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AN INVESTIGATION OF ARCING IN TWO STRUCTURE WEFT KNIT FABRICS

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ABSTRACT

A wide range of weft knitted products is used for apparel, industrial, and medical purposes. Due to the technological advancement of computerized knitting machinery, it is possible to knit different structures side-by-side, in addition to a sequential manner. This research investigated the occurrence of one type of fabric distortion, arcing, when two different structures were knitted side-by-side, where the abutted areas were composed of the combination of any two different structures. Three weft knit structures were selected for this research (single jersey, 1x1 rib, and the moss stitch). The effects of changes in loop length, yarn type, and fiber type on physical properties of dry-relaxed two-structure fabrics are investigated by an adapted ASTM standard. The results of this examination of arcing in knitted structures will be of interest to designers, academicians, and industry.

Keywords: weft knitting, fabric distortion, arcing

1. INTRODUCTION

Products such as sports jerseys, sweaters, compression bandages, filters, bulletproof vests, and fluid absorbing sheets may all contain different knit structures as part of their constructions. The construction may provide each product its optimum performance characteristics. Many types of industries use knit fabrics because of their ability to conform to any dimension. This flexible, elastic fabric adapts easily to body movement which makes it ideal for close fitting garments like orthopedic braces, compression gloves, hosiery, and athletic wear. Precisely engineered products are required, and higher performance standards are required for highly technical products such as skin grafts and vascular grafts (Smith, 2004). Knit fabrics of specific structures have unique properties that may be affected if one structure is knitted side-by-side with another specific or different structure.

In this context there has been minimal research investigating structures that are joined side-by-side, rather than in a sequential manner in terms of the precise relationships that exist between them. Figures 1.1 illustrate two fabric positions, where the dotted line represents the area where two different structures meet, in a side-by-side and sequential manner. The wale (W) direction is vertical and course (C) direction is horizontal in both illustrations. The side-by-side arrangement was the focus of this research.

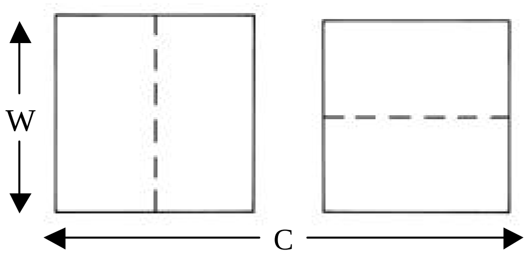

Figure 1.1: Side-by-side and sequential

The interaction of structures may cause deformation such as arcing when structures are adjoined. The degree of deformation may limit structure combinations knitted on the machine when certain aesthetics and functions are desired (Smith, 2004).

Research Objective

The objective of this research was to study structure interactions when knit structures were knitted side-by-side. In the two-structure fabrics created for this work, there were clearly two different structures present and they were not intermingled.

There were two research questions to guide this work.

1.) Does arcing occur when different weft knit structures are knitted side-by-side in a single fabric?
2.) How do loop length, structure combination, yarn type, and fiber type impact arcing?

2. METHODOLOGY

Samples were created using four different yarns and three knit structures knitted side-by-side at three different loop lengths. The amount of arcing in the samples was measured according to a method adapted from ASTM D-3882 Standard Test Method for Bow and Skew in Woven and Knitted Fabrics (ASTM D-3882, 1999).

Knitting Machine

Fabrics were knitted using a Shima Seiki SES124-S, electronically computerized, flat knitting machine. The v-bed machine provided design flexibility and necessary capabilities for this research. The machine specifications are listed in Table 2.1. After knitting, all fabrics were sorted by yarn type and stored at room temperature in separate sealed bins to prevent contamination from dust and foreign fibers. All knitting was completed before the cutting and measuring process was initiated to ensure consistent testing conditions.

Table 2.1: Machine Specifications

Manufacturer	Shima Seiki
Machine Type	Computerized Flat Machine
Machine Model	SES124-S
Machine Gauge	7
Type of Needles	Latch needle with transfer clip
Knitting Speed	0.73 meters/second
Minimum Yarns Fed	2 (acrylic, polyester, polypropylene)
Maximum Yarns Fed	4 (wool)
Full Bed Width	47 inches (119.38 cm)
Knitting Width	45.6 inches (115.8 cm) or 320 needles

Loop Length

Knitters have the option to set the tightness of knitting by varying the loop length. Knit fabrics can be knitted loosely or tightly, but normally are knitted somewhere around the middle tightness depending on the end use of the product and the desired aesthetics. For example, hosiery should be knit tight enough to form fit the body and remain taut during movement and extended wear, but loose enough for comfort and appropriate fit. The fabric dimensions depend on the tightness of the fabric. In fabrics knitted with the same loop length, the fabric dimensions vary with the count of the yarn (Hepworth, 1982). Loosely knitted fabrics are easily extensible and distorted; where as tightly knitted fabrics are more stable and less susceptible to distortions (Shinn, 1955).

Tight, medium, and loose loop lengths were selected for this experiment to show distinct differences in fabric tightness. The stitch cam setting on the machine for a tight loop length was 30, a medium loop length was 40, and a loose loop length was 50. The weft knit structures selected for this experiment consisted of single jersey, 1x1 rib, and moss stitch. Each of these structures was combined to create the following two-structure fabrics: single jersey/1x1 rib, single jersey/moss, and 1x1 rib/moss.

Negative Feed

Negative feed was used to control loop length and to get the loop change as equal as possible between tight and medium loop lengths and between medium and loose loop lengths. This feeding system was used to draw the necessary amount of yarn to produce the two-structure fabric rather than pre-metering the amount of yarn because loop differences between two different knit structures in addition to tightness settings were difficult to predict (Smith, 2004). In observing fabric distortion, using such a loop length approach, it was expected that it would be possible to predict how the fabric would lie in one-structure fabrics, and also predict how one structure would influence another structure in two-structure fabrics.

Yarn

Four specific yarns were chosen for this experiment due to their individual characteristics (Table 2.2). The yarns varied in terms of fiber content, fiber type (staple or filament), and yarn size. The total denier of each yarn was matched as closely as possible. In this experiment, the denier range of 1200 to 1328 was used to produce fabric in three variations of tight, medium, and loosely knit fabrics.

Table 2.2: Yarn Specifications

Fiber Type	Yarn Type	Denier
Acrylic	Spun	1328
Wool	Spun	1328
Polypropylene	Filament	1300
Polyester	Filament	1200

Knit Structures

Three weft knit structures were chosen for this experiment: single jersey, 1x1 rib, and the moss stitch. Single jersey is a common structure that is used extensively because it has a high production rate and is relatively inexpensive to produce (Smith, 2004), but it is easily distorted due to its simplicity and inherent spirality and skew (Lau, 1995). Skew is introduced during the knitting process when courses do not knit horizontally, but rather on an incline (Smith, 1983a).

The 1x1 rib is a common structure, normally used for trim or in the body portion of garments (Hatch, 1993). It is a rather unstable fabric and has tremendous widthwise extensibility. The 1x1 rib is the simplest and most unstable rib fabric, more easily distorted than single jersey especially in the width (Smith, 1983b).

A more stabilized purl, i.e. the moss stitch, was chosen for this experiment due to its balance and rigidity compared to the plain purl structure (Spencer, 2001). Plain purl is extensible lengthwise (Hatch, 1993), but the moss stitch structure is one of the most stable purl fabrics both lengthwise and widthwise. The moss stitch was selected to be the controlling, stable structure in this experiment.

Dry Relaxed State

The fabrics were conditioned and measured in the dry relaxed state in the Digital Design Lab at North Carolina State University. Conditions in the lab were at average room temperature 68-77°F (20-25°C), 20-25% relative humidity.

Fabric Cutting

For each yarn type, 20 samples were cut from each fabric tightness for each structure combination with the exception of the polypropylene fabric from which a minimum of 12 samples were cut based on the availability of the fabric. Twenty samples were selected to ensure an adequate number of samples for purposes of statistical analysis. Samples were cut so that the combination line (the line where the two structures join) was centered in the sample.

Arc Measurements and Calculations

The ASTM D-3882 Standard Test Method for Bow and Skew in Woven and Knitted Fabrics was used as a guide to develop a method in measuring arc in the knit fabric samples. This ASTM standard focuses on measuring bow, the bending of courses; however, the focus of this research is on the bending of wales and is referred to as *arcing*. The test method was also modified to accommodate a smaller sample size rather than using rolls or bolts of fabric.

There are two measurements required for this test method, arc distance and baseline distance. The baseline distance was measured along the line where two structures meet (point A to point B) from one edge of the fabric to the other. The arc distance (C) is measured perpendicular to the baseline distance at the maximum arc point. The fabric samples were consistently positioned with the arc towards the left (Figure 2.1). In the figures, wales appear vertically and courses appear horizontally.

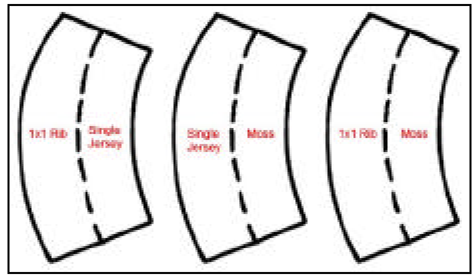

Figure 2.1: Measurement position

Arc distance and baseline distance were measured one time for each sample as shown in Figure 2.2. The distance between the two edges was measured to the nearest 1/16 inch (1mm) with a twelve inch metal ruler and was recorded as the baseline distance. The greatest distance perpendicular from the baseline to the combination line was measured to the nearest 1/16 of an inch (1mm) and was recorded as the arc distance.

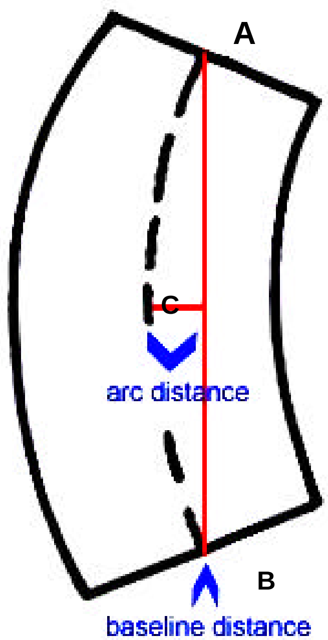

Figure 2.2: Sample measurements

- Black outline = dry relaxed state of the sample.
- Black dotted line = line where two structures join.
- Red lines = straight measured lengths.

The arc distance was divided by baseline distance for each measurement and these values were averaged. Once the averages were determined, the overall percent curvature was calculated using the formula (ASTM D-3882, 1999) for each fabric combination:

$$\% \text{ curvature} = \frac{\text{average arc distance}}{\text{average baseline distance}} \times 100$$

Statistical Analysis

A series of t-tests were conducted to determine whether significant differences in arcing existed among two-structure knit fabrics that varied in loop length, structure type, and yarn type. This inference test compares mean arcing values for samples from two populations (Inferences, 2004). Both null and alternative hypotheses were developed as a foundation for the statistical analysis. An alpha level of .05 was used for all statistical tests.

3. RESULTS AND DISCUSSION

This section summarizes the hypotheses test results in comparing two-structure knit fabrics of different loop lengths, structure combination, and fabrics made from spun and filament yarns and their influences on arc. A clearer understanding of the relationship between fabric properties and arcing was determined when t-test results were analyzed. In this section, although the t-test was conducted for all hypotheses, the ones that were most significant are discussed.

The Effect of Loop Length on Arc

$H1b_0$: There is no significant difference in arcing between the tight and loosely knit fabrics.

$H1b_1$: There is a significant difference in arcing between the tight and loosely knit fabrics.

Tightly knit fabric (M = .034093, SD = .027676) and loosely knit fabric (M = .032794, SD = .025337), t(451) = .526203, p = .599006 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between tight and loosely knit fabric.

Although hypothesis test results of $1b_0$ indicated that there was no significant difference between tight and loosely knit fabric (Figure 3.1), on an average, all tightnesses arced around 30%. In tightly knit fabric, short loops have limited space to move in order to compensate the distortion from neighboring structures. Therefore, the only outlet for distortion was through the bending of wales that caused the fabric to arc. The loosely knit fabric exhibited similar arcing percentages because distortion is more susceptible in loosely constructed fabric due to easily distorted loops. The neighboring structures were able to compensate for distortions from the other structure.

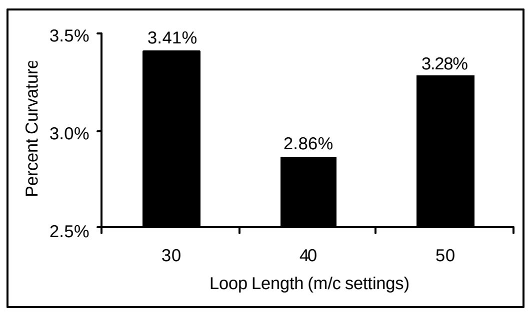

Figure 3.1: Loop Length vs. Percent Curvature

The Effect of Two-Structure Fabrics on Arc

$H2c_0$: This is no significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

$H2c_1$: There is a significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

Single Jersey/Moss fabric had lower arcing values (M = .012344, SD = .012489) than 1x1 Rib/Moss fabric (M = .052848, SD = .020000), $t(383) = -26.1309$, $p = .000000$. This is significant because $p = .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the Single Jersey/Moss fabric and 1x1 Rib/Moss fabric, and that the alternative hypothesis is true.

The arcing difference between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics was due to the difference of structural stability in the single jersey and 1x1 rib structures (Figure 3.2). The instability of the 1x1 rib resulted from the ability to easily extend in width due to alternating front and back wales. Single jersey created less arcing because it consisted of all face loops, which limited extensibility and resisted distortion from the moss structure. In the 1x1 Rib/Moss fabric, the 1x1 rib was the unstable structure. When it was knitted beside the moss, a greater amount of arcing occurred than the Single Jersey/Moss fabric because the 1x1 rib structure was less stable than the single jersey structure.

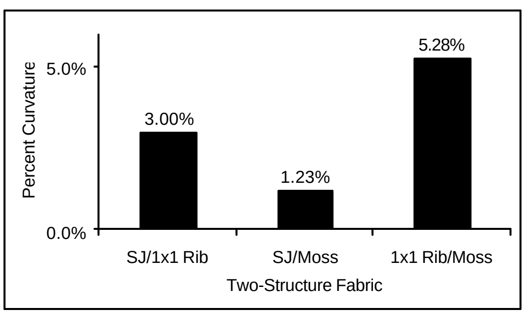

Figure 3.2: Two-Structure Fabric vs. Percent Curvature

The Effect of Spun and Filament Yarns on Arc

The yarns used to knit fabric samples were of different deniers. These yarn images are consistent to one another with regard to scale (Figure 3.3).

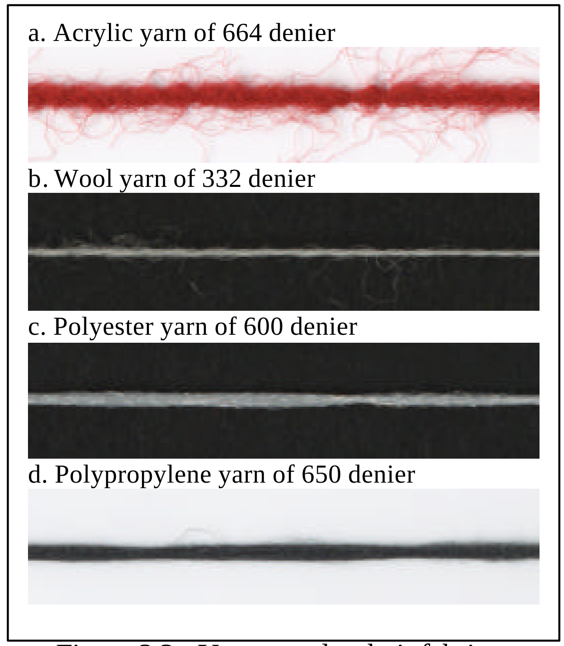

Figure 3.3: Yarns used to knit fabric samples

$H3_0$: There is no significant difference in arcing between two-structure fabrics made from spun and two-structure fabrics made from filament yarns.

$H3_1$: There is a significant difference in arcing between two-structure fabrics made from spun and two-structure fabrics made from filament yarns.

Two-structure fabrics made from spun yarn had higher arcing values (M = .037087, SD = .025337) than two-structure fabrics made from filament yarn (M = .026204, SD = .024248), $t(697) = 5.79968$, $p = .000000$. This is significant because $p = .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the two-structure fabrics made from spun yarn and from filament yarn, and that the alternative hypothesis is true.

The two-structure knits made of spun yarns exhibited higher arcing percentages than those made of filament yarns (Figure 3.4). This could be due to the spirality influences as well as fiber density. Spun yarns were characterized by low fiber density, which influenced more arcing. The lighter weight, in addition to high volume and bulk, resulted in higher arcing percentages because loops had limited space to move around. This prevented a neighboring structure from compensating for distortion imposed by the other structure resulting in bending of wales, thus arcing. Two-structure knits made of filament yarns exhibited lower arcing percentages because they were less voluminous. The loops had more space to move around, which allowed a neighboring structure to compensate for distortions imposed by the other structure resulting in less arcing.

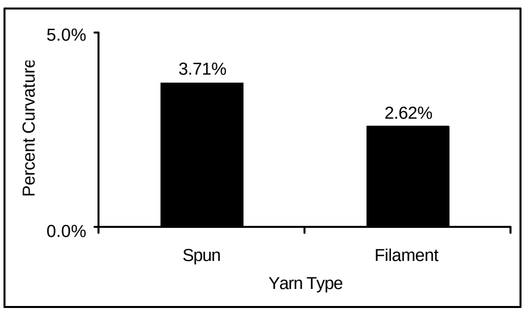

Figure 3.4: Yarn Type vs. Percent Curvature

The Effect Fiber Content in Spun Yarns: Acrylic and Wool

$H4_0$: There is no significant difference in arcing between two-structure fabrics made from acrylic and two-structure fabrics made from wool yarns.

$H4_1$: There is a significant difference in arcing between two-structure fabrics made from acrylic and two-structure fabrics made from wool yarns.

Two-structure fabrics made from acrylic yarn (M = .038243, SD = .027784) and two-structure fabrics made from wool yarn (M = .035931, SD = .022649), t(344) = .864793, p = .387754 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between two-structure fabrics made from acrylic yarn and from wool yarn (Figure 3.5).

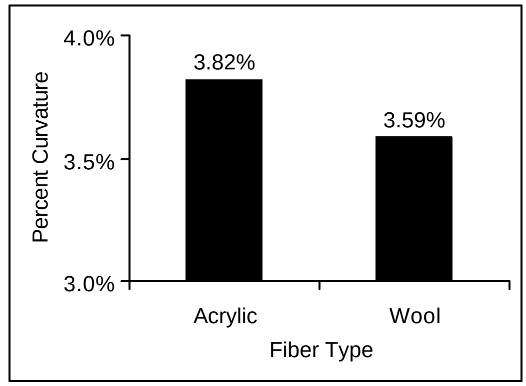

Figure 3.5: Fiber Type vs. Percent Curvature

The spun yarns, acrylic and wool had the same denier = 1328 as well as similar fiber densities, 1.12 and 1.15 respectively. This similarity in denier and fiber density resulted in similar influences on arcing. Both yarns had bulk and volume, which made the fabric more rigid. Two-structure fabrics made from bulky yarn contained less open space for loops to move because the yarn volume occupied that space. Therefore, the rigid fabric prevented the neighboring structure from compensating for distortions from the other structure.

The Effect of Filament Yarns: Polyester and Polypropylene

$H5_0$: There is no significant difference in arcing between two-structure fabrics made from polyester and two-structure fabrics made from polypropylene yarns.

$H5_1$: There is a significant difference in arcing between two-structure fabrics made from polyester and two-structure fabrics made from polypropylene yarns.

Two-structure fabrics made from polyester yarn (M = .025510, SD = .020273) and two-structure fabrics made from polypropylene yarn (M = .026989, SD = .028142), t(283) = -.548472, p = .583800 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between two-structure fabrics made from polyester yarn and from polypropylene yarn (Figure 3.6).

The denier of polypropylene (1300 den, 288 filaments) was greater than polyester (1200 den, 136 filaments) while the fiber density of polypropylene (0.9) was lower than polyester (1.23). The relationship between fiber density and denier of these yarns has balanced each other out in terms of filament count. Therefore, the relationship between fiber densities and denier may have contributed to similar influences on arcing in two-structure fabrics.

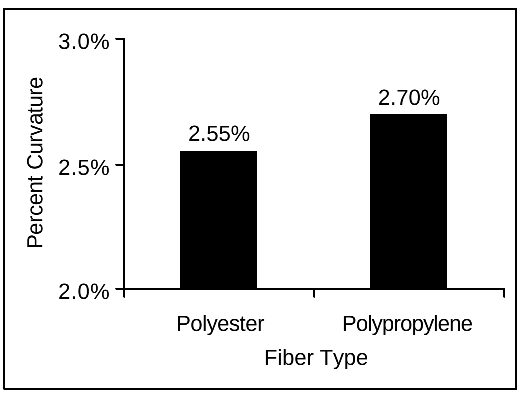

Figure 3.6: Fiber Type vs. Percent Curvature

The results indicated that arcing occurred when two different structures were knitted side-by-side and arcing was effected by the combination of loop length and specific structures. Fabric arcing was also influenced by yarn type and fiber density in relation to filament count.

4. CONCLUSIONS AND FUTURE RESEARCH

Effects of Loop Length on Arc

All fabric tightnesses exhibited arcing, it was determined that fabrics knit tightly and loosely were more susceptible to arcing. Less arcing occurred in the medium fabric compared to tightly and loosely knit fabrics.

Effects of Structure Interactions on Arc

Arcing occurred when two different structures were knitted side-by-side. Arcing was affected by the combination of specific structures and structural stability contributed highly to the amount of arcing. The most arcing occurred in the 1x1 Rib/Moss fabric because the 1x1 rib was the most easily distorted structure compared to single jersey and the moss stitch. An average amount of arcing occurred in the Single Jersey/1x1 Rib fabric because the difference of structural stability between structures was not significant. The least amount of arcing occurred in the Single Jersey/Moss fabric because the moss fabric maintained stability with little or no distortion to the single jersey.

Effects of Yarn Type on Arc

It was concluded that the spun yarns (acrylic and wool) produced more arcing than the filament yarns (polyester and polypropylene) in two-structure fabrics. In comparing the fiber types of acrylic and wool yarns, it was determined that these spun yarns had similar influences on arcing in two-structure fabrics. In comparison of polyester and polypropylene fibers, it was determined that these filament yarns had similar influences on arcing in two-structure fabrics.

The research performed in this study provided the method in measuring arcing and identified the occurrence of arcing when two different structures were knitted side-by-side. Given that this research was an overview of a new approach there are several recommendations for future research.

Sequential and Side-by-Side

Distortions occur when different structures are knitted side-by-side. Recommendations to combine sequential and side-by-side knitting as in a checkerboard layout to test arcing/buckling/distortion may reveal additional influences on distortion.

Different Size Sample

During the cutting process, it was observed that sample size influenced the amount of arcing. The fabrics with short baseline distances created less arcing. A longer baseline distance produced more arcing, but there was a maximum point at which the amount of arcing evened out. Future studies could investigate the influence of sample size on arc. Different size samples could be used to determine the effects on arcing.

Fabric Deformation

Arcing was the only deformation analyzed in this research. It was observed that buckling, where the plane of the fabric is affected, was more evident and pronounced in tightly knit fabrics versus loosely knit fabrics. In addition, the buckling observed in this study created an aesthetically pleasing effect, which represented rouching or ruffling techniques. Further studies on fabric buckling and possibly the relationship with knitted textile design could be undertaken.

Yarn Denier and Diameter

The yarns used in this experiment were not of equal deniers; further research could include yarns of equal deniers so fabrics can be readily compared to each other. The yarn diameter of each yarn varied accordingly to construction and fiber characteristics. Yarn testing can reveal the relationship between yarn characteristics and arcing. Further studies that incorporate yarn testing and their effects on the relaxed state of fabric are suggested.

Stability

Three basic structures: single jersey, 1x1 rib, and moss stitch were used in this experiment to demonstrate how the stability of each structure influenced the amount arcing. More complex knit structures of various stability levels are suggested for future research.

Testing Conditions

Fabrics were conditioned in an uncontrolled environment under the circumstances of the location of the knitting machine. Future conditioning of fabric samples under standard testing conditions 21^{o}C, 65% relative humidity is suggested to eliminate any discrepancies related to testing conditions and its effects on fabric relaxation.

Relaxed States

The fabrics were dry-relaxed in this experiment; therefore analyzing the fabrics in this state does not clearly reveal how the fabric will perform in use. Washing and drying the fabrics to achieve the wet or fully-relaxed state will better emulate consumer laundering instructions as well as performance standards.

Textile Design

Arcing can be used to create volume and form in knitted fabrics to imitate ruffling or rouching effects without creating seams. For example, rouching is a technique of gathering fabric, which produces a rippling effect and may be used to create fullness in the bust area. Arcing may produce similar effects when a compact structure (stable) is knitted with an extensible structure (unstable).

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