of different properties for three different specimens are included as well. From the Table I, it can be observed that Cotton had the highest fabric count and thickness. On the contrary, polyester had the lowest fabric count and thickness. Observations determine that, for all three specimens, increase in thickness corresponded with increase in fabric count.

TABLE I
Structural Properties of the Fabrics

Specimens	Wales Per Inch (WPI)	Course Per Inch (CPI)	Fabric Count	Thickness (mm)
C	39	73	112	0.8
R	51	52	103	0.79
P	36	59	95	0.54

Comfort related performance attributes are shown in Table II. Properties are the stretch, recovery, air permeability and horizontal wicking. Among all 3 specimens, P had the highest stretch, recovery, and air permeability whereas specimen C scored lowest for the same properties. On the other hand, only specimen C showed positive result during horizontal wicking and other two specimens displayed zero wicking.

TABLE II
Comfort Properties of the Fabrics

Specimens	C	R	P
Stretch (%)	153	175	155
Recovery (%)	89.5	91.9	94.9
Air Permeability (ft3/ft2/min)	52	138	199
Horizontal wicking (mm2/s)	0.8	0	0

The results of t-test and Analysis of Variance (ANOVA) of all four comfort properties for all three fiber contents are as shown in Table III. The findings of the study are discussed below by means of table III. All hypotheses were rejected (H1-H4) but H5 was accepted. Each hypothesis is described in details below.

1) Hypothesis 1 (H1): Fiber content will not impact stretch.

Based on the results from ANOVA, all three fabrics differed significantly from each other for stretch ($F_{2.12}$= 31.71, p<.05). See Table III for details. Hypothesis 1 was rejected. Post-hoc analysis revealed that C and R ($t_{8=}$ 7.33*, p<.05) and R and P ($t_{8=}$ 6.33*, p<.05) were significantly different from each other. However, differences were not significant between C and P. Differences between cotton and rayon could be explained based on the length of the fiber that is staple for cotton and filament for rayon. Polyester rayon difference could be based on the fact that polyester is thermoplastic polymer and rayon is a regenerated cellulose.

2) Hypothesis 2 (H2): Fiber content will not impact recovery.

Results from ANOVA revealed that three fabrics were significantly different ($F_{2.12}$= 31.71, p<.05) from each other (Table III). Hypothesis 2 was rejected. Inter-fiber content analysis through for inter-group comparison showed that differences were significant for C and P ($t_{8=}$ 4.61*, p<.05) and R and P ($t_{8=}$ 3.24*, p<.05). However, cotton/spandex and rayon/spandex did not differ significantly. Polyester/spandex had the highest recovery followed by rayon/spandex and cotton/spandex (Table II). Cotton is made from staple fiber and makes sense that it had the lowest recovery.

3) Hypothesis 3 (H3): Fiber content will not impact air permeability.

All fabrics differed significantly from each other ($F_{2.12}$= 281.87* and p<.05) for air permeability Table III). Hypothesis 3 was rejected. Inter group comparisons revealed that cotton different significantly from rayon ($t_{8=}$ 15*, p<.05) and polyester ($t_{8=}$ 28.87*, p<.05), as well as R and P ($t_{8=}$ 8.07*, p<.05). Air permeability was highest for polyester followed by rayon and cotton (Table II). It was interesting to note that this sequence corresponded with fabric thickness (Table 1)
also.

4) Hypothesis 4 (H4): Fiber content will not impact the wicking rate

All three fabrics were significantly different ($F_{2.12}$= 15.66* and p<.05) from each other for their wicking rate (Table III). Hypothesis 4 was rejected. Post-hoc comparisons revealed that differences were significant between C and R ($t_{8=}$ 4.00*, p<.05), C and P ($t_{8=}$ 4.00 *, p<.05). R and P had zero wicking rate. This finding is inconsistent with Gorji and Bagherzadeh who found polyester to have higher wicking ability than cotton [36].

TABLE III
ANOVA and T-Test Results for Comparison of Fabric Comfort Properties

Properties	Specimen	n	Mean	SD	t	Group	F	p
Stretch (%)	C	5	153.00	4.47	7.30	C x R	31.71	0
	R	5	175.00	5.00	0.70	C x P		
	P	5	155.00	5.00	6.30	R x P		
Recovery (%)	C	5	89.52	2.18	2.10	C x R	12.79	0
	R	5	91.93	1.31	4.60	C x P		
	P	5	94.91	1.44	3.40	R x P		
Air Permeability (ft3/ft2/min)	C	5	51.98	1.90	15.00	C x R	281.9	0
	R	5	137.80	12.66	29.00	C x P		
	P	5	198.80	11.21	8.10	R x P		
Wicking (mm2/s)	C	5	0.80	0.45	4.00	C x R	15.66	0
	R	5	0.00	0.00	4.00	C x P		
	P	5	0.00	0.00	0.00	R x P		

5) Hypothesis 5 (H5): Fabric thickness will impact air permeability.

From the result of regression ANOVA (Table IV) between air permeability and thickness, it can be predicted that thickness can reliably predict the air permeability (F= 23.14* and p<.00). The value of R Square was 0.61. This value indicates that air permeability explains 61% of the variance.

TABLE IV
ANOVA Results of Thickness on Air Permeability

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Reg.	35577.48	1	35577.48	23.14*	.00b
	Res.	19984.23	13	1537.25		
	Total	55561.71	14			
a. Air Permeability, b. Predictors: Thickness						
Sig. Significance, Reg. Regression and Res. Residual						

Figure 1 displays a visual representation of the linear co-relation for air permeability and thickness. It shows a negative co-relation between air permeability and thickness. Since, thickness and air permeability are inversely related, hypothesis 5 (H5) was accepted. This finding is consistence with previous literatures ([23], [26])

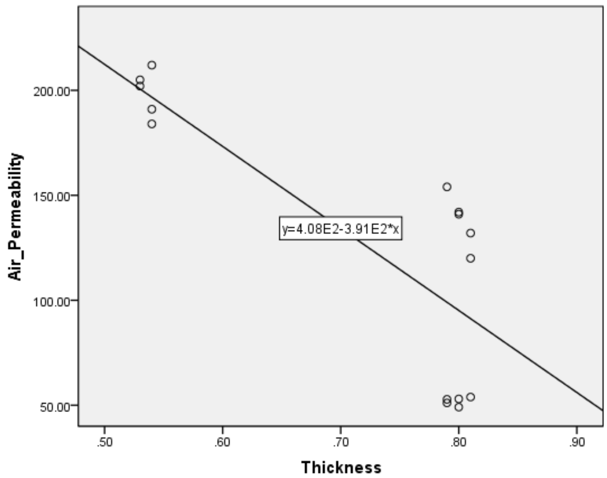

Fig1: Linear Regression Line between Air Permeability and Thickness

6) Hypothesis 6 (H6): *Fabric thickness will impact stretch.*

The result of regression ANOVA between stretch and thickness from Table V shows that the thickness cannot reliably predict the stretch (F= 2.52* and p<.14). Therefore, hypothesis 6 was rejected and this finding is contradictory with previous study [35].

TABLE V
ANOVA Results of Thickness on Stretch

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Reg.	286.43	1	286.42	2.52*	.14b
	Res.	1473.57	13	113.35		
	Total	1760.00	14			
a. Stretch, b. Predictors: Thickness						
Sig. Significance, Reg. Regression and Res. Residual						

7) Hypothesis 7 (H7): *Fabric thickness will impact recovery.*

The result of regression ANOVA (Table VI) between recovery and thickness, shows that the thickness can dependably anticipate the recovery (F= 14.95* and p<.00). The R Square (R^2=0.54) was indicates that the recovery explains 54% of the variance.

TABLE VI
ANOVA Results of Thickness on Recovery

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Reg.	57.29	1	57.29	14.95*	.002b
	Res.	49.81	13	3.83		
	Total	107.10	14			
a. Recovery, b. Predictors: Thickness						
Sig. Significance, Reg. Regression and Res. Residual						

Figure 2 exhibits the visual representation of the linear co-relation for recovery and thickness. It shows a negative co-relation between recovery and thickness. Since, thickness and recovery are inversely related, hypothesis 7 (H7) was accepted. This finding is consistence with previous literatures [35].

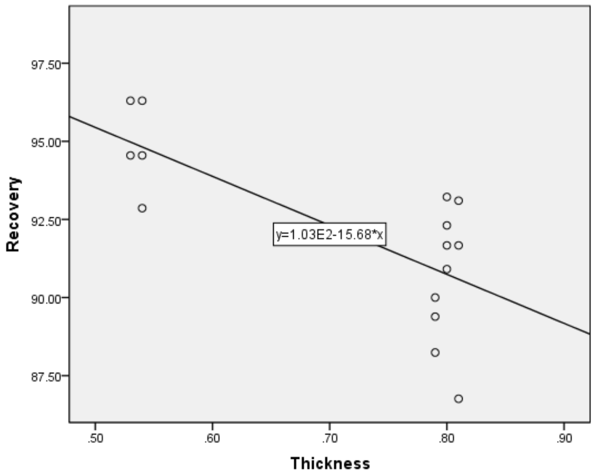

Fig2: Linear Regression Line between Air Permeability and Thickness

8) Hypothesis 8 (H8): *Fabric thickness will impact wicking.*

From the result of regression ANOVA (Table VII) between wicking and thickness, it can be predicted that thickness cannot reliably predict the wicking (F= 2.7* and p<.12). Hypothesis 8 was rejected.

The discussion above indicates that stretch, recovery, air permeability and wicking properties of three selected fabrics varied for the three fiber contents. Overall, Hypothesis H1-H4, H6, and H8 were rejected. Hypothesis H5, H7 were accepted.

TABLE VII
ANOVA Results of Thickness on Stretch

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Reg.	.51	1	.51	2.70*	.12b
	Res.	2.47	13	.19		
	Total	2.98	14			

a. wicking, b. Predictors: Thickness
Sig. Significance, Reg. Regression and Res. Residual

IV. CONCLUSIONS

The study compared comfort properties, such as stretch (between wales), recovery, air permeability and wicking of single jersey knitted fabrics of three different fiber contents. The study showed that fiber content can influence performance attributes of fabric. Statistical analysis revealed that all comfort properties were significantly different for the selected fabrics with few exceptions. It also appeared that polyester/spandex blend had highest air permeability and lowest stretch recovery rate. Surprisingly, both rayon/spandex and polyester/spandex did not show any wicking at all and cotton/spandex showed weak wicking rate. Results revealed that thickness impacted air permeability and recovery but did not impact stretch and wicking.

V. LIMITATION AND FUTURE RESEARCH

Specimens were sourced from the local market, so there was the lack of information on fabric label like yarn size, finish, fabric weight etc. and all those unknown attributes couldn't be controlled. Spandex content of all three fabrics were 5% with 95% of cotton, rayon, and polyester respectively. However, there were variations in thickness, yarn size and fabric count which may have biased test results. Stretch only measured in between wales, because single jersey knit deform more wales wise and stretch between courses ignored in this study. Stretch measurements were measured by the industrial method due to unavailability of machinery, where human error may have the biased result.

Future research can be done with more controlled specimens. More variety in fiber content, blend ratio, fabric structure, yarn size, fabric count can be studied in future. Other comfort properties of fabric like porosity, breathability, heat transfer, sweat transfer can be added as the attribute and tested. Comparison of knit fabric can be studied with other fabric like mesh or nonwoven in terms of comfortability.

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