ABSTRACT

ANDERSON, KIM SUZANNE. Seamless Textiles with Inherent Shape. (Under the direction of Abdelfattah Seyam.)

Currently, the cutting and sewing process is utilized to produce woven products with tailored shape. Unfortunately, there are a number of adverse consequences caused from seams. The goal of this research was to investigate new methods in which a shaped seamless woven product could be produced using current technology.

After a thorough review of the literature, two sets of weaving trials were conducted. In the first set of trials three variables were investigated, specifically 1) different pick densities, 2) different weave constructions and 3) yarns with different degrees of shrinkage. Each variable was manipulated to produce differential shrinkage during the fabric finishing process. In addition, the three variables were utilized in different combinations within a tubular construction in an effort to create inherent shape.

The second set of weaving trials were undertaken to investigate the correlation between fabric width shrinkage and a given set of fabric construction parameters in order to create inherent shape within the fabric. Establishing a reliable correlation between fabric width shrinkage and a given set of parameters could lead to the design and development of fabrics with many different shapes. It was of additional interest to investigate the ability to design shaped fabrics with similar finished fabric tightness. The same set of parameters utilized in the first set of weaving trials were examined in the second set of weaving trials.

A statistical analysis was performed using the results from the second set of weaving trials. The analysis was performed to examine the success of the overall experiment by assessing the contribution each of the three independent variables made to the resulting finished width shrinkage, as well as finished fabric tightness. In addition, the contributions made by the interactions between different combinations of the independent variables were examined with respect to finished fabric width shrinkage and finished fabric tightness.

In order for seamless shaped woven fabrics to be produced without performing additional weaving trials, a predictive model was created. The predictive model would allow a designer to utilize the data generated in the second set of weaving trials to estimate the width shrinkage of a given combination variables. This knowledge would enable a designer to create different shapes by utilizing different combinations of the three variables investigated in this study to produce a specific width shrinkage.

In order to assess the potential for a speedy adoption of a seamless woven textile with inherent shape, an economic feasibility study was completed. Everett Roger's Model of the Innovation-Decision Process was used as a paradigm to aid in the investigation of the economic potential of a seamless shaped textile. Other important economic issues pertaining to a new successful product adoption were addressed, including cannibalism, manufacturing strategies and marketing opportunities.

Utilizing the proposed experimental methods led to a variety of fabrics with inherent shape. A correlation between fabric width shrinkage and a given set of fabric construction parameters was established. The methods developed in this study could be utilized to produce many different fabrics with inherent shape that might be used in a wide variety of applications.

Although seamless shaped fabrics were produced utilizing the methods in this study, future research would be necessary. In this research, none of the fabric samples were tested for physical or mechanical properties. Depending on the intended end use, specific tests would need to be executed to ensure that the seamless shaped products possessed the appropriate characteristics. The ability to reproduce specified dimensions would need to be assessed. In addition, a cost analysis would need to be investigated.

SEAMLESS TEXTILES
WITH INHERENT SHAPE

by

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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment for the Degree of
Doctor of Philosophy

Textile Technology Management

Raleigh, NC
2004

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BIOGRAPHY

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ACKNOWLEDGEMENTS

I would like to thank the five professors on my committee-Dr. Abdelfattah Seyam, Dr. Martin King, Dr. Benham Pourdeyhimi, Dr. George Hodge and Dr. Nancy Cassill for their contribution to this project. Special thanks to Dr. Seyam for providing much appreciated guidance and expertise throughout the project.

Special thanks to Derek Gun of Unifi Incorporated for donating yarn and for his helpful expertise in yarn shrinkage.

Many thanks to William Barefoot for his many hours spent adjusting and refining the weaving equipment, upon which this project depended.

Special thanks to my family for all their support throughout this endeavor.

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PART 1: INTRODUCTION

1.0 INTRODUCTION

In today's volatile global market it has become increasingly difficult for textile mills and apparel manufacturing companies to maintain a competitive advantage. United States textile companies are no longer able to sustain a competitive advantage over their competitors by focusing on cost and quality alone. It is paramount that textile companies think of revolutionary new methods to produce innovative products. To be globally competitive, textile companies should offer products that can not be bought anywhere else. One area with great potential is the production of seamless woven products that have inherent shape. There are many benefits to producing a seamless shaped woven product, as well as numerous new products that could be utilized in a wide variety of markets.

Historically, when a woven product with a tailored shape was needed, cutting and sewing was required. Unfortunately, there are a number of adverse consequences caused from utilizing seams in a woven textile product. First, the process of cutting and sewing is the most labor intensive step in the formation of a product. Second, there is a concentration of stress where the seams are located which jeopardizes performance properties and ultimately results in premature product failure. Third, cutting and sewing is done manually which introduces the potential for human error. Fourth, the sewing process can create needle holes in the fabric as well as damage the yarn. Fifth, fabric scraps produced from the cut and sew process are discarded, resulting in fabric waste. In addition, seams in a garment create a bulkiness especially at the shoulders and underarms which can effect the comfort.

There have been a number of successful attempts to produce seamless textile products with inherent shape in which cutting and sewing is not required. However, the majority of these methods have limitations. The current methods have either limited production speeds; require specialized equipment; still require a manual processing stage; produce fabric that has either structural limitations or inappropriate physical properties for a variety of end uses.

After a thorough review of the literature, two sets of weaving trials were undertaken in order to create shape in a woven structure without cutting or sewing or using any seams of any type. In the first set of trials detailed in Part III, three variables were utilized within a tubular construction, specifically 1) different pick densities, 2) various weave constructions and 3) yarns with differential shrinkage. These variables could potentially be manipulated to cause different amounts of shrinkage within the fabric structure. Most textile fabrics are designed to have minimal shrinkage as well as uniform shrinkage. At the beginning of the design process fabric construction variables are carefully chosen to produce minimum and uniform shrinkage. However, in this study these variables were manipulated to create shape by producing differential shrinkage within the fabric during the finishing process.

The main goal of the second set of weaving trials detailed in Part IV, was to investigate the correlation between fabric width shrinkage and a given set of fabric construction parameters in order to create inherent shape within the fabric. It was of additional interest to investigate the ability to design shaped fabrics that would result in the same or similar finished fabric tightness.

After analyzing the results obtained from Part IV, two statistical models were performed. The first statistical model was utilized to determine the contribution each of the three variables, as well as different combinations of the three variables had on the finished width shrinkage and finished fabric tightness. The second statistical model was a predictive model that was performed in an attempt to enable a designer to produce a variety of different shapes, given a specific combination of the three variables analyzed in this research.

In Part V an economic study was conducted in order to assess the potential for a successful adoption of a seamless woven product with inherent shape. A seamless shaped textile was evaluated in terms of the five components of the persuasion stage from Everett Roger's Model of the Innovation-Decision Process. The persuasion stage is an important indicator as to the potential for a speedy successful adoption of an innovation.

At the persuasion stage the potential adopter establishes either an unfavorable or favorable attitude towards the innovation. The attitude towards the innovation determines whether the potential adopter will either accept or reject the innovation.

Other important economic issues pertaining to a new successful product adoption were addressed, including cannibalism, manufacturing strategies and marketing opportunities. Cannibalism is defined as the process by which a new product gains sales by diverting them from an existing product. Although this research is by no means all inclusive, the issues raised are pertinent and could facilitate a successful adoption of a new product.

The proposed experimental methods in this study could lead to the design and production of seamless woven products with exact shape and dimensions. These new innovative products could potentially be utilized in many applications in a wide variety of markets, including fashion apparel, medical, automotive, aerospace, protective clothing and industrial.

PART II:
LITERATURE REVIEW

2.0 INTRODUCTION

Historically, when a seamless shaped textile product was needed, cutting and sewing was required. There are a number of adverse consequences caused from utilizing seams in a textile product. First, the process of cutting and sewing is the most labor intensive step in the formation of a product. Second, the sewing process can also create needle holes in the fabric as well as damage the fiber within the yarn. The presence of needle holes and damaged fibers could adversely affect the strength and performance of the fabric. Third, there is a concentration of stress where the seams are located which jeopardizes performance properties and ultimately results in premature product failure. Fourth, cutting and sewing is done manually which introduces the potentail for human error. In addition, fabric waste is generated by the cut and sew process and seams in a garment create a bulkiness especially at the shoulders and underarms which can affect the comfort of a garment.

There have been a number of successful attempts to produce a seamless textile product that has an inherent shape in which cutting and sewing is not required. Unfortunately, the majority of these methods have limitations. The current methods have either limited production speeds; require specialized equipment; still require a manual processing stage; produce fabric that has either structural limitations or inappropriate physical properties for a variety of end uses. The current methods that have been utilized to produce seamless textile products with inherent shape will be detailed in the following text.

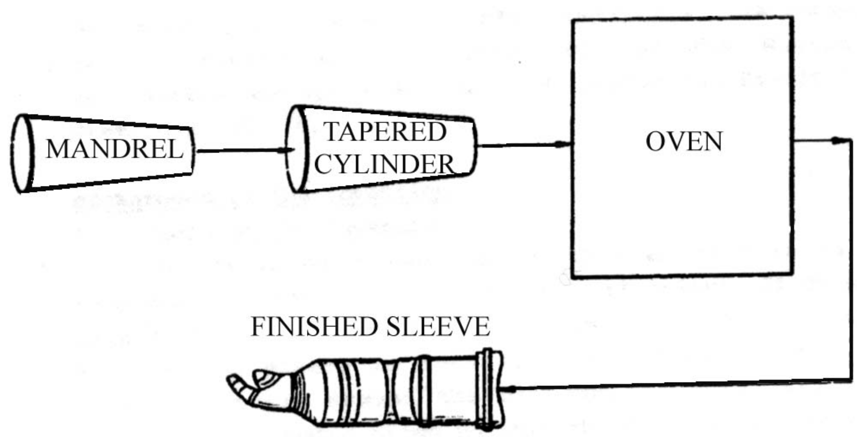
2.1 CURRENT METHODS FOR PRODUCING A SEAMLESS WOVEN TEXTILE PRODUCT WITH INHERENT SHAPE

2.1.1 THE FORMATION OF A SHAPED TUBE BY CUTTING SPECIFIED WARP YARNS TO A PREDETERMINED LENGTH

In 1987, a tapered cylinder of a predetermined length was produced utilizing a shuttle loom. The intent of the invention was to produce an impermeable spacesuit sleeve that would serve as a flexible supporting structure to protect the wearer from the outside environment. The tapered tube is formed on a conventional shuttle loom. Prior to weaving, a selected number of the warp yarns are cut shorter than the full length of the other warp ends. The number of yarns cut and the length of the yarn determines the degree of taper. Warp yarns that are not the full length of the original warp are terminated at specified lengths to form a tapered sleeve (LaPointe, et al., 1987.).

After the sleeve is woven it is placed on a conforming supportive mandrel. The sleeve can be shrunk thermally or chemically. A thermal shrinkage entails placing the woven structure on a mandrel and placing the mandrel in an oven at elevated temperatures, (refer to Figure 2.1). Chemical shrinkage involves wetting the sleeve with methylene chloride at room temperature and allowing it to shrink on the mandrel (LaPointe et al.,1987).

Figure 2.1 Tapered Cylinder, Mandrel, Oven and Finished Sleeve (LaPointe et al., 1987)



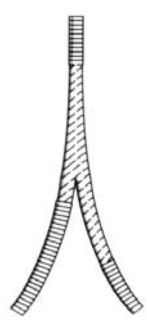
This method has a number of disadvantages. First, each time warp ends needed to be cut, the loom would have to be stopped. Stopping the loom would adversely affect the weaving time. Secondly, the number of warp ends that could be cut at a given time is limited. Cutting too many warp ends could result in holes. This would limit the degree of shape that could be produced. In addition, shorter warp ends are woven and ultimately terminated, therefore the process is not continuous. Warp ends that are terminated would need to be redrawn through the loom each time a new sleeve was woven.

2.1.2 FORMING A SHAPED ARTERIAL PROSTHESIS USING A NARROW WIDTH MULTI-SHUTTLE LOOM

In 1952 a researcher named Voorhees observed a silk suture hanging free in the heart. The suture had become coated with endothelial cells (Callow, 1986). These cells line arteries and prevent blood from clotting (Moreland, 1997). From this observation he surmised that a fabric graft might do the same and avoid clotting. A tube made from sail cloth proved his theory correct and began what is now known as arterial reconstructive surgery (Callow, 1986). Today, polyester textile prostheses are produced in a wide range of sizes, fabric types and configurations by a number of manufacturers.

Historically, a woven tube with a consistent diameter throughout the length has been used to replace a diseased or damaged lumen in the body. A woven tube is basically a tubular fabric with a consistent width. Tubular fabrics are essentially 2D woven fabrics that are joined at the edges to make a tubular product. When a shuttle loom is used the fill yarn loops circumferentially from the bottom layer to the top layer forming a seamless tube with excellent strength (Clarke, 2000). A prosthesis can also be produced in a seamless bifurcated shape. A bifurcated shape refers to a tube that separates into two branches, see Figure 2.2. A narrow width shuttle loom with multiple shuttles is utilized to form a bifurcated tube. One large tube is initially woven with one shuttle, at a given point two shuttles begin weaving simultaneously to form two tubes (Taws, 2003). These seamless shaped products have been used primarily as abdominal prostheses.

Figure 2.2 Example of a Bifurcated Prosthesis (Vascutek Ltd., 2003)



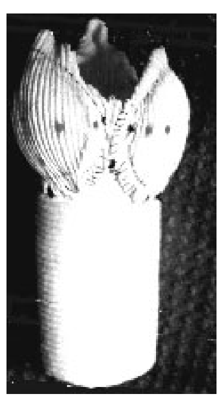
2.1.3 USING A STRAIGHT TUBE AND THE CUT AND SEW PROCESS TO PRODUCE A SHAPED PROSTHESIS SUITABLE FOR THE ASCENDING AORTA

Tubular fabrics have been used to replace or repair damaged or diseased lumens in the body for half a century. In situations where a tube with a tailored shape is needed, cutting and sewing is required. In specific locations such as the ascending aorta a prosthesis with a tailored shape is desirable. The aortic valve pumps blood into the ascending aorta. The blood then goes on through the systemic circulatory system (Guyton, 1974).

The aortic valve consists of three leaflets and three sinuses. The leaflets are mobile parts of the valve and the sinuses are cavities. At the point at which the aorta meets the aortic valve there is a slight tear-shaped bulge. When the ascending aorta becomes diseased it is desirable for the prosthesis to mimic the shape of the human aorta. The straight ascending aortic tubular grafts available at present do not allow the proper preservation of the natural aortic valve. The straight tube prohibits the leaflets from fluttering free. Through time the leaflets in the aortic valve are worn down (Fowler, 2003). For every person the dimensions of the tear-shaped bulge and the diameter of the tube vary slightly (Thubrikar, 2002).

Attempts to imitate the tear shaped bulge of the ascending aorta have been made by utilizing a straight tube and sewing three separate pieces of fabric to one end of the tube, see Figure 2.3.

Figure 2.3 A Shaped Aorta Prosthesis Created From Cutting and Sewing (Thubrikar, 2002)



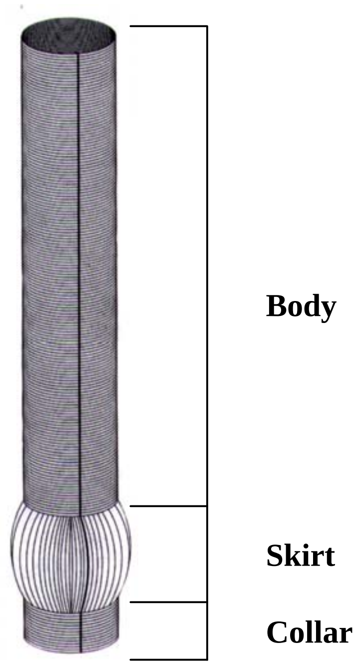
The utilization of the shaped prosthesis created by cutting and sewing is new, therefore information concerning the long-term performance is somewhat limited. However, the production of the prosthesis is manual therefore, subject to human error and labor intensive. Some of the problems attributed to human error are leakage caused from needle holes in the prosthesis. In addition, the thread that is used to sew the prosthesis together is a continuous filament yarn. If the yarn crimps during sewing it can break, resulting in additional labor time and possibly defects (Fowler, 2003).

Another drawback to cutting and sewing is the time it takes to produce the prosthesis. The prosthesis is produced in the operating room right before surgery. It takes approximately thirty minutes to cut and sew one prosthesis. In every operating room there exists a sterile environment. Although thirty minutes may not seem to be an ordinate amount of time, sterile time is costly. The time it takes to cut and sew the prosthesis is valuable time lost by the surgeons who are unable to begin surgery until the prosthesis is complete (Fowler, 2003).

2.1.4 ANOTHER METHOD FOR PRODUCING A SHAPED PROSTHESIS BY UTILIZING A STRAIGHT TUBE AND THE CUT AND SEW PROCESS

Vascutek Ltd is one of the leading designers, manufacturers and marketers of vascular products for the treatment of cardiovascular disease. The company markets a wide range of knitted and woven polyester vascular prosthetic grafts for the treatment of diseased and damaged arteries. One of their newest products was designed to replace a diseased or damaged ascending aorta. The product, known as the Gelweave Valsalva™, is a woven straight tubular fabric in which separate pieces of fabric have been sewn to one end of the tube to mimic the bulge of the human ascending aorta, see Figure 2.4 (Vascutek Ltd, 2003).

Figure 2.4 Gelweave Valsalva™ produced by Vascutek (Vascutek Ltd., 2003)



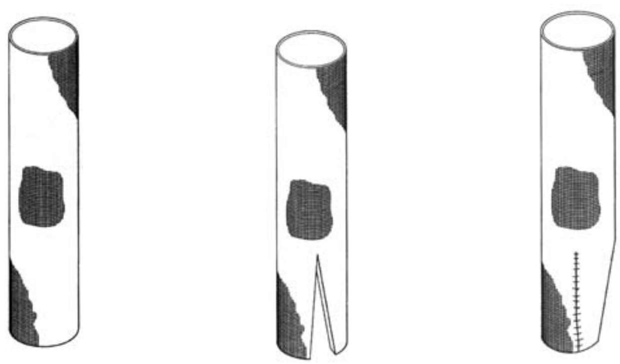
The Gelweave Valsalva™ consists of three distinct parts, a body, a skirt and a collar. The skirt and collar are hand sewn onto the body. The skirt is sited between the body and the collar of the graft. It is designed to provide compliance in a horizontal plane and recreate the anatomy of the sinuses within the aortic valve. The special design of the product allows for smooth closing of the aortic valve leaflets, superior to that obtained with standard cylindrical grafts (Vascutek Ltd, 2003).

Although the Gelweave Valsalva™ prosthetic graft produced by Vascutek Ltd. is a great improvement over a straight tube, the collar and skirt need to be cut and sewn onto the body of the tube. The production of the graft is very labor intensive and expensive. The total production time of one graft is approximately one and half days. In addition the cut and sew process is executed by humans, therefore there is always a potential for human error (Ritchie, 2004).

2.1.5 FORMING A SHAPED TUBE BY ENGAGING AND DISENGAGING SPECIFIED WARP YARNS

A seamless tubular product with gradual changes in the diameter along the length of the tube can be produced by changing the number of warp yarns during weaving. This particular method of forming a tailored-shaped tube has been utilized in medical applications, specifically where a gradual narrowing of the prosthesis at the ends is desired. When a vascular prosthesis is implanted into the body it is paramount that the external diameter of the textile tube matches the internal diameter of the body lumen very closely. The close fit allows the tube to conform to the internal surface of the body lumen. (Nunez, and Schmitt, 1999). Prior to this invention, if a diseased vessel changed from one diameter to a second diameter, the surgeon would compensate for the diameter change by cutting the straight seamless woven graft along the length, see A & B in Figure 2.5. The cut edges were then sutured back together to create a gradual diameter change at the end of the graft, see C in Figure 2.5 (Nunez, and Schmitt, 1999).

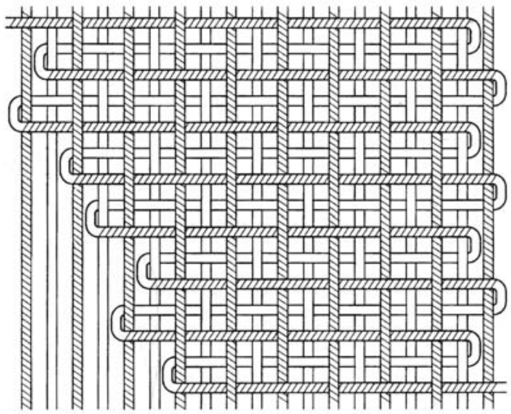
Figure 2.5 A-Straight Tube, B-Cut Tube, C-Sutured Tube to Create Taper (Nunez, and Schmitt, 1999)



A B C

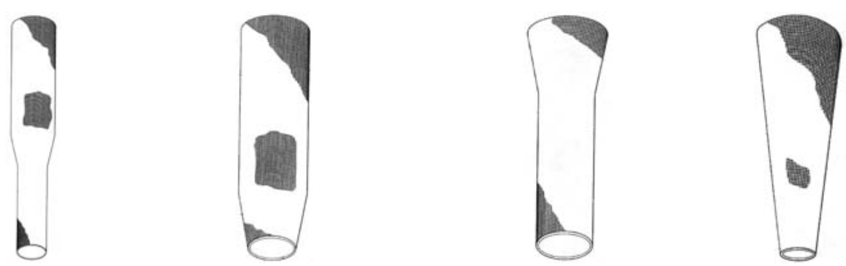
In order to eliminate the additional steps required for cutting and sewing, warp yarns are disengaged where tapering is desired. A shuttle loom equipped with a jacquard shedding motion controlled by computer aided software is required to weave the shaped tube. During the weaving process the shape is produced by dropping the desired number of warp yarns from the end of the tubular flat woven graft. As a result, the filling yarns are not interwoven across the selected warp yarns for that section of the pattern, see Figure 2.6.

Figure 2.6 Process of Disengaging Warp Yarns (Nunez, and Schmitt, 1999)



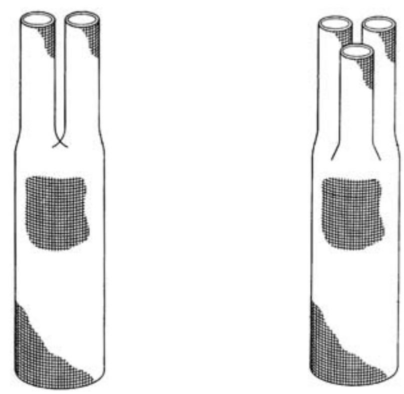
Once the transitional section has been completed the warp yarns are then re-engaged during the weaving process. After weaving, the graft undergoes a heat setting process. A variety of tapered shapes can be produced using this weaving method, see Figure 2.7 (Nunez, and Schmitt, 1999).

Figure 2.7 Examples of Tapered Shapes (Nunez, and Schmitt, 1999)



Another benefit to this method is the ability to produce split grafts such as bifurcated and trifurcated grafts, see Figure 2.8 (Nunez, and Schmitt, 1999).

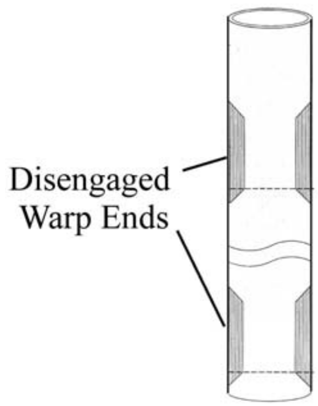
Figure 2.8 Illustration of a Bifurcated and Trifurcated Graft (Nunez, and Schmitt, 1999)



Split grafts consist of a tubular graft section that splits at a crotch area into a plurality of tubular graft sections. During the weaving process of a bifurcated graft it is necessary to split the number of warp yarns at the crotch in order to split the tubular woven graft into two or three separate tubes. The warp yarns are split evenly at the crotch during the weaving process. An odd number of warp yarns are needed to form a continuous tubular plain weave pattern. Therefore, an odd number of warp yarns are used to create the single tube. When the warp yarns are split in half at the crotch area in order to form two tubes, one tube has an odd number of warp yarns and the other tube is left with an even number of warp yarns. This results in an incorrect weave pattern at the fabric edge of one of the tubes. This invention allows one of the warp yarns to be disengaged during the weaving process which enables two tubes to be woven simultaneously both with an odd number of warp ends (Nunez, and Schmitt, 1999).

Unfortunately, this method has a number of disadvantages. In order to prevent holes in the construction, only a gradual taper can be accomplished. Holes occur when more than three warp yarns are disengaged. This results in a conduit that has excessive porosity in which sufficient blood pressure cannot be maintained. In addition, a creel is needed to hold the yarn packages of the disengaged warp ends during the weaving process. As warp ends are disengaged they desist from weaving, therefore they do not possess the same degree of crimp as the warp yarns that remain weaving. The differential crimp between the warp ends results in inconsistent tension which will lead to slackness of the disengaged yarns, ultimately causing warp end breaks. The creel helps to control tension of the disengaged warp ends. In addition, after weaving the warp ends that have been disengaged must be manually cut out which is a time consuming process and results in wasted yarn, see Figure 2.9. The benefits of this process are negated by the disadvantages, therefore unless the products performance is paramount, the traditional cutting and sewing process might be preferable.

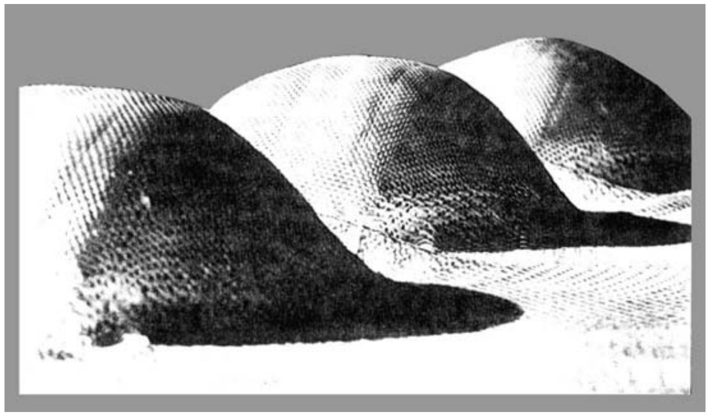
Figure 2.9 Disengaged Warp Ends (Nunez, and Schmitt, 1999)



2.1.6 WOVEN THREE DIMENSIONAL SHAPES PRODUCED DIRECTLY FROM A LOOM

In October 1995, Technical Textiles International reported on a new weaving process developed by Alexander Busgen. The author describes a weaving process in which 3-D preforms are produced directly from the loom. The process can be used to create and produce any 3-D shell shape. It is not clearly defined in the article, however, implied, that a “shell geometry” refers to a dome shape, see Figure 2.10.

Figure 2.10 Dome Shapes ("Woven 3-D Shapes…")



A variety of different shell geometry's can be produced. The preforms are intended for a number of potential applications including automotive interiors, sporting goods, medical and filtration products. A computer controlled weaving machine is used. The weaving machine is equipped with shaping devices that are fitted to the loom. The fitting devices control the length of the weft and warp ("Woven 3-D Shapes…"). In another article Busgen's process is also detailed. The author explains the process in the following quote- "areas woven too large are spaced in too small environment" (Vasavada, et al., 2001). Although not clearly explained in either article, the weft and warp yarns are most likely being over fed in areas in which a bulge is desired to create the 3-D shapes.

Initially, the yarn placement on the 3-D surface is simulated using specially developed software. The geometry, thread spacing and thread orientation can then be adjusted on the computer screen. An individual pattern system is provided for the woven shell. A special jacquard program allows weaves to be assigned to specific areas of the shell. Many variables are adjustable at the computer including number of cloth layers, inter-connections between the layers, and float length of the yarns. Weft yarns have specific insertion data that is programmed into the computer according to the desired shell shape. Warp yarns need to be run from a special creel. This is necessary for consistent warp tension because the warp yarns vary in length ("Woven 3-D Shapes…").

The author states that there are a number of drawbacks to this method. Lengthy preliminary time is needed to design and simulate the woven geometry. More complex shell shapes entail longer preliminary development time before production can begin. Another draw back is that as of 1996 there was only one prototype machine making production capacity very limited. In addition, because of the manual work that is necessary, it is a cost intensive process in which reproduction and quality control is difficult ("Woven 3-D Shapes…").

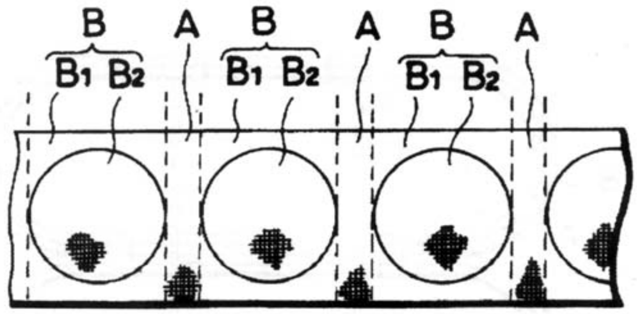
2.1.7 PRODUCING SEAMLESS SHAPED AIRBAGS

In the Japanese patent #5,707,711, a method for producing a seamless shaped air bag is detailed. The shaped bag can be produced on a dobby or jacquard loom. However, if a dobby loom were to be used, only circles with squared edges could be woven. Dobby looms have design limitations due to the number of warp ends that can be individually controlled during weaving. In jacquard weaving, every warp end can be individually controlled, therefore there are fewer design limitations than weaving on a dobby loom.

A variety of weaves have been used including a plain, twill or satin weave. Polyester or polyamide yarn can be used in the construction of the bag. The air bag is created using a combination of connected and unconnected double woven constructions. The author explains the process in the following excerpt accompanied by Figure 2.11 (Kitamura, et al., 1998).

"…first, the non-tubular weave structure **A** is formed by repeating a non-tubular weave until the predetermined length is obtained and then the tubular weave structure **B**, having the connected portion **B1** and the non-connected portion **B2** is manufactured by performing a tubular weave operation…"

Figure 2.11 Seamless Woven Air Bag (Kitamura, et al., 1998)



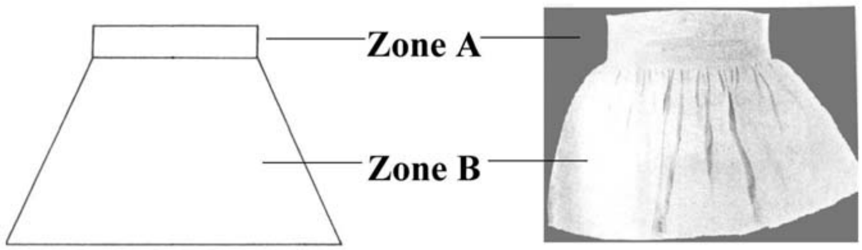
The length of the weft yarn across the width of the connected portion, **B1** is decreased and then increased in the non-connected section of **B2**. The increase in weft length during the weaving of **B2** imparts a tubular or circular shape to the area. After weaving the fabric is coated with a polymer on both sides. A hole is made in each of the non-connected areas (Kitamura, et al., 1998)

2.1.8 UTILIZING ELASTIC AND NON-ELASTIC YARNS TO CREATE GATHERS AND SHAPED GARMENTS

A study which involved the utilization of elastic and non-elastic yarns to create gathers and shape within a woven fabric was conducted in 1972 by A.P. Singh Sawhney at the Textiles Center, Texas Tech University. Singh Sawhney attempts to introduce a method of weaving he refers to as integral weaving in which an entire garment is woven on the loom. He utilizes a tubular woven construction and yarns with differential shrinkage to create "semi-ready-to-wear" garments (Singh Sawhney, 1972)

Shape and gathers are created in different areas or "Zones" of the fabric by incorporating elastic yarns. Figure 2.12 illustrates a sketch of a shaped gathered skirt and the actual product after heat-setting. In this particular example Singh Sawhney utilizes a 5-end sateen weave in both Zone A and Zone B.

Figure 2.12 Gathers Created by Utilizing Non-Elastic and Elastic Yarns (Singh Sawhney, 1972)

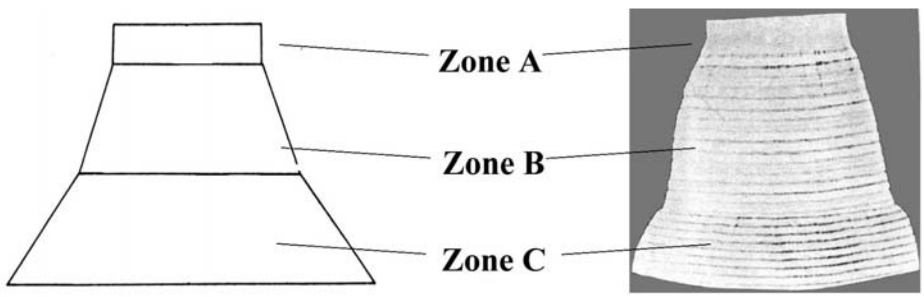


The shape and the gathers are created from non-elastic and elastic yarns. The warp is a 70 denier yarn which consists of 47% cotton, 47% wool with a 6% elastomeric fiber core. In the weft two different yarns are utilized. In Zone A, a 37 (tex) cotton/wool yarn with a 150 denier elastomeric core is utilized in the weft. The yarn causes considerable circumferential shrinkage when the fabric is in a relaxed state. In Zone B a regular 12/2 (Ne) cotton yarn which does not cause any appreciable shrinkage in the relaxed state is utilized. After heat-setting the fabric gathers are formed in Zone B, the rigid zone due to the high differential shrinkage from the elastic yarn used in Zone A (Singh Sawhney, 1972).

The varying fabric cover due to differential shrinkage in the different Zones is admittedly a potential problem. A very coarse, soft-spun cotton filling is intentionally used in Zone B in an attempt to produce an acceptable fabric cover. Singh Sawhney suggest that to produce an even more appropriate fabric cover in Zone B which would be compatible to the fabric cover in Zone A, a weave with more intersections could be used in Zone B.

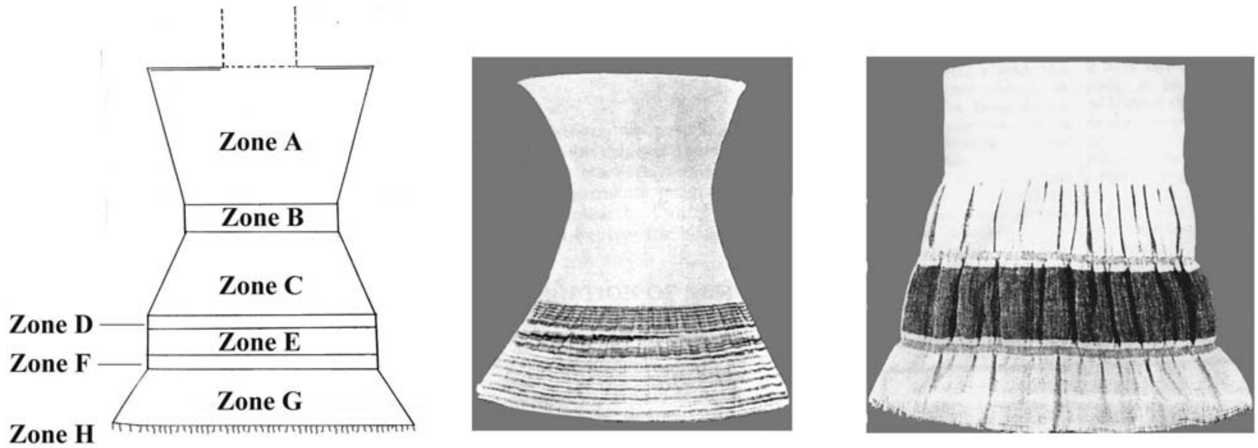
Another example of a shaped skirt created by Singh Sawhney's method is illustrated in Figure 2.13. In this example three different Zones, specifically Zone A, Zone B and Zone C are utilized to create shape. A 2x2 twill weave is used in all three of the Zones. In this example a cotton/wool blended yarn is used to produce a rigid warp. A number of different filling yarns are used. In Zone A, a double yarn consisting of a 70 denier elastomeric core, covered with a cotton/wool in equal blends is used. In Zone B two yarns are utilized, specifically a multiple yarn consisting of a 70 denier elasticomeric core, covered with a cotton/wool in equal blends and a cotton/wool blended yarn. In Zone C a cotton/wool yarn is utilized. Singh Sawhney varies the pick density in an effort to produce a comparable fabric cover. Zone A and Zone C use the same pick density, however, in Zone A the pick density is decreased to half that of Zone B and Zone C (Singh Sawhney, 1972).

Figure 2.13 Gathers Created by Utilizing Non-Elastin and Elastic Yarns (Singh Sawhney, 1972)



Using the same basic principles, Singh Sawhney attempts to produce a woman's dress, see Figure 2.14. In Figure 2.14 a sketch of the intended dress is shown as well as the unfinished dress and the dress after six hand washings. Zones A and B represent the bodice, Zones C,D,E,F,G,and H represent the skirt. A 5-end warp satin weave is used in all zones. The pick density is the same in all zones, specifically 40 picks per inch (Singh Sawhney, 1972).

Figure 2.14 Sketch of Shaped Dress, Unfinished Dress, Dress After Six Hand Washings (Singh Sawhney, 1972)



Sawhney's experiment yields some interesting shapes using simple accessible technology, however, there are a number of draw-backs. Elastomeric weft yarns are challenging to weave. Tension of the yarns needs to be controlled throughout the weaving process. A long-drop box chain is necessary when weaving long pick repeat patterns such as with the shaped dress. In addition, consistent fabric tightness is also an important consideration. Sawhney suggests strategically combining different qualities of filling yarns such as fiber type, stretch, bulk, twist, ply and size to achieve compatible fabric cover. He also suggests cramming picks and using tighter weaves with a greater number of filling intersections in more open areas. He states that the garments produced in his experiment have no significant fabric-cover problems. However, if the fabrics were to be dyed significant problems might exist.

2.1.9 UTILIZING AN ADJUSTABLE REED TO PRODUCE A SEAMLESS SHAPED TEXTILE

A number of professionals have investigated the possibility of designing an adjustable reed. The premise of an adjustable reed is that by some mechanical method the dents could be moved either further apart or closer together. As the reed was contracted or expanded the warp density would be changed without having to re-draw each warp end. A contractible reed could also be used to produce a shaped fabric. This would be accomplished by contracting the reed where narrower fabric widths were desired or expanding the reed in areas that wider widths were desired. Unfortunately, an adjustable reed has a number of inherent problems (Faber, 2002).

The term “unit” is used by professionals to refer to the thickness of the flat metal wire which comprises part of a dent, and the space between two reed dents. Reeds are designed to have a specific % of the total unit allotted to air space and a specific % of the total unit allotted to wire space. At the initial stages of design, each reed is engineered so that a fabric with specific aesthetic characteristics and physical properties can be produced. During contraction or expansion of an adjustable reed the unit is changed. Changing the unit has adverse effects on both the aesthetic and physical properties of the resulting cloth. For this reason the design and implementation of an adjustable reed has not yet been pursued (Faber, 2002).

Even if an adjustable reed was produced, some challenges might be encountered if the reed were to be utilized to create shape during the formation of a fabric. Expanding the reed to widen the width of the fabric would decrease the warp density. Decreasing the warp density would cause increased shrinkage during fabric finishing. The shape produced by expanding the adjustable reed might be negated by the increased shrinkage from the decreased warp density.

2.1.10 UTILIZING A FAN REED TO FORM A SHAPED TUBE

Fan-shaped reeds were first used in the warping process to adjust the width of the warp sheet. Before weaving a warp beam must be made. A warp beam consists of a set of warp yarns that lie parallel to one another. Collectively the warp yarns are referred to as a warp sheet. During the process of making a warp, fan-shaped reeds are used to adjust the width of the warp sheet to fit on the warp beam (Faber, 2002). Fan reeds have also been used during weaving to produce decorative fabric designs. Fan-shaped reeds can extend across the entire width of the loom, see Figure 2.15, or the reed can be made up of small multiple fan shaped reeds, see Figure 2.16.

Figure 2.15 Diagram of a Single Fan-Shaped Reed (Faber, 2002)

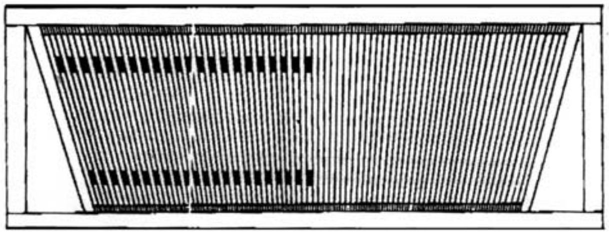
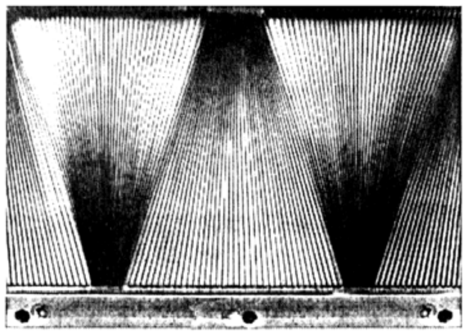
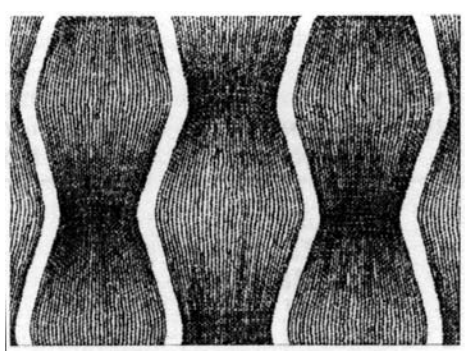


Figure 2.16 Multiple Fan-Shaped Reed (Seidl and Kellenberger, 1993)



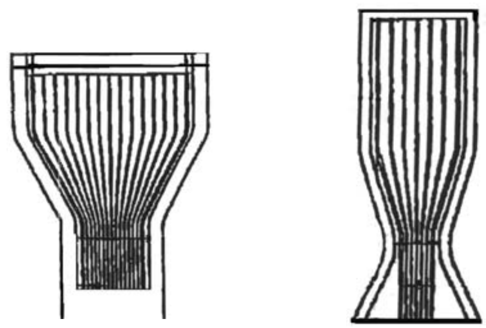
The fan-shaped reed is composed of inclined reed dents ("Fan-Shaped Reed…"). After the insertion of a specified number of picks, a lever moves the fan-shaped reed up or down. The vertical movement of the reed displaces the warp yarns within each dent. The threads are pushed sideways producing a wavy arrangement as well as varying the number of warp yarns per inch. Figure 2.17 shows the warp displacement that can be achieved using a fan-shaped reed (Seidl and Kellenberger, 1993).

Figure 2.17 Representation of the Principle of Warp Displacement (Seidl and Kellenberger, 1993)



Fan reeds can also be used to produce tubular fabrics with inherent shape. A single fan reed can be installed on a shuttle loom. The single fan reed can be lowered and raised with a lever to produce small adjustments in the warp width. A variety of seamless tubular shapes have been produced using a shuttle loom that has been equipped with a fan-shaped reed, see Figure 2.18.

Figure 2.18 Examples of Tubular Shapes Produced on a Shuttle Loom Equipped With a Fan-Shaped Reed (Faber, 2002)



Unfortunately, fan shaped reeds can only be used on looms in which the reed moves horizontally during the beat-up process. High speed looms such as air and water jet and rapier looms all have reeds that pivot during the beat-up process. During the beat-up process the pivoting motion causes the warp ends to move up and down within the dents. If a fan-shaped reed were to be used the up and down motion within an incline dent would causes the warp ends to abrade and break. In addition, the movement of the warp ends within an inclined dent would result in unintentional fabric width adjustments. For these reasons fan shaped reeds can only be used on a loom in which the reed moves horizontal during the beat-up process (Faber, 2002).

Even if a fan shaped reed were to be utilized in a loom in which the reed moved horizontally, a number of problems might be encountered. Fan shaped reeds can lead to abrading of the warp ends during weaving. The beam width is fixed, however the fabric width is changing during weaving. At the point in which the beam width is wider than the fabric width, the outer warp ends on both sides could rub on the reed, which could abrade the outer ends.

Another disadvantage to utilizing a fan reed to produce inherent shape in a woven fabric is that only a relatively small amount of shape can be achieved. The shape is achieved by moving the fan reed up and down, thereby displacing each warp end within the inclined dent. Only a relatively small amount of shape can be achieved because there is a limited incline in which reed dents can be placed. If reed dents are placed at too steep of an incline, weaving will become difficult. Therefore, if a greater degree of angle is needed the reed would have to be heightened. This would result in a heavier reed, making adjustments of the reed harder and resulting in lower loom speeds.

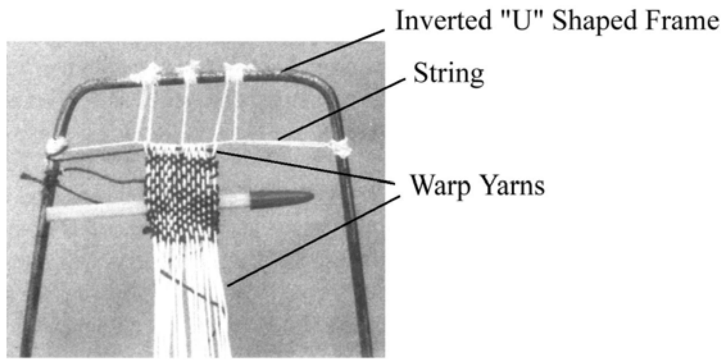
In addition, a fan shaped reed would displace the ends causing varying warp density within a fabric. Areas with less warp ends would shrink more, whereas areas with more warp ends would lead to less shrinkage. The shape produced by displacing the ends in the fan reed might be negated by the increased or decreased shrinkage caused from varying warp density.

2.1.11 HERMENEUTIC APPROACH TO A SEAMLESS TUNIC

This study was prompted by the author's fascination of a passage in St John's Bible. The passage states: "the coat was without seam, woven from top throughout." The author carefully analyzed the quote in an effort to reproduce the coat as it might have been done many centuries previously. From the statement, "woven from top throughout" the author surmises that the coat was woven on a vertical loom, which was commonly used by early civilizations (Primentas, 1997).

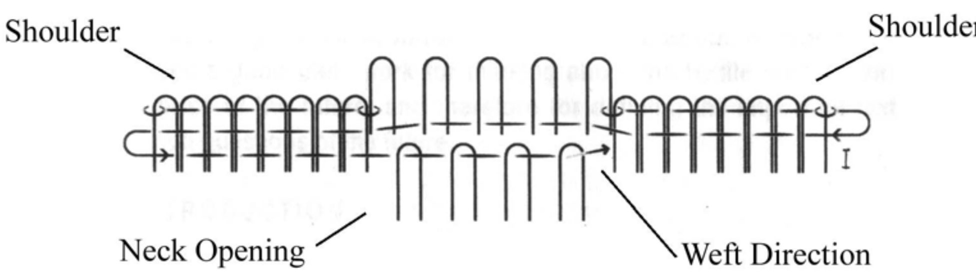
The author devised a miniature version of a vertical loom. He constructed an inverted "U" shaped frame. A string is secured tightly across at the top of the "U" shaped frame. Warp yarns are passed over the string, having one half of their length on the left side and one half of their length on the right side, see Figure 2.19.

Figure 2.19 Reproduction of a Vertical Loom (Primentas, 1997)



The ends of each warp yarn are secured to pins that are mounted to a block at the foot of the inverted "U" shaped frame. The blocks are grouped accordingly to create the appropriate shed for each pick. One shuttle is passed through designated warp yarns to form the shoulders and the neck opening, see Figure 2.20.

Figure 2.20 Shoulder and Neck Opening (Primentas, 1997)



After the shoulders and neck opening are formed a second shuttle is introduced. One shuttle creates a front piece of cloth while the other shuttle creates a back piece of cloth. These two pieces are unconnected to form the area of the coat in which the arm holes are positioned. When the required size of arm holes is accomplished, the second shuttle is removed and a tubular construction continues until the required length is woven. The method devised in this experiment is dependent on meticulous hand executed procedures. Although it is an interesting experiment, this particular method would be challenging to reproduce with today's modern equipment (Primentas, 1997).

2.2 OTHER FABRIC FORMING PROCESSES IN WHICH A TEXTILE PRODUCT WITH INHERENT SHAPE CAN BE PRODUCED

2.2.1 SHAPED KNITTING

Recently, the knit industry has undergone some major advances in the development of seamless whole garment knitting. One of the main factors for exploring and pursuing the ability to produce seamless whole garments was the "labor trap" (Millington, 2000). For a number of years the garment industry has found it difficult to compete on product price with countries that have a plethora of low wage labor available. In addition, the more labor that is required to complete the garment the more vulnerable the garment producer becomes. Interestingly, the break through of whole garment knitting has been achieved without a single new advancement in the fundamental knitting process adopted by William Lee when he invented the hand stocking frame in 1589. The basic principles of knitting remain the same (Millington, 2000).

Today, there are knitting machines that can either knit shaped panels or seamless whole garments. Knitted shaped panels can be sewn together, thereby eliminating the cutting process. The cutting and sewing process is entirely eliminated by utilizing knitting machines that produce seamless whole garments. Several machine makers of flat knitting machines are now able to produce whole seamless garments. This is accomplished by utilizing multi-needle/transfer knitting beds (Millington, 2000). The machine starts by knitting three separate tubes, two sleeves and a bodice. The three pieces are then joined under the shoulder, creating one large tube. The number of active needles is then gradually reduced, so the tube diameter decreases up to the neckline. The collar is then knitted and the garment is finished (Stoll, 1998). There are a number of advantages to full body knitting besides the elimination of the cutting and sewing process. Other advantages include the elimination of uncomfortable seams at the shoulders and underarms and the reduction of fabric waste generated during the cutting process ("Shima Seiki's…"and Stoll, 1998).

The full body knitting machines are capable of knitting numerous shapes and various structures that possess different physical and aesthetic characteristics. In addition to fashion apparel, there are many potential applications for seamless shaped multi-dimensional fabrics. Seamless shaped knitted fabrics could be used in products designed for the industrial, aerospace, automotive, medical and protective clothing industries ("Flat-Knitting…"). Unfortunately, there are some disadvantages in the manufacture of shaped knits.

The installation of machines capable of knitting full body garments has proceeded with some caution ("Flat-Knitting…"). Countries that have a large population willing to work for low wages can produce huge quantities at very low prices. The capital cost of the knitting time alone on a full body garment machine can still exceed the price that a cut and sewn knitted garment could be purchased for in China (Stoll, 1998).

There are design limitations to the full body knitting machines. Designs can not be applied to both the front and the back panels during knitting. There are also limitations concerning the type of yarns that can be used. In addition, although fabric waste is eliminated in full body knitting by eliminating the cutting process, waste can be generated through faults. If there is a fault in one of the sleeves, then the other part of the garment has to be thrown away, including the other sleeve and the front and back panels (Stoll, 1998).

In some cases knit constructions do not have the appropriate physical properties and are therefore not suited for some end uses. For example, in medical applications, specifically for implantable arterial prostheses, the performance characteristics vary according to the demands of the location in which they are used. Knitted prostheses are used because they are easy to suture and possess acceptable thrombogenicity, which is the ability to cause blood to clot. These particular characteristics make them exceptionally suitable for replacement or bypass of the abdominal aorta and iliac arteries. (Savage, et al., 1984). However, knitted vascular grafts generally have higher porosity and lower strength than woven grafts. In addition, weft knitted structures have a tendency to unravel, particularly when cut at an angle, and possess inferior dimensional stability (Hoffman, 1984). Woven grafts are characterized as having high strength and low porosity, therefore they are preferred to knitted grafts in high-pressure flow areas (Savage, et al., 1984).

2.2.2 BRAIDING

Braiding is one of the simplest and oldest forms of fabric production. A braided structure is formed by the diagonal interlacing of yarns. Braiding can be classified as either two-dimensional or three-dimensional. A two-dimensional braid can be either circular or flat. Three-dimensional braiding is relatively new and is mainly used for the production of composites (Adanur, 1995).

2.2.2.1 TWO-DIMENSIONAL BRAIDING

Crossing a number of yarns diagonally so that each yarn passes alternately over and under one or more yarns forms a two-dimensional circular or flat braid. Circular braided structures can be made in many shapes. Circular braids have a hollow center. The tube can be braided about a central core of yarns, producing a solid braid composed of a core and a sleeve. The core can be any shape. The braided structure conforms to the core making it possible to develop braided structures of many different types of complex shapes (Adanur, 1995).

Although a variety of shapes can be produced there are a number of disadvantages in the 2-dimensional circular braiding process. The size of the braid is dependent on a number of factors, one of which is the number of yarn carriers (Adanur, 1995). If a large shape is desired, numerous yarn carriers are necessary. A large number of carriers takes up a good deal of valuable manufacturing space. In addition, yarn tension becomes hard to control when numerous yarn carriers are used. Although the braided structure is suitable for a wide range of applications, there are others in which the construction is very poorly suited. When used as an implantable medical device, braided structures have a tendency to unravel when the surgeon tries to suture it (Moreland, 1997). Braided structures are also not suitable constructions for apparel.

2.2.2.2 THREE DIMENSIONAL BRAIDING

Three-dimensional braiding is relatively new compared to two-dimensional braiding. The first three-dimensional braiding machine was developed in the 1960's. The process is mostly utilized to produce structural textile composites. As of 1995 there were no commercially available three-dimensional braiding machines. The main reason for this is that every different three-dimensional braided structure requires a different machine with specific characteristics and dimensions. Therefore, companies and academic institutions custom build three-dimensional braiding machines according to their specific needs (Adanur, 1995).

An orthogonal interlacing of multi-yarn systems forms three-dimensional braided structures. In the three-dimensional braided process yarns can be interlaced to form a multilayer 3-D structure (Adanur, 1995). The three-dimensional process can produce a variety of complex shapes. However, limited control, speed, dimensions and precision are associated with the majority of machines. Although there have been recent efforts to minimize these disadvantages, improved machines are not currently commercially available (Mungalov and Bogdanovich, 2002). In addition, the three-dimensional braided structure is not suited for a variety of end-uses.

2.3 CONCLUSION

The development and production of seamless woven products that have inherent shape has great potential. There are many benefits to producing a seamless shaped woven fabric, as well as numerous new products that could be utilized in a wide variety of markets. There are a number of different methods that can be used to produce a seamless woven product that has a tailored shape. However, the majority of these methods have limitations. The methods have either limited production speeds; still require a manual operation; the process requires expensive equipment; the resulting product has structural limitations; or the product has inappropriate physical properties for the specific end use.

Shape within a fabric could be produced by utilizing specific variables, such as different pick densities, various weave constructions and yarns with different degrees of shrinkage. Most textile professionals know that utilizing these variables in a fabric construction will affect the shrinkage of the fabric during finishing. However, the potential for producing a shaped fabric by utilizing these variables has not been fully investigated, researched or well documented.

Typically these variables are carefully chosen at the beginning of the design process to produce minimal and uniform shrinkage. However, they could also be manipulated to create shape by producing differential shrinkage within the fabric when it was scoured and exposed to heat during the finishing process. Modern textile equipment has made the manipulation of these variables possible. The ability to be able to quickly and easily change and manipulate these variables before the weaving process has made it potentially possible to design shaped fabrics at high speeds and low production costs.

The amount of fabric shrinkage that occurs during finishing is not only attributed to the shrinkage behavior of fibers and yarns but also to the structural features of the fabric. It is important to note that the features that cause shrinkage are interrelated and interdependent. Collins demonstrated that the ends density and the picks density can affect the shrinkage of the fabric. These features as well as yarn size can account for shrinkage's as large as 10% or more in cotton fabrics (Collins, 1951). However, Collin's findings were never utilized to create shape. With modern weaving equipment the pick density can be quickly changed at specified areas, enabling fabrics to be woven with the same or different yarn densities. Varying degrees of tightness within the fabric can be obtained by using different filling yarn densities in a woven construction. When fewer filling threads are inserted into the fabric, the fabric is looser. When exposed to heat during the finishing process, the looser areas have more room to come in than the areas comprised of more filling yarns. This results in a higher percentage of shrinkage in the looser areas than in the areas of the fabric that consist of more filling yarns. Combinations of loose and tight pick densities could be utilized to create differential shrinkage and ultimately shape.

Another structural feature of a fabric other than yarn density that can affect fabric shrinkage is the weave design. Different weave designs could potentially be utilized to produce differential shrinkage within a fabric construction and ultimately shape. A woven fabric is formed by interlacing two yarns, the warp and weft, which lie at right angles to one another. The weave pattern is determined by the way in which the warp and filling yarns pass over and under one another or how they interlace. The differential shrinkage between weaves has to do with the number of intersections and the float length per weave repeat.

A plain weave has the maximum amount of interlacings of the weft and warp yarns. Early research on wool fabrics demonstrated that weaves with a high number of intersections such as plain weaves shrank less than weaves with fewer intersections (Johnson, 1938). This basic rule is true regardless of the fiber used in the construction of the cloth. Because twill, satin and basket weaves have fewer interlacings, they are looser weaves than a plain weave. The looser the weave or the fewer the interlacings within a weave repeat, the more room there is for the fabric to come in or shrink when it is exposed to heat during finishing. Therefore, a twill, satin or basket weave would shrink more than a plain weave constructed of the same thread density and yarns.

There are numerous variables that affect fabric shrinkage- including filling yarn density, weave design and fiber type, which affect fabric tightness and ultimately shrinkage. Typically, textile fabrics are designed with reasonable tightness to have minimal uniform shrinkage. However, to produce shape, a high shrink yarn could be used in combination with a lower shrink yarn.

The three variables discussed, specifically different pick densities, various weave constructions and yarns with differential shrinkage were investigated in an effort to create inherent shape within the fabric, by producing differential shrinkage. In the next section (Part III) of this research, weaving trials were executed in order to examine the possibility of creating shape by utilizing the three variables.

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PART III:

FORMING NARROW WIDTH TUBULAR CONSTRUCTIONS WITH INHERENT SHAPE

3.0 INTRODUCTION

In this study weaving trials were undertaken in an effort to produce a variety of seamless shaped woven tubular fabrics. There are a number of different ways in which a seamless woven product with a tailored shape can be produced. However, the majority of these methods have limitations. To achieve the goal, three variables were examined. The intention was to create differential shrinkage during the finishing process, ultimately producing inherent shape within the fabric. The methods used in the study were designed to minimize the previous drawbacks encountered in other experiments, specifically limited production speeds and the need for expensive equipment. The proposed experimental method could potentially lead to the design and production of seamless shaped products that would be suitable for a wide variety of applications in many diverse markets including medical, apparel, automotive, aerospace and industrial. The following text details the study in which different filling yarn densities, different weave designs and filling yarns with different degrees of shrinkage were utilized in a woven tubular construction in an effort to create shape.

Two looms were utilized to create a variety of different woven tubular samples with inherent shape. The specifications used to produce each set of samples from the two different looms will be detailed individually. The studies are distinguished by the looms in which the samples were woven, specifically the Muller LN 59317A shuttle weaving machine (Set One) and the AVL industrial dobby weaving machine (Set Two).

3.1 TRIALS CONDUCTED ON THE MULLER LN 59317A

The Muller LN 59317A loom was utilized to produce a variety of narrow width fabric samples with inherent shape. In an effort to create shape, different combinations of the three variables were examined, specifically different weft yarn densities, different weave designs and yarns with different degrees of shrinkage in a tubular construction.

3.1.1 EXPERIMENTAL PROCEDURE

3.1.1.1 MATERIALS

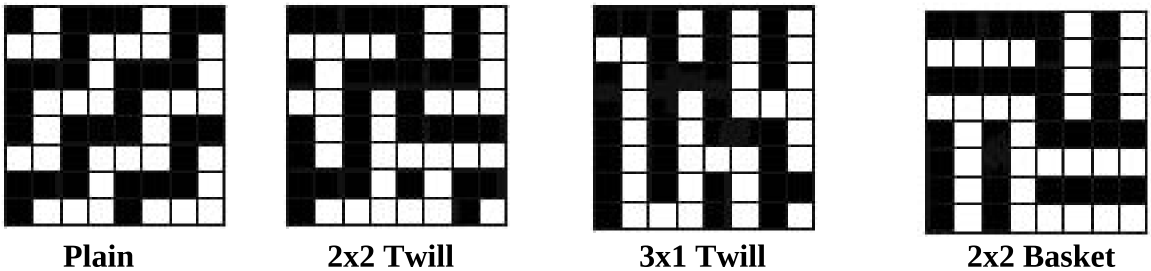
Two different filling yarns were utilized, specifically a high shrink 200 denier partially oriented polyester yarn (POY), and 70 denier textured polyester yarn. The warp consisted of the 70 denier textured polyester yarn. The yarns were tested for shrinkage using the ASTM D 2259-02 test method (Standard Test Method for Shrinkage of Yarns**,** 2002). The yarns were tested following the dry heat and the boil method. In the ASTM 2259-02 procedure it specifies that the tension force be calculated corresponding to 0.5 cN/tex. After consulting an expert, this was believed to be a mistake and a 0.05 cN/tex was used instead (Pegram, 2003). A specific temperature and time is not specified in the dry method of the ASTM D 2259-02. It is recommended that the parties involved with testing agree upon these two specifications. After consulting an expert in the field of yarn shrinkage, the polyester yarns were tested at 190°C for 30 minutes (Petit, 2003). A 40 wrap skein was used (Petit, 2003).

When measuring the pre-length of the POY, it stretched under tension greater than a 500 gram weight. Therefore, it was recommended that a 500 gram weight be used to measure the pre and post lengths of the POY yarn skeins (Pegram, 2003).

3.1.1.2 WEAVE DESIGNS

In an effort to produce shaped tubular fabrics, four different tubular double cloth constructions were utilized, namely a plain, 2x2 basket, 2x2 twill and 3x1 twill weave designs. These weaves were chosen because previous experiments have shown that basket weaves shrink more than twill weaves and twill weaves shrink more than plain weaves. In addition, the choice of weave designs was limited due to the number of harnesses on the Muller LN 59317A loom. The weave designs are detailed in Figure 3.1.

Figure 3.1 Double Cloth Weave Designs Used in Set One



3.1.1.3 WEFT THREAD DENSITIES

The maximum and minimum filling yarn density of the 70 denier yarn was determined for each of the four weave designs. The minimum filling yarn density of the 200 denier yarn was also determined for each weave design. The maximum filling yarn density is the highest possible number of picks that can be woven for a given weave and yarns using a particular weaving machine. The maximum filling yarn density can be calculated, however in these trials the maximum filling yarn density was based on the capabilities of the loom. The minimum filling yarn density was decided subjectively based on sample integrity. Filling yarn densities below the minimum would produce an unstable fabric. Table 3.1 details the thread densities used.

Table 3.1 Maximum and Minimum Pick Density for the Filling Yarns of Each Weave Design Woven on the Muller Weaving Machine

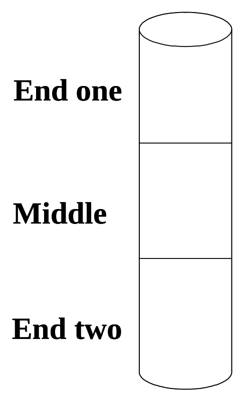
Weave Design (Double Cloth)	Maximum picks/cm 70 denier Polyester filling	Minimum picks/cm 70 denier Polyester filling	Minimum picks/cm 200 denier Polyester filling
Plain	20.87	13.77	11.81
2x2 Twill	31.50	18.11	14.96
3x1 Twill	33.07	18.11	15.75
2x2 Basket	33.07	19.86	15.75

3.1.1.4 FABRIC FORMATION

Samples were woven on a Muller LN 59317A shuttle weaving machine**.** The reed was 4.44 cm wide with a total of 60 dents. 4 ends were threaded through each dent to produce a total of 240 ends. Warp yarns were threaded through eight harnesses in a straight draw configuration.

Tubular samples were designed to have two identical end sections and a middle section, see Figure 3.2. The two end sections were designed with a set of variables that would maximize shrinkage. The middle section was designed with a set of variables that would minimize shrinkage.

Figure 3.2 Tubular Design of Samples Woven on the Muller Loom



A total of 12 samples were woven to assess the amount of shrinkage that could be obtained utilizing different combinations of the three variables, specifically, different weave designs, different pick densities and two weft yarns with different degrees of shrinkage. Table 3.1A lists the sample fabrics that were woven and the set of variables used to construct each sample, see Appendix A.

3.1.1.5 FABRIC FINISHING

Fabric samples were submerged in a 60°C water bath containing a surfactant and soda ash for 30 minutes. During the 30 minutes the samples were agitated by manual stirring, followed by a thorough rinse and then air dried. The samples were turned inside out and the process was repeated.   The samples were then heat set on a Mathis steamer in a relaxed state at 120°C for 30 minutes (King, 2002).

3.1.1.6 EVALUATION

Specific measurements were taken before and after the finishing process of the ends and middle sections from each sample. The following formula was used to calculate the percentage of width shrinkage (*S*) in the end and middle sections that occurred after the finishing process:

Formula 3.1 Percentage of Width Shrinkage

$$S_{wf} = \frac{(W_l - W_f)*100}{W_l}$$

Where

W_l = Flattened fabric width before finishing, and

W_f = Finished fabric width

In addition, the finished flattened width dimensions of each section were compared and evaluated to determine the difference. The percent difference between the finished flattened width of the end sections and the finished flattened width of the middle section of some samples were calculated and evaluated. Formula 3.2 was used to calculate the percent difference (*D*) between the sections.

Formula 3.2 Percent Difference Between the Finished Flattened Width of the End Sections and the Finished Flattened Width of the Middle Sections

$$D = \frac{(W_{middle} - W_{end})*100}{W_{middle}}$$

Where W_{middle} =Finished fabric width of the middle sections, and

W_{end} =Finished fabric width of the end sections

3.1.2 RESULTS AND DISCUSSION

In order to create shape in a woven structure without cutting or sewing or using any seams of any type three variables were examined. These variables can be manipulated to cause different amounts of shrinkage within the fabric structure. Only the results of width shrinkage are reported due to: (1) the results showed that the width shrinkage is significantly higher than the length shrinkage and (2) in this study the sample shape is mostly impacted by the width shrinkage. It should be mentioned here that the length shrinkage is an important design parameter in determining the finished length of each section of the sample.

The end and middle dimensions of each of the fabric samples produced on the Muller LN 59317A were taken at the widest part of the sample. The results produced from utilizing each of the three variables and different combinations of the three variables within the fabric construction will now be reviewed.

3.1.2.1 UTILIZING DIFFERENT WEFT YARN DENSITIES

Four samples were woven in order to evaluate the amount of shape that could be produced using different weft yarn densities. The weave design was constant.

A loose pick density was utilized in the two end sections of all four samples to maximize shrinkage. In the middle section a higher pick density was used to obtain less shrinkage as compared to the end sections. All samples were constructed with the 70 denier textured polyester yarn. Table 3.2 details the weave design, weft yarn density and the flattened width dimensions before and after finishing.

Table 3.2 Weave Design, Pick Density, and Flattened Width Dimensions Before and After Finishing of Samples 1, 2, 3 and 4

Section	Sample ID	Weave Design	Pick Den cm^{-1}	Flattened Width Before Finishing (cm)	Flattened Width After Finishing (cm)
End One	1	Plain	13.77	3.5	3.2
	2	2x2T	18.11	3.3	2.7
	3	3x1T	18.11	3.0	2.6
	4	2x2Bas	19.68	2.9	2.2
Middle	1	Plain	20.87	3.4	3.2
	2	2x2T	31.50	3.1	2.7
	3	3x1T	33.07	2.8	2.5
	4	2x2Bas	33.07	2.6	2.0
End Two	1	Plain	13.77	3.5	3.2
	2	2x2T	18.11	3.3	2.7
	3	3x1T	18.11	3.0	2.6
	4	2x2Bas	19.68	2.9	2.2

Note-T= Twill, Bas= Basket

It is interesting to note that there is a difference in the flattened width dimensions between the end sections and the middle section before finishing. In all of the four samples, before finishing, the end sections have a larger flattened width than the middle section. The change in the dimensions between the sections that occurred before finishing can possibly be attributed to inappropriate warp yarn tension.

As predicted, the end sections with the looser filling yarn density did shrink more than the middle sections during the finishing process. However, the end sections did not shrink enough to produce any significant difference in the width dimensions of the end and middle sections in any of the four samples. The amount of shrinkage that occurred in the end and middle sections after finishing is detailed in Table 3.3. The percent difference of the finished flattened width dimensions between the end and the middle sections is also detailed in Table 3.3.

Table 3.3 Width Shrinkage of the End and Middle Sections and D* of Samples 1, 2, 3 and 4

Sample ID	Weave Design	Shrinkage of End Sections	Shrinkage of Middle Sections	D*
1	Plain	8.57	5.88	0
2	2x2 T	18.2	12.9	0
3	3x1 T	13.33	10.7	4.0
4	2x2 Bas	24.0	23.0	10.0

Note-T= Twill, Bas= Basket

*** See Equation 3.2**

It can be observed that changing weft yarn density alone resulted in no difference in the finished flattened width dimension of the end and middle sections of samples 1 and 2. This was unexpected and most likely is due to insufficient warp yarn control. These samples were constructed with the plain and 2x2 twill weaves, respectively. Samples 3 and 4, which were constructed with 3x1 twill and a 2x2 basket weaves, respectively resulted in a finished flattened middle width dimension that was less than the finished flattened end width dimensions. Sample 3 which was constructed with a 3x1 twill had a 4% difference in the finished ends and middle sections, and sample 4, constructed with the 2x2 basket weave had a 10% difference in the flattened width dimensions of the end and middle section.

3.1.2.2 UTILIZING DIFFERENT WEFT YARN DENSITIES AND DIFFERENT WEAVE DESIGNS

Two samples were woven to evaluate the degree of shrinkage that could be produced utilizing different weft yarn densities and different weave designs. Three different weave designs were utilized, specifically a plain, twill and basket weave. Differential shrinkage between weaves has to do with the number of intersections and the float length per weave repeat. A plain weave has the maximum amount of interlacings of the weft and warp yarns. Weaves with a high number of intersections such as plain weaves shrink less than weaves with fewer intersections (Johnson, 1938). This basic rule is true regardless of the fiber used in the construction of the cloth. Because twill and basket weaves have fewer interlacings, they are looser weaves than a plain weave. The looser the weave or the fewer the interlacings within a fabric, the more room there is for the fabric to come in or shrink when it is exposed to heat during finishing.

To maximize shrinkage in the end sections a 3x1 twill and a 2x2 basket weave were used. A plain weave was utilized in the middle section of both samples. Both samples were constructed with the textured 70 denier in the weft. The weave designs, different weft yarn densities and the flattened width dimensions before and after finishing of samples 5 and 6 are detailed in Table 3.4.

Table 3.4 Weave Design, Pick Density, and Flattened Width Dimensions Before and After Finishing of Samples 5 and 6

Section	ID	Weave Design	Pick Den cm^{-1}	Flat Width Before Finishing (cm)	Flat Width After Finishing (cm)
End One	5 6	3x1 T 2x2 Bas	18.11 19.68	3 2.5	2.7 2.2
Middle	5 6	Plain Plain	20.87 20.87	3.3 3.1	3 2.8
End Two	5 6	3x1 T 2x2 Bas	18.11 19.68	3 2.5	2.7 2.2

Note-T= Twill, Bas= Basket

After finishing, sample 5 had a 10% difference between the middle and end sections. Sample 6 had a 21.4% difference between the middle and end sections after finishing, which resulted in a noticeable shape. Figure 3.3 shows a photograph of sample 6 and details the variables utilized to construct the sample.

Figure 3.3 Photograph of Sample 6 Along With Filling Yarn, Weave Design, On-loom Pick Density, and Flattened Width Dimensions (After Finishing) of Each Section

Section	Yarn	Weave	Pick Den, cm^{-1}	Flat Width, cm	Sample
					6
End 1	70 den	2x2 Basket	19.68	2.2	
Middle	70 den	Plain	20.87	2.8	
End 2	70 den	2x2 Basket	19.68	2.2	
Percent difference in dimensions between the end sections and the middle section					21.4

Note den = denier

As expected, the differential shrinkage that occurred in sample 6 can be attributed to the differential shrinkage between the 2x2 basket weave and the plain weave. Previous research has demonstrated that basket weaves have a greater capacity to shrink than satin and twill weaves (Brierley, 1931). This explains why the 2x2 basket weave had considerable shrinkage during finishing compared to the 3x1 twill weave. The higher shrinkage of basket weaves is attributed to the way in which the warp and weft yarns are interlaced. In basket weaves, filling (or warp) yarns are woven in groups, while in other weaves the yarns are individually woven. This permits the warp and the weft yarns within the basket weave construction to override one another during weaving and fabric finishing, resulting in a higher shrinkage than in other types of weaves.

3.1.2.3 UTILIZING DIFFERENT WEFT YARN DENSITIES AND WEFT YARNS WITH DIFFERENT DEGREES OF SHRINKAGE

Before the weaving trials, the two yarns used in this experiment, specifically the POY 200 denier polyester yarn and the textured 70 denier polyester yarn were tested for shrinkage following the ASTM D 2259-02 test method for both the dry heat and the boil procedure. The results are shown in Table 3.5.

Table 3.5 Results from the ASTM D 2259-02 Yarn Shrinkage Tests

Yarn	Method	Shrinkage (%)
70 denier textured polyester	ASTM D 2259-02 Dry	5.88
70 denier textured polyester	ASTM D 2259-02 Boil	2.94
High shrink 200 denier polyester	ASTM D 2259-02 Dry	51.47
High shrink 200 denier polyester	ASTM D 2259-02 Boil	49.41

A POY was used because of its high shrinkage characteristics. There are various commercial polyester melt-spinning processes that produce yarns with different degrees of molecular orientation in the spun fiber. Polyester spinning processes that operate at speeds of 500-1500 m/min produce a low oriented spun yarn (LOY). Processes operating at speeds of 1500-2500 m/min produce a medium oriented yarn (MOY). Processes operating at speeds of 2500-4000 m/min produce a partially oriented yarn (POY) (Davis and Talbot 1990).

In the last twenty five years the importance of POY has grown rapidly. The higher process speeds of POY have increased the productivity of the spinning heads. Polyester yarns processed at lower spinning speeds undergo morphological changes when stored, therefore they are not age stable. POY is processed at higher spinning speeds which gives it more molecular orientation than yarns processed at lower speeds. The greater degree of orientation in POY makes it more age-stable (Clayton et al., 1976).

POY is also suitable for use in simultaneous draw texturing as opposed to the sequential draw-texturing process. In the sequential draw-texturing process the two steps are carried out separately. In the simultaneous process the drawing and texturing processes are carried out together. The simultaneous process is preferable because it eliminates the need for two heated zones. Because of the amorphous, unoriented nature of the lower spun yarns they are difficult to run in the simultaneous process. Yarns spun at higher speeds have a greater molecular orientation and therefore are suitable to the simultaneous draw texturing process (Clayton et al., 1976).

POY is made up of oriented and unoriented amorphous regions and crystalline regions. Shrinkage results from a disorientation of the oriented amorphous regions (Bhatt and Bell, 1976). Because of the amount of amorphous regions in POY, it is considered to be unstable. However, POY was used in this experiment because it was easily obtainable and a stable yarn with comparable shrinkage could replace the POY if the trials were successful.

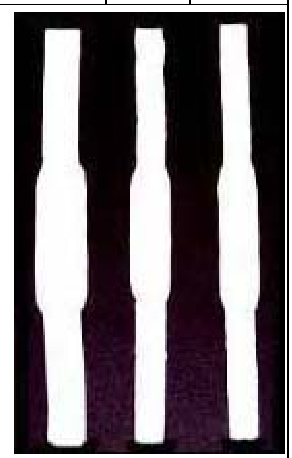
It can be observed that in both the dry heat and boil shrinkage tests that the 200 denier POY has a comparably higher shrinkage than the 70 denier textured polyester yarn.

Samples 1A, 2A, 3A and 4A were woven utilizing two variables, namely filling yarns with differential shrinkage and different filling yarn densities. Each of the four samples was constructed with a different weave design. To compare and contrast the amount of shape produced from the two variables utilized, the percent difference between the end and middle sections was calculated.

Out of the four samples, sample 4A, which was constructed with a 2x2 basket weave, had the smallest percent difference between the finished flattened width of the middle and end sections. The flattened finished width dimension of the end sections was 1.6 cm and the flattened finished width dimension of the middle section was 2 cm. This resulted in a 20% difference between the end and middle sections. Sample 1A had a

30.3% difference between the end and middle sections and samples 2A and 3A had a 30.7% difference. From this data it can be concluded that about the same amount of shape was produced from the variables used to construct samples 1A, 2A and 3A. Photographs of the samples with the greatest difference in dimensions, 1A, 2A and 3A are shown in Figure 3.4. The parameters used in each of the three sections (i.e., end one and two and the middle section) of all four samples are detailed to the left.

Figure 3.4 Photograph of Samples 1A, 2A & 3A Along With Filling Yarn, Weave, On-Loom Pick Density and Flattened Width Dimensions (After Finishing) of Each Section

<table>
<tr><th rowspan="2">Section</th><th rowspan="2">Yarn</th><th rowspan="2">Weave</th><th rowspan="2">Pick Den, cm^{-1}</th><th rowspan="2">Flat Width, cm</th><th colspan="3">Sample</th></tr>
<tr><th>1A</th><th>2A</th><th>3A</th></tr>
<tr><td>End 1</td><td>HS, 200 den</td><td>1A- Plain
2A- 2x2 T
3A- 3x1 T
4A-Bas</td><td>1A - 11.81
2A - 14.96
3A - 15.75
4A - 15.75</td><td>1 A - 2.3
2 A - 1.8
3 A - 1.8
4A - 1.6</td><td colspan="3" rowspan="3"></td></tr>
<tr><td>Middle</td><td>70 den</td><td>1A- Plain
2A- 2x2 T
3A- 3x1 T
4A - Bas</td><td>1A- 20.87
2 A - 31.50
3 A -33.07
4A -33.07</td><td>1 A - 3.3
2 A - 2.6
3 A - 2.6
4A - 2</td></tr>
<tr><td>End 2</td><td>HS, 200 den</td><td>1A- Plain
2A- 2x2 T
3A- 3x1 T
4A - Bas</td><td>1 A - 11.81
2 A - 14.96
3 A - 15.75
4A -15.75</td><td>1 A - 2.3
2 A - 1.8
3 A - 1.8
4A - 1.6</td></tr>
<tr><td colspan="5">Percent difference in dimensions between the end sections and the middle section</td><td>30.3</td><td>30.7</td><td>30.7</td></tr>
</table>

Note-T= Twill, Bas= Basket and den= denier

3.1.2.4 UTILIZING DIFFERENT WEFT YARN DENSITIES, DIFFERENT WEAVE DESIGNS AND WEFT YARNS WITH DIFFERENT DEGREES OF SHRINKAGE

Three variables were utilized in the construction of samples 5A and 6A in an effort to create shape. In order to maximize shrinkage in the end sections, the 200 denier high shrink filling yarn was used with a loose filling yarn density, as well as a loose weave design. The middle sections were constructed with the lower shrink 70 denier yarn, a tight filling yarn density and a tight weave to minimize shrinkage. Of the twelve samples detailed thus far, samples 5A and 6A obtained the greatest degree of shape. The variables utilized to construct these two samples allowed the highest dimensional difference between the end and middle sections (35.5% and 43.3 % for samples 5A and 6A, respectively). Figure 3.5 details the parameters used to construct samples 5A and 6A.

Figure 3.5 Photographs of Samples 5A & 6A Along With Filling Yarn, Weave, On-Loom Pick Density and Flattened Width Dimensions (After Finishing) of Each Section

Section	Yarn	Weave	Pick Den, cm^{-1}	Flat Width, cm	Sample	
					5A	6A
End 1	HS, 200 den	5A- 3x1 T 6A- 2x2 B	5A- 15.75 6A- 15.75	5A- 2.0 6A- 1.7		
Middle	70 den	5A- Plain 6A- Plain	5A- 20.87 6A- 20.87	5A- 3.1 6A- 3.0		
End 2	HS, 200 den	5A- 3x1 T 6A- 2x2 B	5A- 15.75 6A- 15.75	5A- 2.0 6A- 1.7		
Percent difference in dimensions between the end sections and the middle section					35.5	43.3

Note-T= Twill, B = Basket and den= denier

3.2 TRIALS CONDUCTED ON THE AVL INDUSTRIAL DOBBY

The AVL industrial dobby loom was utilized to produce a variety of tubular fabric samples with inherent shape. The samples woven on the AVL loom were wider than the samples woven on the narrow width Muller loom. The samples produced on the AVL loom would be suited to other types of end-uses than the samples woven on the Muller loom. In an effort to create shaped samples through differential shrinkage, different amounts of high shrink yarn were used in combination with a lower shrink yarn within the fabric construction.

3.2.1 EXPERIMENTAL PROCEDURE

3.2.1.1 MATERIALS

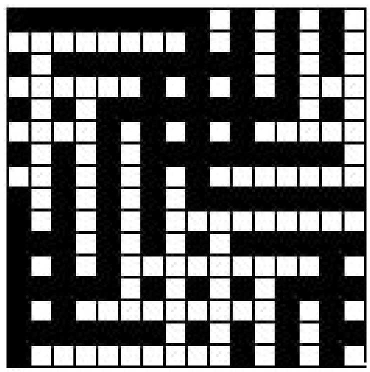
Two different filling yarns, specifically a high shrink textured 140 denier 4 ply (total of 560 denier) nylon and a 300 denier 2 ply (total of 600 denier) textured polyester yarn were utilized. The warp consisted of the 300 denier 2 ply polyester yarn. The yarns were tested for shrinkage using the ASTM D 2259-02 test method (Standard Test Method for Shrinkage of Yarns). Both the dry heat and boil procedure were used to test the yarns for shrinkage. In the ASTM 2259-02 procedure it specifies that the tension force be calculated corresponding to 0.5 cN/tex. After consulting an expert this was believed to be a mistake and a 0.05 cN/tex was used instead (Pegram). A specific temperature and time is not specified in the dry method of the ASTM D 2259-02. As stated earlier, it is recommended that the parties involved with testing agree upon these two specifications. After consulting an expert in the field of yarn shrinkage, the polyester yarn was tested in a dry oven at 190°C for 30 minutes (Petit, 2003). The nylon yarn was tested in a dry oven at 150°C for 30 minutes. A 40 wrap skein was used (Petit, 2003).

Due to conflicting results, the nylon was tested at 60 minutes at 150°C. The nylon was also retested before it was plied at 150°C for 30 minutes.

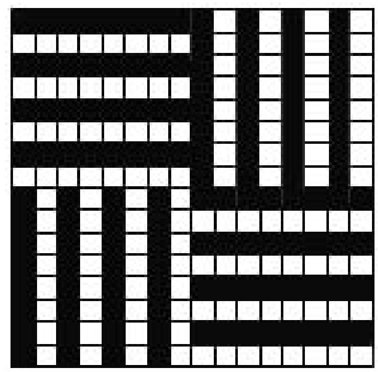
3.2.1.2 WEAVE DESIGNS

Two different tubular double cloth constructions were utilized, namely a 4x4 basket weave, and a 4x4 twill weave. The weave designs are detailed in Figure 3.6.

Figure 3.6 Double Cloth Weave Designs Used in Set Two



4x4 Twill



4x4 Basket

3.2.1.3 WEFT THREAD DENSITIES

A constant filling yarn density of 10.63 picks/cm was utilized in all the tubular samples woven on the AVL industrial dobby loom.

3.2.1.4 FABRIC FORMATION

Samples were woven on an AVL industrial dobby weaving machine. The reed was 68.6 cm wide and had 15.35 dents/cm. Only 25.4 cm of the reed was utilized. Two ends were threaded through each dent to produce a total of 30.7 ends/cm. A straight draw configuration was used. A total of sixteen harnesses were utilized.

Two different pick patterns were utilized. One pick pattern was comprised of six different repeats. The other pick pattern was comprised of nine distinct repeats. Each pick pattern incorporated different combinations of high shrink and lower shrink yarn in an effort to produce tubular samples with varying degrees of taper along the length.

Table 3.8 and Table 3.9 detail the two different pick pattern repeats and the amount of fabric woven of each repeat.

Table 3.6 First Pick Pattern Repeat

Section	Pick Pattern	Fabric Length (cm)
1	All HS	12.70
2	2 HS & 1 LS	7.62
3	1 HS & 1 LS	7.62
4	1 HS & 2 LS	7.62
5	All LS	12.70
6	All HS	12.70

Note: HS = High Shrink
LS = Lower Shrink

Table 3.7 Second Pick Pattern Repeat

Section	Pick Pattern	Fabric Length (cm)
1	All LS	12.70
2	7 LS & 1 HS	7.62
3	6 LS & 2 HS	7.62
4	5 LS & 3 HS	7.62
5	4 LS & 4 HS	7.62
6	3 LS & 5 HS	7.62
7	2 LS & 6 HS	7.62
8	1 LS & 7 HS	7.62
9	All HS	12.70

Note: HS = High Shrink
LS = Lower Shrink

A total of three samples will be detailed in this study. Two samples were woven utilizing the first pick repeat pattern. One of the samples was constructed with the double cloth 4x4 twill weave design and the other sample was constructed with the 4x4 double cloth basket weave design. The third sample was woven utilizing the second pick repeat pattern. A double cloth 4x4 twill weave was utilized.

3.2.1.5 FABRIC FINISHING

Fabric samples were submerged in a 60°C water bath containing a surfactant and soda ash for 30 minutes. During the 30 minutes the samples were agitated by manual stirring, followed by a thorough rinse and then air dried. The samples were turned inside out and the process was repeated. Fabric samples were dried at 90°C for 30 minutes. The samples were then heat-set on a Fleissner through air dryer at 170°C for 30 seconds (Gunn, 2002).

3.2.1.6 EVALUATION

The width dimensions were taken before and after the finishing process for each section of the three samples. From this data the percent shrinkage of the width was determined and compared to the amount of high shrink yarn utilized in each section. Formula 3.3 was used to calculate the percentage of width shrinkage (*S*) in each section:

Formula 3.3 Percent Shrinkage of the Fabric Width

$$S_{fab} = \frac{(W_{ol} - W_f)*100}{W_l}$$

Where W_{0l} = On-loom fabric width (warp width in the reed), and

W_f = Finished fabric width

3.2.2 RESULTS AND DISCUSSION

A number of successful seamless shaped tubular fabrics were woven utilizing different amounts of high shrink yarn in combination with a lower shrink yarn. The combinations of yarns produced a variety of interesting shapes with varying degrees of taper. Only the results of width shrinkage are reported due to: (1) the results showed that the width shrinkage is significantly higher than the length shrinkage and (2) the sample shape is mostly impacted by the width shrinkage.

Two tubular samples were woven utilizing the first pick repeat pattern. The samples will be referred to as 1B and 2B. A high shrink 4 ply 140 denier (total 560 denier) yarn was used in combination with a lower shrink 300 denier 2 ply (total 600 denier) yarn. Before the weaving trials, each yarn was tested for shrinkage using the ASTM D 2259-02 standard test method. The yarns were tested using both the dry heat and boil procedure. Initially each yarn was tested at the temperatures specified in the Experimental Procedure section for 30 minutes. The results are detailed in Table 3.8.

Table 3.8 Results from the ASTM D 2259-02 Shrinkage Test

Yarn	Method	% Shrinkage
High shrink 140 denier 4 ply nylon	**ASTM D 2259-02 Dry**	**7.82**
High shrink 140 denier 4 ply nylon	**ASTM D 2259-02 Boil**	**27.21**
300 denier 2 ply polyester	**ASTM D 2259-02 Dry**	**11.76**
300 denier 2 ply polyester	**ASTM D 2259-02 Boil**	**10.59**

The results from the ASTM 2259-02 boil method clearly demonstrated that the nylon had a higher shrinkage than the polyester. The dry heat method resulted in 7.82% shrinkage of the nylon yarn. It was anticipated that the nylon yarn would result in a higher percent shrinkage in both the dry heat and the boil procedure. Due to the unexpected results the nylon yarn was tested again for 60 minutes at 150°C. In addition, a sample of the unplied nylon yarn was tested following the ASTM 2259-02 dry method at 150°C for 30 minutes. After 60 minutes the plied nylon yarn increased in shrinkage to 11.5% shrinkage. After 30 minutes the unplied yarn had 15% shrinkage. From these results it was surmised that more time was required to get an accurate shrinkage of the nylon yarn.

Two samples were woven utilizing the first pick repeat detailed in Table 3.6. The samples were constructed with two different double cloth constructions, specifically a 4x4 twill and a 4x4 basket weave. After the samples were heat-set the width dimensions were taken for each of the six sections. The dimensions were taken at the point of transition from one section to another on all sections except section five. The width dimension in section five was taken at the widest part of the sample. The reason for taking the width dimension at the widest point in this particular section was because section five was composed entirely of the lower shrink polyester. Section five was followed by section six, which was composed entirely of the higher shrink nylon. The juxtaposed position of these two sections resulted in section five having a drastic reduction in width as it approached section six. Sections one through four had gradual taper because there was a gradual introduction of the lower shrink polyester yarn.

The finished width dimensions for each of the six sections were compared to the on-loom dimensions and the percent shrinkage was calculated. The results can be seen in Table 3.9.

Table 3.9 Section, Finished Width Dimensions and Percent Shrinkage of Samples 1B and 2B Woven with the First Repeat Pattern

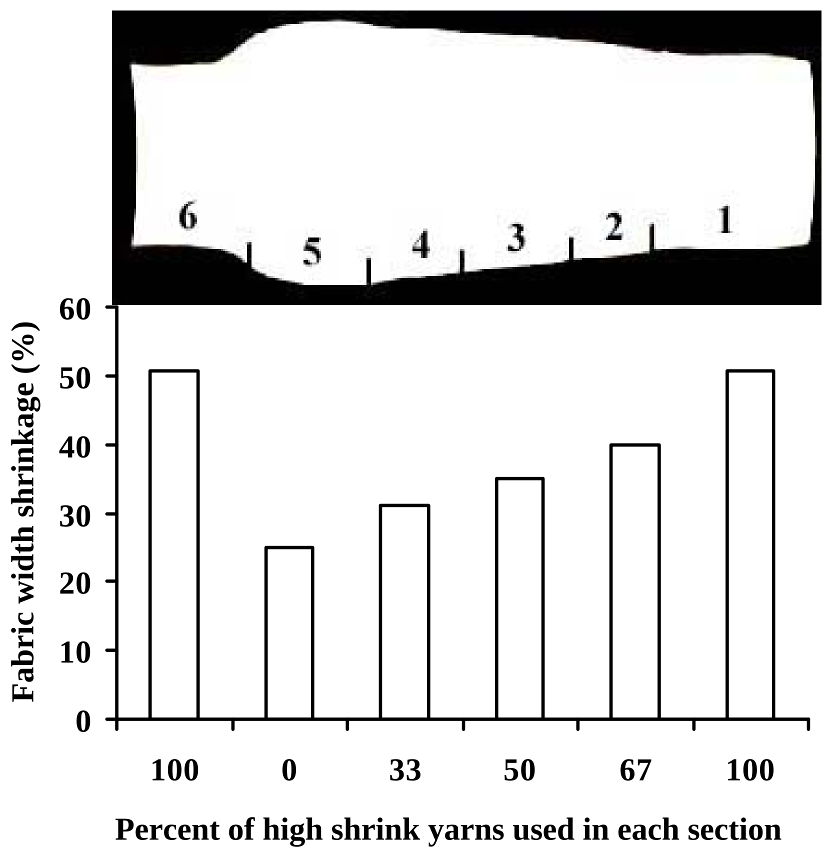
Section	Finished Width Dimension (cm)		Percent Width Shrinkage (%)	
	1B	2B	1B	2B
1	12.5	12.5	50.79	50.79
2	15	15	41	41
3	16	15.5	37	39
4	17.5	16.5	31	35
5	19	17.5	25	31
6	12.5	12.5	50.79	50.79

Note-On-Loom Width Dimension = 25.4 cm

Both samples 1B and 2B are approximately 50 cm long. From the results it can be noted that there was only a slight difference in the amount of shrinkage between the sections of samples 1B and 2B. As expected sample 2B which was constructed with a 4x4 basket weave shrank slightly more than sample 1B, which was constructed with a 4x4 twill. As stated earlier basket weaves shrink more than twill or satin weaves. The higher shrinkage of basket weaves is attributed to the way in which the warp and weft yarns are interlaced. In basket weaves, warp (or filling) yarns are woven in groups, while in other weaves the yarns are individually woven. This permits the warp and the weft yarns of a basket weave to come in closer as compared to other types of weaves (Brierley, 1931).

The finished flattened dimensions of the width of both samples illustrates that there is a direct correlation in the percent of width shrinkage and the amount of high shrink yarn. As expected, the percentage of width shrinkage increases as the amount of high shrink filling yarn increases. A photograph of sample 1B is shown in Figure 3.7**.** The relationship between the percentage of the number of the higher shrink nylon yarn and the percentage of width shrinkage of each section is clearly illustrated in Figure 3.7.

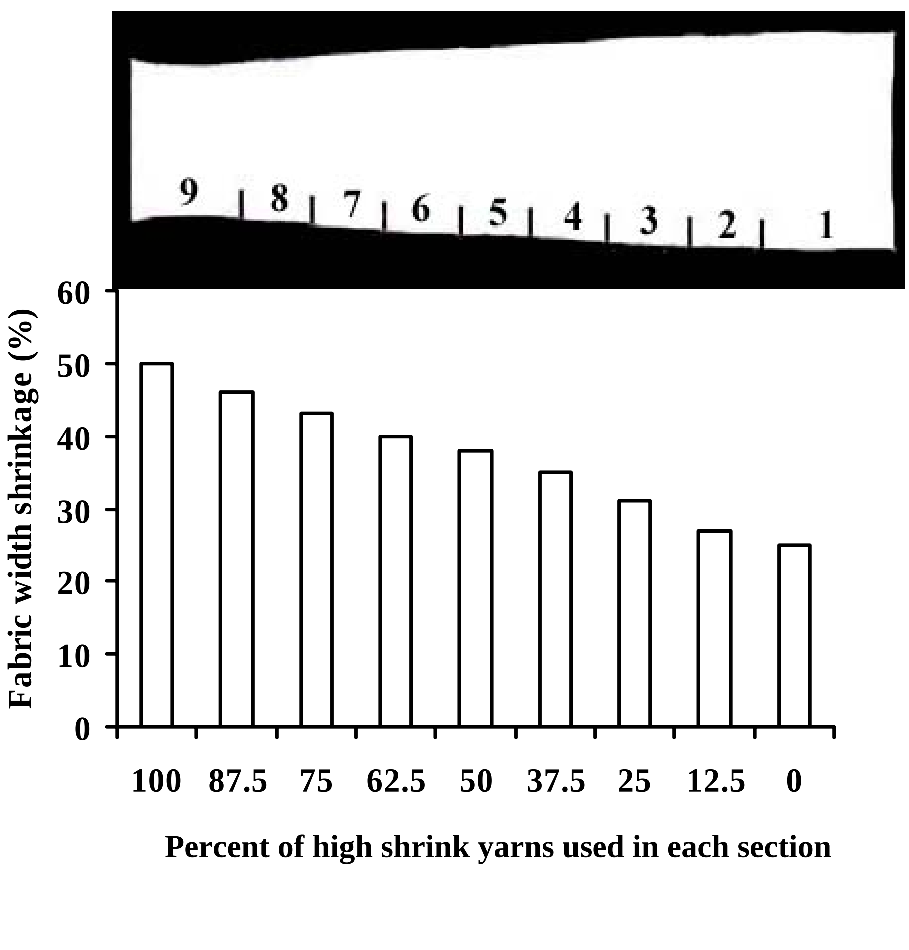
Figure 3.7 Photograph of Tubular Sample 1B and the Relationship Between Percentage of the Number of High Shrink Filling Yarn and Percentage of Width Shrinkage of Each Section, Weave Design: 4x4 Twill, On-loom Filling Yarn Density: 10.63 picks/cm



Sample 3B was constructed with the second pick repeat pattern, see Table 3.7. The second pick repeat pattern was a slightly more intricate pick pattern than the first pick repeat pattern. A 4x4 twill weave was utilized. The filling yarn density was not varied. The sample is approximately 74 cm long. Sample 3B has nine distinct sections. Figure 3.8 shows a photograph of the tubular sample after finishing, the percentage of the number of high shrink filling yarn used in each section and the percentage of shrinkage in the width direction.

Again, a direct correlation between the percent of width shrinkage and the amount of high shrink yarn used can be observed. As expected, the percentage of width shrinkage increases as the amount of high shrink filling yarn increases.

Figure 3.8 Photograph of Tubular Sample 3B and the Relationship Between Percentage of the Number of High Shrink Filling Yarn and Percentage of Width Shrinkage of Each Section, Weave Design: 4x4 Twill, On-loom Filling Yarn Density: 10.63 picks/cm



Utilizing different amounts of the higher shrink yarn resulted in different percentages of width shrinkage, which produced varying degrees of taper in samples 1B, 2B and 3B. The direct correlation between the amount of high shrink yarn used in the fabric construction and the resulting percentage of width shrinkage could allow for the engineering of numerous shapes.

3.3 CONCLUSION

It has been shown that seamless woven products with inherent shape can be produced continuously on conventional textile equipment, therefore, avoiding the need for special equipment. Three variables were investigated, specifically, different filling yarn densities, different weave designs and filling yarns with different degrees of shrinkage. A variety of seamless shaped woven fabrics were produced utilizing different combinations of the variables. These variables could potentially be manipulated to produce fabrics with a variety of desired shapes and dimensions. These products could be utilized in a wide variety of applications. While the range of difference between the dimensions of shaped fabrics reported here is broad (10%- 43.3%), a broader range could be easily achieved, if the need arose, by selecting a wider range of the variables.

In order to experiment more fully with the three variables, additional fabrics were woven on a double rapier Picanol GTM loom. Further investigation was undertaken to better understand the correlation between fabric width shrinkage and specific fabric construction parameters in order to create shape. It was of additional interest to investigate the correlation between fabric tightness and fabric width shrinkage. The details of the study using the Picanol GTM loom are detailed in the next section.

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PART IV:

INFLUENCE OF CONSTRUCTION PARAMETERS ON FABRIC WIDTH SHRINKAGE

4.0 INTRODUCTION

After the results from the previous trials performed on the Muller LN 59317A shuttle weaving machine and the AVL industrial dobby weaving machine were evaluated, additional weaving trials were executed on a double rapier Picanol GTM loom. The main goal of this research was to investigate the correlation between fabric width shrinkage and a given set of fabric construction parameters in order to create inherent shape within the fabric. It was of additional interest to investigate the ability to design shaped fabrics that would possess similar or the same finished fabric tightness. The goals were accomplished by weaving fabrics with different sets of parameters to produce a variety of width shrinkages. The on-loom and finished fabric tightness of each fabric was calculated. The finished fabric tightness was compared and contrasted to the finished width shrinkage. The on-loom and finished fabric tightness were also compared and contrasted. Two statistical models were developed to evaluate the contribution each variable had to finished width shrinkage and finished fabric tightness. A predictive model was also developed in an attempt to predict the finished width shrinkage that would be produced from a given set of construction parameters.

Further investigation into the tightness factor was deemed important for a number of reasons. The impetus for previous research of fabric tightness was to relate the degree of tightness to fabric properties (Seyam and El-Shiekh, 1993). Fabric properties include a number of aesthetic characteristics such has drape and hand (a characteristic perceived by touch), as well as a number of mechanical characteristics that determine a fabric's performance. Both aesthetic and mechanical properties determine what type of products a fabric could appropriately be utilized in. The degree of tightness of a fabric has been found to affect a number of mechanical properties including fabric elasticity, air permeability and fabric shrinkage (Seyam and El-Shiekh, 1994). The elasticity of a fabric is defined as the extent of elongation upon application of tension and the recovery to its original length and shape when the tension is released. Air permeability is the degree of porosity in a fabric, or the ease with which air passes through it. Air permeability is important in a number of applications because it reveals fundamental qualities of cloth such as warmth in blankets and air resistance in parachute cloth.

Fabric tightness can be used to construct similar fabrics that may differ in one or more construction parameters. By knowing the fabric tightness, the designer is able to design and produce a fabric with consistent fabric properties and quality. In many applications consistent aesthetic and mechanical properties as well as superior quality are paramount features that must be obtained, and maintained in order to satisfy the specific end use (Seyam and El-Shiekh, 1994).

Three variables that were explored in the previous trials were chosen for further investigation. The three variables were 1) different pick densities, 2) different weave designs and 3) weft yarns with different degrees of shrinkage. A total of ninety double cloth constructions were woven utilizing different combinations of the three variables.

A statistical analysis was performed using the results from the data from the weaving trials. The analysis was performed to examine the success of the overall experiment by assessing the contribution each of the three variables made to the resulting finished width shrinkage, as well as finished fabric tightness. In order for seamless shaped woven fabrics to be produced without performing additional weaving trials, a predictive model was created. The following text details the experimental design and the results produced from this study.

4.1 EXPERIMENTAL DESIGN

4.1.1 MATERIALS

4.1.1.1 WEFT AND WARP YARNS

Three different weft yarns with different degrees of shrinkage were utilized. Unifi, Inc. supplied two of the yarns, specifically a 400 denier textured ultra low shrink (ULS) yarn and a 300 denier textured polyester yarn (PET). E.I. Du Pont de Nemours & Co., Inc. supplied a 300 denier multicomponent textured elastic yarn referred to as Type 400. A 265 denier spun cotton yarn was used in the warp.

4.1.2 YARN TESTING

4.1.2.1 SHRINKAGE TESTS

Four different yarn shrinkage tests were utilized, specifically the Leesona skein shrinkage method (Lessona Corporation, 2002); a boil and dry heat shrinkage test obtained from Hamby Textiles Research Laboratories Inc. (Brooke, 2003); and the ASTM D 4031-95a standard test method for bulk properties of textured yarn (Standard Test Method for Bulk Properties of Textured Yarns, 2001).

Yarn shrinkage procedures are designed to test specific types of yarn, depending on the fiber and manufacturing process, therefore not all of the four procedures were used to test each of the three weft yarns. The Leesona method and the ASTM D 4031-95a standard test method were used to test all three of the weft yarns.

Only smaller lengths of the warp yarn were available therefore, the test method obtained from Hamby Textiles Research Laboratories Inc. was utilized to test the warp yarn. This method requires a 15 cm skein therefore, the warp yarn was tested for shrinkage using both the boil and dry method. Before each shrinkage test was performed, the warp yarn was tested for size. It was determined that a starch size was applied to the yarn (Livengood, 1983). Before testing the warp yarn following the dry shrinkage procedure, the yarn was desized. The unscoured and scoured lengths were recorded before testing, following the dry shrinkage procedure. The warp yarn was desized during the boil test procedure.

The yarn shrinkage method acquired from Hamby Textiles Research Laboratories Inc. is unpublished therefore the test method is detailed (Brooke, 2003).

Hamby Test Method-Boil

1. Measure three 15 cm single wrap skeins.
2. Calculate the appropriate weight in grams by using the following formula:

$$Weight = YarnDenier * 2 * 0.1$$

3. Attach one weight on each skein and measure the length of each skein.
4. Immerse the skeins in boiling water without the weight for 30 minutes.
5. Remove the skeins from the boiling water and relax dry.
6. Attach the weight and measure the skein length.
7. Calculate the % shrinkage using the following formula:

Formula 4.1 Percent Yarn Shrinkage

$$S_y = \frac{L_0 - L_b}{L_0}$$

Where

L_o = Original length of skein

L_b = Length of skein after boil off

Hamby Test Method-Dry Heat

1. Measure three 15 cm single wrap skeins.
2. Calculate the appropriate weight in grams by using the following formula:

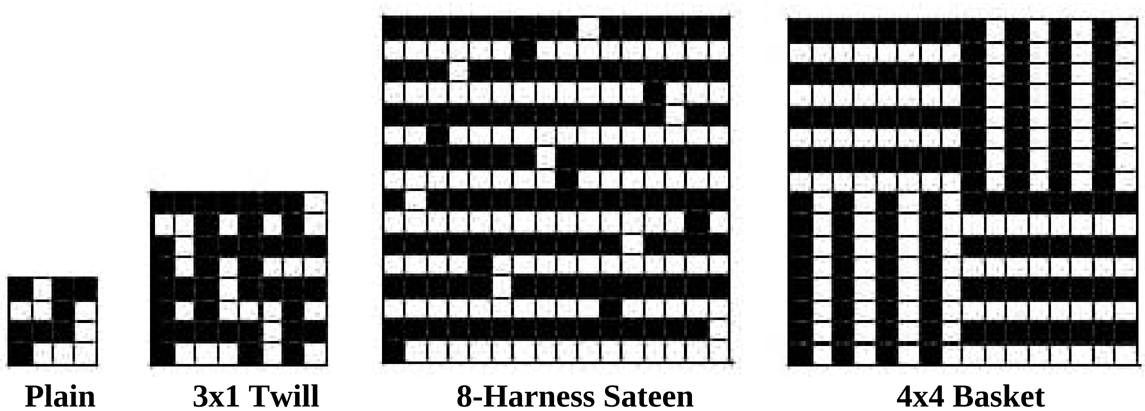
$$Weight = YarnDenier * 2 * 0.1$$

3. Attach one weight on each skein and measure the length of each skein.
4. Put skeins in dry oven set at 196 C^o for 30 minutes.
5. Attach the weight and measure the skein length.
6. Calculate the % shrinkage using formula 4.1.

4.1.3 WEAVE DESIGNS

Four double cloth constructions were utilized, specifically a plain, a 3x1 twill, an 8-harness sateen and a 4x4 basket weave. A double cloth construction was utilized because of the warp density. In a single layer cloth there were 40.94 ends per cm. In order to produce a wider range of fabric tightness factors, a double cloth construction was used which produced two fabric layers, each with a warp density of 20.47 ends per cm. The weave designs are detailed in Figure 4.1.

Figure 4.1 Double Cloth Weave Designs



4.1.4 WEFT THREAD DENSITIES

Different pick densities were evaluated in each of the four different weaves. A total of ninety fabrics were woven using the three different weft yarns, four different weaves and different pick densities.

4.1.5 FABRIC FORMATION

The double rapier Picanol GTM weaving machine was used to weave the fabric samples. The loom was equipped with sixteen harnesses. The warp ends were threaded in a straight draw configuration with 4 ends per dent. There were a total of 20.47 ends per centimeter in each layer of the double cloth constructions. The details of the weaving trials are shown in Table 4.1B located in Appendix B.

4.1.6 FABRIC FINISHING

The fabric samples were removed from the loom, cut and surged on all sides, scoured and desized in a Burlington paddle dyeing machine at 95° C for fifteen minutes. A 20:1 liquor ratio (L.R.) was used. The L.R. determines the volume or weight of the bath to the weight of the material, expressed as X:1.

The bath contained a soaping agent, specifically APOLLOSCOUR SDRS and an enzyme, specifically Thermozyme® 60 L. The recommended amount of APOLLOSCOUR SDRS (1g/liter of bath) and Thermozyme® 60 L (5g/liter of bath) were added to the bath. The samples were extracted after the scouring process and dried at 90°C for thirty minutes. The sample fabrics were heat-set on a Fleissner through air dryer at 170°C for 30 seconds (Gunn, 2003). Samples were ironed at low dry heat.

4.1.7 EVALUATION

4.1.7.1 EVALUATION OF THE PERCENT SHRINKAGE OF THE WIDTH, LENGTH AND AREA

To evaluate the degree of fabric shrinkage in both the width and the length direction, each of the ninety samples were marked with five different 10 cm x 10 cm squares across the width of the fabric. The fabric was marked with the 10 cm x 10 cm squares while on the loom. Width and length measurements of each square were taken after the fabric sample was removed from the loom and after finishing. From these measurements the average percent change of the width, the length and the area were calculated for each of the ninety samples off the loom and after finishing. The following formulas were used to calculate the percent change.

Formula 4.2 Percent Width Shrinkage Off-Loom (Grey)

$$S_{wg} = \frac{(W_{wl} - W_{wg})*100}{W_l}$$

Where: W_{wl} = Fabric width on the loom
W_{wg} = Grey fabric width (or off-loom width)

Formula 4.3 Percent Width Shrinkage After Finishing

$$S_{wf} = \frac{(W_{wl} - W_{wf})*100}{W_{wl}}$$

Where

W_{wl} = Fabric width on the loom
W_{wf} = Fabric width after finishing

Formula 4.4 Percent Length Shrinkage Off-Loom (Grey)

$$S_{\mathrm{lg}} = \frac{(L_{ll} - L_{\mathrm{lg}})*100}{L_{ll}}$$

Where

L_{ll} = Fabric length on the loom
L_{lg} = Grey fabric length (off the loom length)

Formula 4.5 Percent Length Shrinkage After Finishing

$$S_{lf} = \frac{(L_{ll} - L_{lf})*100}{L_{ll}}$$

Where

L_{ll} = Fabric length on the loom
L_{lf} = Fabric length after finishing

Formula 4.6 Percent Area Shrinkage Off-Loom (Grey)

$$S_g = \frac{(A_l - A_g)*100}{A_l}$$

Where:

A_l = Fabric area on the loom
A_g = Grey fabric area (off the loom fabric area)

Formula 4.7 Percent Area Shrinkage After Finishing

$$S_f = \frac{(A_l - A_f)*100}{A_l}$$

Where

A_l = Fabric area on the loom
A_f = Fabric area after finishing

The shrinkage values for the off-loom and finished width, length and area are detailed in Tables 4.4B and 4.5B in Appendix B.

4.1.7.2 OFF- LOOM AND FINISHED THREAD DENSITY

Pick density was initially determined while each sample was on the loom by changing the loom gear set-up. The average pick density (cm) was also recorded after the cloth was removed from the loom and after finishing**.** This data was calculated from the average length measurements obtained from the five 10 cm x 10 cm squares for each of the ninety samples using the following formulas.

Formula 4.8 Off-Loom Pick Density

$$t_{2g} = \frac{(L_{ll} * t_{2l})*100}{L_{\mathrm{lg}}}$$

Where

L_{ll} = Fabric length on the loom, cm
t_{2l} = On loom pick density cm^{-1}
L_{lg} = Average grey fabric length, cm

Formula 4.9 Finished Pick Density

$$t_{2f} = \frac{(L_{ll} * t_{2l})*100}{L_{lf}}$$

Where

L_{ll} = Fabric length on the loom, cm
t_{2l} = on loom pick density, cm^{-1}
L_{lf} = Average fabric length after finishing, cm

Similarly, the end density was calculated off-loom and after finishing as well. The end density was calculated in the same manner as picks per centimeter, except the average fabric width off-loom and after finishing were used instead of the average fabric length off-loom and after finishing. The on-loom, off-loom and finished warp density and weft density are detailed in Tables 4.2B and 4.3B in Appendix B.

4.1.7.3 FINISHED WARP AND FILLING COVER AND COVER FACTOR

The finished warp and filling cover and cover factors were calculated using the following formulas:

Formula 4.10 Finished Warp Cover and Cover Factor

Finished warp cover can be expressed as

$C_{1f} = \frac{d_1}{p_{1f}}$ or as percentage $C_{1f} = \frac{d_1 * 100}{p_{1f}}$

and finished cover factor is given by

$$K_{1f} = \frac{28 d_1}{p_{1f}}$$

Where

C_{1f} = Finished warp cover, %

d_1 = Warp yarn diameter, cm

p_{1f} = Finished warp spacing, cm

Formula 4.11 Finished Weft Cover and Cover Factor

Finished weft cover is given by

$$C_{2f} = \frac{d_2}{p_{2f}} \quad \text{or as percentage} \quad C_{2f} = \frac{d_2 * 100}{p_{2f}}$$

and finished weft cover factor is given by

$$K_{2f} = \frac{28 d_2}{p_{2f}}$$

Where

C_{2f} = Finished warp cover, %

d_2 = Weft yarn diameter

p_{2f} = Finished pick spacing, cm

The finished warp and weft cover and cover factors for each sample can be seen in Table 4.6B in Appendix B.

The general relationships of maximum theoretical warp and weft cover factors as a function of warp and weft weave factors were derived. The proofs for these equations are given later.

Formula 4.12 Maximum Warp Cover and Cover Factor

$$C_{1max} = \frac{d_1}{p_{1min}} = \frac{M_1}{1 + \frac{\pi}{4}(M_1 - 1)}, \quad \text{and} \quad K_{1max} = \frac{28 d_1}{p_{1min}} = \frac{28 M_1}{1 + \frac{\pi}{4}(M_1 - 1)}$$

Where

C_{1max} = Maximum warp cover

K_{1max} = Maximum warp cover factor

M_1 = Warp Weave Factor (See Formula 4.15 & 4.16)

Formula 4.13 Maximum Weft Cover and Cover Factor

$$\mathrm{C}_{2\max} = \frac{M_2}{1+\frac{\pi}{4}(M_2-1)}, \quad \text{and} \quad \mathrm{K}_{2\max} = \frac{28*M_2}{1+\frac{\pi}{4}(M_2-1)}$$

Where

C_{2max} = Maximum weft cover

K_{1max} = Maximum weft cover factor

M_2 = Weft Weave Factor (See Formula 4.15 & 4.16)

A general maximum weavability equation relating maximum warp and weft cover factors to weave factors derived by Seyam (2001) is shown below.

Formula 4.14 General Weavability-Limit Relationship

$$\sqrt{1-[\frac{28M_1/K_{\max 1}-\pi/4(M_1-1)}{(1+\beta)}]^2}+\sqrt{1-[\frac{\{28M_2/K_{\max 2}-\pi/4(M_2-1)\}\beta}{(1+\beta)}]^2}=1$$

Where:

K_{1max} = Maximum warp cover factor

K_{2max} = Maximum weft cover factor

M_1 = Warp weave factor (See Formula 4.15 & 4.16)

M_2 = Filling weave factor (See Formula 4.15 & 4.16)

$\beta = d_2/d_1$

d_2 = diameter of the weft yarn

d_1 = diameter of the warp yarn

Formulas 4.12-4-14 determine the boundaries of the maximum construction. Fabrics that possess covers (or cover factors) that are higher values than the calculated boundaries are impossible to weave.

4.1.7.4 RUSSELL'S TIGHTNESS FACTOR

Russell's tightness factor was determined for each of the ninety samples. The weft, warp and fabric tightness were determined at three different stages, specifically on-loom, after the samples were removed from the loom and after finishing.

To calculate Russell's tightness factor, the weave factor and yarn diameter first need to be calculated. The yarn diameter for each of the three weft yarns and warp yarn was calculated using Formula 4.15. Yarn diameter in cm is expressed in terms of yarn count in the tex system.

Formula 4.15 Yarn Diameter

$$d = \frac{1}{280.2}\sqrt{\frac{N_t}{\phi\rho}}$$

Where d = Yarn diameter in cm

N_t = Yarn number in tex (g/km)

ϕ = Yarn packing fraction (or factor) = ρ_y/ρ_f

ρ_f = Fiber density (g/cm^3)

ρ_y = Yarn density (g/cm^3)

Various data including the warp packing factor, the weft packing factor, warp fiber density and weft fiber density are necessary to calculate the yarn diameter. The packing factor has been found experimentally to be 0.6 for spun and textured filament yarn. The parameter is influenced by fiber, yarn type and fabric construction. Fiber density is dependent on the type of fiber used to construct each yarn. Table 4.1 details the fiber type, yarn type, packing factor and the fiber density for each yarn used in this experiment.

Table 4.1 Fiber Type, Yarn Type, Packing Factor and Fiber Density of Each Yarn Used in the Experiment

Yarn	Fiber Type	Yarn Type	Packing Factor pf (g/cm^3)	Fiber Density py/pf = (g/cm^3)
Weft One ULS	Polyester	Textured	0.6	1.38
Weft Two PET	Polyester	Textured	0.6	1.38
Weft Three Type 400	Polyester	Textured	0.6	1.38
Warp	Cotton	Spun	0.6	1.52

The weave factor is a numerical value that must also be calculated in order to calculate Russell's tightness factor. The weave factor expresses the number of interlacings of warp and filling yarns in a given weave repeat. The weave factor for both the warp and filling was calculated using the following formulas.

Formula 4.16 Warp Weave Factor

$$M_1 = \frac{N_1}{i_1}$$

Formula 4.17 Filling Weave Factor

$$M_2 = \frac{N_2}{i_2}$$

Where

M_1 = Warp weave factor

N_1 = Number of warp ends per weave repeat

i_1 = Number of filling intersections per weave repeat

M_2 = Filling weave factor

N_2 = Number of filling ends per weave repeat

i_2 = Number of warp intersections per weave repeat

The number of intersections per design repeat, number of threads per design repeat and the weave factors are shown in Table 4.2

Table 4.2 Weave Factors of each of the Four Weave Designs

Weave	N_1	i_1	N_2	i_2	M_1	M_2
Plain	**2**	**2**	**2**	**2**	**1**	**1**
3x1 Twill	**4**	**2**	**4**	**2**	**2**	**2**
8-H Sateen	**8**	**2**	**8**	**2**	**4**	**4**
4x4 Basket	**8**	**2**	**8**	**2**	**4**	**4**

The warp or filling weave factor and the diameter of the warp and filling yarns were used to calculate the theoretical warp and filling yarn densities.

Formula 4.18 Theoretical Thread Densities

$$t_{1r} = \frac{M_1}{M_1 d_1 + d_2}$$

$$t_{2r} = \frac{M_2}{M_2 d_2 + d_1}$$

t_{1r} = Theoretical warp density of reference fabric

t_{2r} = Theoretical pick density of reference fabric

In order to calculate the fabric, warp and filling tightness the following formulas were used.

Formulas 4.19, 4.20 and 4.21 Fabric, Warp and Filling Tightness

$$C_{fab} = \frac{t_1 + t_2}{t_{1r} + t_{2r}}$$

$$C_1 = \frac{t_1}{t_{1r}}$$

$$C_2 = \frac{t_2}{t_{2r}}$$

Where:

C_{fab} = Fabric tightness

C_1 = Warp tightness

C_2 = Filling tightness

t_1 = Theoretical warp density

t_2 = Theoretical pick density

The on-loom, off-loom and finished warp, weft and fabric tightness factors are detailed in Table 4.7B, 4.8B and 4.9B in Appendix B.

4.1.7.5 STATISTICAL MODEL

In order to evaluate the success of the overall experiment in this study, as well as the contribution each independent variable made to finished width shrinkage and finished fabric tightness, two statistical models were developed. In each model the pick density was treated as a numerical parameter and the weave and filling yarn type were considered as categorical variables. The justification of treating each variable in this manner is given later in Section 4.3.2. A GLM (General Linear Model) was utilized, see formula 4.22.

Formula 4.22 GLM Model Statement

$$S_{wf} = pd \quad weave \quad wy \quad pd * weave \quad pd * wy \quad weave * wy$$

Where S_{wf} = Width shrinkage of finished fabric, %
pd = Pick density, picks/cm,
$weave$ = Weave design, and
wy = Weft yarn type

All of the ninety data points were utilized in the statistical model which evaluated finished fabric width shrinkage. In the model designed to evaluate finished fabric tightness, thirteen of the ninety data points were excluded. The reason for excluding the thirteen data points will be discussed in section 4.2.4.1. The complete SAS code for these models can be seen in Tables 4.10B and 4.11B.

A predictive model was also developed. The goal of producing a predictive model was to attempt to predict finished width shrinkage, without having to execute additional weaving trials. The prediction was based on the data collected from the ninety fabric samples woven on the Picanol GTM loom. The GLM (General Linear Model) procedure was utilized to estimate the predictive values for the width shrinkage of finished fabrics in terms of independent parameters and their interactions. The independent parameters in the model are pick density, weave design, and filling yarn type. A similar GLM model statement to the one shown in Formula 4.22 was used to generate the predictive finished width shrinkage, however, an additional command was added.

Formula 4.23 GLM Model Statement

$$S_{wf} = pd \quad weave \quad wy \quad weave * pd \quad weave * wy \quad pd * wy \text{ / dist = normal type3}$$

Where S_{wf} = Width shrinkage of finished fabric, %
pd = Pick density, picks/cm,
$weave$ = Weave design, and
wy = Weft yarn type

4.2 RESULTS

This study was undertaken to better understand the correlation between the fabric width shrinkage and a specific set of parameters. It was of additional interest to investigate the correlation of the fabric width shrinkage and the resulting finished fabric tightness. Three variables were utilized, specifically 1) different pick densities, 2) different weave designs and 3) yarns with differential shrinkage. Ninety different double cloth constructions were woven utilizing three different weft yarns with different degrees of shrinkage, four different weave designs and different pick densities. Russell's construction factor was utilized to calculate the on-loom, off-loom and finished fabric tightness factors. In the Results Section the following observations will be examined and compared and contrasted:

- The percentage of yarn shrinkage of the three different weft yarns and the warp yarn obtained from shrinkage tests
- The correlation between the crimp contraction of the three weft yarns and the resulting fabric width shrinkage
- The finished width shrinkage produced from the three weft yarns
- The finished width shrinkage produced from the four different weave designs
- The finished fabric tightness in terms of finished fabric width shrinkage
- The on-loom and finished fabric tightness

In addition, two statistical models were performed. The first model was performed to evaluate the contribution made by the three variables individually, as well as the contributions made by the interactions between different combinations of the variables to finished width shrinkage and finished fabric tightness. The second statistical model was a predictive model. The predictive model was designed to enable a designer to utilize the data generated in this experiment to estimate the finished width shrinkage that would be produced from a given set of the variables investigated in this study.

4.2.1 YARN SHRINKAGE TESTS

In this experiment three different weft yarns were utilized. A 400 denier ultra low shrink (ULS) polyester yarn was utilized along with a 300 denier standard polyester (PET). Polyester yarn with shrinkage values of less than 5% are categorized as having low shrinkage. Lower shrinkage polyester yarns can be obtained by altering processes, temperatures and the amount of fiber stretching during the drawing process. Standard polyester is designed to have approximately 12% yarn shrinkage (Gunn, 2003).

The third yarn was a 300 denier elastomeric yarn composed of polyester. The yarn is referred to as Type 400. The Type 400 yarn was designed to be used in applications that require low to moderate stretch. Type 400 is a multi-component yarn in which two different polymers are joined together. When exposed to heat, each polymer undergoes different amounts of shrinkage, producing a smooth and regular helical crimp ("New Dupont Type 400", 2001). The Type 400 yarn was used in this experiment because of its high percentage oft shrinkage.

Three different shrinkage tests were performed. Only test methods that were appropriate for the yarn type were used to test each yarn.

4.2.1.1 SHRINKAGE RESULTS OBTAINED FROM THE LESSONA METHOD

The Leesona method is most frequently used to test the shrinkage of textured yarns (Leesona Corporation, 2002). All three of the textured weft yarns were tested following the Leesona method. The cotton warp was not tested following this method for a number of reasons. The warp yarn was only available in 80 cm pieces, therefore the requested skein length could not be made. In addition, cotton is not a textured yarn.

Unifi Inc. which supplied the two polyester yarns also supplied shrinkage data obtained from their in-house testing, following the Leesona method. The shrinkage values from Unifi Inc. will be included with the test values obtained in this experiment.

Table 4.3 details the shrinkage values obtained from Unifi Inc. for the two polyester yarns as well as the test results obtained from the shrinkage tests conducted by the author.

Table 4.3 Results from the Leesona Skein Shrinkage Test

Yarn	Skein Shrinkage (%) $(L_b-L_a)/L_b \times 100$	Skein Shrinkage Obtained from Unifi Inc.
ULS	1.14	2.5
PET	5.45	11.2
Type 400	31.57	No data available

Where L_b = Length of skein before exposure to heat
L_a = Length of skein after exposure to heat

From the shrinkage data obtained by the supplier it was expected that the ULS would have the lowest percent shrinkage, followed by the PET. As expected the ULS yarn did have the lowest percent shrinkage followed by the PET. The Type 400 resulted in the highest amount of shrinkage. It can be observed that the values obtained from Unfi Inc. were slightly higher than the values obtained from the Leesona tests conducted in this experiment. This might be due to slight variations in temperature as well as experience of the tester.

4.2.1.2 SHRINKAGE RESULTS OBTAINED FROM THE ASTM 4031-95a METHOD.

In order to further investigate the shrinkage potential of the three weft yarns the yarns were tested following the ASTM 4031-95a procedure. The ASTM 4031-95a is used to test the change in length of a tensioned skein of textured yarn due to the change in crimp characteristics brought about by exposure to wet or dry heat. The test is limited to crimped, continuous multifilament yarns. From the data collected, bulk shrinkage, skein shrinkage, crimp contraction can be calculated. Bulk shrinkage is defined as either the measure of potential stretch and power of stretch yarn or a measure of bulk of a textured-set yarn. Skein shrinkage is the measure of true intrinsic yarn shrinkage not including crimp contraction. Crimp contraction is an indicator of crimp capacity or a characterization of a yarn's ability to contract under tension (Standard Test Method for Bulk Properties of Textured Yarns). The values obtained for bulk shrinkage, skein shrinkage and the crimp contraction for each of the three weft yarns are detailed in Table 4.4.

Table 4.4 Shrinkage Results From the ASTM 4031-95a

Yarn	Bulk Shrinkage (%) $100(C_b-C_a)/C_b$	Skein Shrinkage (%) $100(L_b-L_a)/L_b$	Crimp Contraction (%) $100(L_a-C_a)/L_a$
ULS	5.91	1.21	5.70
PET	28.4	3.86	26.60
Type 400	49.87	8.52	55.17

Where L_b = Length of skein under heavy load before heating
L_a = Length of skein under heavy load after heating
C_b = Length of skein under light load before heating
C_a = Length of skein under light load after heating

As expected, the ULS yarn resulted in the lowest bulk shrinkage, skein shrinkage and crimp contraction values, followed by the standard PET and the Type 400. These results were expected.

4.2.1.3 SHRINKAGE REAULTS OBTAINED FROM HAMBY RESEARCH LABORATORY: BOIL AND DRY HEAT METHOD

The boil and dry heat shrinkage methods obtained from Hamby Research Laboratories are recommended for textured filament and spun yarns. The cotton warp yarn was tested following the boil and dry heat procedure obtained from Hamby Research Laboratories. The results of the shrinkage test are shown in Table 4.5.

Table 4.5 Shrinkage Results from Hamby Research Laboratory's Boil and Dry Heat Method

Yarn	Boil Procedure (%) $(L_b-L_a)/L_b \times 100$	Dry Heat (%) (Lb-La)/Lb x 100
Cotton Warp	**0.8**	**0.64**

Where L_b = Length of skein before exposure to heat
L_a = Length of skein after exposure to heat

The cotton yarn was desized before the yarn was tested following the dry method. During the desizing procedure the yarn shrank 2.35%. The yarn was desized during the boil procedure. This is most likely why the boil method resulted in a slightly higher percent shrinkage.

4.2.2 THE CRIMP CONTRACTION OF THE THREE WEFT YARNS EVALUATED IN TERMS OF THE RESULTING FABRIC WIDTH SHRINKAGE

The crimp contraction data obtained from the ASTM 4031-95a procedure was used to investigate the correlation between the weft yarn shrinkage and the fabric width shrinkage. The crimp contraction is an indicator of crimp capacity or a characterization of a yarn's ability to contract under tension. It is important to note that in the text of the ASTM 4031-95a test procedure it states that values obtained by the test should not be used to predict similar properties in fabricated structures except in narrow well-defined comparisons. The text further expounds upon the subject, stating that attempts to relate yarn performance to fabric performance might result in poor correlations unless other factors affecting yarn shrinkage and fabric finishing are eliminated (Standard Test Method for Bulk Properties of Textured Yarns). However, the crimp contraction was deemed to be the best available data to investigate the correlation between weft yarn shrinkage and fabric width shrinkage. See Figures 4.2-4.5.

Figure 4.2

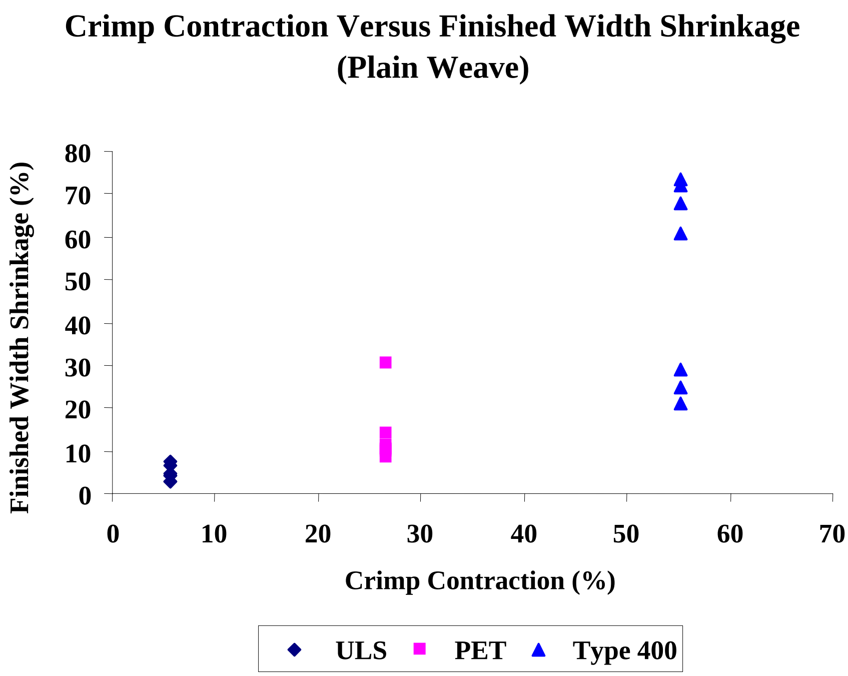


Figure 4.3

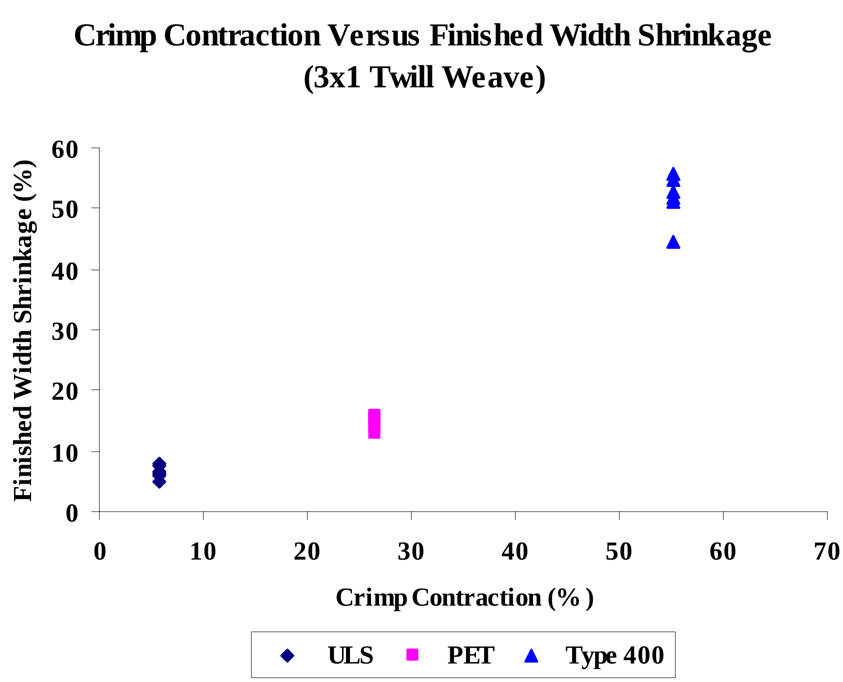


Figure 4.4

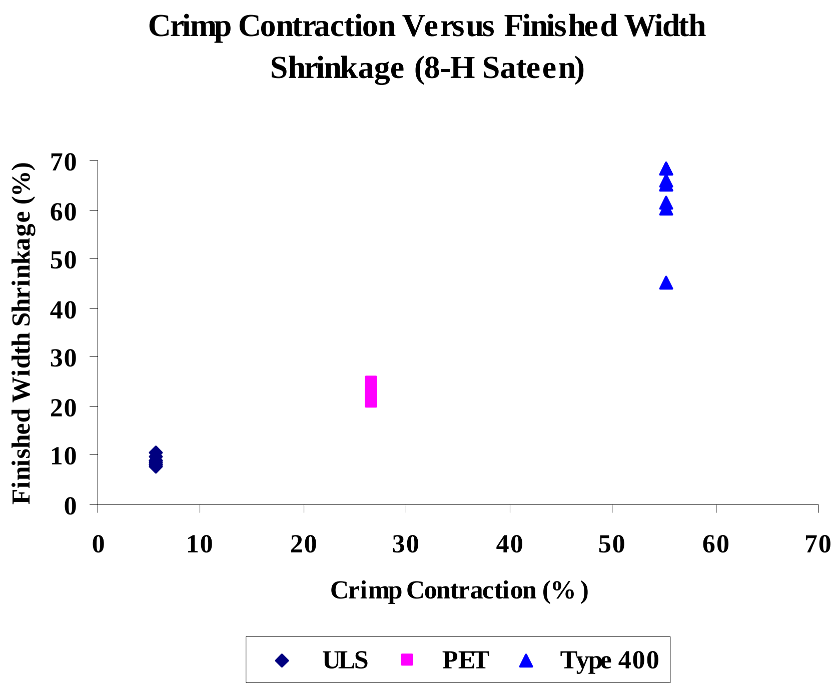
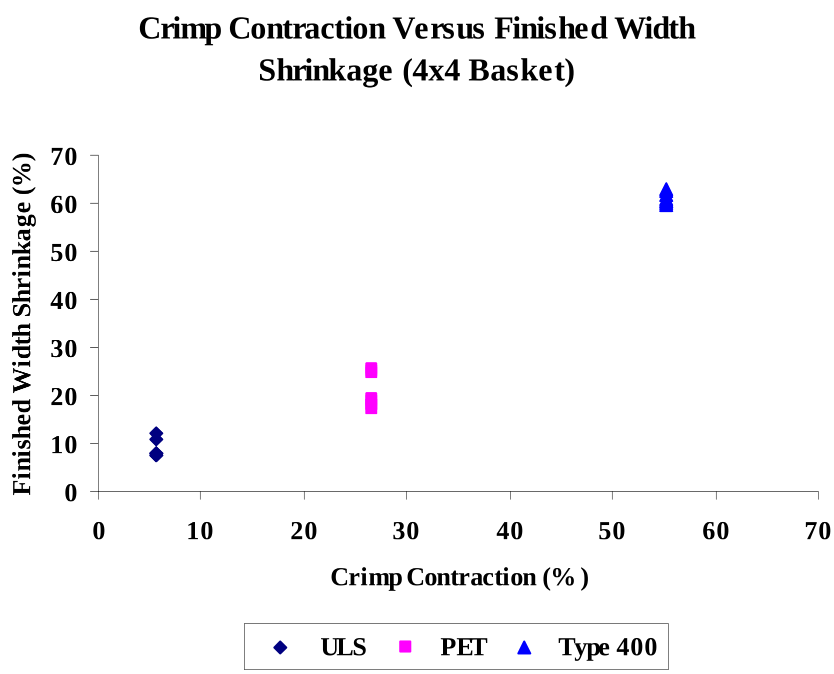


Figure 4.5



It can be observed in the four graphs that in all cases the fabrics constructed with the ULS weft yarn resulted in the least amount of finished fabric width shrinkage. The ULS weft yarn had a 5.70% crimp contraction which was the lowest of the three weft yarns. The fabrics constructed with the ULS weft yarn resulted in finished fabric width shrinkages between 2.6 and 10.8, indicating a fairly close correlation between weft yarn shrinkage and finished width shrinkage.

The PET yarn had the second highest crimp contraction, 26.60%. The fabrics constructed with the PET weft yarn resulted in the second highest fabric width shrinkage with the exception of one sample, which had a higher degree of finished width shrinkage than the other fabrics constructed with the PET weft yarn, see Figure 4.2. The sample was constructed with the lowest pick density producing a very loose structure which resulted in a high degree of finished width shrinkage. Excluding the high shrinkage of that one fabric, the fabrics constructed with the PET weft yarn which utilized a plain weave, had finished fabric width shrinkages ranging from 8.4-14.2. This range was lower than the crimp contraction. A plain weave has the greatest number of intersections in a given space. The high number of intersections makes it a tight weave that experiences less shrinkage than other weaves during finishing. Therefore, the shrinkage of the yarn within the fabric was less than the crimp contraction.

The fabrics which were constructed with the PET weft yarn and the 3x1 twill weave had finished fabric width shrinkages ranging from 13-15.8. The twill weave had a higher range of shrinkage values than the plain weave. Twill weaves have fewer intersections in a given space than a plain weave, resulting in a higher degree of shrinkage during finishing. However, the shrinkage range was still quite a bit lower than the crimp contraction of the PET yarn.

The fabrics constructed with the PET yarn which utilized the 8-H sateen and the 4x4 basket weaves had finished fabric width shrinkages that ranged from 17.2-25.4. Sateen and basket weaves have fewer intersections in a given space than a twill weave, resulting in a higher degree of shrinkage. The higher range of fabric width shrinkage resulted in a stronger correlation between the finished fabric width shrinkage and the crimp contraction of the PET weft yarn in the fabrics constructed with the 8-H sateen and the 4x4 basket weaves, than those fabrics constructed with the plain or twill weave.

The Type 400 weft yarn had the highest crimp contraction, 55.17%. The vast majority of the fabrics constructed with the high shrink Type 400 weft yarn resulted in the highest finished width shrinkage. The exception was the three fabrics constructed with the plain weave. These fabrics had a finished width shrinkage that ranged from 18.8-25.4, which was lower than any of the other fabrics constructed with the Type 400 yarn. Excluding these points the other fabrics had a range of finished width shrinkage from 44.6-73.6. Most of the finished width shrinkages fell between 50 and 60 percent, which indicates a strong correlation between the finished width shrinkage and the crimp contraction.

The above results reflect the fact that yarn shrinkage and fabric tightness impact the finished fabric shrinkage. The descending order of the weaves utilized in terms of tightness was plain, 3x1 twill, 8-harness sateen, and 4x4 basket. The order is determined by the number of weave intersections per weave design. It is expected that as the number of weave intersections (or tightness) increases, the fabric shrinkage decreases due to the fact that each weave intersection occupies a smaller distance within the fabric.

4.2.3 THE EVALUATION OF THE YARN SHRINKAGE BEHAVIOR OF THE THREE DIFFERENT WEFT YARNS IN TERMS OF FINISHED FABRIC TIGHTNESS AND FINISHED WIDTH SHRINKAGE

Russell's construction factor was utilized to calculate on-loom, off-loom and finished fabric tightness. The construction factor enables the examiner to compare and contrast different yarn types by including the packing factor and the fiber density in the yarn diameter equation. These two parameters and the weave help to predict the shrinkage behavior of a fabric. The yarn shrinkage behavior of the three different weft yarns was examined in terms of finished fabric tightness and finished width shrinkage.

It can be clearly noted from the graphs shown in Figures 4.6-4.9 (which compare the finished fabric tightness and the finished width shrinkage) that the fabrics constructed with the ULS weft yarn had the least amount of finished width shrinkage regardless of the fabric tightness factor. The fabrics constructed with the standard PET yarn in the weft had the second least amount of finished width shrinkage except for one point, see Figure 4.6. The samples constructed with the Type 400 weft yarn had the greatest amount of fabric width shrinkage. In all of the yarn shrinkage test that were conducted, the ULS yarn had the least amount of shrinkage potential. The PET yarn had the second lowest amount of shrinkage and the Type 400 yarn had the greatest degree of shrinkage potential. Obviously, differential width shrinkage and ultimately shape in the fabric width direction can be successfully manipulated by using weft yarns with different degrees of shrinkage.

Figure 4.6

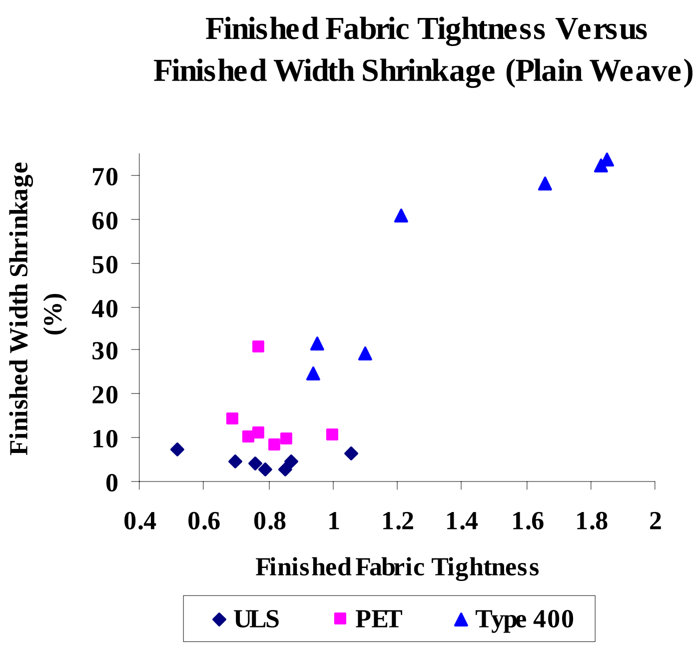


Figure 4.7

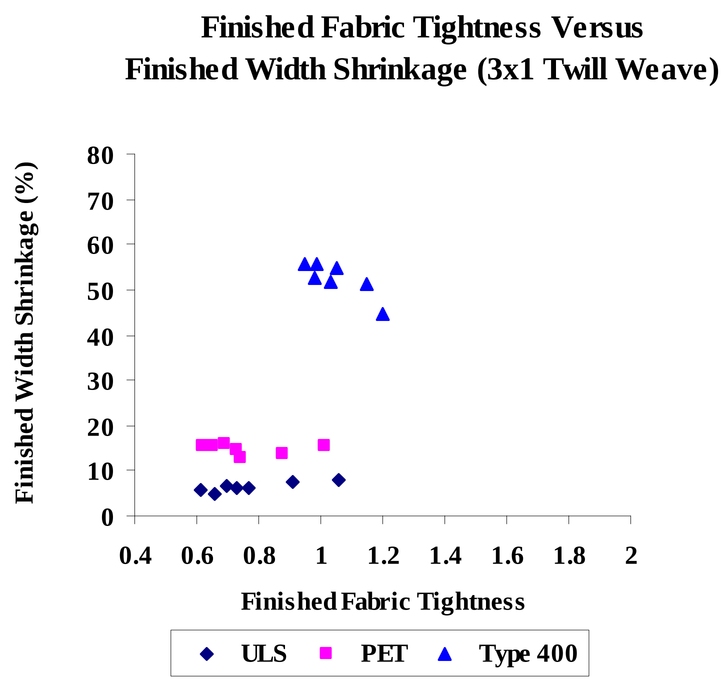


Figure 4.8

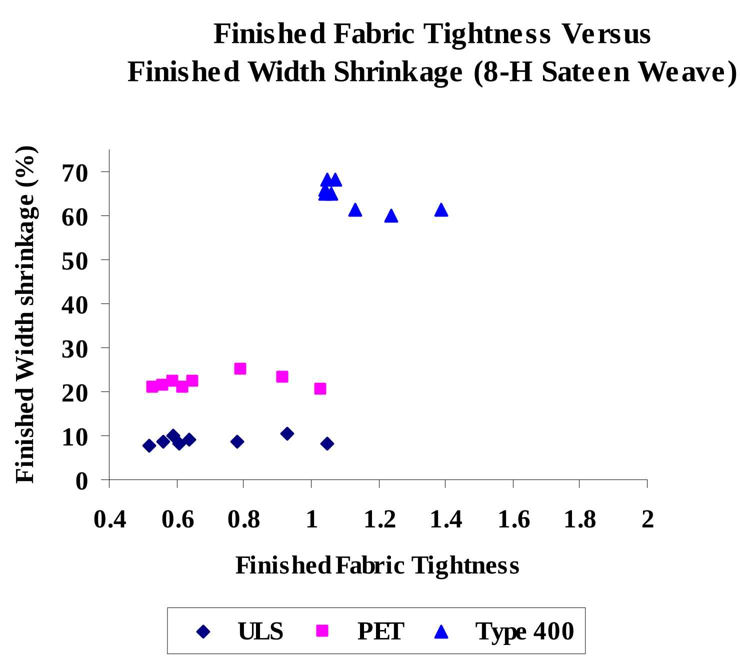
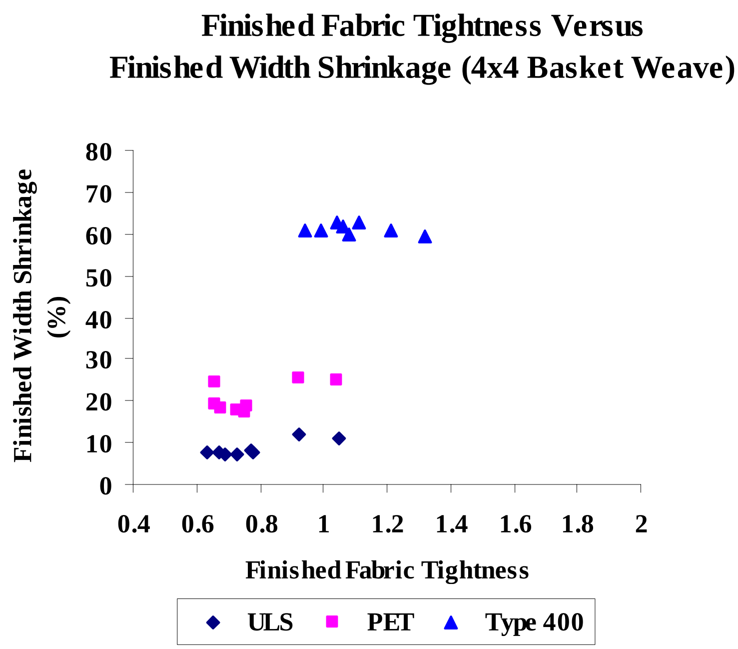


Figure 4.9



4.2.4 RESULTS OBTAINED FROM THE EVALUATION OF FINISHED FABRIC TIGHTNESS WITH RESPECT TO FINISHED WIDTH SHRINKAGE AND ON-LOOM FABRIC TIGHTNESS

In the mid 1960's Russell introduced a tightness theory which he referred to as construction factor. Russell's tightness theory has been utilized extensively for a number of reasons. The theory is simple; different weaves can be evaluated, so it can be used to compare tightness of fabrics constructed with different weave designs; tightness is expressed in terms of warp and filling yarn diameters, therefore it can be used for any yarn type made of any fiber allowing the examiner to compare fabrics of different yarn and fiber type; and the warp tightness calculations account for the filling and vice versa, which means that for fabrics made of the same warp and different filling yarns, warp tightness is varied (Seyam and El-Shiekh, 1994).

The ninety fabrics produced in this study had a range of on-loom fabric tightness factors between 0.4 - 1.0. A template measuring 10 cm x 10 cm was used to make five measurements across the width of each sample. The average of the width and length measurements as well as the end and pick densities were used to calculate the weft, warp and fabric tightness factors at three different stages of fabric formation, specifically on-loom, off-loom and after finishing.

The width shrinkage was the most important data because it determined the amount of shape that could be achieved. The length shrinkage is important because it affects the amount of finished length that can be expected from the parameters used in each construction. However, the main goal of this study was to produce shape through varying the fabric width, therefore, this discussion will focus on examining the finished width shrinkage.

The finished fabric tightness was compared and contrasted with respect to the percentage of finished width shrinkage and on-loom fabric tightness. There was a negligible difference between the on-loom and off-loom fabric tightness, therefore the on-loom fabric tightness was used to compare and contrast to the finished fabric tightness. From this data, pertinent information was obtained and investigated:

- The finished fabric tightness and width shrinkage resulting from fabrics constructed with the same weave design, however, different weft yarn
- The interaction between the fabric samples constructed with different sets of parameters, utilizing the five width measurements from each sample
- Finished fabric tightness and finished width shrinkage resulting from fabrics constructed with different weave designs, however, the same weft yarn
- Resulting finished fabric tightness from a given set of parameters
- The finished fabric tightness produced from a specific on-loom fabric tightness
- The correlation between finished fabric tightness and the on-loom fabric tightness with respect to the weft yarns and the weaves designs

4.2.4.1 THE FINISHED FABRIC TIGHTNESS AND WIDTH SHRINKAGE RESULTING FROM A SPECIFIC WEAVE AND THREE DIFFERENT WEFT YARNS

It was expected that the finished width shrinkage would decrease as the fabric tightness increased. Fabric tightness increases as the number of picks within the fabric increases. A greater number of picks per unit length results in a tighter fabric construction which inhibits shrinkage during finishing. A number of observations can be made from the graphs comparing the finished fabric tightness with the finished width shrinkage, refer to Figures 4.6-4.9. The finished width shrinkage of the fabrics constructed with the ULS weft yarn (regardless of the weave design) showed no significant change in finished width shrinkage as the fabric tightness increased. The lack of change in the finished width shrinkage with increased finished fabric tightness is most likely due to the shrinkage potential of the ULS weft yarn. The yarn had a very low potential for shrinkage, therefore during fabric finishing the ULS yarn shrank very little resulting in minimal width shrinkage regardless of the tightness of the fabric.

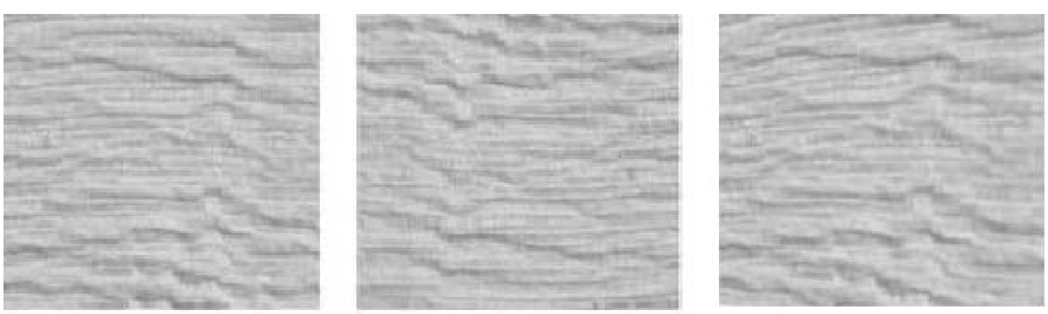
The fabrics constructed with the PET weft yarn showed a similar trend to the fabrics constructed with the ULS weft yarn, excluding one rogue data point, see Figure 4.6. The finished width shrinkage of the fabrics constructed with the PET weft yarn varied slightly as the finished fabric tightness increased, see Figures 4.6-4.9. Although the PET weft yarn had a higher degree of shrinkage potential than the ULS yarn, it evidently did not have enough shrinkage potential to significantly alter the finished width shrinkage as the finished fabric tightness increased.

The plain weave fabrics that were constructed with the Type 400 weft yarn resulted in finished width shrinkages that are worth commenting on, see Figure 4.6. The finished fabric width shrinkage of four of the fabrics constructed with the plain weave and the Type 400 weft yarn, were all significantly high compared to the other three fabric finished width shrinkages constructed, with the same weave and weft yarn. It was expected that the finished width shrinkage would vary as fabric tightness varied, however, the difference was significant.

The fabrics that utilized the 3x1 twill and the 8-H sateen weave that were constructed with the Type 400 weft yarn, demonstrated a decrease in finished width shrinkage as the finished fabric tightness increased, see Figures 4.7 and 4.8. The finished width shrinkage of the fabrics constructed with the 4x4 basket weave and the Type 400 weft yarn fluctuated slightly as the fabric tightness factor increased. However, there was neither a distinguishable increase nor decrease in finished fabric width shrinkage as the finished fabric tightness factor increased, see Figure 4.9.

To further investigate the outlying points in the graphs, each fabric sample was visually examined. It was noted that in three of the samples, permanent horizontal wrinkles were observed, specifically samples 1, 31 and 61, see Figure 4.10. A pick density of 2.93 picks per cm and a plain weave construction were utilized to produce each sample. The low pick density produced unstable fabrics that wrinkled during finishing. The wrinkles could not be removed with ironing. The inability to remove the wrinkles made it challenging to collect correct length dimensions. In an effort to collect a more accurate finished length dimension, the fabrics were tensioned with an embroidery hoop. Unfortunately, it was impossible to estimate how much tensioning would be required to remove the wrinkles. The inability to obtain an accurate length measurement adversely affected the finished pick density calculation, which in turn made it impossible to calculate an accurate finished fabric tightness factor. For this reason, samples 1, 31 and 61 were excluded from any evaluation which involved finished fabric tightness.

Figure 4.10 Horizontal Wrinkling of Samples 1, 31 and 61



Sample 1 **Sample 31** **Sample 61**

It was also observed that three of the fabrics constructed with the Type 400 weft yarn and a plain weave (62, 63, and 64) had permanent vertical wrinkles, see Figure 4.11. An unsuccessful attempt was also made to remove the vertical wrinkling. None of the other finished fabrics constructed with the other three weave designs appeared to have permanent wrinkling. In a plain weave design each weft yarn passes successively over and under each warp yarn, providing the greatest number of intersections in any given space. The combination of the high shrink potential of the Type 400 weft yarn, the very loose construction and the number of yarn intersections within the plain weave resulted in a great deal of wrinkling during the finishing process.

Figure 4.11 Finished Fabrics Constructed With the First Four Loosest Pick Densities, Specifically 62, 63 and 64

Sample 62 **Sample 63** **Sample 64**

The inability to collect an accurate finished width dimension from samples 62, 63 and 64 made it impossible to calculate an accurate finished end density. The inability to obtain an accurate finished end density, in turn made it impossible to calculate an accurate finished fabric tightness factor. For this reason, samples 62, 63 and 64 were excluded from any evaluation which involved finished fabric tightness.

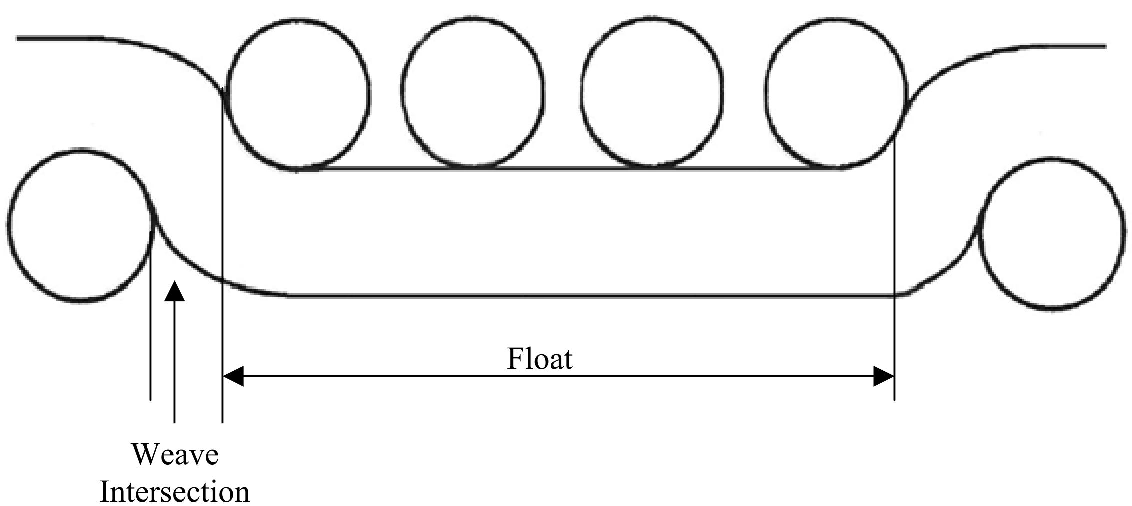
To further investigate the phenomenon of surface wrinkling, the finished warp and filling cover factors were evaluated. It was observed, see Table 4.6B in Appendix B, that a number of cover factors appeared to be suspiciously high. A cover factor that exceeds 100% can be obtained if the yarns are jammed to the point that they flatten within the woven construction. However, some of the cover factors far exceeded 100%, suggesting that some type of surface distortion might be present. In order to accurately determine if surface distortion was present, causing an excessively high cover factor, the theoretical maximum cover factor for each weave design used in this study needed to be determined.

4.2.4.2 DERIVATION OF THE THEORETICAL MAXIMUM COVER FACTOR

In order to determine if some type of surface distortion such as wrinkling existed on each fabric sample, an equation for the theoretical maximum cover factor was derived. The derivation of the formula is in part based on previous research by Love (Seyam, 2001). The derivation will be explained in terms of the maximum warp cover and cover factor, however, the same information can also be applied to the maximum filling cover and cover factor by exchanging 'warp' for 'filling' and visa versa.

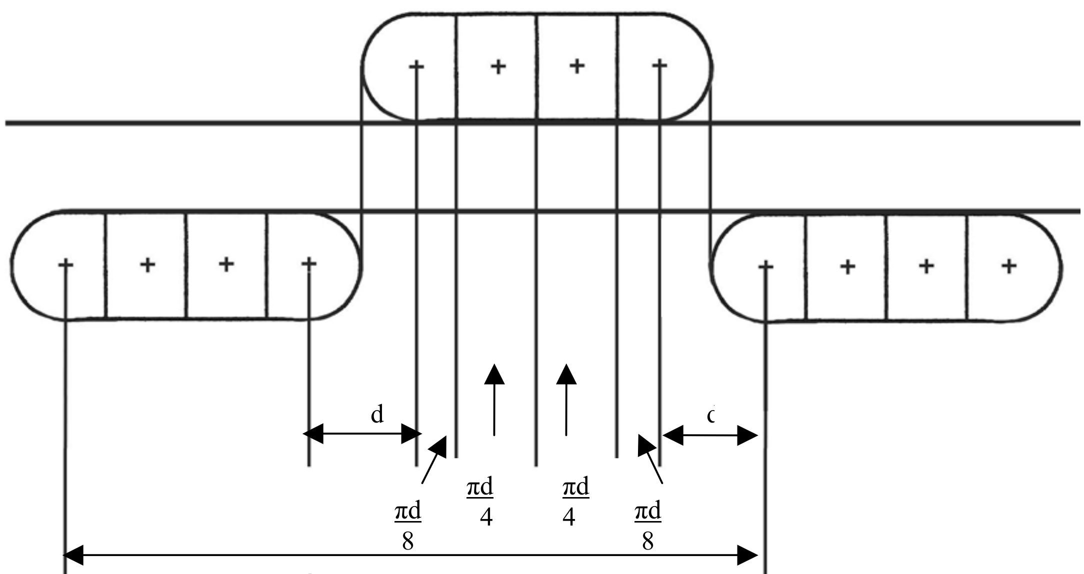
In Figure 4.12, a cross section of an unfinished fabric is illustrated. It can be seen from the cross section that due to crimp, the yarns are not in the same plane. It can also be noticed in the figure that at the weave intersection there is a space which is occupied by the intersecting filling yarn.

Figure 4.12 Cross Section of the Warp Yarns in a Fabric Before Finishing



If a high shrink weft yarn is used within the construction of the fabric, during finishing the fabric experiences a high degree of width shrinkage. The high degree of width shrinkage may result in what Love referred to as a jamming effect, resulting in maximum cover. Love assumed that within a jammed construction, the warp yarns under (or over) the filling float followed a racetrack configuration, with a uniform density that was equal to the original circular yarn (Seyam, 2001). In order to derive the maximum cover factor for a general weave it was also assumed that in a jammed condition, the filling yarn becomes completely straight- possessing no crimp. Figure 4.13 is a graphic illustration of a cross section of a jammed construction for a general weave according to Love's racetrack geometry (Seyam, 2001).

Figure 4.13 Cross Section of the Warp Yarns in a Fabric in a Jammed Condition After Finishing



There are two warp spacings, which need to be considered in order to derive the maximum warp cover factor. The two spacing are d, at the interlacing, and $\pi d/4$ under the float. To derive the maximum warp cover factor from the geometry assumed in a jammed condition, the average warp spacing needs to be found.

Let

$\overline{p}_{1\min}$ = Average warp spacing

i_1 = Number of interlacing per weave repeat

N_1 = Number of yarns per weave repeat

M_1 = Warp weave factor = N_1 / i_1

The weave repeat length can be expressed as follows:

$$\mathrm{N}_1 \overline{\mathrm{p}}_{1\min} = i_1 d_1 + \left(N_1 - i_1\right)\frac{\pi d_1}{4} \tag{1}$$

$$\overline{\mathrm{p}}_{1\min} = \frac{i_1 d_1 + \left(N_1 - i_1\right)\frac{\pi d_1}{4}}{N_1} \tag{2}$$

$$\overline{\mathrm{p}}_{1\min} = \frac{\frac{i_1}{i_1} d_1 + \left(\frac{N_1}{i_1} - \frac{i_1}{i_1}\right)\frac{\pi d_1}{4}}{\frac{N_1}{i_1}} \tag{3}$$

$$\overline{\mathrm{p}}_{1\min} = \frac{d_1 + \left(M_1 - 1\right)\frac{\pi d_1}{4}}{M_1} \tag{4}$$

The maximum warp cover and cover factor can be derived from equation 4 as:

$$\mathrm{C}_{1\max} = \frac{\mathrm{d}_1}{\overline{\mathrm{p}}_{1\min}} = \frac{M_1}{1 + \frac{\pi}{4}(M_1 - 1)} \tag{5}$$

$$\mathrm{K}_{1\max} = \frac{28\mathrm{d}_1}{\overline{\mathrm{p}}_{1\min}} = \frac{28M_1}{1 + \frac{\pi}{4}(M_1 - 1)} \tag{6}$$

Similarly, the maximum weft cover and cover factor can be derived as:

$$C_{2max} = \frac{d_2}{p_{2min}} = \frac{M_2}{1 + \frac{\pi}{4}(M_2 - 1)} \qquad (7)$$

$$K_{2max} = \frac{28d_2}{p_{2min}} = \frac{28M_2}{1 + \frac{\pi}{4}(M_2 - 1)} \qquad (8)$$

Using Formulas 5-8, the maximum cover and cover factors for the four weaves used in this study were calculated (Seyam, 2001). Table 4.6 shows the maximum warp cover and cover factors for each of the weaves used in this experiment.

Table 4.6 Calculated Maximum Warp and Filling Cover and Cover Factors

Weave	C_1 and C_2	K_1 and K_2 $=28^* C_1$
Plain	1.0	28
4-Harness (3x1 Twill)	1.12	31.4
8-Harness (8-H Sateen) (4x4 Basket)	1.19	33.4

Although permanent wrinkles were not visible, the cover factors for samples 22, 30, 75, 76, 77, 82 and 90 were higher than the calculated maximum cover factor. In order to produce a graphical illustration, the general weavability-limit relationship was graphed. The data points which make up the curve in the general weavability-limit relationship represent a given fabric with a specified warp and filling warp cover factor. Either end of the curve represents a fabric that is in a jammed state, as the condition shown in Figure 4.13. If a point falls outside the parameters of the curve, it can be categorized as un-weavable. However, the fabrics have all been woven, therefore it can be concluded that there is some type of surface distortion or wrinkling present, see Figure 4.1B and 4.2B in Appendix B.

In Figure 4.1B it can be observed that samples 22 and 30 had a warp and filling cover factor of 12.7, 36.9 and 13.0, 36.3 respectively. Sample 22 was constructed with an ULS yarn and a 8-H sateen weave. Sample 30 was constructed with an ULS yarn and a 4x4 basket weave. The calculated maximum cover factor was 33.4. It can be clearly seen from the figure that both points fell outside the weavability limit.

In Figure 4.2B samples 75.76,77,78,79, 82 and 90 are graphed. Samples 75-79 and 82 were constructed with the Type 400 weft yarn and 8-H sateen weave. The finished warp and filling cover factors can be seen in Table 4.6B in Appendix B. Samples 75, 76 and 77 all fell outside the weavability limit, therefore it was concluded that surface wrinkling was present. Sample 78 and 79 fell on the line of the weavability limit. For this reason these points were not excluded. Sample 82 fell on the line as well. However, this sample had a high weft cover, specifically, 33.3. Because the warp pre-exist the weft it is highly unlikely for a jammed condition to exist. A jammed condition in which the warp would become completely straight with no crimp is very unlikely. For this reason sample 82 was excluded.

Sample 90 was constructed with the Type 400 weft yarn and a 4x4 basket weave. Through experimental work, Brierley, found that basket weaves experience an overriding effect in weaving and in fabric finishing. The overriding is due to the fact that in basket weaves, threads weave together in groups. In a basket weave there are no neighboring intersections. The absence of neighboring intersections allows the threads in basket weaves to override (Brierley, 1952). The overriding effect caused in combination with the high shrinkage of the Type 400 weft yarn caused this fabric to have the highest overall cover factor. The point which represents this fabric fell out of the weavability zone and was therefore excluded.

In conclusion, the presence of horizontal wrinkles in samples 1, 31 and 61 made it impossible to calculate an accurate finished fabric tightness. The presence of vertical wrinkling in samples 62, 63 and 64 also made it impossible to calculate an accurate finished fabric tightness. Samples 22, 30, 75, 76, 77, 82 and 90 had cover factors that exceeded the calculated maximum cover factor, which indicated that there was surface distortion. For this reason, these points were excluded from any examinations which involve finished fabric tightness.

It is important to note that a good deal of width shrinkage was obtained from the parameters used in these fabrics. In addition, the wrinkling effect could be seen as an appealing aesthetic characteristic. Therefore, the set of parameters utilized to construct these fabrics could be very advantageous to the design and development of a seamless shaped textile. In addition, an accurate finished shrinkage could be obtained, therefore these points were not excluded from any analysis which involved finished width shrinkage.

4.2.4.3 THE FINISHED FABRIC TIGHTNESS AND WIDTH SHRINKAGE RESULTING FROM A SPECIFIC WEAVE AND THREE DIFFERENT WEFT YARNS WITH POINTS EXCLUDED

The following graphs illustrate the finished fabric tightness versus the finished width shrinkage with the samples that possessed surface distortion removed.

Figure 4.14

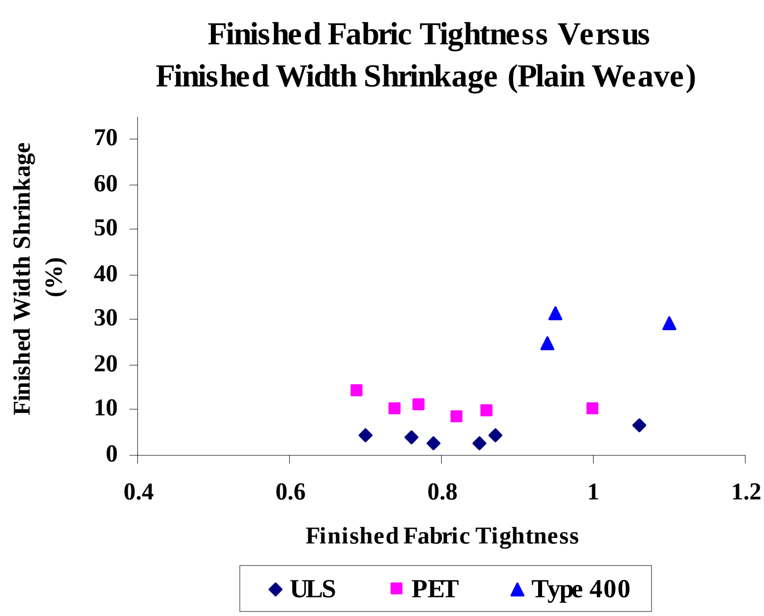


Figure 4.15

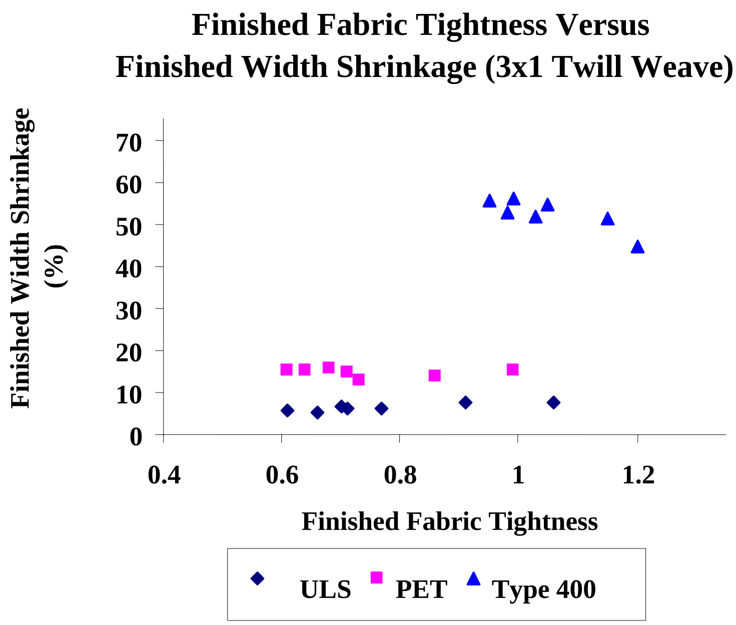


Figure 4.16

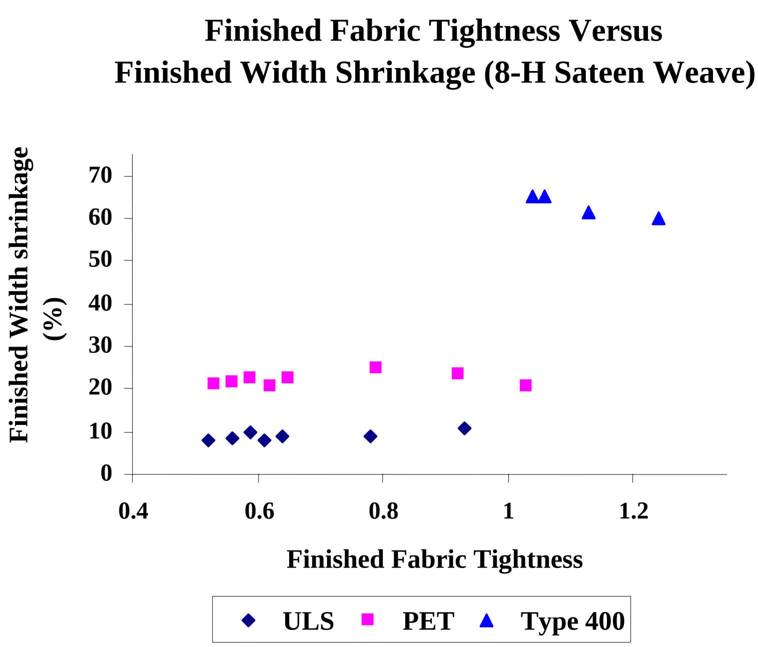
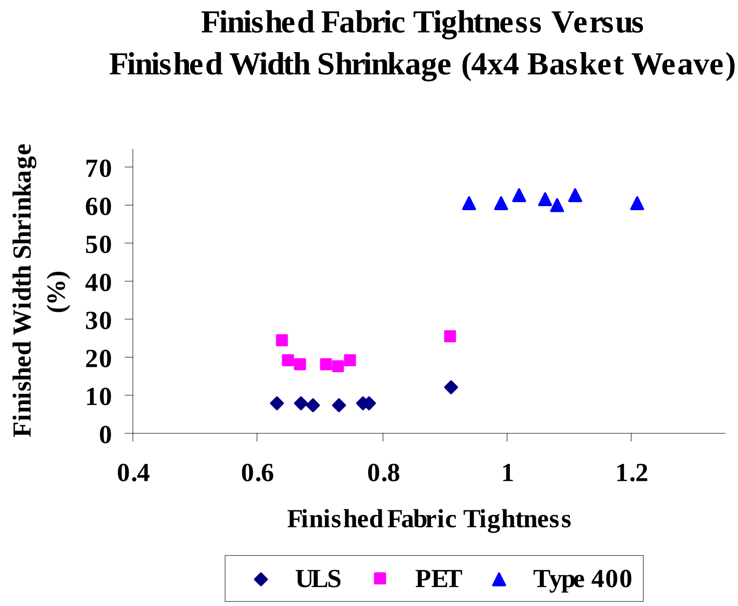


Figure 4.17



It can be noted from Figures 4.14-4.17, that the finished width shrinkage of the fabrics constructed the ULS weft yarn, changed very little as finished fabric tightness increased. It was expected that the percent of width shrinkage would decrease as finished fabric tightness increased, however, a prominent trend might not have been produced due to the low shrinkage potential of the ULS weft yarn.

The data points that represent the fabrics constructed with the plain weave and the 4x4 basket weave, and the PET weft yarn, show that the percent of width shrinkage changed very little as finished fabric tightness increased.

For the fabrics constructed with the plain weave and the Type 400 weft yarn, there were only three samples, therefore it is difficult to accurately determine a trend concerning finished fabric tightness and finished width shrinkage. There appeared to be a comparably steep decline in finished width shrinkage as fabric tightness increased in the fabrics constructed with the 3x1 twill, the 8-H sateen and the Type 400 weft yarn. Evidently the high percent shrinkage of the Type 400 weft yarn was able to take advantage of the looser structure at lower fabric tightness factors, pulling the fabric in, during finishing, resulting in a higher width shrinkage.

Basically no change appeared to take place in finished width shrinkage as fabric tightness increased in the fabrics constructed with a basket weave and the Type 400 weft yarn. As stated earlier, in basket weaves, threads weave together in groups, therefore there are no neighboring intersections. The absence of neighboring intersections causes an overriding effect, which causes a higher degree of shrinkage than in other weaves (Brierley, 1931).

4.2.4.4 INVESTIGATING THE INTERACTION BETWEEN FABRIC SAMPLES CONSTRUCTED WITH DIFFERENT SETS OF PARAMETERS

It was deemed necessary to further investigate the potential for possible interaction between the different sets of parameters. The percentage of width shrinkage of each data point on the graphs shown thus far, represents the average of five measurements. In order to investigate a possible interaction between the data points, the finished fabric tightness and finished width shrinkage of all of the five measurements were plotted (as opposed to the average of the five measurements), see Figures 4.18-4.21.

Figure 4.18

Finished Fabric Tightness Versus
Finished Width Shrinkage of Five Width Dimensions
(Plain Weave)

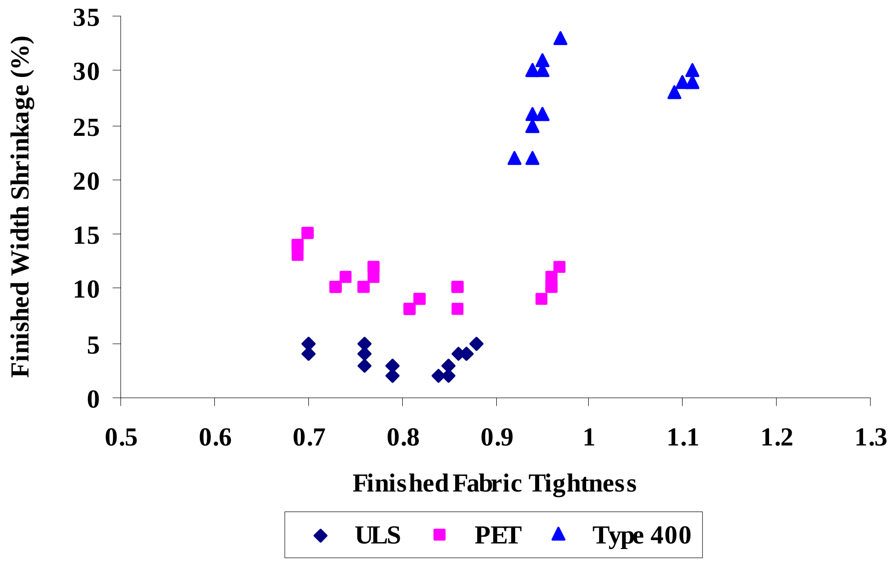


Figure 4.19

Finished Fabric Tightness Versus
Finished Width Shrinkage of Five Width Dimensions
(3x1 Twill Weave)

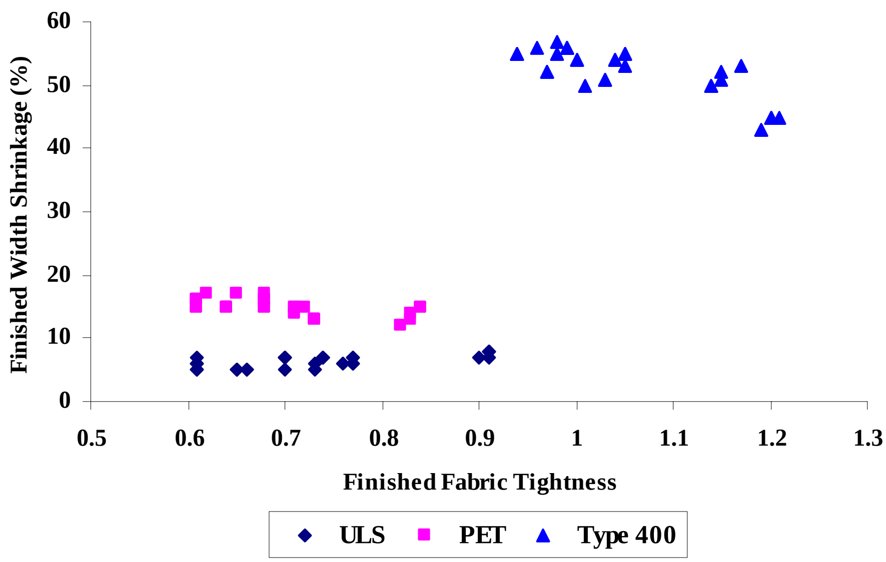


Figure 4.20

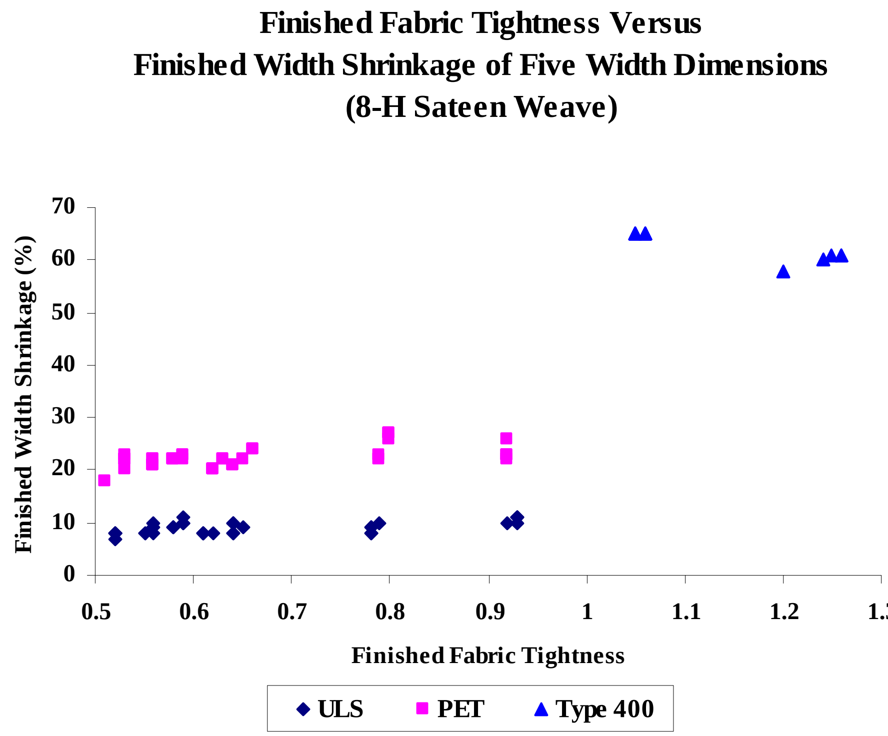
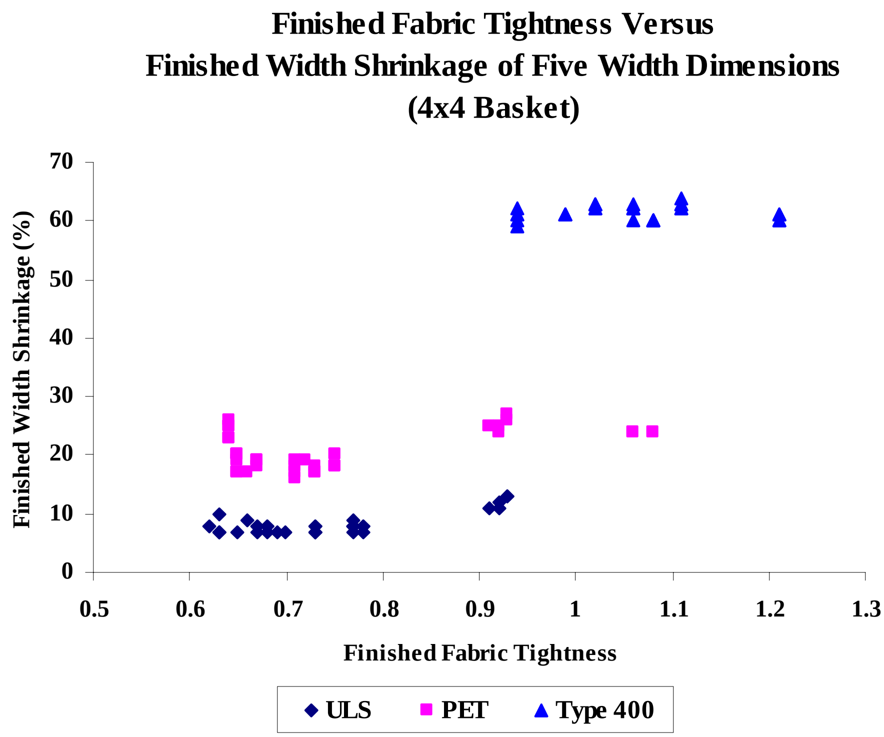


Figure 4.21



There appeared to be little interaction between the data points of the five measurements, each representing a specific weave, weft yarn and pick density, therefore, the average of the five measurements was used in the additional examinations that were made in this study.

4.2.4.5 PRODUCING SPECIFIC FINISHED FABRIC TIGHTNESS FROM A GIVEN SET OF PARAMETERS

One of the goals of this research was to determine if fabrics constructed with a given set of construction parameters would result in different finished width shrinkages, however, the same or similar finished fabric tightness. Early researchers found that there was a strong correlation between the tightness of a fabric and the physical, mechanical and aesthetic properties of the fabric (Seyam, 2002). Therefore, it was believed to be important to evaluate the potential for producing a fabric constructed with different sets of parameters that would produce differential shrinkage, and ultimately shape, and at the same time possess the same or a similar finished tightness.

The graphs in Figures 4.14-4.17, clearly illustrate that fabrics constructed with the same weave design, however, different weft yarns, can be produced with similar or the same finished fabric tightness, and different finished width shrinkage. From these results it can be concluded that fabrics with different degrees of shrinkage caused from different weft yarns, can be produced with either a similar or the same fabric tightness. It should be mentioned that the loom utilized in this experiment, specifically the Picanol GTM, had a limited ability to change picks per unit length. Most modern looms can quickly and easily change the picks per unit length to any number desired. The ability to quickly and easily change the picks per unit length would allow for fabrics with a wider range of finished fabric tightness factors to be produced. Therefore, with appropriate experimentation it might be possible to produce fabrics with differential shrinkage utilizing different weft yarns with the exact finished fabric tightness.

4.2.4.6 THE FINISHED FABRIC TIGHTNESS AND FINISHED WIDTH SHRINKAGE RESULTING FROM THE FOUR DIFFERENT WEAVES

The finished fabric tightness of the four different weave designs was compared and contrasted to the finished width shrinkage, see Figures 4.22-4.24. The main reason for evaluating the relationship between these parameters was to assess the different amount of width shrinkage produced from the different weave designs at different degrees of finished fabric tightness. Russell's tightness factor allows the examiner the ability to compare and contrast the tightness of fabrics constructed with different weave designs.

Figure 4.22

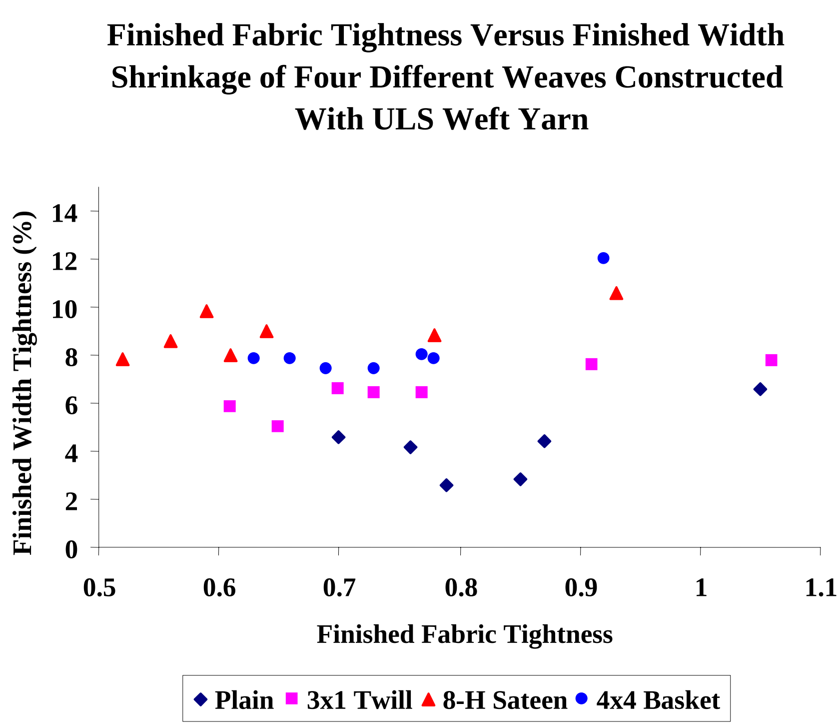


Figure 4.23

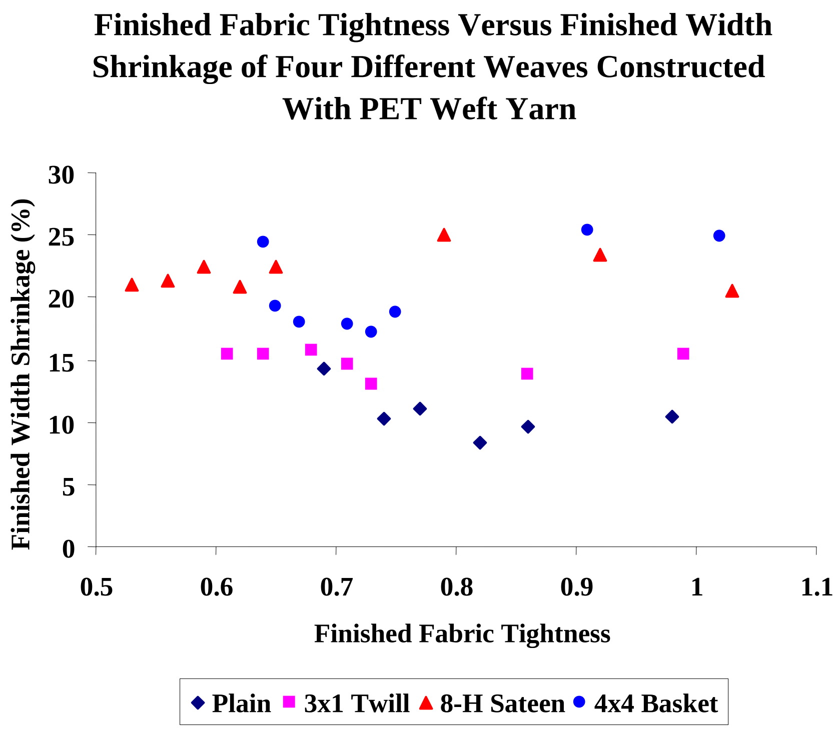
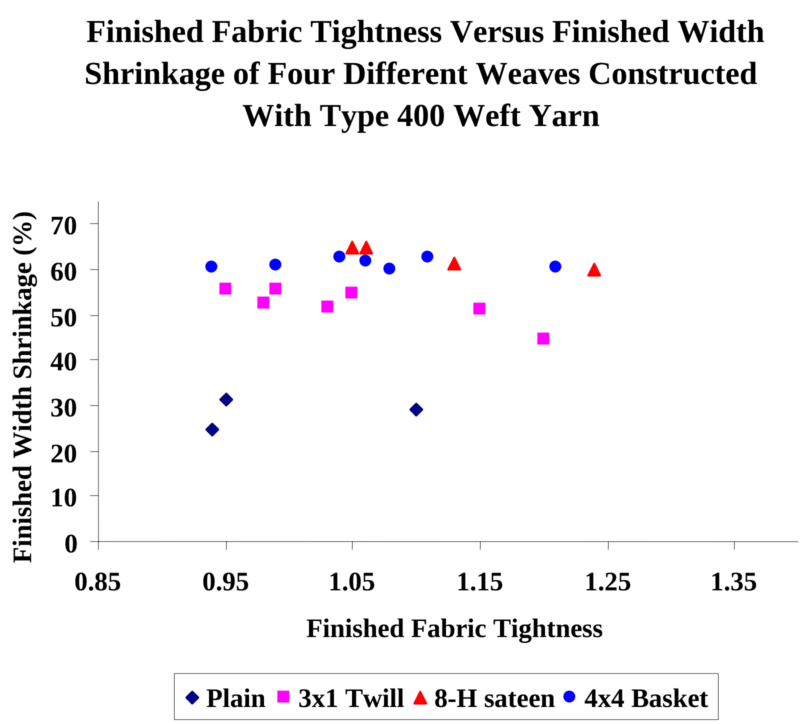


Figure 4.24



Figures 4.22-4.24 clearly show that the least amount of finished width shrinkage was produced from the vast majority of the fabrics constructed with the plain weave. Figures 4.22-4.24, also illustrate that the vast majority of the fabrics constructed with the 3x1 twill weave had the second least amount of finished width shrinkage.

It can be observed from Figures 4.22-4.24, that at the lower fabric tightness factors the majority of fabrics constructed with the 8-H sateen weave had a higher percent finished width shrinkage than the fabrics constructed with the 4x4 basket weave. However, at the higher fabric tightness factors the fabrics constructed with the 4x4 basket weave had a higher percent finished width shrinkage than the fabric constructed with the 8-H sateen weave.

Weaves may have the same number of threads per weave design and the same number of yarn intersections per weave design, but have different shrinkage potential. For example an 8-H sateen and a 4x4 basket weave have the same weave factor but are different weave types with different shrinkage behavior.

As mentioned earlier, basket weaves undergo an overriding effect. In the 1930's, S. Brierley did extensive experimental work on the subject of cloth setting. He found that in cloths that were constructed with weaves that had up to 2 floats the threads were held firmly in position. However, in fabrics that contain longer floats there is a displacement of the threads. He proved this phenomenon by measuring the thickness of different cloths that were constructed with weaves containing different float lengths. As the float length increased, the fabric thickness increased. The increase in fabric thickness of the fabrics constructed with longer floats was due to an overriding of the threads that occurred during weaving (Brierley, 1931).

Brierley went on to further investigate this phenomenon by evaluating different weave types. He divided simple weaves into three main classes (Brierley, 1952):

1. Regular twill weaves made with a move of one
2. Satin and sateen weaves
3. Regular basket weaves

Through experimentation he noted that basket weaves were thicker than the other two classes of weaves, indicating that a greater degree of overriding of the yarns occurred. The overriding is due to the fact that in basket weaves, threads weave together in groups, therefore there are no neighboring intersections. The absence of neighboring intersections allows the threads in basket weaves to override because there is nothing to prevent the occurrence of the phenomenon (Brierley, 1952). Overriding of the threads not only occurs in weaving but also in fabric finishing, therefore a greater amount of shrinkage occurs.

Satin and sateen weaves have more neighboring intersections than basket weaves, therefore a satin and sateen weave will experience less overriding of the threads than a basket weave. A twill weave has more neighboring intersections within the weave design than a satin or sateen weave, resulting in less overriding of the threads (Brierley, 1931). For this reason it is likely the fabrics constructed with the basket weave had a slightly greater amount of shrinkage than the fabrics constructed with the sateen weave at the tighter fabric tightness factors, see Figures 4.22 and 4.24.

It was also deemed important to investigate whether fabrics constructed with different weaves, resulting in different finished width shrinkages, could have a similar or the same finished fabric tightness. It can be clearly seen from the graphs in Figures 4.22-4.24, that a number of fabrics with different degrees of finished width shrinkage had a similar or the same finished fabric tightness. From these results it can be surmised that fabrics constructed with different weaves, and having different degrees of shrinkage can be produced with either a similar or the same fabric tightness. Combinations of different weave designs resulting in different width shrinkages could be incorporated into a product to create shape. It should be noted that the loom utilized in this experiment had limited design capabilities. The ability to quickly and easily change the weave design, as well as assign different weaves in specific areas, would allow for a wider range of finished fabric tightness and shapes.

4.2.4.7 THE FINISHED FABRIC TIGHTNESS RESULTING FROM A SPECIFIC ON-LOOM FABRIC TIGHTNESS

In this experiment, fabrics were constructed with a different set of construction parameters to produce a range of on-loom fabric tightness factors between 0.4-1.0. After fabric finishing the resulting finished fabric tightness was then compared and contrasted with the on-loom fabric tightness, see Figures 4.25-4.27.

The graphs which compare on-loom and finished fabric tightness could be of great use to designers. The information would allow the designer to know before the weaving process what finished fabric tightness could be expected from a specific on-loom fabric tightness.

Figure 4.25

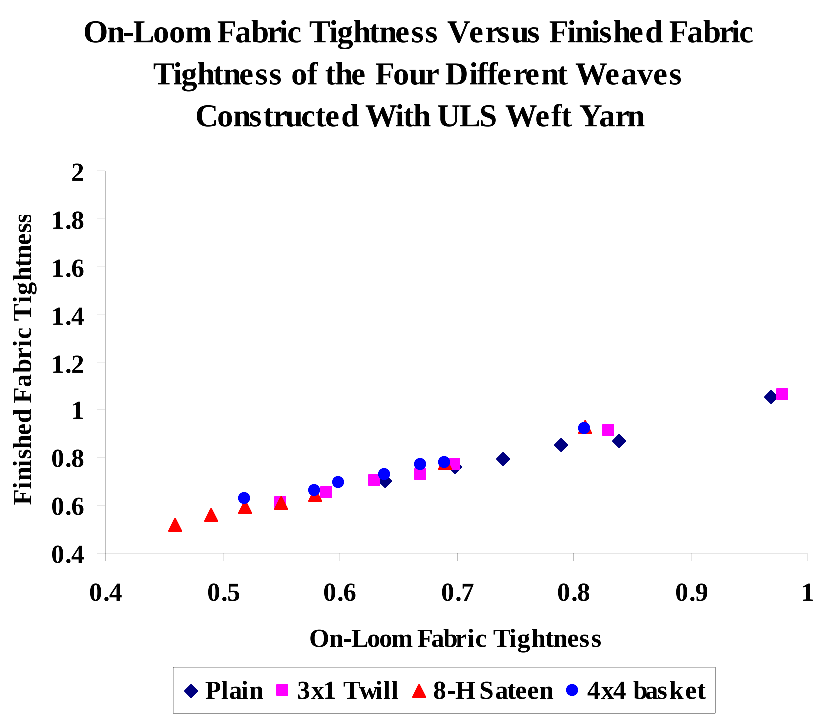


Figure 4.26

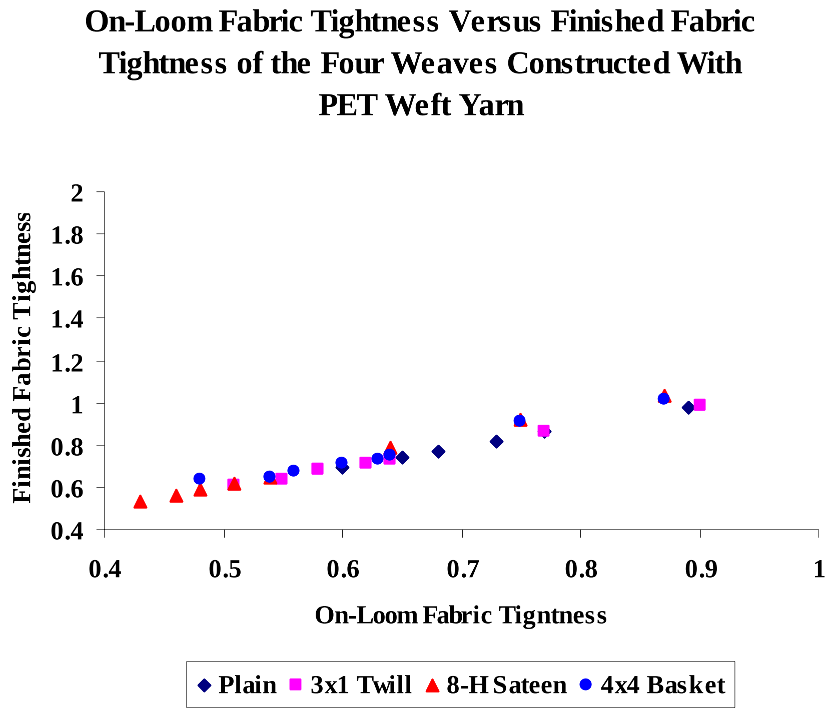
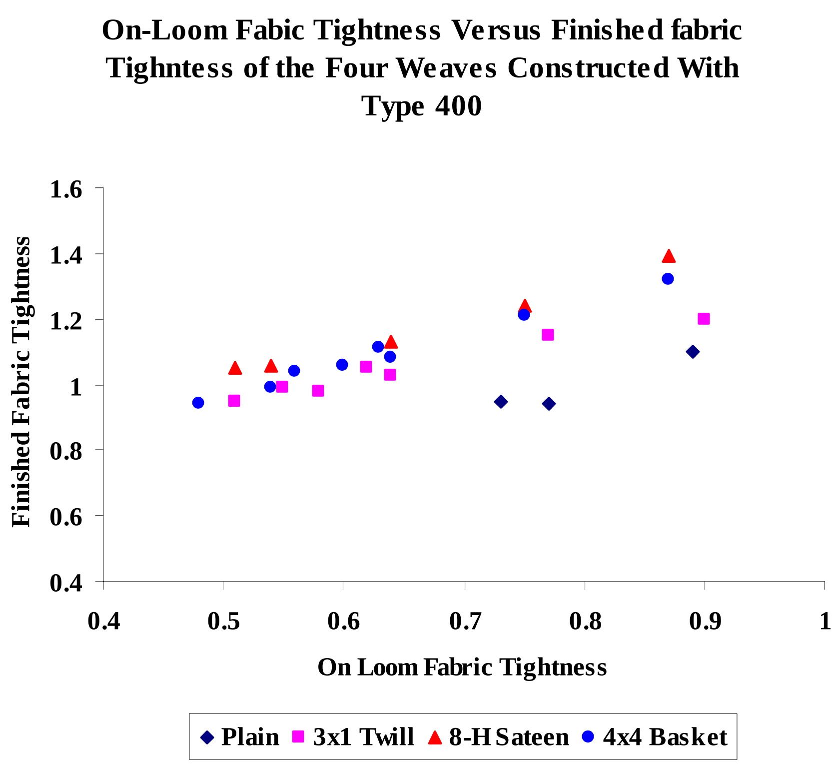
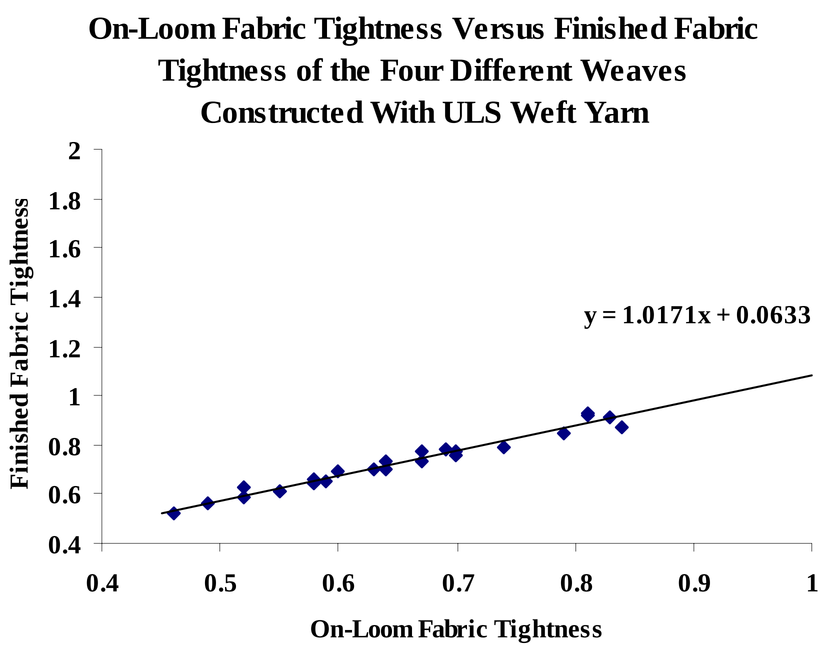


Figure 4.27

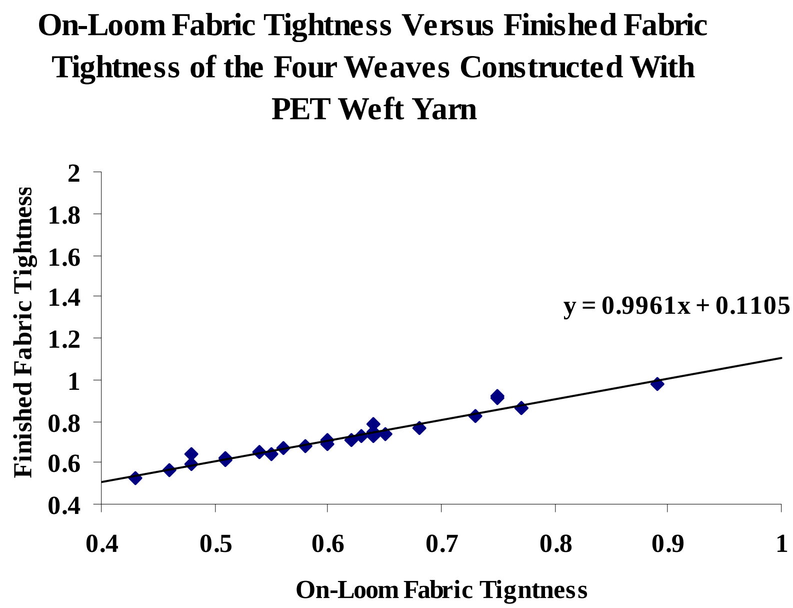


There appeared to be a strong correlation between the on-loom and finished fabric tightness factors of the fabrics constructed with the ULS and the PET weft yarn. Although not as strong, a correlation between the on-loom and finished fabric tightness of the fabrics constructed with the Type 400 weft yarn also appeared to exist. To further investigate the correlation between the on-loom and finished fabric tightness, a regression line was applied, see Figures 4.28-4.30.

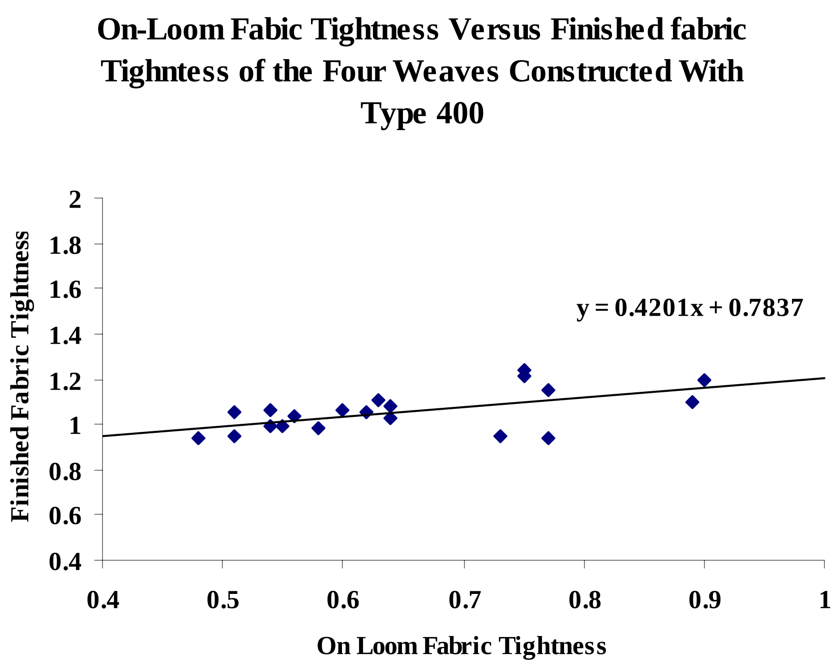
Figures 4.28



Figures 4.29



Figures 4.30



It can be noted from the slope of the lines in Figures 4.28 and 4.29, which illustrate the fabrics constructed with the ULS and the PET weft yarn, that there is a strong correlation between the on-loom fabric tightness and the finished fabric tightness. The slope of the line in Figure 4.30, illustrates that there is less of a correlation between the on-loom fabric tightness and the finished fabric tightness of the fabrics constructed with the Type 400 weft yarn. This is most likely due to the high shrinkage potential of the Type 400 weft yarn. Regardless of the on-loom fabric tightness of the fabric, the high shrinkage potential of the Type 400 weft yarn was able to shrink the fabric to the fullest extent.

Although scattergraphs can be utilized to gauge the strength of the relationship between on-loom fabric tightness and finished fabric tightness, a more formal method based on calculation was utilized. The correlation coefficient, also known as Pearson's coefficient, was generated from a statistical model, see SAS Code, Table 4.11B and Table 4.12B, in Appendix B. The correlation coefficient gives a numerical value for the degree of correlation. It is calculated on the basis of how far each point lies from the 'best-fit' regression line (Steel et al, 1997). Table 4.7 shows the correlation coefficient between on-loom fabric tightness and finished fabric tightness of the fabrics constructed with the three different weft yarns,

Table 4.7 The Correlation Coefficients Between On-loom Fabric Tightness and Finished Fabric Tightness for the Fabrics Constructed with Each of the Three Weft Yarns

Weft Yarn	Correlation Coefficient
ULS	0.99
PET	0.98
Type 400	0.56

A correlation coefficient that is close to 1 indicates a perfect positive correlation. At the other extreme, a correlation coefficient that is 0 means zero correlation. It is important to note that the strength of the relationship is dependent on the ability to obtain exact measurements. For example, if the experiment entails measurements that can be completely accurately collected, a strong relationship would only be indicated by a coefficient correlation that was 0.95-1. However, if measurements are more difficult to collect, such as those from human subjects, a correlation of 0.5 is considered to be strong. This experiment is considered one in which fairly accurate measurements are collected, however not exact. The data in this experiment is not considered exact, because the method utilized to collect the measurements is subject to some degree of human error (Hale).

A correlation coefficient of the fabrics constructed with the ULS and PET weft yarns had almost a perfect correlation, indicating a strong relationship between on-loom and finished fabric tightness. The correlation coefficient of the fabrics constructed with the Type 400 weft yarn was comparably less than the correlation coefficient of the fabrics constructed with the ULS and PET weft yarns. The high shrinkage potential of the Type 400 yarn is not accounted for in the finished fabric tightness calculation. This obviously lead to a much weaker relationship between the on-loom and finished fabric tightness.

In addition, the correlation between the on-loom fabric tightness and the finished fabric tightness of the fabrics constructed with different weave designs was evaluated in terms of the correlation coefficient. Table 4.8 below shows the correlation coefficient for each weave.

Table 4.8 The Correlation Coefficients Between On-loom Fabric Tightness and Finished Fabric Tightness for the Fabrics Constructed with Each of the Four Weave Designs

Weave	Correlation Coefficient
Plain	0.89
3x1 Twill	0.58
8-H Sateen	0.69
4x4 Basket	0.40

It can be seen from the correlation coefficient in Table 4.8 that the fabrics constructed with the plain weave had the strongest correlation between on-loom fabric tightness and finished fabric tightness, followed by the 8-H sateen, 3x1 twill and the 4x4 basket weaves.

To more closely evaluate the correlation between on-loom fabric tightness and finished fabric tightness, each set of fabrics constructed with each of the four weaves was graphed, see Figures 4.31-4.34.

Figure 4.31

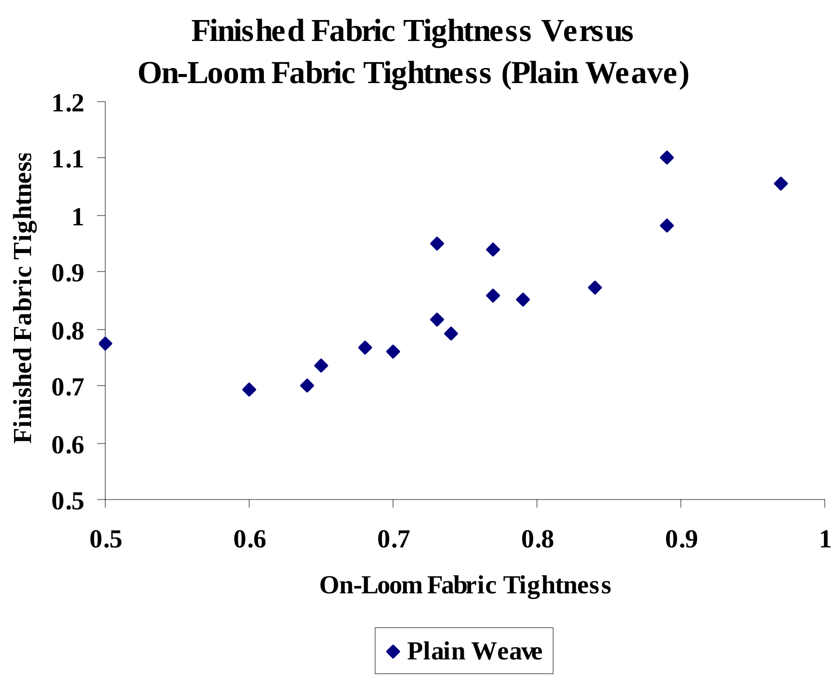


Figure 4.32

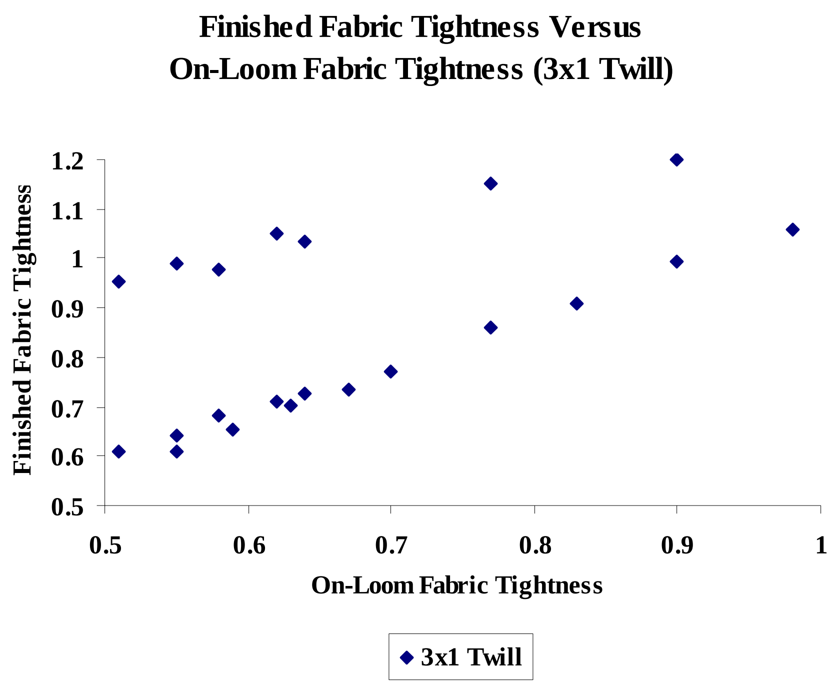


Figure 4.33

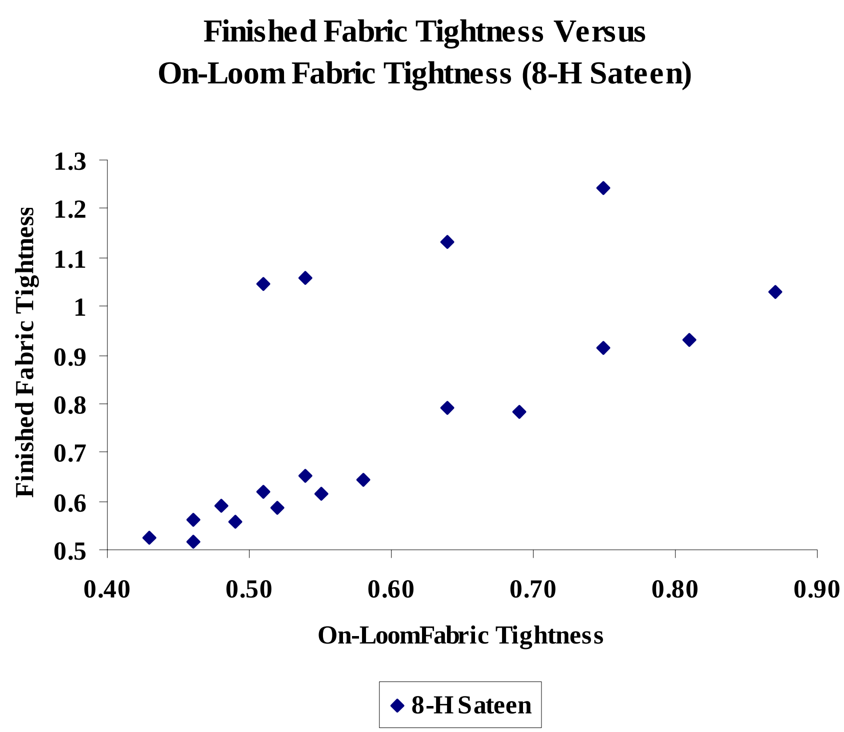
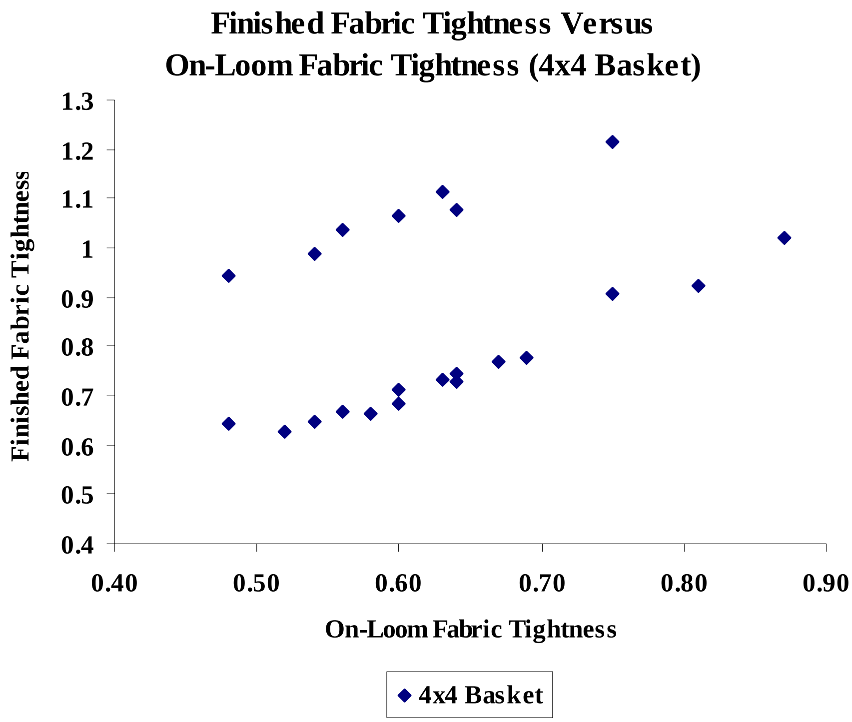


Figure 4.34



Other than the graph which illustrates the fabrics constructed with the plain weave, the graphs illustrating the fabrics constructed with the 3x1 twill, 8-H sateen and the 4x4 basket show two very distinct sets of data. The correlation coefficient calculated for the plain weave fabrics was the highest. The higher correlation coefficient is due to the fact that two distinct sets of data do not exist. In the other three graphs, one set of data represents the fabrics constructed with the Type 400 weft yarn and the other set of data represents the fabrics constructed with the PET and ULS weft yarns. It is interesting to note that four of the seven fabrics constructed with the Type 400 weft yarn and the plain weave design were excluded. This left three fabrics in the analysis of the plain weave fabrics constructed with the Type 400 weft yarn. The exclusion of the four data points made the correlation between on-loom fabric tightness and finished fabric tightness of the plain weave fabrics stronger than the three other weaves.

The finished fabric tightness of the fabrics constructed with the Type 400 weft yarn was comparably higher than the on-loom fabric tightness for the fabrics constructed with the ULS and the PET weft yarn, resulting in two sets of data. The two sets of data can account for the lower correlation coefficients calculated for the fabrics constructed with the twill, sateen and basket weave, than the coefficient calculated for the plain weave. It is important to note, that if the data representing the fabrics constructed with the Type 400 weft yarn were excluded, there would be a much stronger correlation between on-loom fabric tightness and finished fabric tightness.

4.3 STATISTICAL MODELS

One of the main goals of this experiment was to produce differential shrinkage within a fabric and ultimately shape by utilizing selected fabric construction parameters. In order to assess the overall success of this experiment as well as the contribution that each of the variables, specifically, the three weft yarns, four weave designs and different pick densities had on finished width shrinkage, a statistical model was developed. The statistical model was also designed to evaluate the contribution made to finished width shrinkage by different combinations of the three variables. An additional model was developed to evaluate the contribution of each of the three variables to finished fabric tightness, as well as combinations of the three variables.

When evaluating finished width shrinkage, the data for all the samples was utilized. As stated in Section 4.2.4.2, because of the presence of three-dimensional surface distortion produced during fabric finishing, an accurate finished fabric tightness was impossible to calculate. Therefore, thirteen fabrics were excluded. However, when evaluating finished width shrinkage, the three-dimensional surface distortion did not affect the measurement of the finished width shrinkage. Therefore, all the data points were used. The model in which the finished width shrinkage was evaluated, will be referred to as the Full Data Set. The model in which the finished fabric tightness was evaluated, will be referred to as the Reduced Data Set.

In addition, utilizing the data generated in this experiment, a predictive statistical model was developed. This type of model could be used by designers to predict the amount of finished width shrinkage that would be produced from a given set of construction parameters. A fairly approximate finished width prediction was obtained through simple calculations.

4.3.1 EVALUATION OF EXPERIMENT

To evaluate the overall experiment, two analysis of variance tables were developed. The SAS code for these tables can be seen in Table 4.10B and 4.11B, in Appendix B. To determine the overall success of the model, the p-value is evaluated. When the p-value is 0.05 or less, it is considered to be significant, meaning the variables contributed to the outcome or to the dependent variable (Steel et al, 1997). In this case, the dependent variable is either finished width shrinkage or finished fabric tightness. It can be noted in the two analysis of variance tables (see Tables 4.14B and 4.15B Appendix B) that both of the p-values for the overall models were well below 0.05, indicating that the independent variables were significant and contributed to both the finished width shrinkage and the finished fabric tightness.

The second part of the variance tables takes a closer look at the individual variables (pick density, weave and weft yarn), as well as the significance of different combinations of the variables. It must be noted that in this experiment there were three independent variables, specifically, three different weave designs, four weft yarns and 7 or 8 different pick densities. Some pick densities were either too loose or too tight for a specific weave, therefore, were not utilized in every weave construction. Because there was not a combination of every weave design, weft yarn and pick density, the models are considered imperfect. However, the term "imperfect" should be seen as strictly a statistical one. By no means does it imply that the research models are invalid. Categorizing the model as "imperfect", means that the Type III SS should be evaluated, not the Type I SS. The Type I SS squares is order based, meaning the order in which the data is typed in effects the outcome data. In this case, the data representing pick density needs to be readjusted. In the Type III SS the data representing pick density has been readjusted for all other effects in the model (Osborne, 2004).

The p-value indicates whether or not there is evidence to suggest that the three variables used in this study contributed to finished width shrinkage and finished fabric tightness. The model was also designed to evaluate the significance that different contributions of the three variables had on finished width shrinkage and finished fabric tightness. The p-values listed in both Tables 4.14B and 4.15B, indicate that each individual and independent variable contributed to finished width shrinkage and finished fabric tightness. It can also be seen from the data that different combinations of the independent variables, contributed to finished width shrinkage and finished fabric tightness. It can be noted in Tables 4.14B and 4.15B that the weaves contributed the least to finished fabric width shrinkage and finished fabric tightness. However, the contribution was still significant.

4.3.2 STAITICAL MODEL DEVELOPED TO PREDICT FINISHED FABRIC WIDTH SHRINKAGE

A predictive model was developed in an attempt to predict finished width shrinkage from the data generated in this study. The ability to predict shrinkage could minimize weaving trials. In addition, the model revealed more specific information as to the contribution the individual variables had on finished width shrinkage.

The predictive model developed in this study, utilized the finished width shrinkage data obtained from the samples produced in the weaving trials to predict an estimate. A predictive estimate is generated for each variable and all combinations of the variables. The predictive estimate represents the contribution that each variable and combination of variables made to finished fabric width shrinkage. For this type of research, in which fairly accurate measurements are collected, it is recommended that at least 80-90 data samples are utilized to produce an accurate prediction (Hale, 2004). In this research there were a total of ninety fabrics woven and evaluated for finished width shrinkage.

In statistical models, variables can be continuous or categorical. Determining whether or not a variable should be continuous or categorical depends to a large degree, on the amount of measurable data available. It was decided that the pick density would be programmed in to be a continuous variable, therefore the numerical pick densities were utilized. The four weaves and three weft yarns were designated as categorical variables. One of the categorical variables is assigned to be the base line. In this case, the plain weave was chosen to be the base line out of the four weaves, and the ULS weft yarn was chosen to be the base line out of the three weft yarns. The base line variable is assigned a zero estimate. It should be pointed out that this does not mean that it is given a zero contribution. The program adjusts the zero amount to accurately reflect the variable's contribution to finished width shrinkage (Boos, 2004). Therefore, it is a random choice as to which variable is assigned to be the base line. Unfortunately, the p-value is not calculated for the base line variables.

Once the information is put into the SAS program, estimates for each variable and combinations of the variables are generated, see Table 4.16B in Appendix B. From these estimates the finished width shrinkage can be calculated. An example below demonstrates how the finished fabric shrinkage is calculated. The specific example shows the calculation of finished width shrinkage for a fabric constructed with a 3x1 twill weave, ULS weft yarn and a 13.66 pick density.

$$\%Shrink=16.67 + (13.66)(-1.03) + (-12.4) + 0 + (13.66)(1.14) + 0 + 0 = 5.77$$

The actual finished width shrinkage that was measured from the fabric sample constructed with these parameters was 5%. In this case, the calculated prediction was very close to the actual data.

Table 4.17B in Appendix B, lists the actual width shrinkage and the predicted width shrinkage for each of the ninety fabric samples. The majority of the predictions for the finished fabric width shrinkages of the plain weave fabrics are fairly far off. Some of the plain weave fabrics had unexpectedly high shrinkages, due to surface wrinkling, whereas others had comparably lower width shrinkages. The large fluctuation in data most likely made it difficult to produce accurate finished width predictions. Within a group of samples constructed with a specified weft yarn and weave, the finished width shrinkage predictions were not exact, however fairly accurate. It was concluded that a fairly accurate bench mark could be predicted for a given group of fabrics that were constructed with a specific weft yarn and weave. However, exact predictions could not be produced.

The model also displays the standard error, see Table 4.16B in Appendix B. The standard error measures the random variation within a single variable. If this project were to be redone, there would most likely be some variations in the data. The standard error takes into account these variations.

The other information worth commenting on in Table 4.16B is the p-values. In Table 4.16B the p-value was first given for the overall model. Each variable was then further analyzed by calculating the p-value for the pick density, weave and weft yarn. The variables are even more specifically analyzed by breaking down the weaves into each of the four individual weaves and the weft yarns into each of the three individual weft yarns. The p-value is also calculated for each of the different combinations of the individual variables. As stated earlier the program is unable to calculate the p-value for the variable which is assigned as the base line. Therefore, there are not p-values for the plain weave or any combination containing the plain weave, as well as for the ULS weft yarn or any combination containing the ULS weft yarn. However, the p-values that were calculated, offer some interesting information.

It can be noted from the p-values in Table 4.16B that the three weaves had significant values, indicating they contributed to shrinkage. The p-values calculated for PET and Type 400 also had significant p-values, indicating a significant contribution. The interaction between the pick density and weaves also contributed to finished width shrinkage. Although the p-value for the Type 400 weft yarn and the pick densities indicated a significant contribution, the contribution of the PET weft yarn and the pick densities was not significant. The p-value (0.4889) indicates that there were no additional effects to finished width shrinkage from the interaction between the PET weft yarn and the pick densities. Other interactions that indicate that there was no additional effect to finished width shrinkage are from the 3x1 twill and the PET; 3x1 twill and the Type 400; 4x4 basket and the PET; and the 8-H sateen and the PET. The interaction of PET with other variables did not contribute additionally to finished width shrinkage. This is probably due to the relatively low shrinkage potential of PET. It is likely that the p-values for the ULS weft yarn would have revealed the same trends. In addition, there was no additional contribution from either weft yarn and the 3x1 twill weave.

4.4 CONCLUSION

In this experiment three variables that were explored in previous trials (see Part III) were chosen for further investigation. The three variables were 1) different pick densities, 2) different weave designs and 3) different weft yarns with different degrees of shrinkage. The main goal of this research was to investigate the correlation between fabric width shrinkage and a given set of fabric construction parameters in order to create inherent shape within the fabric. In addition, the finished fabric tightness was compared and contrasted to the fabric width shrinkage and the on-loom fabric tightness.

Ninety fabrics were woven, each constructed with a different set of construction parameters. On-loom fabric tightness factors were produced in a range of 0.4-1.0. From this research a number of conclusions were made, specifically:

- The shrinkage properties of each of the three weft yarns were evaluated utilizing a two shrinkage tests. The shrinkage tests revealed that the ULS yarn had the least amount of shrinkage followed by the PET, which was followed by the Type 400 yarn.

- The crimp contraction accurately correlated to the fabric width shrinkage of the fabrics constructed with the ULS weft yarn.

- For the fabrics constructed with the plain and twill weave and the PET weft yarn, the crimp contraction was not accurately correlated with the fabric width shrinkage.

- For the fabrics constructed with the sateen and basket weaves and the PET weft yarn, the crimp contraction accurately correlated with the fabric width shrinkage.

- For the majority of the fabrics constructed with the Type 400 weft yarn, the crimp contraction accurately correlated to the fabric width shrinkage.

- Differential width shrinkage and ultimately shape in the fabric width direction can be successfully manipulated by using weft yarns with different degrees of shrinkage.

- The vast majority of fabrics constructed with the ULS weft yarn had the least amount of shrinkage followed by the fabrics constructed with PET and, lastly the Type 400 weft yarn.

- The calculated maximum cover factor was derived to determine if non-visual surface distortion was present in seven samples. From the maximum cover factor it was determined that surface distortion existed on seven samples, even though it was not visible.

- Except for the fabrics constructed with a plain weave, the fabrics which utilized the ULS weft yarn had very little change in finished width shrinkage as finished fabric tightness increased.

- The finished with shrinkage changed very little in the fabrics constructed with the PET weft yarn, as the finished fabric tightness increased.

- Because of the lack of data, no discernable trend could be found regarding finished width shrinkage and finished fabric tightness in the fabrics constructed with the Type 400 weft yarn and the plain weave.

- There was a comparably large decline in finished width shrinkage as finished fabric tightness increased in the fabrics constructed with the Type 400 weft yarn and the twill and sateen weaves.

- There was almost no change in finished fabric shrinkage with increased finished fabric tightness in the fabrics constructed with the Type 400 weft yarn and a basket weave.

- Fabrics constructed with the same weave design and different weft yarns can result in different percentages of finished fabric width shrinkages, however, possess the same or similar finished fabric tightness.

- Most of the fabric constructed with a plain weave resulted in the least amount of shrinkage followed by the fabrics constructed with the 3x1 twill.

- At the lower fabric tightness factors, the majority of fabrics constructed with the 8-H sateen weave had a higher percent finished width shrinkage than the fabrics constructed with the 4x4 basket weave.

- At the tighter fabric tightness factors the fabrics constructed with the 4x4 basket weave had a higher percent finished width shrinkage than the fabrics constructed with the 8-H sateen weave.

- Fabrics constructed with the same weft yarn and different weaves can be developed to possess different degrees of shrinkage and similar or the same fabric tightness factor.

- The correlation coefficient revealed that there was a strong relationship between the on-loom and finished fabric tightness of the fabrics constructed with the ULS and PET weft yarn.

- The correlation coefficient revealed that there was not a strong relationship between the on-loom and finished fabric tightness of the fabrics constructed with the Type 400 weft yarn.

- The correlation coefficient revealed that there was a strong relationship between the on-loom and finished fabric tightness of the fabrics constructed with the plain weave.

- The correlation coefficient revealed that there was a relatively weak relationship between the on-loom and finished fabric tightness of the fabrics constructed with twill, sateen and basket weaves.

- It was concluded that the weaker relationship of the twill, sateen and basket weaves between the on-loom and finished fabric tightness (as compared to the plain weave) was attributed to the high finished fabric tightness of the fabrics constructed with the Type 400 weft yarn.

- The p-values generated by a statistical model revealed that each of the three independent variables contributed to finished width shrinkage and finished fabric tightness.

- The p-values generated by a statistical model revealed that combinations of the three independent variables contributed to finished width shrinkage and finished fabric tightness.

- A statistical model illustrated that the four different weave designs, three weft yarns and the different pick densities, individually contributed to finished width shrinkage and finished fabric tightness.

- The p-values for the interaction between the pick density and the weave designs, and the interaction between the Type 400 weft yarn and the pick density were all significant.

- The predictive model revealed that there was no additional effect to finished width shrinkage from the interactions of the PET and picks density; PET and a 3x1 twill; Type 400 and a 3x1 twill; PET and a 4x4 basket; and PET and an 8-H sateen.

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PART V:

EVALUATION OF THE ECONOMIC FEASIBILITY OF A SEAMLESS WOVEN PRODUCT WITH INHERENT SHAPE

5.0 INTRODUCTION

The successful development of new products for new markets is critical to the viability of a firm. New product development has become even more crucial in today's volatile market due to the constant introduction of new technologies, global competition and changing market needs (Dougherty, 1990). However, getting a new product adopted even when it has obvious advantages is often very difficult (Rogers, 1995). A common erroneous belief is that great innovations will sell themselves- potential customers will realize the obvious benefits of the new product and adopt it (Rogers, 1995). Ironically, many highly respected firms with promising products have failed to see the product through to a successful adoption despite clear evidence of a market need and support (Rackham, 1998). Obviously more than just a beneficial innovation is needed for a successful adoption to occur (Rogers, 1995). This portion of the paper will address important economic issues a firm must consider in order to ensure a successful and timely adoption of a new innovative product. The economic issues discussed will be related directly to the product detailed in this study, specifically a seamless woven textile with inherent shape.

5.1 EVALUATING THE ECONOMIC FEASIBILITY OF A NEW PRODUCT AND ITS MARKET

5.1.1 ROGERS' MODEL: DIFFUSION OF INNOVATION

A firm must decide whether or not it is economically feasible to pursue new technologies that could potentially lead to innovative products. Foremost, a firm must evaluate the intended market in which the product is targeted. The specific needs of the intended market in which the innovation is targeted plays a crucial role in the product's economic success. In order to evaluate the intended market the firm must find ways to analyze issues that are specific to the market. A highly respected source on this subject is Everett Rogers. The research that Rogers's has conducted in the area of new innovations and their markets is referred to as "diffusion of innovation" **(**Rogers, 1995**)**. He defines diffusion as "the process by which an innovation is communicated through certain channels over time among members of a social system" **(**Rogers, 1995**:** 35).

Communication refers to a special type in which the messages are concerned with new ideas. The process is one in which the participants create and share information with one another in order to reach a mutual understanding. (Rogers, 1995). Rogers defines an innovation as an idea, practice or object that is perceived as new by an individual or other units of adoption (Rogers, 1995).

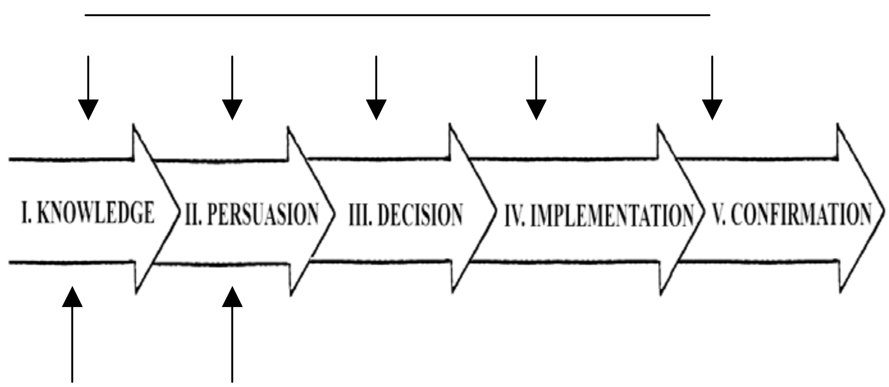
Roger's research is in part concerned with how individuals or groups of individuals respond to a new innovation. Analyzing an individual's response and reaction to a new innovation can be exceedingly beneficial to a firm who is attempting to predict the probable economic outcome concerning a specific new product. Rogers describes the process in which an individual evaluates a new innovation as the innovation-decision process (Rogers, 1995). The innovation-decision process is segmented into five stages, specifically the (1) knowledge, (2) persuasion, (3) decision, (4) implementation and (5) confirmation stage, see Figure 5.1.

Rogers collectively defines the stages of the innovation-decision process as: The process through which an individual (or other decision-making unit) passes (1) from first knowledge of an innovation, (2) to forming an attitude toward the innovation (3) to a decision to adopt or reject, (4) to implementation of the new idea, (5) to confirmation of this decision (Rogers, 1995).

Figure 5.1 A Model of the Stages in the Innovation-Decision Process (Rogers, 1995)

COMMUNICATION CHANNELS

Prior Conditions
1. **Previous Practice**
2. **Felt needs/problems**
3. **Innovativeness**
4. **Norms of the social systems**



Characteristics of The Decision Making Unit

1. **Socioeconomic Characteristics**
2. **Personality variables**
3. **Communication behavior**

Perceived Characteristics of the Innovation

1. **Relative Advantage**
2. **Compatibility**
3. **Complexity**
4. **Trialability**
5. **Observability**

Source: Rogers, Everett. Diffusion of Innovation. The Free Press. Fourth Addition. New York. 1995: 170.

Any new innovation introduces a degree of uncertainty into diffusion. Uncertainty implies a lack of predictability, of structure, of information. Information is a means of reducing uncertainty (Rogers, 1995). Although all five stages of the innovation-decision process are important for a firm to consider, the persuasion stage is a crucial point in which the general perception of the product is developed. At the persuasion stage an individual seeks innovation-evaluation information in order to reduce uncertainty about an innovation's expected consequences (Rogers, 1995). The main outcome of the persuasion stage results in either a favorable or unfavorable attitude toward the innovation and therefore can greatly influence the success of the adoption of a new product (Rogers, 1995). In addition, the rate of adoption or relative speed with which an innovation is adopted by the market is highly dependent on the five components that make up the persuasion stage.

The persuasion stage consists of five components, specifically, relative advantage, compatibility, complexity, trialability and observability. Each component is defined as follows (Rogers, 1995).

- **Relative Advantage** is the degree to which an innovation is perceived as better than the idea it supersedes. The greater the perceived relative advantage of an innovation, the more rapid its rate of adoption will be.

- **Compatibility** is the degree to which an innovation is perceived as being consistent with the existing values, past experiences and needs of potential adopters. An idea that is incompatible with the values and norms of a social system will not be adopted as rapidly as an innovation that is compatible.

- **Complexity** is the degree to which an innovation is perceived as difficult to understand and use.

- **Trialability** is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the installment plan will generally be adopted more quickly than innovations that are not divisible.

- **Observability** is the degree to which the results of an innovation are visible to others. The easier it is for individuals to see the results of an innovation, the more likely they are to adopt it.

Theoretically, the five components of the persuasion stage appear to be important factors to consider when assessing an innovation's potential success. However, to assess the true impact they might have on an innovation's adoption, it is interesting to analyze the outcome of actual situations in which they have been applied. By examining the Model of the Innovation-Decision Process, particularly the five components of the persuasion stage, in an actual situation will help to determine the true effectiveness they might have on a successful adoption.

There are numerous textile and non-textile examples in which parts or all of the Model of the Innovation-Decision Process have been utilized to promote the successful adoption of an innovation or to assess the potential for a successful adoption of a new innovation. A classic non-textile example of how the five components of the persuasion stage were used to produce one of the fastest diffusing innovations ever was that of Nintendo, the video company. The president, Hiroshi Yamauchi very astutely and intuitively utilized the five components of the persuasion stage to achieve a very rapid rate of adoption (Rogers, 1995).

Interestingly, there are very early examples in the textile industry that closely parallel the Nintendo story. In the early 1900's rayon yarns were introduced. Initially, the fabrics were of high quality, however, with the high rate of growth many manufacturers began to produce inferior work by using inexpensive finishing operations. After one washing the garments constructed with the cheap rayon went from a silk like fabric to resembling cheesecloth. The bombardment of low quality rayon had a devastating effect. Customers became disgusted and the word rayon became associated with negative connotations, signifying the lowest and most inexpensive type of merchandise made (Hathorne, 1964).

In the 1950's other synthetic fibers were introduced. Learning from the rayon fiasco, the companies were more prudent with their manufacturing and merchandising practices. The successful adoption of many of these synthetic fibers can be attributed to the intuitive utilization of the components of the persuasion stage. In order to encourage consumer's perception of the new fibers as better than the idea it superseded companies carefully controlled the quantity and quality of their new products. Retail outlets were carefully chosen and widely separated. Companies encouraged consumer's perception of the product as being consistent with existing products by having the products designed and made by well-established designers and manufactures. Producers made every effort to supply the finest merchandise to minimize any confusion or distrust. The products were carefully designed and extensively tested. Companies used well-planned advertisements in recognizable fashion magazines to encourage positive visibility of their products (Hathorne, 1964).

More recently, there have been a number of academic studies that have utilized the Model of the Innovation-Decision Process to help understand customer's attitudes towards certain textile-related innovations. In 2000, Michael Dancausse did an extensive investigation on the potential success that internet e-commerce might have in the apparel sector. Dancausse's premise was that in order to be successful in an e-commerce venture there was certain criterion the company must possess. In order for a company to obtain success in an e-commerce business, it was important for the employees involved with the e-commerce venture to: a) understand the use of e-commerce and the Internet as a business strategy, b) understand what constitutes an effective web site and c) understand the ways in which a web site can be evaluated (Dancausse, 2000).

Dancausse collected information utilizing a variety of methods. He then utilized the Model of the Innovation-Decision Process to evaluate the information. He specifically used the persuasion stage and its five components to evaluate certain criterion concerning not only the company's target customers but also the attitudes of the employees within the company towards e-commerce, as well as the company's e-commerce business plan (Dancausse, 2000). The methods Dancausse utilized to evaluate and assess the information as it relates to the five components of the persuasion stage are as follows:

Persuasion – Attitudes toward Internet e-commerce

Relative Advantage – The benefits of Internet e-commerce

Compatibility - Internet e-commerce tends to be consistent with the values and culture of the company

Complexity – The level of difficulty in understanding e-commerce for the company and its target customers

Trialability – The manner in which e-commerce was established either stepwise and incremental or all at once

Observability – Level of difficulty in observing the performance of the e-commerce business plan

Other studies have utilized the Model of the Innovation-Decision Process to aid in the understanding of certain phenomena. In order for a company to capitalize on certain phenomena it is important to first understand it. In 1996, Stephanie Foust did an extensive study on casual dressing in the workplace. In the mid 1990's casual dressing began to become more accepted in the traditional business environment. Foust believed that a better understanding of the ways in which employees viewed casual dressing as well as a company's policies concerning casual dress could lead to valuable information for both textile and apparel companies (Foust, 1996).

Foust utilized Roger's Model of the Innovation-Decision Process to obtain a) a better understanding of the Casual Workplace phenomenon, including the duration of the phenomenon and what type of apparel was considered appropriate in an office environment, and b) an understanding of how casual clothing impacts employee morale and productivity. Foust designed a series of questions which were in part based on the five components of the persuasion stage. The questions were designed to evaluate people's attitudes with respect to the five components.

Relative Advantage – The Casual Workplace policy provides a clear benefit over the dress code policy that preceded it

Compatibility – The Casual Workplace tends to be consistent with the values and culture of my company

Complexity – The Casual Workplace is understood by the employees of my company

Trialability – The Casual Workplace could not be canceled easily

Observability – The Casual Workplace has had a visible impact for all company employees to see

The information Foust obtained utilizing Roger's model had strong implications as to how textile and apparel companies needed to adjust marketing and merchandising strategies in order to capitalize on the casual dress phenomenon (Foust, 1996).

5.1.2 SUCCESSFUL DIFFUSION OF THE INNOVATION: A SEAMLESS WOVEN PRODUCT WITH INHERENT SHAPE

As earlier stated in the Introduction section of this paper, there are a number of adverse consequences caused from utilizing seams in a textile product. The cut and sew process is the most labor intensive step in the formation of a product; during the process the needles can create holes in the fabric as well as damage the fiber within the yarn, which can affect the strength and performance of the fabric; there is a concentration of stress where the seams are located which can jeopardizes the product's performance; cutting and sewing is done manually which introduces the potential for human error; and seams can create bulkiness in a garment which can cause discomfort to the wearer. For these reasons it might be anticipated that a seamless shaped fabric that can be produced without the need for specialized equipment might be superior to a shaped product that utilizes seams, and therefore, be quickly adopted. However, as acutely stated by Rogers, more than just a beneficial innovation is needed for a successful adoption to occur (Rogers, 1995).

In order to assess the economic viability of the product detailed in this study, specifically a seamless woven fabric with inherent shape, the product will be directly evaluated in terms of the five components of the persuasion stage. A seamless shaped woven product could potentially be utilized in a wide variety of industries including fashion apparel, medical and industrial markets. Where it is deemed important, specific issues concerning a specific product and its potential market will be addressed. It is important to note that the success of the product would not depend solely on the attitudes of the end user toward the product but also the manufacturer of the product and any middle activity that might transpire in an effort to expedite the product to the end user. The possible attitudes of the various parties that might be involved with a successful adoption will be evaluated in terms of the five components of the persuasion stage.

5.1.2.1 RELATIVE ADVANTAGE

Potential consumers want to know the degree to which the new product is better than an existing product (Rogers, 1995). Relative Advantage is the degree to which an innovation is perceived as better than the idea it supersedes, therefore the greater the perceived relative advantage the greater potential for adoption (Rogers, 1995). In order for a successful adoption to occur, it would be paramount that the potential adopters believe that a seamless woven product would have obvious benefits over a traditional shaped product that utilized seams. A seamless woven product with inherent shape would likely have a relative advantage over products that utilized seams to the manufacturer, the supplier and the end user.

For many textile products regardless of the end use, the presence of seams could have adverse consequences. Sewing seams is labor intensive, therefore one of the most costly stages in the production of all products that utilize seams. The ability to entirely bypass or minimize the cut and sew process would have many benefits to a manufacturer. The process of cutting and sewing is also executed manually, which increases the possibility for human error. For these reasons a shaped seamless woven product would have a relative advantage over a shaped woven product that utilized seams.

The presence of seams can adversely affect the strength and performance of a product. It is paramount for medical devices to have long lasting and superior performance. In some cases it is desirable for the medical device to last the life of the patient. If doctors were able to provide a product that possessed superior performance to that of an existing products the new product would be perceived to have a relative advantage over the existing product.

For the potential end user of a seamless shaped woven product there might also be clear benefits over a traditional product that utilizes seams. Seams can create bulkiness in a garment especially at the crotch, shoulders and under the arm, causing discomfort to the wearer. In addition, a seamless garment might provide superior aesthetic attributes to a garment.

5.1.2.2 COMPATIBILITY

Compatibility is the degree to which an innovation is perceived as being consistent with the existing values, past experiences and needs of potential adopters. An innovation that is more compatible is less uncertain to the potential adopter.

Compatibility helps give meaning to the new innovation so that it is regarded as being familiar. It is important that the innovation be thought of as compatible with social and cultural values (Rogers, 1995). Another dimension of compatibility is the degree to which the innovation meets a felt need. Potential innovators might not recognize the need of an innovation until they are aware of it. Once the need is recognized, adoption usually occurs at a fast rate (Rogers, 1995).

Seamless woven products would be compatible with consumer market needs because they would provide a product that would enhance reliability. The ability of the product to be trustworthy and dependable would increase the chances of a successful speedy adoption. Enhanced reliability and dependability would be especially important if the product were to be used in a medical application. As mentioned earlier, it is often desirable for a medical product to last the life of the patient. Improved reliability and dependability would be attributes that would be important to both doctors and patients. Enhanced dependability and reliability would increase the likelihood of the adoption of any product in which the application had life saving potential.

5.1.2.3 COMPLEXITY

Complexity is the degree to which an innovation is perceived as difficult to understand and use. The perceived complexity of an innovation is negatively related to its rate of adoption (Rogers, 1995). It is probable that a seamless woven product would be seen as less complex than a woven product that utilized seams. The cutting and sewing process is labor intensive and complex. If cutting and sewing could be minimized or bypassed, the manufacturing process would most likely be made easier. The seamless shaped woven product would entail less extensive experience with past or present technologies that are necessary in the cut and sew process.

5.1.2.4 TRIALABILITY

Trialability is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried before the potential adopter is committed to them are generally adopted more quickly than innovations that can not be tried (Rogers, 1995). The product detailed in this study can be produced on conventional textile equipment, therefore, specialized expensive equipment is not required. If a manufacturer was interested in producing a product of this nature they would be able to experiment with initial trials without investing in expensive equipment, specialized expertise or timely changeovers of the machinery.

Unlike some innovations such as a new improved food or fertilizer, it would be challenging to allow the potential adopter to partake in trialability. However, diligent design and testing of the product before its introduction would limit failure for the potential adopter.

5.1.2.5 OBSERVABILITY

Observability is the degree to which the results of an innovation are visible to others. The easier it is for individuals to see positive results of an innovation, the more likely they are to adopt it. Rogers's research suggests that innovations with ambiguous results have less observability (Rogers, 1995). A seamless shaped woven product, regardless of the intended application, would have beneficial results to adopters.

Seamless products can be produced on available textile weaving machines. The variables utilized to produce seamless shaped products are different weave designs, different pick densities and weft yarns with different degrees of shrinkage. With modern textile equipment these three variables can be manipulated. Weave designs can be selected prior to weaving with a computer aided design system (CAD). Variable pick densities can be controlled by individual motors which control the let-off and take-up. Up to twelve different filling yarns can be woven utilizing an automatic filling selector. Therefore, specialized expensive equipment is not necessary. In addition utilizing conventional equipment would negate the need for specialized expertise.

The ability to completely bypass or minimize the cut and sew process would have observable benefits to the manufacturer regardless of the end use. As earlier stated the presence of seams can result in premature failure of a product. If seams were not present in the product, the product could potentially have superior performance and aesthetic characteristics over a product with seams. The potential for improved physical and mechanical properties would provide doctors with an observably better product to offer their patience. In addition, seams can also create bulkiness, which can be uncomfortable in certain garments. A seamless garment most likely would provide more comfort.

Other benefits would include less labor and equipment that could potentially save the company money. A seamless product would also allow the company to offer customers exciting new innovative products.

Companies could increase observability through creative advertising. Advertising can be an invaluable tool that can be used to emphasize the potential positive results of an innovation. Prudent advertising can also increase the visibility of the product, which in turn increases the observability. For these reasons observability would most likely contribute to the rate of a successful adoption of a shaped seamless woven product.

Analyzing the specific innovation detailed in this study, that is a shaped seamless woven product in the context of Roger’s five components of the persuasion stage indicates that there is a good potential for a successful and speedy adoption. Table 5.1 summarizes the ways in which the five components could possibly contribute to a successful and speedy adoption.

Table 5.1 Summary Table: Evaluating a Seamless Shaped Product in Relation to Roger's Five Components of the Persuasion Stage

Relative Advantage	**Reduced Labor Cost**	**Improved Performance**	**Improved Comfort**
Compatibility	**Enhanced Reliability**	**Enhanced Dependability**	**Trustworthy**
Complexity	**Less Expertise Required**	**No Specialized Equipment**	**Less Labor Needed**
Trialability	**Available Equipment**	**No Specialized Equipment**	**No Expertise Necessary**
Observability	**Superior Mechanical Properties**	**Improved Performance**	**Excellent Aesthetic Characteristics**

5.2 EXPERT'S OPINIONS TO FURTHER VALIDATE THE SUCCESSFUL ADOPTION OF A SHAPED SEAMLESS WOVEN PRODUCT INTENDED FOR A MEDICAL APPLICATION

Thus far, the economic viability of a seamless woven product with inherent shape has been directly evaluated in terms of the five components of the persuasion stage. The evaluation has in a large part been dependent on the assumption that a shaped product that utilizes seams has some inherent drawbacks to a seamless shaped product. To more accurately predict the potential economic viability of a seamless shaped product, three experts were asked various questions to possibly shed more insight into the potential successful adoption of a seamless shaped woven product.

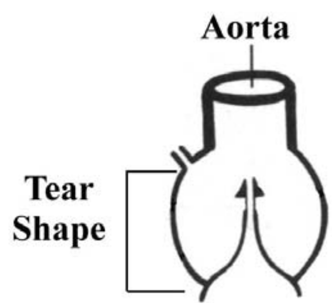
Due to the scope of this paper it would be unreasonable to evaluate the many different products that a seamless shaped product could be used. For this reason, one end use was chosen for this portion of the study, specifically a medical prosthesis. Three professionals were chosen to evaluate the potential for a successful and timely adoption of a seamless shaped product. Each individual was asked to contribute their attitudes toward a seamless shaped woven product in terms of the components of the persuasion stage. In order to assess the relative advantage, compatibility and observability, two experts who are currently involved in some aspect of the medical industry were interviewed. To assess the complexity and trialability components that might be associated with a seamless prosthesis a professional who is an expert in modern weaving equipment was selected.

5.2.1 ASSESSING THE POTENTIAL FOR THE INNOVATION TO HAVE A RELATIVE ADVANTAGE, COMPATIBILITY AND OBSERVABILITY: BRENT FOWLER

Brent Fowler is the laboratory manager at Heineman Medical Research Laboratory in Charlotte, North Carolina. Heineman Medical Research Laboratory is devoted to the study of cardiovascular disease. At Heineman laboratories researchers explore such diverse and critically relevant areas as heart preservation, heart transplantation, new surgical techniques and laser applications (Heineman, 2004).

A recent project that the Heineman Medical Research Laboratory has been involved in is the creation of a shaped prosthesis intended for the ascending aorta. The goal is to design a new aortic root prosthesis which will allow the preservation of the normal geometry and function of the aortic valve, thereby increasing longevity of the valve. The specifics of the study are detailed in the Literature Review section of this paper. The aortic valve consists of three leaflets and three sinuses. The leaflets are mobile parts of the valve and the sinuses are cavities. At the point at which the aorta meets the aortic valve there is a slight tear-shaped bulge, see Figure 5.2 (Thubrikar, 2001).

Figure 5.2 Longitudinal Section of the Aortic Valve (Pansky and House, 1969)



Prior to creating the shaped prosthesis a straight tube was used to replace the diseased or damaged aorta. Unfortunately, the straight tube prohibited the leaflets from fluttering free. Through time the leaflets in the aortic valve were worn down (Fowler, 2003).

Fowler was actively involved with the development of the shaped prosthesis, which has now been implanted into approximately fourteen patients. From testing and invivo results, Fowler believes that the shaped prosthesis Heineman is offering will have a greater longevity than the straight tube. The shape in the prosthesis is produced from the cutting and sewing process. The shape created from the cutting and sewing process allows the prosthesis to better handle the movement of the leaflets.

Although the shaped prosthesis offers advantages over the straight tube, Fowler adamantly believes a seamless shaped prosthesis would be much more advantageous than a shaped prosthesis, which utilizes seams (Fowler, 2003).

Fowler says one of the main drawbacks of the shaped prosthesis is the cutting and sewing process that is necessary to produce it. The cut and sew process is executed by humans, therefore Fowler says there is always a chance for error. Some of the problems attributed to human error are leakage of the prosthesis caused from needle holes that can occur during sewing. In addition, the thread that is used is a continuous filament yarn. If the yarn crimps during sewing it can break.

Another drawback to the cut and sew process is the time it takes to produce the prosthesis. The prosthesis is produced in the operating room right before surgery. It takes approximately thirty minutes to cut and sew one prosthesis. In every operating room there exists a sterile environment. Although thirty minutes does not appear to be an ordinate amount of time, Fowler says that sterile time is very costly. The time it takes to cut and sew the prosthesis is valuable time lost by the surgeons who are unable to begin surgery until the prosthesis is completed (Fowler, 2003).

Fowler believes a shaped prosthesis that could be produced without utilizing the cut and sew process would be a tremendous improvement. A “shelf ready” prosthesis would minimize the current quality control problems associated with the cut and sew process, resulting in improved performance, enhanced reliability and dependability. Although Heinemen Laboratory has not done any marketing or cost analysis, Fowler believes that bypassing the thirty minutes of sterile time needed to produce the current prosthesis would most likely reduce cost (Fowler, 2003).

To assess the economic viability of a seamless shaped vascular prosthesis, Folwer’s comments will be related to three of the five components of the persuasion stage, specifically relative advantage, increased compatibility and improved observability, The ways in which these three components could positively impact a successful adoption of a seamless shaped prosthesis will be addressed.

A seamless shaped prosthesis can be produced without cutting and sewing. By bypassing the cut and sew process the possibility of human error would be reduced. The reduction of human error would result in improved performance. Improved performance would in turn enhance reliability and dependability to both the surgeon and the patient. Improved performance would also result in improved trustworthiness. In addition, labor costs would be reduced. By avoiding the cut and sew process the thirty minutes of sterile operating room time currently needed to produce a seamed shaped prosthesis would not be necessary. Therefore, the availability of a shelf ready seamless shaped prosthesis would result in reduced labor costs. Fowler's insight indicates that a seamless woven prosthesis with inherent shape would most likely have a relative advantage over the existing prosthesis which utilizes seams. His insights also strongly indicate that a seamless shaped prosthesis would be perceived as compatible with existing values as well as having minimal complexity.

5.2.2 ASSESSING THE POTENTIAL FOR THE INNOVATION TO HAVE A RELATIVE ADVANTAGE, COMPATIBILITY AND OBSERVABILITY: MAC RITCHIE

Vascutek Ltd. was founded in 1982 and has grown to be one of the world's leading designers, manufacturers and marketers of vascular products for the treatment of cardiovascular disease. The company markets a wide range of both knitted and woven vascular prosthetic grafts for the treatment of diseased or damaged arteries. Vascutek Ltd. caters to vascular surgeons throughout the world. The company is dedicated to continuous research and development in order to design and develop innovative products that will address the most challenging medical situations (Vascutek Ltd., 2004).

Vascutek Ltd. has recently introduced a new and improved product that is intended to replace a diseased or damaged ascending aorta (see the Literature Review section for details). Mac Ritchie is a long time sales associate for Vascutek Ltd. and has been actively promoting the distribution of the new prosthetic graft known as the Gelweave Valsalva™. Approximately 18,000 Gelweave Valsalva™ grafts are sold each year. The Gelweave Valsalva™ graft is expertly hand crafted in Scotland. Each graft is custom made in approximately four hours. After the graft is assembled it undergoes four individual tests to ensure the assembly has been successfully executed. The total time to produce a Gelweave Valsalva™ is approximately one and half days (Ritchie, 2004).

The shaping created by the cut and sew process of the Gelweave Valsalva™ graft allows for smooth closing of the aortic leaflets which is far superior to the standard cylindrical grafts. However, Ritchie strongly believes "the perfect graft is not there yet". Once an aortic graft is implanted into the body it can dilate between 20%-40%. Through time the seams become weakened from continual dilation, which ultimately can result in premature rupture at the suture line. Ritchie believes that if a shaped graft could be produced without seams the performance would most likely be far superior to the current graft which utilizes seams to produce the inherent shape (Ritchie, 2004).

The research and development time is another critical issue in which a company needs to address. The time frame between initial development and the introduction to market can be rather lengthy for a medical device. The Gelweave Valsalva™ graft is constructed with yarns that have already been approved, therefore development time was greatly reduced. Ritchie states that Vascutek Ltd. is constantly in search of new and improved material, however, to develop and introduce a graft constructed with new material a lengthy research and development time would be necessary. At least two to five years would be needed to develop a graft that was not constructed with materials that have been already approved (Ritchie, 2004). Ritchie is indeed correct as to the lengthy product development time entailed with medical devices, particularly those products that support or sustain the patient's life. Before an implant can be marketed it must be thoroughly tested in both animal trials and human tests (Case, 2000).

Ritchie's comments clearly indicate that a seamless vascular prosthesis with inherent shape would have benefits over a shaped prosthesis that utilizes seams.

Ritchie's comments can be evaluated in the context of three of the five components of the persuasion stage, specifically the relative advantage, the compatibility and the obervability. The absence of seams in a prosthetic graft would clearly result in a relative advantage as well as obvious observable benefits by improving the performance. This in turn would result in enhanced product reliability and dependability. These two attributes would fulfill the expectations presented by the compatibility component.

5.2.3 ASSESSING THE INNOVATION IN TERMS OF COMPLEXIBILITY AND TRIALABILITY: JOHN TAWS

John Taws is the owner of Fletcher Industries in Southern Pines, North Carolina. Fletcher Industries specializes in the manufacture of shuttle looms. Fletcher Industries is capable of making the highest quality shuttle looms which can be designed according to the customer's specifications. Taws was interviewed in an effort to obtain an insight into the complexity and trialability issues that might be associated with the manufacturer of a seamless shaped woven prosthesis.

A seamless tubular shaped textile suitable for a medical prosthesis would have to be woven on a narrow width shuttle loom. It has been theorized that a seamless shaped prosthesis produced on a shuttle loom would be easier to produce than a shaped prosthesis that utilizes seams. One of the benefits of producing a seamless shaped prosthesis is that specialize equipment or expertise would not be required.

In order to produce a seamless shaped prosthesis specific variables are utilized during the weaving process to produce shape. The variables that are utilized include different pick densities, different weave designs, weft yarns with differential shrinkage and different amounts of high shrink yarn used in combination with lower shrink yarns. Taws was asked pointed questions concerning the necessary equipment and expertise that would be required to successfully utilized theses variables in the manner needed to produce inherent shape.

Taws stated that in order to manipulate the variables detailed in this study, specialized equipment would not be necessary. Today's modern shuttle looms are capable of quickly and easily changing pick densities and weave designs. (Taws, 2003).

Taws stated that Fletcher Industries manufacturers shuttle looms that are able to handle four different weft yarns. When asked if he would anticipate problems running weft yarns with different degrees of shrinkage, he stated that he is mostly concerned with warp preparation. However, if the yarns had different amount of stretch Taws noted that he would want a "pro manning the loom". It can be concluded that although many years of experience are required to become a good weave technician, if challenging weft yarns were to be used, one of the best technicians would most likely be required (Taws, 2003).

Today's modern shuttle looms are equipped with sophisticated CAD systems that allow for quick changes needed to produce a seamless shaped product. Unfortunately, shuttle looms still have speed limitations. The boat-shaped shuttle, which is the traditional filling carrier, is large and bulky- requiring excessive energy to propel it across the width of the loom and decelerate it upon delivery. Mechanical problems concerning acceleration and deceleration of the large mass are the primary reasons that loom speeds are slow compared to shuttleless looms. The maximum speed of a narrow width shuttle loom that would be needed to produce a prosthesis is about 200 pick per minute (Taws, 2003). In comparison, shuttless looms can run at speeds ranging from 900 – 1800 picks/minute. However, recently, needle looms which can run up to 1,800 picks per minute and are capable of weaving tubular constructions and different weft yarns have been introduced.

John Taws was interviewed to gain insight into the potential complexity and trialability issues that might be associated with a seamless shaped product. It is clear from the information gathered from the interview that the variables utilized to produce a shaped seamless product could be manipulated on available textile equipment. Therefore, there would be no need for specialized equipment. The absence of specialized equipment would enable a textile manufacturing company to embark on weaving trials without an expensive initial investment.

Weaving trials could be conducted on available equipment in which a trained weaving technician would be competent to handle. However, the variables utilized in this study are manipulated in an atypical manner. It could be very possible that technical issues would be encountered during the weaving trials in which a highly skilled weaving technician was needed.

5.3 BUSINESS ISSUES RELATED TO SEAMLESS TECHNOLOGY

5.3.1 CANNIBALIZATION

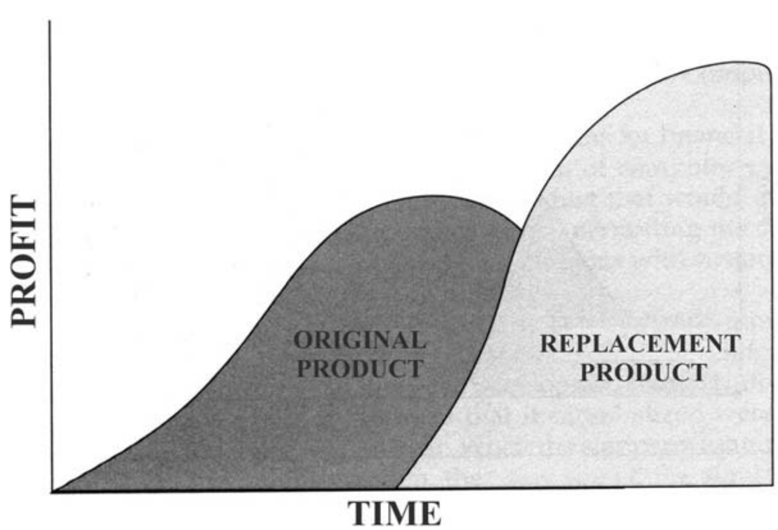
Typically most companies consider the introduction of a new product as having a positive outcome. The introduction of new products is thought of as resulting in market expansion and new customers. However, many companies fail to consider cannibalization. Cannibalization is a threat for the vast majority of new product launches (Lomax, 1996). For companies that are involved with new product innovation which entails the continuous upgrade and replacement of existing products, cannibalization is a recurring strategic issue. Cannibalization occurs when a new product replaces an existing product. It becomes a particularly difficult issue for a company when the introduction of a new product is economically unfavorable to the existing product. Ironically cannibalization is either one of the most misunderstood or most overlooked strategies in many companies. Often companies do not understand the basic concepts of cannibalization (McGrath, 2001).

There are numerous definitions of cannibalization. A broad definition defines cannibalization as the process by which a new product gains sales by diverting them from an existing product. The real threat of cannibalization is that customers of an existing product are lost to a newer improved product (Lomax, 1996). This is an especially challenging economic situation when the same firm offers both the existing product and the new product.

Cannibalization is more than likely an inevitable consequence of any new product launch (Lomax, 1996). However, it can result in either a normal aspect of product strategy or a major strategic dilemma. A major dilemma results when the new product is less profitable than the product it replaces (McGrath, 2001). It is important for companies to be able to avoid a dilemma when introducing a new product. The occurrence of a normal cannibalization or a major dilemma is in a large part dependent on where the existing product is in its life cycle (McGrath, 2001).

The concept of a product's lifecycle is based on the assumption that all products have a finite lifecycle. A product's lifecycle is plotted over a given period using a biological analogy of growth, development and decline (Atkinson, 1995). A normal case of cannibalization occurs when the existing product is nearing the end of its life cycle. The company sustains sales of the older product by reducing its price over several years. The new product that is intended to replace the older product is then introduced, usually at a higher price. Utilizing the price difference of the older and newer product the company manages an economically healthy sales mix (McGrath, 2001). The normal case of cannibalization is illustrated in Figure 5.3.

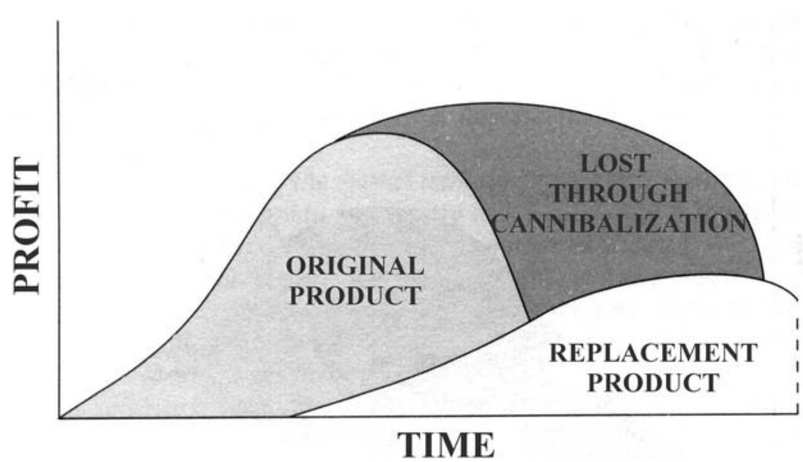
Figure 5.3 Normal Case of Cannibalization



Source: McGrath, Michael. Product Strategy for High-Technology Companies. The McGeaw-Hill Companies, Inc. 2001: 259

Cannibalization becomes a problem when the replacement product is introduced too early, resulting in a premature death of the older product. Figure 5.4 illustrates the way in which cannibalization can result in reduced profits for the company. Reduced profits occur when the new replacement product is introduced when the existing product is still successful. The introduction of the new product causes the sales and profits of the older product to decline as sales are transferred to the replacement product. Another additional and adverse outcome to this situation is that the replacement product's profits can be lower than the existing products. The difference can be attributed to the lower prices or higher costs of the replacement product. This scenario is illustrated in Figure 5.4. The shaded area represents lost profits (McGrath, 2001).

Figure 5.4 Abnormal Case of Cannibalization



Source: McGrath, Michael. "Product Strategy for High-Technology Companies." The McGeaw-Hill Companies, Inc. 2001: 260

Identifying cannibalization can be difficult (Lomax, 1996). Therefore, it can be beneficial to look at what causes it to help identify it. There are four main causes of cannibalization (McGrath, 2001):

1. One of the obvious causes of cannibalization is when the newer replacement product is sold at a lower price resulting in a lower profit per unit, ***and*** the lower price does not sufficiently increase market share or size.

2. A second cause of cannibalization is when a company attempts to simultaneously sell and market two products, a newer improved product and an older existing one. If the newer product's profit is less than the revenue of the older product that it cannibalized the result will be a loss in revenue.

3. A third cause of cannibalization occurs when the new product requires a different manufacturing process from the existing product. Profit can be loss due to investment entailed with changing current manufacturing processes. Often even when a company has the know how to design and manufacture a superior product the customer is unwilling to pay a higher price. After changing manufacturing processes the company is unable to make the older product and sometimes can't generate the necessary sales from the new product to cover manufacturing changes.

4. A fourth cause of cannibalization occurs when a product is seen as a high risk product. This type of cannibalism can have a detrimental effect especially on market leaders. A company can cannibalize its position in the market with a failed product, resulting in loss of old and new customers.

The most likely causes of cannibalism and how it might be avoided should be evaluated before the introduction of a new product. The potential problems that cannibalization might present with the introduction of the product detailed in this study, will now be addressed. Each cause of cannibalization will be considered in the context of the product detailed in this study.

5.3.2 INVESTIGATING THE POTENTIAL FOR CANNIBALIZATION WITH THE INTRODUCTION OF A SHAPED SEAMLESS PRODUCT

In order to avoid the four causes of cannibalization, a company would have to carefully consider a) the introductory price of the product; b) the expected market share of the new product; c) the life cycle of the existing product; d) all labor and capital investment that would be needed to produce the new product; e) any machinery changeovers that would be necessary; f) and the intended end use of the product (McGrath, 2001). Each cause of cannibalization will now be considered in the context of a seamless shaped woven product.

To avoid the first cause of cannibalism it would be important for a company to closely evaluate and research the introductory price of the new product. The company would need to also carefully consider the degree to which the expected market share would increase before pricing the new product (McGrath, 2001). A seamless woven product with a tailored shape could possibly be manufactured at a lower price. The shape being inherent in the product would eliminate or minimize the cutting and sewing process. Cutting and sewing is the most labor-intensive process in the manufacturer of a shaped textile product, therefore costly. If this step could be eliminated or minimized the product could potentially be produced cheaper than a traditional product that utilizes seams. However, pricing at the lowest price point possible might not be prudent. A company would have to carefully evaluate the introductory price and the expected market share of the new product. If the replacement product was sold at too low of a price and its market share did not sufficiently increase the company could loose valuable revenues.

A company can choose two different sales strategies, specifically a simultaneous or a sequential strategy. A simultaneous sales strategy occurs when the existing product is sold simultaneously with the new product. A sequential sales strategy occurs when the existing product is discontinued before the new product is introduced. To avoid the second cause of cannibalism a company would need to decide which sales strategy would be appropriate. The stage of the existing product in its life cycle would in part determine which strategy would be most profitable. If the existing product was nearing the end of its life cycle it might be advisable to introduce the newer improved product. The two products could be successfully sold simultaneously if the existing product and the new product were priced to encourage a beneficial sales mix. However, if the older product was in a growth stage and bringing in a healthy revenue it would most likely be better not to introduce the newer improved product.

The company's decision to choose a simultaneous or sequential sales strategy would also depend on other factors. The relative patience of the customer concerning the introduction of the new product would need to be evaluated. If customers are eager to purchase a higher-end new product, than a sequential introduction might be better than a simultaneous introduction strategy. If customers are eagerly awaiting the introduction of a new product they will probably be more willing to purchase the product at a higher price (Moorthy, 1992).

The third cause of cannibalization would most likely not pose a serious threat to the introduction of a seamless shaped textile product. The product detailed in this study can be produced using available textile equipment. Expensive new equipment or major machinery changeovers would not necessary to produce the new product. The simplicity of the manufacturing process is one of its benefits. Most modern textile mills are equipped with looms that have the capabilities necessary to weave the product detailed in the study. A major adjustment of the existing manufacturing processes would not be necessary, therefore a costly changeover could be avoided. In addition, if desired, the company could simultaneously manufacture the existing product with the new product.

The fourth cause of cannibalism could possibly be a threat depending on the specific end-use of the product. With certain products there is an expected higher risk. Products that involve human life would of course entail an increased risk. For example, medical devices and certain industrial products would most likely be considered to be a higher risk than an apparel product. The potential consequences of the fourth cause of cannibalization would be dependent on the final end use of the product.

5.3.3 MANUFACTURING STRATEGY FOR A SHAPED SEAMLESS PRODUCT

An efficient manufacturing process is essential to the success of any new product launch. The more advanced and complex the technology necessary to produce the new product, the more challenging it is to manage a successful manufacturing strategy. The product detailed in this study utilizes available textile equipment to produce an innovative new product. Most modern mills are equipped with machinery that would be capable of producing a shaped seamless woven product utilizing the methods detailed in this study. The product could be produced on available textile equipment without negatively affecting machine speeds. Although the absence of new advanced technology would eliminate many of the manufacturing problems entailed with a new product launch, challenges would still exist.

5.3.3.1 MACHINERY

The weaving process detailed in this study is executed on available weaving machines, however, the fabric produced is far from a typical textile fabric. The inherent shape created in the product is accomplished by utilizing different pick densities, different weft yarns and different weave designs. Depending on the desired shape, the pick density could be programmed as needed. Different weft yarns were also incorporated into the construction at specific areas to increase or decrease the width of the fabric. Depending on the end use of the product and the desired shape, different weaves can be utilized as well. These variables are typically manipulated in the manufacture of conventional fabrics. The variables can be automatically programmed prior to the weaving process. However, in the production of a seamless woven product with shape these three variables are manipulated in a manner that is atypical to available weaving.

In conventional weaving, pick densities are not changed as often as required in the process detailed in this study. Although many conventional fabrics are constructed with different weft yarns, rarely are yarns used that might change the width of the fabric during weaving. Although many fabrics, such as jacquard fabrics, incorporate many different weaves to create a desired pattern, they do not utilize weaves in the way in which the method detailed in this study does. To produce shaped woven fabrics directly from the loom, it is necessary to change pick densities and weaves. Different weft yarns that can change the fabric width during weaving are also incorporated into the fabric structure. However, with modern weaving equipment the weaving process would not pose a great challenge for an experienced weaving technician. The finishing of the fabric could potentially introduce unexpected challenges. In order to successfully produce the textile product detailed in this study it would be paramount to have a highly skilled manufacturing team that was involved with every aspect of the design and development of the product.

5.3.3.2 LABOR AND CAPITAL INVESTMENT

Today, textile mills compete on a global level. Over the last twenty years with the introduction of advanced technology, the manufacturing emphasis of many industries has switched from labor productivity to capital productivity. The successful manufacture of a woven product with inherent shape would most likely require a firm to switch its emphasis from labor productivity to capital productivity as well. The manufacturer of a seamless shaped textile would be quite different from many textile products that require cutting and sewing. The elimination of the cutting and sewing process would eliminate the need for the traditional labor intensive production systems. The focus would be on the capabilities of the equipment and the technicians. The successful production of a seamless shaped product would require highly skilled technicians that were involved with creative problem solving, able to anticipate problems, and push beyond the standard capabilities of the equipment.

5.3.3.3 INTEGRATED MANUFACTURING PROCESSES

In the early 1960's due to a number of popular business philosophies, manufacturing managers were all but eradicated from the corporate hierarchy. Manufacturing managers were not part of the strategic planning. They were left out and became discouraged (Skinner, 1987). Today, manufacturing strategies should be utilized to align the firm's productive resources and technology with their strategic goals (Hill & Westbrook, 1997). In order to accomplish this, it is necessary for the manufacturing team to be involved with processes other than manufacturing (Heap et al., 1995).

Traditional product development models have not linked the processes involved with product development. They were deigned to operate as a series of specialized tasks: design, prototyping, manufacturing, assembly, finishing, testing and marketing. However, design personnel rarely have expertise in prototyping or manufacturing therefore, designs that present difficulties in manufacturing are not addressed until the product is ready to be produced. Waiting to address manufacturing problems results in a number of adverse consequences including time delays and undesirable costs. Designers need to be aware of how the product design will affect the manufacturing process (Heap et al., 1995). Unfortunately, it is unreasonable to expect employees to be well versed in all stages of the product development process. It is more reasonable to have the manufacturing team involved with the design and prototyping process. Involvement of this nature helps the manufacturing team to anticipate and alleviate potential problems.

The involvement of the manufacturing team in the design and prototyping process would be exceedingly beneficial with the development of a seamless shaped woven product. Technicians in the weaving laboratory and personnel involved with dyeing and finishing are well aware of the capabilities of the equipment. The variables utilized to create the shape within the fabric could potentially cause a number of challenges that would be difficult to deal with during the weaving and finishing processes. Varying tension and tightness throughout the fabric caused from different pick densities and weave designs, and varying fabric widths from the incorporation of different weft yarns are just some of the challenges entailed with producing this product. By involving the manufacturing team in the design process many of the problems that might arise due to these variables could be eliminated or minimized.

5.4 MARKETING OPPORTUNITIES

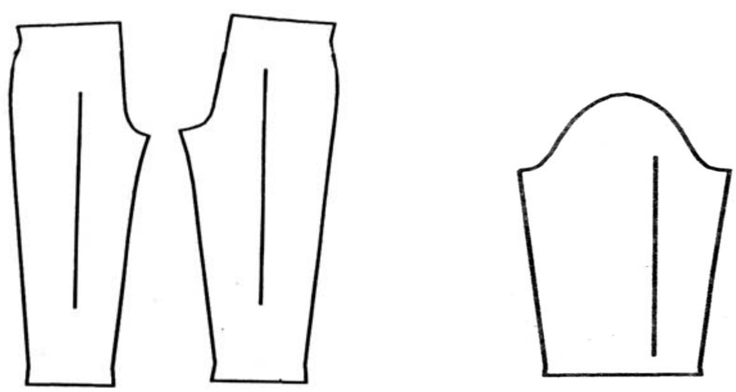
Woven textiles have inherent characteristics that make them ideally suited for a wide range of applications. Textiles are strong, flexible and lightweight. By utilizing the methods outlined in this study it could be possible to design a wide variety of different shaped seamless woven products. These new superior products could potentially be utilized in many applications in a wide variety of markets, such as fashion apparel, protective clothing, medical, automotive and industrial.

5.4.1 FASHION APPAREL

Today, the vast majority of apparel is produced by the cutting and sewing process. This process is exceedingly labor-intensive. Although there are knit machines that are capable of producing seamless shaped panels as well as whole seamless garments, currently weaving machines are unable to accomplish this (“Flat-Knitting…”. 1999). Besides eliminating the labor-intensive process of cutting and sewing there are a number of other benefits to producing a seamless shaped garment. There is a reduction of fabric waste that is generated in traditional cutting operations. In addition, and the seams in a garment create bulkiness especially at the shoulders and underarms which can adversely affect the comfort of the garment.

In garment design a base pattern called a sloper or a block is used as the basis for making a pattern for many different garment styles (Burns & Bryant, 177). A basic sleeve and pant leg are shown in Figure 5.5.

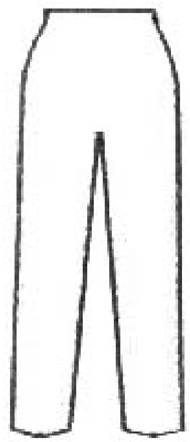
Figure 5.5 Examples of Different Pattern Shapes

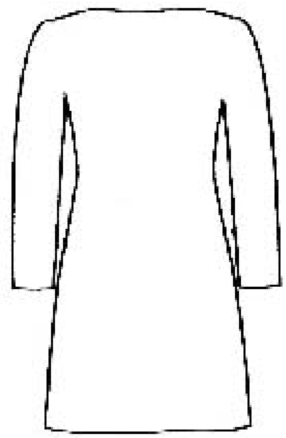


PANT LEGS **SLEEVE**

From a sloper many different garment styles can be designed by adding design details such as collars, cuffs, pleats and pockets (Burns & Bryant, 1997). When basic pattern pieces are sewn together, they form a tapered tube. Pants can be viewed as two tubes that taper outward towards the hips. The two pant legs are joined together at the crotch and become one large tube. A dress can be viewed as three tubes, the sleeves being two tubes and the bodice one. The sleeve can be seen as one tube that tapers inward toward the wrist. The bodice is basically one large tube, which typically tapers in at the waist, then out toward the point at which the sleeves connect. Figure 5.6 illustrates a pair of pants and dress.

Figure 5.6 Examples of Standard Pant and a Dress Design



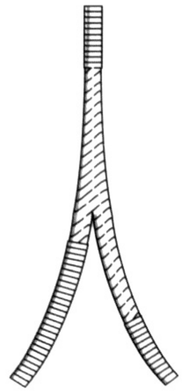


FINISHED PANTS **FINISHED DRESS**

Tubular fabrics are produced on shuttle looms. By utilizing the variables outlined in this study a variety of shaped tubes were produced. These shaped tubes could be used as a sleeve, pant leg or dress bodice. The pieces could be sewn together to create garments. Utilizing seamless shaped tubes as pattern pieces would greatly minimize the cut and sew process.

A multi-shuttle loom could potentially be used to create whole seamless garments. Multi-shuttle looms are used to create multiple tubes that are connected during the weaving process. A bifurcated prosthesis is probably the best known application in which a multi-tubular fabric is used, see Figure 5.7.

Figure 5.7 A Bifurcated Prosthesis (Vascutek Ltd., 2003)



Bifurcated prostheses are produced on a narrow width multi-shuttle loom. The tubes within a bifurcated product are straight tubes that do not vary in width along the length of each tube. In order to produce a whole garment, a wide width multi-shuttle loom could be utilized. During weaving the appropriate set of variables detailed in this study could be employed to produce shape within the tubes, ultimately producing a whole woven garment in which the cut and sew process could be entirely bypassed.

5.4.2 PROTECTIVE CLOTHING

The importance of seamless woven garments could extend beyond fashion apparel. A seamless woven garment could have life saving potential when used as a protective garment. Safety and protective garments refer to garments and other fabric-related items designed to protect the wearer from harsh environmental effects that may result in injury or death (Adanur, 1995). For years the military has used protective garments to protect the wearer from a host of environmental conditions including rain, snow, cold, heat and wind. However, new threats such as chemical and biological warfare have extended the list of conditions in which the wearer needs to be protected (Adanur, 1995). Not only military personnel depend on protective clothing. Firefighters wear protective clothing to protect them against extreme heat and fire, healthcare workers wear garments that protect them against contagious diseases. Workers in the horticulture field wear garments to protect them against pesticides and other chemicals.

Seams can be a location in the garment in which chemicals and other contaminates can penetrate. A form fitted garment that was constructed without seams could potentially be more effective at protecting the wearer than a traditional garment produced from the cut and sew process. Using the same process outlined in the previous section, a seamless garment could be produced that would be appropriate for protective clothing.

5.4.3 MEDICAL APPLICATIONS

Textiles have been used in various medical applications for thousands of years (Lyman, 1991). Today the use of textiles in medicine and surgery is an expansive and growing industry. As the industry has grown new design challenges have arisen. In many medical applications a seamless product with inherent shape is needed.

Textiles have been used since the 1950's to replace diseased or damaged lumens in the body. In a number of situations, tubes with varying degrees of taper are needed. One situation (detailed in the Literature Review section of this paper) in which a tapered tube is necessary is when a textile vascular prosthesis is implanted into the body. In order for the prosthesis to conform to the body lumen, the external diameter of the textile tube must match the internal diameter of the body lumen (Nunez, and Schmitt, 1999).

Another situation (also detailed in the Literature Review section of this paper) in which a shaped tube is needed is in the replacement of a diseased or damaged ascending aorta. There is a slight tear shaped bulge at the point at which the ascending aorta meets the aortic valve. It is important for the textile prosthesis to mimic the tear shape. The tear shape varies slightly from person to person (Thubrikar, 2001).

Currently a number of shaped prostheses, which are produced by the cut and sew process, are being utilized. However, a narrow width seamless shaped tube could be produced on a shuttle loom using the techniques outlined in this study. It is also important to note that the variables can be manipulated in such a way that the dimensions can be altered. The ability to slightly alter dimensions would enable a shaped prostheses to be tailored according to the dimensions required for a specific person.

5.4.4 AUTOMOTIVE, AEROSPACE AND INDUSTRIAL PRODUCTS

A seamless woven textile product with a tailored shape could also have many potential applications in other fields. In the automotive, aerospace and a number of industrial fields a seamless woven shaped product could be used in a variety of belts, hoses and specialized covers. The variables investigated in this study could be manipulated to produce many different kinds of shapes depending on the specifications of the product.

5.5 CONCLUSION

In today's competitive business environment it is crucial that firms stay on the cutting edge of product innovation. However, many promising products fail to succeed even when there appears to be a market need. In order to assess the economic viability of a new product, companies can utilize the five components of the persuasion stage outlined by Everett Rogers. The main outcome of the persuasion stage results in either a favorable or unfavorable attitude toward the innovation and therefore can greatly influence the success of the adoption of a new product (Rogers, 1995). In addition, the rate of adoption or relative speed with which an innovation is adopted by the market is highly dependent on the five components that make up the persuasion stage.

Companies must examine other issues before launching new products. The phenomenon known as cannibalization must be considered. Cannibalization is an especially challenging economic situation that is often overlooked by companies. Companies must also evaluate their manufacturing facility and devise a strategy before embarking on a new product launch. To alleviate potential manufacturing problems, manufacturing personnel should be included in the initial design stages of the new product. The machinery and personnel necessary to produce the product should also be examined.

The various marketing opportunities should be evaluated. Often new products are suitable to a wide range of applications. A variety of potential markets should be investigated and examined. The product detailed in this study could potentially have a number of applications in many diverse fields.

There are many economic issues a company must consider in order for a successful new product adoption to occur. This portion of the paper has addressed some of the issues that might expedite a successful adoption of a seamless woven product with inherent shape. However, there are additional issues, which should be addressed in order for a successful and speedy adoption to occur. Although this paper is by no means all inclusive, the issues raised are pertinent and could facilitate a successful adoption of a product.

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PART VI:

SUMMARY AND FUTURE RESEARCH

6.0 SUMMARY AND FUTURE RESEARCH

The goal of this study was to produce a variety of seamless shaped woven fabrics using available equipment. After a thorough review of the literature it was concluded that although there have been a number of successful attempts to produce seamless textile products with inherent shape, there were limitations to each process. The current methods have either limited production speeds; require specialized equipment; still require a manual processing stage; produce fabric that has either structural limitations or inappropriate physical properties for a variety of end uses.

A woven product with a tailored shape could potentially have numerous benefits over a shaped product produced by the traditional cut and sew process. There are a number of adverse consequences caused from utilizing seams in a woven textile product, specifically the process of cutting and sewing is the most labor intensive step in the formation of a product, there is a concentration of stress where the seams are located which jeopardizes performance properties and ultimately results in premature product failure, cutting and sewing is done manually which introduces the potentail for human error, fabric scraps produced from the cut and sew process are discarded, resulting in fabric waste. In addition, seams in a garment create a bulkiness especially at the shoulders and underarms which can effect the comfort.

Previous studies have proven that selected fabric construction variables will result in differential shrinkage. However, the potential for producing a shaped fabric by utilizing these variables has not been fully investigated, researched or well documented. Modern weaving equipment has made the automatic manipulation of these variables possible. The ability to be able to quickly and easily program a computer to select specific construction factors before the weaving process, has made it possible to design shaped fabrics at high speeds and low production costs. The proposed experimental methods in this study could lead to the design and production of seamless woven products with exact shape and dimensions. These new innovative products could potentially be utilized in many applications in a wide variety of markets, including fashion apparel, medical, automotive, aerospace, protective clothing and industrial markets.

Two sets of trials were conducted in this experiement. The first set of trials (detailed in Part III) were conducted on two looms, specifically a Muller LN 59317A shuttle loom and an AVL industrial dobby loom. In order to create shape in a woven structure without cutting or sewing or using any seams of any type, three variables were investigated. These three variables can be manipulated to cause different amounts of shrinkage within the fabric structure. The three variables included, 1) different filling yarn densities, 2) different weave designs and 3) filling yarns with different degrees of shrinkage

After the results from the first set of trials were evaluated, additional weaving trials were executed on a double rapier Picanol GTM loom. The same three variables used in Part III of this paper were selected for further investigation. In Part IV of this study the correlation between a given set of parameters and the fabric width shrinkage in was investigated. In addition, the finished width shrinkage and fabric tightness were more thoroughly investigated. The degree of tightness of a fabric affects the quality of the fabric and the fabric properties. By choosing the correct tightness a designer can achieve the highest possible fabric quality as well as produce a fabric with the desired properties for the specific end use (Seyam and El-Shiekh, 1993).

After the evaluation of the data generated in Part IV, a number of statistical models were developed. The statistical models were developed for two main purposes. First, to assess the contribution the three independent variables made to finished width shrinkage and finished fabric tightness. Secondly, to devise a model which could estimate the finished width shrinkage, given a set of construction parameters. A predictive model would avoid the need for additional weaving trials.

In addition, to the weaving trials that were conducted in Part III and in Part IV, an economic feasibility study of a seamless woven product with inherent shape was undertaken. To assess the economic viability of the product detailed in the study, the product was evaluated in terms of the five components of the persuasion stage from Everett Roger's Model of the Innovation-Decision Process (Rogers, 1995). Other important economic issues pertaining to a new successful product adoption were addressed, including cannibalism, manufacturing strategies and marketing opportunities. Although the investigation was by no means all inclusive, the issues raised were pertinent and could facilitate a successful adoption of a new product.

In this study a variety of seamless fabrics with inherent shape were successfully produced on available textile equipment. In addition, the economic feasibility study that was conducted indicated that a successful adoption of a seamless woven textile with inherent shape might be possible in a variety of applications. Although there were many positive outcomes, additional research would need to be undertaken to insure that a seamless shaped woven product could be successfully produced and marketed.

A seamless shaped product could potentially be utilized in a wide range of applications. Each application would present a host of challenges that would need to be addressed.

In this study a variety of fibers were utilized, including nylon, polyester and cotton. Although these fibers are suitable to a wide range of applications, there are some applications in which they would not be suited. Depending on the specific application, the appropriate fiber would have to be selected and additional weaving trials conducted.

In this experiment, inherent shape was achieved through differential shrinkage within the fabric construction.   Although no tests were conducted, it is highly likely that a shaped fabric produced by the methods detailed in this study would possess different physical characteristics.   It is likely that areas of the fabric that experienced a greater degree of shrinkage would be tighter and denser resulting in different mechanical and physical characteristics from those areas that experienced less shrinkage. For some applications, additional physical and mechanical tests would have to be conducted.

In specific applications, slight variations in dimensions would be necessary. Small variations in shape might present a problem as far as consistency of shape and reproducibility of a shape. Further investigation would be needed to assess the ability to change shape in small increments and the reproducibility of the shape.

Cost would be an important issue that would need to be addressed before a manufacturing program was launched. A shuttle loom would be used to produce seamless shaped tubes. Shuttle looms are considerably slower than shuttleless looms. The time saved by avoiding the cutting and sewing stage would need to be compared and contrasted to the extra weaving time that would be needed to produce shaped tubes on a wide width shuttle loom.

It might be possible that a seamless shaped product might have improved aesthetic appeal over a traditional product produced by the cut and sew process. Studies would need to be conducted to better predict the possible reactions that might be expected by potential consumers.

In this study a number of successful seamless fabrics with inherent shape were produced utilizing available textile equipment. The economic feasibility study conducted indicated that a product of this type might be successfully adopted in a wide range of applications. However, even with these positive results further research would be necessary before a successful manufacturing strategy chould be launched.

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PART VII:
APPENDICES

APPENDIX A

PART III:

FORMING NARROW WIDTH TUBULAR CONSTRUCTIONS WITH INHERENT SHAPE

Table 3.1A Samples Woven on the Muller Weaving Machine Utilizing Different Weave Designs, Different Pick Densities and Weft Yarns with Differential Shrinkage

Sample ID	**Weave Design Used in Each Section**			**Pick Density Used in Each Section**			**Weft Yarn Used in Each Section**		
	End One	Middle	End Two	End One	Middle	End Two	End One	Middle	End Two
1	Plain	Plain	Plain	Min	Max	Min	70 denier	70 denier	70 denier
1A	Plain	Plain	Plain	Min	Max	Min	200 denier	70 denier	200 denier
2	2x2 Twill	2x2 Twill	2x2 Twill	Min	Max	Min	70 denier	70 denier	70 denier
2A	2x2 Twill	2x2 Twill	2x2 Twill	Min	Max	Min	200 denier	70 denier	200 denier
3	3x1 Twill	3x1 Twill	3x1 Twill	Min	Max	Min	70 denier	70 denier	70 denier
3A	3x1 Twill	3x1 Twill	3x1 Twill	Min	Max	Min	200 denier	70 denier	200 denier
4	2x2 Basket	2x2 Basket	2x2 Basket	Min	Max	Min	70 denier	70 denier	70 denier
4A	2x2 Basket	2x2 Basket	2x2 Basket	Min	Max	Min	200 denier	70 denier	200 denier
5	3x1 Twill	Plain	3x1 Twill	Min	Max	Min	70 denier	70 denier	70 denier
5A	3x1 Twill	Plain	3x1 Twill	Min	Max	Min	200 denier	70 denier	200 denier
6	2x2 Basket	Plain	2x2 Basket	Min	Max	Min	70 denier	70 denier	70 denier
6A	2x2 Basket	Plain	2x2 Basket	Min	Max	Min	200 denier	70 denier	200 denier

APPENDIX B

PART 1V:

SHAPED FABRICS DESIGNED IN TERMS OF SPECIFIC FABRIC CONSTRUCTION PARAMETERS

Table 4.1B Detail of Trials Woven on the Picanol GTM Loom

Trial	Weft Yarn	Weave	On-Loom Pick Density
Identification	**Fiber Type**	**Double Cloth**	**picks/cm**
1	Ultra Low Shrink	Plain	2.93
2	Ultra Low Shrink	Plain	7.25
3	Ultra Low Shrink	Plain	9.76
4	Ultra Low Shrink	Plain	11.43
5	Ultra Low Shrink	Plain	13.66
6	Ultra Low Shrink	Plain	15.61
7	Ultra Low Shrink	Plain	21.19
8	Ultra Low Shrink	3x1 Twill	11.43
9	Ultra Low Shrink	3x1 Twill	13.66
10	Ultra Low Shrink	3x1 Twill	15.61
11	Ultra Low Shrink	3x1 Twill	17.84
12	Ultra Low Shrink	3x1 Twill	19.52
13	Ultra Low Shrink	3x1 Twill	27.32
14	Ultra Low Shrink	3x1 Twill	35.68
15	Ultra Low Shrink	8-H Sateen	11.43
16	Ultra Low Shrink	8-H Sateen	13.66
17	Ultra Low Shrink	8-H Sateen	15.61
18	Ultra Low Shrink	8-H Sateen	17.84
19	Ultra Low Shrink	8-H Sateen	19.52
20	Ultra Low Shrink	8-H Sateen	27.32
21	Ultra Low Shrink	8-H Sateen	35.68
22	Ultra Low Shrink	8-H Sateen	44.60
23	Ultra Low Shrink	4x4 Basket	15.61
24	Ultra Low Shrink	4x4 Basket	19.52
25	Ultra Low Shrink	4x4 Basket	21.19
26	Ultra Low Shrink	4x4 Basket	23.97
27	Ultra Low Shrink	4x4 Basket	26.2
28	Ultra Low Shrink	4x4 Basket	27.32
29	Ultra Low Shrink	4x4 Basket	35.68
30	Ultra Low Shrink	4x4 Basket	44.61

Trial	**Weft Yarn**	**Weave**	**On-Loom Pick Density**
Identification	**Fiber Type**	**Double Cloth**	**picks/cm**
31	PET	Plain	2.93
32	PET	Plain	7.25
33	PET	Plain	9.76
34	PET	Plain	11.43
35	PET	Plain	13.66
36	PET	Plain	15.61
37	PET	Plain	21.19
38	PET	3x1 Twill	11.43
39	PET	3x1 Twill	13.66
40	PET	3x1 Twill	15.61
41	PET	3x1 Twill	17.84
42	PET	3x1 Twill	19.52
43	PET	3x1 Twill	27.32
44	PET	3x1 Twill	35.68
45	PET	8-H Sateen	11.43
46	PET	8-H Sateen	13.66
47	PET	8-H Sateen	15.61
48	PET	8-H Sateen	17.84
49	PET	8-H Sateen	19.52
50	PET	8-H Sateen	27.32
51	PET	8-H Sateen	35.68
52	PET	8-H Sateen	44.61
53	PET	4x4 Basket	15.61
54	PET	4x4 Basket	19.52
55	PET	4x4 Basket	21.19
56	PET	4x4 Basket	23.97
57	PET	4x4 Basket	26.2
58	PET	4x4 Basket	27.32
59	PET	4x4 Basket	35.68
60	PET	4x4 Basket	44.61

Trial	Weft Yarn	Weave	On-Loom Pick Density
Identification	Fiber Type	Double Cloth	picks/cm
61	PET	4x4 Basket	44.61
62	Type 400	Plain	2.93
63	Type 400	Plain	7.25
64	Type 400	Plain	9.76
65	Type 400	Plain	11.43
66	Type 400	Plain	13.66
67	Type 400	Plain	15.61
68	Type 400	Plain	21.19
69	Type 400	3x1 Twill	11.43
70	Type 400	3x1 Twill	13.66
71	Type 400	3x1 Twill	15.61
72	Type 400	3x1 Twill	17.84
73	Type 400	3x1 Twill	19.52
74	Type 400	3x1 Twill	27.32
75	Type 400	3x1 Twill	35.68
76	Type 400	8-H Sateen	11.43
77	Type 400	8-H Sateen	13.66
78	Type 400	8-H Sateen	15.61
79	Type 400	8-H Sateen	17.84
80	Type 400	8-H Sateen	19.52
81	Type 400	8-H Sateen	27.32
82	Type 400	8-H Sateen	35.68
83	Type 400	8-H Sateen	44.61
84	Type 400	4x4 Basket	15.61
85	Type 400	4x4 Basket	19.52
86	Type 400	4x4 Basket	21.19
87	Type 400	4x4 Basket	23.97
88	Type 400	4x4 Basket	26.2
89	Type 400	4x4 Basket	27.32
90	Type 400	4x4 Basket	35.68

Table 4.2B On-loom, Off-loom and Finished Warp Density

Trial	On-Loom Warp Density	Off-Loom Warp Density	Finished Warp Density
ULS Weft Yarn	**ends/cm**	**ends/cm**	**ends/cm**
1	20.47	20.72	22.11
2	20.47	20.47	21.46
3	20.47	20.47	21.37
4	20.47	20.47	21.02
5	20.47	20.47	21.06
6	20.47	20.47	21.41
7	20.47	20.55	21.92
8	20.47	20.59	21.73
9	20.47	20.47	21.55
10	20.47	20.85	21.92
11	20.47	20.51	21.87
12	20.47	20.89	21.87
13	20.47	20.47	22.15
14	20.47	20.53	22.25
15	20.47	20.55	22.20
16	20.47	20.68	22.40
17	20.47	20.64	22.69
18	20.47	20.47	22.25
19	20.47	20.93	22.49
20	20.47	20.47	22.45
21	20.47	20.68	22.90
22	20.47	20.53	22.32
23	20.47	20.59	22.20
24	20.47	20.59	22.20
25	20.47	20.51	22.11
26	20.47	20.80	22.11
27	20.47	20.59	22.25
28	20.47	20.47	22.20
29	20.47	20.89	23.26
30	20.47	20.76	22.95

Trial	On-Loom Warp Density	Off-Loom Warp Density	Finished Warp Density
PET Weft Yarn	**ends/cm**	**ends/cm**	**t1=ends/cm**
31	20.47	20.47	29.50
32	20.47	20.47	23.86
33	20.47	20.47	22.80
34	20.47	20.76	23.00
35	20.47	20.51	22.35
36	20.47	20.68	22.64
37	20.47	20.64	22.85
38	20.47	20.76	24.20
39	20.47	20.64	24.20
40	20.47	20.89	24.31
41	20.47	20.72	23.97
42	20.47	20.64	23.53
43	20.47	20.76	23.75
44	20.47	20.85	24.20
45	20.47	20.80	25.91
46	20.47	20.72	26.04
47	20.47	20.89	26.38
48	20.47	20.51	25.85
49	20.47	20.85	26.38
50	20.47	20.68	27.29
51	20.47	20.89	26.72
52	20.47	20.93	25.78
53	20.47	20.93	27.08
54	20.47	20.68	25.33
55	20.47	20.51	24.96
56	20.47	20.68	24.90
57	20.47	20.85	24.72
58	20.47	20.97	25.21
59	20.47	21.19	27.44
60	20.47	21.37	27.22

Trial	On-Loom Warp Density	Off-Loom Warp Density	Finished Warp Density
Type 400 Weft Yarn	**ends/cm**	**ends/cm**	**ends/cm**
61	20.47	38.19	52.22
62	20.47	21.15	77.54
63	20.47	21.87	73.63
64	20.47	20.55	63.97
65	20.47	20.76	25.98
66	20.47	21.19	27.22
67	20.47	20.93	28.91
68	20.47	23.37	46.10
69	20.47	21.92	46.31
70	20.47	22.69	43.19
71	20.47	21.87	45.09
72	20.47	23.10	42.29
73	20.47	22.35	41.95
74	20.47	22.59	36.95
75	20.47	25.27	64.78
76	20.47	26.11	64.78
77	20.47	38.62	60.21
78	20.47	24.14	58.49
79	20.47	24.54	58.49
80	20.47	25.65	53.03
81	20.47	25.52	51.43
82	20.47	23.47	43.55
83	20.47	28.91	51.95
84	20.47	28.99	52.49
85	20.47	24.25	54.73
86	20.47	32.60	53.59
87	20.47	23.86	55.03
88	20.47	24.54	51.18
89	20.47	30.10	51.95
90	20.47	24.84	50.67

Table 4.3B On-loom, Off-loom and Finished Weft Density

Trial ULS Weft Yarn	On-Loom Pick Density picks/cm	Off-Loom Pick Density picks/cm	Finished Pick Density picks/cm
1	2.93	3.00	4.68
2	7.25	7.30	8.71
3	9.76	10.10	11.40
4	11.43	11.98	13.10
5	13.66	14.35	15.56
6	15.61	16.43	16.23
7	21.2	22.08	23.50
8	11.43	11.59	13.25
9	13.66	13.94	16.11
10	15.61	15.96	18.41
11	17.84	18.06	20.32
12	19.52	19.67	22.43
13	27.32	27.88	30.02
14	35.68	36.84	38.66
15	11.43	11.56	13.60
16	13.66	13.69	16.15
17	15.61	15.74	17.94
18	17.84	17.91	20.32
19	19.52	19.63	21.98
20	27.32	27.99	31.92
21	35.68	37.17	41.49
22	44.61	46.89	50.37
23	15.61	15.77	21.15
24	19.52	19.63	23.86
25	21.19	21.57	25.40
26	23.97	24.21	28.40
27	26.2	26.52	31.12
28	27.32	27.32	31.54
29	35.68	36.71	39.64
30	44.61	45.71	49.57

Trial	On-Loom Pick Density	Off-Loom Pick Density	Finished Pick Density
PET Weft Yarn	picks/cm	picks/cm	picks/cm
31	2.93	2.99	6.54
32	7.25	7.35	8.50
33	9.76	9.96	11.46
34	11.43	11.63	12.81
35	13.66	14.05	15.63
36	15.61	16.23	17.38
37	21.2	21.90	22.94
38	11.43	11.43	13.60
39	13.66	13.80	15.56
40	15.61	15.74	17.98
41	17.84	18.17	20.27
42	19.52	19.71	21.68
43	27.32	27.93	29.57
44	35.68	36.11	37.56
45	11.43	11.47	13.35
46	13.66	13.66	15.74
47	15.61	15.61	17.54
48	17.84	17.95	20.46
49	19.52	19.63	22.23
50	27.32	27.99	31.62
51	35.68	36.56	41.59
52	44.61	45.99	50.92
53	15.61	15.93	21.04
54	19.52	19.71	22.96
55	21.19	21.31	24.69
56	23.97	24.31	28.27
57	26.2	26.36	29.84
58	27.32	27.54	30.49
59	35.68	36.78	40.09
60	44.61	46.47	48.91

Trial	On-Loom Pick Density	Off-Loom Pick Density	Finished Pick Density
Type 400 Weft Yarn	**picks/cm**	**picks/cm**	**picks/cm**
61	2.93	3.00	4.07
62	7.25	7.30	8.54
63	9.76	9.94	11.54
64	11.43	11.61	13.54
65	13.66	13.85	14.50
66	15.61	15.90	16.54
67	21.2	21.63	22.32
68	11.43	11.59	13.07
69	13.66	13.66	15.25
70	15.61	15.83	17.62
71	17.84	17.95	20.04
72	19.52	19.67	21.88
73	27.32	27.32	29.50
74	35.68	35.82	37.72
75	11.43	11.43	12.75
76	13.66	13.83	15.21
77	15.61	15.67	17.34
78	17.84	17.84	19.60
79	19.52	19.67	20.54
80	27.32	27.76	31.33
81	35.68	36.48	41.20
82	44.61	45.80	50.69
83	15.61	16.03	18.36
84	19.52	19.55	21.12
85	21.19	21.36	22.63
86	23.97	23.97	25.77
87	26.2	26.36	27.93
88	27.32	27.42	29.06
89	35.68	36.26	38.53
90	44.61	45.71	47.46

Table 4.4B Off-loom Width, Length and Area Shrinkage Values

Trial	Width Shrinkage Off-Loom	Length Shrinkage Off-Loom	Area Shrinkage Off-Loom
ULS Weft Yarn	**%**	**%**	**%**
1	1.20	2.40	3.57
2	0.00	0.80	0.80
3	0.00	3.40	3.40
4	0.00	4.60	4.60
5	0.00	4.80	4.80
6	0.00	5.00	5.00
7	0.40	4.00	4.38
8	0.60	1.40	1.99
9	0.00	2.00	2.00
10	1.80	2.20	3.96
11	0.20	1.20	1.40
12	2.00	0.80	2.78
13	0.00	2.00	2.00
14	0.29	3.14	3.42
15	0.40	1.20	1.60
16	1.00	0.20	1.20
17	0.80	0.80	1.59
18	0.00	0.40	0.40
19	2.20	0.60	2.79
20	0.00	2.40	2.40
21	1.00	4.00	4.96
22	0.29	4.86	5.13
23	0.60	1.00	1.59
24	0.60	0.60	1.20
25	0.20	1.80	2.00
26	1.60	1.00	2.58
27	0.60	1.20	1.79
28	0.00	0.00	0.00
29	2.00	2.80	4.74
30	1.40	2.40	3.77

Trial	Width Shrinkage Off-Loom	Length Shrinkage Off-Loom	Area Shrinkage Off-Loom
PET Weft Yarn	**%**	**%**	**%**
31	0.00	2.00	2.00
32	0.00	1.40	1.40
33	0.00	2.00	2.00
34	1.40	1.80	3.17
35	0.20	2.80	2.99
36	1.00	3.80	4.76
37	0.80	3.20	3.97
38	1.40	0.00	1.40
39	0.80	1.00	1.79
40	2.00	0.80	2.78
41	1.20	1.80	2.98
42	0.80	1.00	1.79
43	1.40	2.20	3.57
44	1.80	1.20	2.98
45	1.60	0.40	1.99
46	1.20	0.00	1.20
47	2.00	0.00	2.00
48	0.20	0.60	0.80
49	1.80	0.60	2.39
50	1.00	2.40	3.38
51	2.00	2.40	4.35
52	2.20	3.00	5.13
53	2.20	2.00	4.16
54	1.00	1.00	1.99
55	0.20	0.60	0.80
56	1.00	1.40	2.39
57	1.80	0.60	2.39
58	2.40	0.80	3.18
59	3.40	3.00	6.30
60	4.20	4.00	8.03

Trial	Width Shrinkage Off-Loom	Length Shrinkage Off-Loom	Area Shrinkage Off-Loom
Type 400 Weft Yarn	**%**	**%**	**%**
61	46.40	2.40	47.69
62	3.20	0.80	3.97
63	6.40	1.80	8.08
64	0.40	1.60	1.99
65	1.40	1.40	2.78
66	3.40	1.80	5.14
67	2.20	2.00	4.16
68	12.40	1.40	13.63
69	6.60	0.00	6.60
70	9.80	1.40	11.06
71	6.40	0.60	6.96
72	11.40	0.80	12.11
73	8.40	0.00	8.40
74	9.40	0.40	9.76
75	19.00	0.00	19.00
76	21.60	1.20	22.54
77	47.00	0.40	47.21
78	15.20	0.00	15.20
79	16.60	0.80	17.27
80	20.20	1.60	21.48
81	19.80	2.20	21.56
82	12.80	2.60	15.07
83	29.20	2.60	31.04
84	29.40	0.20	29.54
85	15.60	0.80	16.28
86	37.20	0.00	37.20
87	14.20	0.60	14.71
88	16.60	0.40	16.93
89	32.00	1.60	33.09
90	17.60	2.40	19.58

Table 4.5B Finished Width, Length and Area Shrinkage Values

Trial	Width Shrinkage Finished	Length Shrinkage Finished	Area Shrinkage Finished
ULS Weft Yarn	**%**	**%**	**%**
1	7.40	37.40	42.03
2	4.60	16.80	20.63
3	4.20	14.40	18.00
4	2.60	12.80	15.07
5	2.80	12.20	14.66
6	4.40	3.80	8.03
7	6.60	9.80	15.75
8	5.80	13.80	18.80
9	5.00	15.20	19.44
10	6.60	15.20	20.80
11	6.40	12.20	17.82
12	6.40	13.00	18.57
13	7.60	9.00	15.92
14	8.00	7.71	15.10
15	7.80	16.00	22.55
16	8.60	15.40	22.68
17	9.80	13.00	21.53
18	8.00	12.20	19.22
19	9.00	11.20	19.19
20	8.80	14.40	21.93
21	10.60	14.00	23.12
22	8.29	11.43	18.77
23	7.80	26.20	31.96
24	7.80	18.20	24.58
25	7.40	16.60	22.77
26	7.40	15.60	21.85
27	8.00	15.80	22.54
28	7.80	13.40	20.15
29	12.00	10.00	20.8
30	10.80	10.00	19.72

Trial	Width Shrinkage Finished	Length Shrinkage Finished	Area Shrinkage Finished
PET Weft Yarn	**%**	**%**	**%**
31	30.60	55.20	68.91
32	14.20	14.80	26.90
33	10.20	14.80	23.49
34	11.00	10.80	20.61
35	8.40	12.60	19.94
36	9.60	10.20	18.82
37	10.40	7.60	17.21
38	15.40	16.00	28.94
39	15.40	12.20	25.72
40	15.80	13.20	26.91
41	14.60	12.00	24.85
42	13.00	10.00	21.70
43	13.80	7.60	20.35
44	15.40	5.00	19.63
45	21.00	14.40	32.38
46	21.40	13.20	31.78
47	22.40	11.00	30.94
48	20.80	12.80	30.94
49	22.40	12.20	31.87
50	25.00	13.60	35.20
51	23.40	14.20	34.28
52	20.60	12.40	30.45
53	24.40	25.80	43.90
54	19.20	15.00	31.32
55	18.00	14.20	29.64
56	17.80	15.20	30.29
57	17.20	12.20	27.30
58	18.80	10.40	27.24
59	25.40	11.00	33.61
60	24.80	8.80	31.42

Trial	Width Shrinkage Finished	Length Shrinkage Finished	Area Shrinkage Finished
Type 400 Weft Yarn	**%**	**%**	**%**
61	60.80	28.00	71.78
62	73.60	15.20	77.61
63	72.20	15.40	76.48
64	68.00	15.60	72.99
65	21.20	5.80	25.77
66	24.80	5.60	29.01
67	29.20	5.00	32.74
68	55.60	12.60	61.19
69	55.80	10.40	60.40
70	52.60	11.40	58.00
71	54.60	11.00	59.59
72	51.60	10.80	56.83
73	51.20	7.40	54.81
74	44.60	5.40	47.59
75	68.40	10.40	71.69
76	68.40	10.20	71.62
77	66.00	10.00	69.40
78	65.00	9.00	68.15
79	65.00	5.00	66.75
80	61.40	12.80	66.34
81	60.20	13.40	65.53
82	53.00	12.00	58.64
83	60.60	15.00	66.51
84	61.00	7.60	63.96
85	62.60	6.40	64.99
86	61.80	7.00	64.47
87	62.80	6.20	65.11
88	60.00	6.00	62.40
89	60.60	7.40	63.52
90	59.60	6.00	62.02

Table 4.6B Finished Warp and Filling Covers and Cover Factors

Trial	Finished Warp Cover Factor	Finished Filling Cover Factor	Finished Warp Cover	Finished Filling Cover
ULS Weft Yarn	K_1	K_2	C_1 (%)	C_2 (%)
1	12.57	3.42	44.88	12.23
2	12.20	6.37	43.57	22.76
3	12.15	8.34	43.39	29.80
4	11.95	9.59	42.67	34.24
5	11.97	11.38	42.76	40.66
6	12.17	11.87	43.48	42.41
7	12.46	17.20	44.50	61.42
8	12.35	9.70	44.12	34.64
9	12.25	11.79	43.75	42.10
10	12.46	13.47	44.50	48.11
11	12.43	14.87	44.41	53.10
12	12.43	16.41	44.41	58.62
13	12.59	21.97	44.98	78.46
14	12.65	28.29	45.04	101.04
15	12.62	9.95	45.08	35.55
16	12.73	11.82	45.47	42.20
17	12.90	13.13	46.08	46.89
18	12.65	14.87	45.18	53.10
19	12.79	16.08	45.67	57.43
20	12.76	23.35	45.57	83.41
21	13.02	30.36	46.49	108.43
22	12.69	36.86	45.32	125.55
23	12.62	15.48	45.08	55.28
24	12.62	17.46	45.08	62.35
25	12.57	18.59	44.88	66.39
26	12.57	20.78	44.88	74.22
27	12.65	22.77	45.18	81.32
28	12.62	23.08	45.08	82.43
29	13.22	29.74	47.23	106.20
30	13.05	36.27	46.60	129.54

Trial	Finished Warp Cover Factor	Finished Filling Cover Factor	Finished Warp Cover	Finished Filling Cover
PET Weft Yarn	**K_1**	**K_2**	**C_1 (%)**	**C_2 (%)**
31	16.77	4.14	59.89	14.80
32	13.56	5.39	48.44	19.25
33	12.96	7.26	46.28	25.93
34	13.08	8.12	46.70	28.99
35	12.70	9.90	45.37	35.37
36	12.87	11.02	45.98	39.34
37	12.99	14.54	46.39	51.93
38	13.76	8.62	49.13	30.78
39	13.76	9.86	49.13	35.21
40	13.82	11.40	49.36	40.70
41	13.63	12.85	48.67	45.88
42	13.38	13.74	47.77	49.08
43	13.50	18.74	48.22	66.92
44	13.76	23.80	49.13	85.00
45	14.73	8.46	52.61	30.21
46	14.81	9.97	52.88	35.62
47	15.00	11.12	53.56	39.70
48	14.69	12.97	52.48	46.30
49	15.00	14.09	53.56	50.31
50	15.52	20.04	55.42	71.57
51	15.19	26.35	54.26	94.12
52	14.66	32.27	52.35	115.26
53	15.39	13.33	54.98	47.61
54	14.40	14.55	51.44	51.96
55	14.19	15.65	50.69	55.88
56	14.16	17.91	50.56	63.98
57	14.06	18.91	50.20	67.54
58	14.33	19.32	51.19	69.00
59	15.60	25.41	55.71	90.73
60	15.48	31.00	55.27	110.71

Trial	Finished Warp Cover Factor	Finished Filling Cover Factor	Finished Warp Cover	Finished Filling Cover
Type 400 Weft Yarn	**K_1**	**K_2**	**C_1 (%)**	**C_2 (%)**
61	29.69	2.58	106.03	9.21
62	44.08	5.41	157.44	19.34
63	41.86	7.31	149.51	26.11
64	36.37	8.58	129.89	30.64
65	16.96	9.19	60.59	32.82
66	15.48	10.48	55.27	37.43
67	16.44	14.14	58.71	50.51
68	26.21	8.28	93.61	29.59
69	26.33	9.66	94.03	34.50
70	24.55	11.17	87.69	39.88
71	25.63	12.70	91.55	45.37
72	24.04	13.86	85.87	49.52
73	23.85	18.70	85.17	66.77
74	21.01	23.90	75.02	85.36
75	36.83	8.08	131.53	28.86
76	36.83	9.64	131.53	34.43
77	34.23	10.99	122.25	39.26
78	33.25	12.42	118.75	44.37
79	33.25	13.02	118.75	46.49
80	30.15	19.85	107.68	70.91
81	29.24	26.11	104.43	93.25
82	21.16	33.26	72.92	118.78
83	29.54	11.64	105.49	41.56
84	29.84	13.38	106.57	47.80
85	31.12	14.34	111.13	51.23
86	30.47	16.33	108.80	58.33
87	31.28	17.70	111.73	63.22
88	29.09	18.41	103.91	65.77
89	29.54	24.42	105.49	87.21
90	28.81	30.07	102.88	107.41

Table 4.7B On-Loom, Off-loom and Finished Warp Tightness Factor

Trial	On-Loom Warp Tightness Factor	Off-Loom Warp Tightness Factor	Finished Warp Tightness Factor
ULS Weft Yarn			
1	0.95	0.96	1.03
2	0.95	0.95	1.00
3	0.95	0.95	0.99
4	0.95	0.95	0.98
5	0.95	0.95	0.98
6	0.95	0.95	0.99
7	0.95	0.95	1.02
8	0.68	0.69	0.73
9	0.68	0.68	0.72
10	0.68	0.70	0.73
11	0.68	0.68	0.73
12	0.68	0.70	0.73
13	0.68	0.68	0.74
14	0.68	0.69	0.74
15	0.55	0.55	0.60
16	0.55	0.55	0.60
17	0.55	0.55	0.61
18	0.55	0.55	0.60
19	0.55	0.56	0.60
20	0.55	0.55	0.60
21	0.55	0.55	0.61
22	0.55	0.55	0.60
23	0.55	0.55	0.60
24	0.55	0.55	0.60
25	0.55	0.55	0.59
26	0.55	0.56	0.59
27	0.55	0.55	0.60
28	0.55	0.55	0.60
29	0.55	0.56	0.62
30	0.55	0.56	0.62

Trial	On-Loom Warp Tightness Factor	Off-Loom Warp Tightness Factor	Finished Warp Tightness Factor
PET Weft Yarn			
31	0.88	0.88	1.27
32	0.88	0.88	1.02
33	0.88	0.88	0.98
34	0.88	0.89	0.99
35	0.88	0.88	0.96
36	0.88	0.89	0.97
37	0.88	0.89	0.98
38	0.65	0.66	0.77
39	0.65	0.65	0.77
40	0.65	0.66	0.77
41	0.65	0.66	0.76
42	0.65	0.65	0.74
43	0.65	0.66	0.75
44	0.65	0.66	0.77
45	0.53	0.54	0.67
46	0.53	0.54	0.68
47	0.53	0.54	0.68
48	0.53	0.53	0.67
49	0.53	0.54	0.68
50	0.53	0.54	0.71
51	0.53	0.54	0.69
52	0.53	0.54	0.67
53	0.53	0.54	0.70
54	0.53	0.54	0.66
55	0.53	0.53	0.65
56	0.53	0.54	0.65
57	0.53	0.54	0.64
58	0.53	0.54	0.65
59	0.53	0.55	0.71
60	0.53	0.55	0.71

Trial	On-Loom Warp Tightness Factor	Off-Loom Warp Tightness Factor	Finished Warp Tightness Factor
Type 400 Weft Yarn			
61	0.88	1.64	2.24
62	0.88	0.91	3.33
63	0.88	0.94	3.16
64	0.88	0.88	2.75
65	0.88	0.89	1.28
66	0.88	0.91	1.17
67	0.88	0.90	1.24
68	0.65	0.74	1.46
69	0.65	0.69	1.46
70	0.65	0.72	1.37
71	0.65	0.69	1.43
72	0.65	0.73	1.34
73	0.65	0.71	1.33
74	0.65	0.71	1.17
75	0.53	0.66	1.68
76	0.53	0.68	1.68
77	0.53	1.00	1.56
78	0.53	0.63	1.52
79	0.53	0.64	1.52
80	0.53	0.67	1.38
81	0.53	0.66	1.34
82	0.53	0.61	1.14
83	0.53	0.75	1.35
84	0.53	0.75	1.36
85	0.53	0.63	1.42
86	0.53	0.85	1.39
87	0.53	0.62	1.43
88	0.53	0.64	1.33
89	0.53	0.78	1.35
90	0.53	0.64	1.32

Table 4.8B On-Loom, Off-loom and Finished Weft Tightness Factor

Trial	On-Loom Weft Tightness Factor	Off-Loom Weft Tightness Factor	Finished Weft Tightness Factor
ULS Weft Yarn			
1	0.14	0.14	0.22
2	0.34	0.34	0.40
3	0.45	0.47	0.53
4	0.53	0.56	0.61
5	0.63	0.67	0.72
6	0.72	0.76	0.75
7	0.98	1.03	1.09
8	0.41	0.42	0.48
9	0.50	0.51	0.58
10	0.57	0.58	0.67
11	0.65	0.66	0.74
12	0.71	0.71	0.81
13	0.99	1.01	1.09
14	1.29	1.34	1.40
15	0.36	0.36	0.42
16	0.43	0.43	0.50
17	0.49	0.49	0.56
18	0.56	0.56	0.63
19	0.61	0.61	0.69
20	0.85	0.87	1.00
21	1.11	1.16	1.29
22	1.39	1.46	1.57
23	0.49	0.49	0.66
24	0.61	0.61	0.74
25	0.66	0.67	0.79
26	0.75	0.76	0.89
27	0.82	0.83	0.97
28	0.85	0.85	0.98
29	1.11	1.15	1.24
30	1.39	1.43	1.55

Trial	On-Loom Weft Tightness Factor	Off-Loom Weft Tightness Factor	Finished Weft Tightness Factor
PET Weft Yarn			
31	0.13	0.13	0.28
32	0.31	0.32	0.37
33	0.42	0.43	0.49
34	0.49	0.50	0.55
35	0.59	0.60	0.67
36	0.67	0.70	0.75
37	0.91	0.94	0.00
38	0.37	0.37	0.45
39	0.45	0.45	0.51
40	0.51	0.52	0.59
41	0.58	0.60	0.66
42	0.64	0.65	0.71
43	0.90	0.92	0.97
44	1.17	1.18	1.23
45	0.32	0.32	0.37
46	0.38	0.38	0.44
47	0.43	0.43	0.49
48	0.49	0.50	0.57
49	0.54	0.54	0.62
50	0.76	0.78	0.88
51	0.99	1.01	1.15
52	1.24	1.27	1.41
53	0.43	0.44	0.58
54	0.54	0.55	0.64
55	0.59	0.59	0.68
56	0.66	0.67	0.78
57	0.73	0.73	0.83
58	0.76	0.76	0.84
59	0.99	1.02	1.11
60	1.24	1.29	1.36

Trial	On-Loom Weft Tightness Factor	Off-Loom Weft Tightness Factor	Finished Weft Tightness Factor
Type 400 Weft Yarn			
61	0.13	0.13	0.17
62	0.31	0.31	0.37
63	0.42	0.43	0.50
64	0.49	0.50	0.58
65	0.59	0.59	0.62
66	0.67	0.68	0.71
67	0.91	0.93	0.96
68	0.37	0.38	0.43
69	0.45	0.45	0.50
70	0.51	0.52	0.58
71	0.58	0.59	0.66
72	0.64	0.64	0.72
73	0.90	0.90	0.97
74	1.17	1.17	1.24
75	0.32	0.32	0.35
76	0.38	0.38	0.42
77	0.43	0.43	0.48
78	0.49	0.49	0.54
79	0.54	0.55	0.57
80	0.76	0.77	0.87
81	0.99	1.01	1.14
82	1.24	1.27	1.40
83	0.42	0.44	0.51
84	0.54	0.54	0.59
85	0.59	0.59	0.63
86	0.66	0.66	0.71
87	0.73	0.73	0.77
88	0.76	0.76	0.81
89	0.99	1.00	1.07
90	1.02	1.27	1.31

Table 4.9B On-Loom, Off-loom and Finished Fabric Tightness Factor

Trial	On-Loom Fabric Tightness Factor	Off-Loom Fabric Tightness Factor	Finished Fabric Tightness Factor
ULS Weft Yarn			
1	0.54	0.88	0.62
2	0.64	0.61	0.70
3	0.70	0.68	0.76
4	0.74	0.69	0.79
5	0.79	0.74	0.85
6	0.84	0.80	0.87
7	0.97	0.91	1.05
8	0.55	0.56	0.61
9	0.59	0.57	0.65
10	0.63	0.62	0.70
11	0.67	0.64	0.73
12	0.70	0.69	0.77
13	0.83	0.80	0.91
14	0.98	0.94	1.06
15	0.46	0.49	0.52
16	0.49	0.54	0.56
17	0.52	0.73	0.59
18	0.55	0.56	0.61
19	0.58	0.59	0.64
20	0.69	0.72	0.78
21	0.81	0.83	0.93
22	0.94	0.93	1.05
23	0.52	0.60	0.63
24	0.58	0.65	0.66
25	0.60	0.61	0.69
26	0.64	0.76	0.73
27	0.67	0.67	0.77
28	0.69	0.70	0.78
29	0.81	0.89	0.91
30	0.94	0.95	1.05

Trial	On-Loom Fabric Tightness Factor	Off-Loom Fabric Tightness Factor	Finished Fabric Tightness Factor
PET Weft Yarn			
31	0.50	0.50	0.77
32	0.60	0.60	0.69
33	0.65	0.65	0.74
34	0.68	0.70	0.77
35	0.73	0.74	0.82
36	0.77	0.79	0.86
37	0.89	0.91	0.98
38	0.51	0.52	0.61
39	0.55	0.55	0.64
40	0.58	0.59	0.68
41	0.62	0.63	0.71
42	0.64	0.65	0.73
43	0.77	0.78	0.86
44	0.90	0.92	0.99
45	0.43	0.43	0.53
46	0.46	0.46	0.56
47	0.48	0.49	0.59
48	0.51	0.52	0.62
49	0.54	0.54	0.65
50	0.64	0.65	0.79
51	0.75	0.77	0.92
52	0.87	0.90	1.03
53	0.48	0.49	0.64
54	0.54	0.54	0.65
55	0.56	0.56	0.67
56	0.60	0.60	0.71
57	0.63	0.63	0.73
58	0.64	0.65	0.75
59	0.75	0.78	0.91
60	0.87	0.91	1.02

Trial	On-Loom Fabric Tightness Factor	Off-Loom Fabric Tightness Factor	Finished Fabric Tightness Factor
Type 400 Weft Yarn			
61	0.54	0.88	1.21
62	0.64	0.61	1.85
63	0.70	0.68	1.83
64	0.74	0.69	1.66
65	0.79	0.74	0.95
66	0.84	0.80	0.94
67	0.97	0.91	1.10
68	0.55	0.56	0.95
69	0.59	0.57	0.99
70	0.63	0.62	0.98
71	0.67	0.64	1.05
72	0.70	0.69	1.03
73	0.83	0.80	1.15
74	0.98	0.94	1.20
75	0.46	0.49	1.04
76	0.49	0.54	1.07
77	0.52	0.73	1.04
78	0.55	0.56	1.05
79	0.58	0.59	1.06
80	0.69	0.72	1.13
81	0.81	0.83	1.24
82	0.94	0.93	1.26
83	0.52	0.60	0.94
84	0.58	0.65	0.99
85	0.60	0.61	1.04
86	0.64	0.76	1.06
87	0.67	0.67	1.11
88	0.69	0.70	1.08
89	0.81	0.89	1.21
90	0.94	0.95	1.32

Table 4.10B SAS Code for Full Data Set

```
options nodate pageno = 1;
data tight;
input trial weave $ pd wy $ shrink oltight fintight;
cards;
1    PLAIN     2.93      ULS  7.4         0.54 0.62
2    PLAIN     7.25      ULS  4.60        0.64 0.70
3    PLAIN     9.76      ULS  4.20        0.70 0.76
4    PLAIN     11.43     ULS  2.60        0.74 0.79
5    PLAIN     13.66     ULS  2.80        0.79 0.85
6    PLAIN     15.61     ULS  4.40        0.84 0.87
7    PLAIN     21.2      ULS  6.60        0.97 1.06
8    3X1TWILL  11.43     ULS  5.80        0.55 0.61
9    3X1TWILL  13.66     ULS  5.00        0.59 0.66
10   3X1TWILL  15.61     ULS  6.60        0.63 0.70
11   3X1TWILL  17.84     ULS  6.40        0.67 0.73
12   3X1TWILL  19.52     ULS  6.40        0.70 0.77
13   3X1TWILL  27.32     ULS  7.60        0.83 0.91
14   3X1TWILL  35.68     ULS  8.00        0.98 1.06
15   8-HSATEEN 11.43     ULS  7.80        0.46 0.52
16   8-HSATEEN 13.66     ULS  8.60        0.49 0.56
17   8-HSATEEN 15.61     ULS  9.80        0.52 0.59
18   8-HSATEEN 17.84     ULS  8.00        0.55 0.61
19   8-HSATEEN 19.52     ULS  9.00        0.58 0.64
20   8-HSATEEN 27.32     ULS  8.80        0.69 0.78
21   8-HSATEEN 35.68     ULS  10.60       0.81 0.93
22   8-HSATEEN 44.61     ULS  8.29        0.94 1.05
23   4X4BASKET 15.61     ULS  7.80        0.52 0.63
24   4X4BASKET 19.52     ULS  7.80        0.58 0.67
25   4X4BASKET 21.19     ULS  7.40        0.60 0.69
26   4X4BASKET 23.97     ULS  7.40        0.64 0.73
27   4X4BASKET 26.2      ULS  8.00        0.67 0.77
28   4X4BASKET 27.32     ULS  7.80        0.69 0.78
29   4X4BASKET 39.64     ULS  12          0.81 0.91
30   4X4BASKET 44.61     ULS  10.8        0.94 1.05
31   PLAIN     2.93      PET  30.6        0.50 0.77
32   PLAIN     7.25      PET  14.20       0.60 0.69
33   PLAIN     9.76      PET  10.20       0.65 0.74
34   PLAIN     11.43     PET  11.00       0.68 0.77
35   PLAIN     13.66     PET  8.40        0.73 0.82
36   PLAIN     15.61     PET  9.60        0.77 0.86
37   PLAIN     21.2      PET  10.40       0.89 0.98
38   3X1TWILL  11.43     PET  15.40       0.51 0.61
39   3X1TWILL  13.66     PET  15.40       0.55 0.64
```

40	3X1TWILL	15.61	PET	15.80		0.58	0.68	
41	3X1TWILL	17.84	PET	14.60		0.62	0.71	
42	3X1TWILL	19.52	PET	13.00		0.64	0.73	
43	3X1TWILL	27.32	PET	13.80		0.77	0.86	
44	3X1TWILL	35.68	PET	15.40		0.90	0.99	
45	8-HSATEEN	11.43	PET	21.00		0.43	0.53	
46	8-HSATEEN	13.66	PET	21.40		0.46	0.56	
47	8-HSATEEN	15.61	PET	22.40		0.48	0.59	
48	8-HSATEEN	17.84	PET	20.80		0.51	0.62	
49	8-HSATEEN	19.52	PET	22.40		0.54	0.65	
50	8-HSATEEN	27.32	PET	25.00		0.64	0.79	
51	8-HSATEEN	35.68	PET	23.40		0.75	0.92	
52	8-HSATEEN	44.61	PET	20.60		0.87	1.03	
53	4X4BASKET	15.61	PET	24.40		0.48	0.64	
54	4X4BASKET	19.52	PET	19.20		0.54	0.65	
55	4X4BASKET	21.19	PET	18.00		0.56	0.67	
56	4X4BASKET	23.97	PET	17.80		0.60	0.71	
57	4X4BASKET	26.2	PET	17.20		0.63	0.73	
58	4X4BASKET	27.32	PET	18.80		0.64	0.75	
59	4X4BASKET	35.68	PET	25.4		0.75	0.91	
60	4X4BASKET	44.61	PET	24.8		0.87	1.02	
61	PLAIN	2.93	TYPE400		60.8	0.50	1.21	
62	PLAIN	7.25	TYPE400		73.60		0.60	1.85
63	PLAIN	9.76	TYPE400		72.20		0.65	1.83
64	PLAIN	11.43	TYPE400		68.00		0.68	1.66
65	PLAIN	13.66	TYPE400		31.40		0.73	0.95
66	PLAIN	15.61	TYPE400		24.80		0.77	0.94
67	PLAIN	21.2	TYPE400		29.20		0.89	1.10
68	3X1TWILL	11.43	TYPE400		55.60		0.51	0.95
69	3X1TWILL	13.66	TYPE400		55.80		0.55	0.99
70	3X1TWILL	15.61	TYPE400		52.60		0.58	0.98
71	3X1TWILL	17.84	TYPE400		54.60		0.62	1.05
72	3X1TWILL	19.52	TYPE400		51.60		0.64	1.03
73	3X1TWILL	27.32	TYPE400		51.20		0.77	1.15
74	3X1TWILL	35.68	TYPE400		44.60		0.90	1.20
75	8-HSATEEN	11.43	TYPE400		68.40		0.43	1.04
76	8-HSATEEN	13.66	TYPE400		68.40		0.46	1.07
77	8-HSATEEN	15.61	TYPE400		66.00		0.48	1.04
78	8-HSATEEN	17.84	TYPE400		65.00		0.51	1.05
79	8-HSATEEN	19.52	TYPE400		65.00		0.54	1.06
80	8-HSATEEN	27.32	TYPE400		61.4		0.64	1.13
81	8-HSATEEN	35.68	TYPE400		60.2		0.75	1.24
82	8-HSATEEN	50.69	TYPE400		53.00		0.87	1.26
83	4X4BASKET	15.61	TYPE400		60.6		0.48	0.94
84	4X4BASKET	19.52	TYPE400		61.00		0.54	0.99
85	4X4BASKET	21.19	TYPE400		62.60		0.56	1.04
86	4X4BASKET	23.97	TYPE400		61.80		0.60	1.06

```
87   4X4BASKET 26.2      TYPE400   62.80     0.63 1.11
88   4X4BASKET 27.32     TYPE400   60.000.64 1.08
89   4X4BASKET 35.68     TYPE400   60.6 0.75 1.21
90   4X4BASKET 44.61     TYPE400   59.6 0.87 1.32
;
title "Full Data Set";
proc glm data = tight;
class weave wy;
model shrink  = pd weave wy pd*weave pd*wy weave*wy;
run;
proc genmod data = tight;
class weave wy;
model shrink = pd weave wy pd*weave pd*wy weave*wy / dist =
normal type3;
run;
proc sort data = tight;
by weave;
run;
proc univariate;
var shrink;
by weave;
run;
quit;
```

Table 4.11B SAS Code for Reduced Data Set

```
options nodate pageno = 1;
data tight;
input trial weave $ pd wy $ shrink oltight fintight;
cards;
2    PLAIN    7.25     ULS  4.60 0.64 0.70
3    PLAIN    9.76     ULS  4.20 0.70 0.76
4    PLAIN    11.43    ULS  2.60 0.74 0.79
5    PLAIN    13.66    ULS  2.80 0.79 0.85
6    PLAIN    15.61    ULS  4.40 0.84 0.87
8    3X1TWILL 11.43    ULS  5.80 0.55 0.61
9    3X1TWILL 13.66    ULS  5.00 0.59 0.66
10   3X1TWILL 15.61    ULS  6.60 0.63 0.70
11   3X1TWILL 17.84    ULS  6.40 0.67 0.73
12   3X1TWILL 19.52    ULS  6.40 0.70 0.77
13   3X1TWILL 27.32    ULS  7.60 0.83 0.91
15   8-HSATEEN 11.43   ULS  7.80 0.46 0.52
16   8-HSATEEN 13.66   ULS  8.60 0.49 0.56
17   8-HSATEEN 15.61   ULS  9.80 0.52 0.59
18   8-HSATEEN 17.84   ULS  8.00 0.55 0.61
19   8-HSATEEN 19.52   ULS  9.00 0.58 0.64
20   8-HSATEEN 27.32   ULS  8.80 0.69 0.78
21   8-HSATEEN 35.68   ULS  10.600.81 0.93
23   4X4BASKET 15.61   ULS  7.80 0.52 0.63
24   4X4BASKET 19.52   ULS  7.80 0.58 0.67
25   4X4BASKET 21.19   ULS  7.40 0.60 0.69
26   4X4BASKET 23.97   ULS  7.40 0.64 0.73
27   4X4BASKET 26.2    ULS  8.00 0.67 0.77
28   4X4BASKET 27.32   ULS  7.80 0.69 0.78
29   4X4BASKET 39.64   ULS  12   0.81 0.91
32   PLAIN    7.25     PET  14.20     0.60 0.69
33   PLAIN    9.76     PET  10.20     0.65 0.74
34   PLAIN    11.43    PET  11.00     0.68 0.77
35   PLAIN    13.66    PET  8.40      0.73 0.82
36   PLAIN    15.61    PET  9.60      0.77 0.86
37   PLAIN    21.2     PET  10.40     0.89 0.98
38   3X1TWILL 11.43    PET  15.40     0.51 0.61
39   3X1TWILL 13.66    PET  15.40     0.55 0.64
40   3X1TWILL 15.61    PET  15.80     0.58 0.68
41   3X1TWILL 17.84    PET  14.60     0.62 0.71
42   3X1TWILL 19.52    PET  13.00     0.64 0.73
43   3X1TWILL 27.32    PET  13.80     0.77 0.86
45   8-HSATEEN 11.43   PET  21.00     0.43 0.53
46   8-HSATEEN 13.66   PET  21.40     0.46 0.56
47   8-HSATEEN 15.61   PET  22.40     0.48 0.59
48   8-HSATEEN 17.84   PET  20.80     0.51 0.62
49   8-HSATEEN 19.52   PET  22.40     0.54 0.65
```

```
50   8-HSATEEN 27.32     PET  25.00     0.64 0.79
51   8-HSATEEN 35.68     PET  23.40     0.75 0.92
53   4X4BASKET 15.61     PET  24.40     0.48 0.64
54   4X4BASKET 19.52     PET  19.20     0.54 0.65
55   4X4BASKET 21.19     PET  18.00     0.56 0.67
56   4X4BASKET 23.97     PET  17.80     0.60 0.71
57   4X4BASKET 26.2      PET  17.20     0.63 0.73
58   4X4BASKET 27.32     PET  18.80     0.64 0.75
59   4X4BASKET 35.68     PET  25.4 0.75 0.91
60   4X4BASKET 44.61     PET  24.8 0.87 1.02
65   PLAIN     13.66     TYPE400   31.40     0.73 0.95
66   PLAIN     15.61     TYPE400   24.80     0.77 0.94
67   PLAIN     21.2      TYPE400   29.20     0.89 1.10
68   3X1TWILL  11.43     TYPE400   55.60     0.51 0.95
69   3X1TWILL  13.66     TYPE400   55.80     0.55 0.99
70   3X1TWILL  15.61     TYPE400   52.60     0.58 0.98
71   3X1TWILL  17.84     TYPE400   54.60     0.62 1.05
72   3X1TWILL  19.52     TYPE400   51.60     0.64 1.03
73   3X1TWILL  27.32     TYPE400   51.20     0.77 1.15
74   3X1TWILL  35.68     TYPE400   44.60     0.90 1.20
78   8-HSATEEN 17.84     TYPE400   65.00     0.51 1.05
79   8-HSATEEN 19.52     TYPE400   65.00     0.54 1.06
81   8-HSATEEN 35.68     TYPE400   60.2 0.75 1.24
83   4X4BASKET 15.61     TYPE400   60.6 0.48 0.94
84   4X4BASKET 19.52     TYPE400   61.00     0.54 0.99
85   4X4BASKET 21.19     TYPE400   62.60     0.56 1.04
86   4X4BASKET 23.97     TYPE400   61.80     0.60 1.06
87   4X4BASKET 26.2      TYPE400   62.80     0.63 1.11
88   4X4BASKET 27.32     TYPE400   60.00     0.64 1.08
89   4X4BASKET 35.68     TYPE400   60.6 0.75 1.21
;
title1 "With Data Points removed";
proc glm data = tight;
class weave wy;
model fintight = pd weave wy weave*pd weave*wy pd*wy;
run;
proc sort data = tight;
by weave;
run;
proc gplot data = tight;
plot oltight * fintight;
by weave;
symbol i = r v = star;
run;
proc corr data = tight;
var oltight fintight pd;
by weave;
```

```
run;
proc sort data = tight;
by wy;
run;
proc gplot data = tight;
plot oltight * fintight;
by wy;
symbol i = r v = star;
run;
proc corr data = tight;
var oltight fintight pd;
by wy;
run;
proc corr data = tight;
var oltight fintight pd;
run;

quit;
```

Table 4.12B Correlation Coefficient for the On-Loom and Finished Fabric Tightness of the Fabrics Constructed with the Three Weft Yarns

Note:
oltight = on-loom fabric tightness
fintight = finished fabric tightness

Weft Yarn=ULS

The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 28
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000 <.0001	0.99063
fintight	0.99063 <.0001	1.00000

Weft Yarn =PET

The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 29
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000 <.0001	0.98305
fintight	0.98305 <.0001	1.00000

Weft Yarn=TYPE400

The CORR Procedure

3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 21
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000	0.56265 0.0079
fintight	0.56265 0.0079	1.00000

Table 4.13B Correlation Coefficient for On-Loom and Finished Fabric Tightness of the Fabrics constructed with the Four Weave Designs

Note:
oltight = on-loom fabric tightness
fintight = finished fabric tightness

Weave=PLAIN
The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 15
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000	0.89668 <.0001
fintight	0.89668 <.0001	1.00000

Weave=3X1TWILL
The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 21
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000	0.57793 0.0061
fintight	0.57793 0.0061	1.00000

Weave=8-H SATEEN
The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 20
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000	0.69314 0.0007
fintight	0.69314 0.0007	1.00000

Weave=4X4 BASKET
The CORR Procedure
3 Variables: oltight fintight pd

Pearson Correlation Coefficients, N = 22
Prob > |r| under H0: Rho=0

	oltight	fintight
oltight	1.00000	0.40140 0.0641
fintight	0.40140	1.00000

Table 4.14B Analysis of Variance Table with Respect to Finished Fabric Tightness Reduced Data Set

The GLM Procedure

Class Level Information

Class	Levels	Values
weave	4	3X1TWILL 4X4BASKE 8-HSATEE PLAIN
wy	3	PET TYPE400 ULS

Number of Observations Read	78
Number of Observations Used	78

Note:
oltight = on-loom fabric tightness
fintight = finished fabric tightness
pd = pick density
wy = weft yarn

Reduced Data Set
Overall Model
Dependent Variable: Finished Tightness

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	2.69407082	0.15847475	458.79	<.0001
Error	60	0.02072534	0.00034542		
Corrected Total	77	2.71479615			

R-Square	Coeff Var	Root MSE	fintight Mean
0.992366	2.215608	0.018586	0.838846

Source	DF	Type I SS	Mean Square	F Value	Pr > F
pd	1	0.83882216	0.83882216	2428.40	<.0001
weave	3	0.39358623	0.13119541	379.81	<.0001
wy	2	1.31858374	0.65929187	1908.65	<.0001
pd*weave	3	0.00620539	0.00206846	5.99	0.0012
weave*wy	6	0.12407883	0.02067981	59.87	<.0001
pd*wy	2	0.01279448	0.00639724	18.52	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
pd	1	0.66123901	0.66123901	1914.29	<.0001
weave	3	0.00556597	0.00185532	5.37	0.0024
wy	2	0.17855907	0.08927953	258.46	<.0001
pd*weave	3	0.01827829	0.00609276	17.64	<.0001
weave*wy	6	0.13603531	0.02267255	65.64	<.0001
pd*wy	2	0.01279448	0.00639724	18.52	<.0001

Table 4.15B Analysis of Variance Table with Respect to Finished Width Shrinkage Full Data Set

The GLM Procedure

Class Level Information

Class	Levels	Values
weave	4	3X1TWILL 4X4BASKE 8-HSATEE PLAIN
wy	3	PET TYPE400 ULS

Number of Observations Read	90
Number of Observations Used	90

Note:

pd = pick density
wy = weft yarn

Full Data Set
Overall Model
Dependent Variable: Width Shrinkage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	44687.63725	2628.68454	87.93	<.0001
Error	72	2152.50476	29.89590		
Corrected Total	89	46840.14201			

R-Square	Coeff Var	Root MSE	shrink Mean
0.954046	19.83379	5.467714	27.56767

Source	DF	Type I SS	Mean Square	F Value	Pr > F
pd	1	18.22263	18.22263	0.61	0.4375
weave	3	1269.70995	423.23665	14.16	<.0001
wy	2	41846.18256	20923.09128	699.86	<.0001
pd*weave	3	878.86654	292.95551	9.80	<.0001
pd*wy	2	178.85301	89.42650	2.99	0.0565
weave*wy	6	495.80256	82.63376	2.76	0.0179

Source	DF	Type III SS	Mean Square	F Value	Pr > F
pd	1	604.43445	604.43445	20.22	<.0001
weave	3	260.26087	86.75362	2.90	0.0407
wy	2	10203.27821	5101.63910	170.65	<.0001
pd*weave	3	879.57294	293.19098	9.81	<.0001
pd*wy	2	460.96949	230.48475	7.71	0.0009
weave*wy	6	495.80256	82.63376	2.76	0.0179

Table 4.16B Predictive Model for Finished Width Shrinkage

Full Data Set
The GENMOD Procedure

Model Information

Data Set	WORK.TIGHT
Distribution	Normal
Link Function	Identity
Dependent Variable	shrink

Number of Observations Read	90
Number of Observations Used	90

Class Level Information

Class	Levels	Values
weave	4	3X1TWILL 4X4BASKE 8-HSATEE PLAIN
wy	3	PET TYPE400 ULS

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	72	2152.5048	29.8959
Scaled Deviance	72	90.0000	1.2500
Pearson Chi-Square	72	2152.5048	29.8959
Scaled Pearson X2	72	90.0000	1.2500
Log Likelihood		-270.5605	

Algorithm converged.

Analysis of Parameter Estimates

Parameter			DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept			1	16.6664	3.0900	10.6102	22.7227	29.09	<.0001
pd			1	-1.0272	0.2118	-1.4423	-0.6121	23.52	<.0001
weave	3X1TWILL		1	-12.4047	4.4635	-21.1531	-3.6563	7.72	0.0055
weave	4X4BASKE		1	-16.4776	4.7157	-25.7202	-7.2351	12.21	0.0005
weave	8-HSATEE		1	-10.6321	4.0937	-18.6556	-2.6086	6.75	0.0094
weave	PLAIN		0	0.0000	0.0000	0.0000	0.0000	.	.
wy	PET		1	10.0051	3.1183	3.8934	16.1169	10.29	0.0013
wy	TYPE400		1	53.5308	3.0927	47.4693	59.5924	299.60	<.0001
wy	ULS		0	0.0000	0.0000	0.0000	0.0000	.	.
pd*weave	3X1TWILL		1	1.1404	0.2371	0.6757	1.6051	23.13	<.0001
pd*weave	4X4BASKE		1	1.3367	0.2245	0.8967	1.7767	35.45	<.0001
pd*weave	8-HSATEE		1	1.1490	0.2135	0.7306	1.5674	28.97	<.0001
pd*weave	PLAIN		0	0.0000	0.0000	0.0000	0.0000	.	.
pd*wy	PET		1	-0.1006	0.1454	-0.3856	0.1844	0.48	0.4889
pd*wy	TYPE400		1	-0.5782	0.1414	-0.8552	-0.3011	16.73	<.0001
pd*wy	ULS		0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	3X1TWILL	PET	1	0.2514	3.8962	-7.3850	7.8877	0.00	0.9486
weave*wy	3X1TWILL	TYPE400	1	3.8626	3.8855	-3.7528	11.4780	0.99	0.3202
weave*wy	3X1TWILL	ULS	0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	4X4BASKE	PET	1	4.9163	4.2155	-3.3459	13.1785	1.36	0.2435
weave*wy	4X4BASKE	TYPE400	1	14.5951	4.1833	6.3959	22.7943	12.17	0.0005
weave*wy	4X4BASKE	ULS	0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	8-HSATEE	PET	1	5.5942	3.9519	-2.1514	13.3398	2.00	0.1569
weave*wy	8-HSATEE	TYPE400	1	14.7979	3.9531	7.0499	22.5459	14.01	0.0002
weave*wy	8-HSATEE	ULS	0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	PLAIN	PET	0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	PLAIN	TYPE400	0	0.0000	0.0000	0.0000	0.0000	.	.
weave*wy	PLAIN	ULS	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale			1	4.8905	0.3645	4.2258	5.6597		

NOTE: The scale parameter was estimated by maximum likelihood.

Table 4.17B Actual and Predicted Width Shrinkages Using All Data Points

Trial Identification	Weave Design	Actual Width Shrinkage (%)	Predicted Shrinkage (%)
1	Plain	7.40	13.66
2	Plain	4.60	9.22
3	Plain	4.20	6.64
4	Plain	2.60	4.93
5	Plain	2.80	2.63
6	Plain	4.40	0.63
7	Plain	6.60	-5.10
8	3x1 Twill	5.80	5.56
9	3x1 Twill	5.00	5.81
10	3x1 Twill	6.60	6.03
11	3x1 Twill	6.40	6.28
12	3x1 Twill	6.40	6.47
13	3x1 Twill	7.60	7.35
14	3x1 Twill	8.00	8.30
15	8-H Sateen	7.80	7.43
16	8-H Sateen	8.60	7.70
17	8-H Sateen	9.80	7.94
18	8-H Sateen	8.00	8.21
19	8-H Sateen	9.00	8.41
20	8-H Sateen	8.80	9.36
21	8-H Sateen	10.60	10.38
22	8-H Sateen	8.29	11.47
23	4x4 Basket	7.80	5.02
24	4x4 Basket	7.80	6.23
25	4x4 Basket	7.40	6.75
26	4x4 Basket	7.40	7.61
27	4x4 Basket	8.00	8.30
28	4x4 Basket	7.80	8.64
29	4x4 Basket	12.00	11.23
30	4x4 Basket	10.80	14.00

Trial Identification	Weave Design	Actual Width Shrinkage (%)	Predicted Shrinkage (%)
31	Plain	30.60	23.37
32	Plain	14.20	18.49
33	Plain	10.20	15.66
34	Plain	11.00	13.78
35	Plain	8.40	11.27
36	Plain	9.60	9.07
37	Plain	10.40	2.77
38	3x1 Twill	15.40	14.66
39	3x1 Twill	15.40	14.69
40	3x1 Twill	15.80	14.71
41	3x1 Twill	14.60	14.74
42	3x1 Twill	13.00	14.76
43	3x1 Twill	13.80	14.86
44	3x1 Twill	15.40	14.97
45	8-H Sateen	21.00	21.88
46	8-H Sateen	21.40	21.92
47	8-H Sateen	22.40	21.96
48	8-H Sateen	20.80	22.01
49	8-H Sateen	22.40	22.05
50	8-H Sateen	25.00	22.21
51	8-H Sateen	23.40	22.39
52	8-H Sateen	20.60	22.58
53	4x4 Basket	24.40	18.37
54	4x4 Basket	19.20	19.19
55	4x4 Basket	18.00	19.54
56	4x4 Basket	17.80	20.12
57	4x4 Basket	17.20	20.58
58	4x4 Basket	18.80	20.82
59	4x4 Basket	25.40	22.56
60	4x4 Basket	24.80	24.43

Trial Identification	Weave Design	Actual Width Shrinkage (%)	Predicted Shrinkage (%)
61	Plain	60.80	65.49
62	Plain	73.60	58.56
63	Plain	72.20	54.53
64	Plain	68.00	51.85
65	Plain	21.20	48.27
66	Plain	24.80	45.14
67	Plain	29.20	36.18
68	3x1 Twill	55.60	56.34
69	3x1 Twill	55.80	55.30
70	3x1 Twill	52.60	54.40
71	3x1 Twill	54.60	53.36
72	3x1 Twill	51.60	52.58
73	3x1 Twill	51.20	48.95
74	3x1 Twill	44.60	45.06
75	8-H Sateen	68.40	69.15
76	8-H Sateen	68.40	68.13
77	8-H Sateen	66.00	67.24
78	8-H Sateen	65.00	66.22
79	8-H Sateen	65.00	65.45
80	8-H Sateen	61.40	61.89
81	8-H Sateen	60.20	58.08
82	8-H Sateen	53.00	54.00
83	4x4 Basket	60.60	64.12
84	4x4 Basket	61.00	63.07
85	4x4 Basket	62.60	62.62
86	4x4 Basket	61.80	61.87
87	4x4 Basket	62.80	61.27
88	4x4 Basket	60.00	60.97
89	4x4 Basket	60.60	58.73
90	4x4 Basket	59.60	56.33

Figure 4.1B Maximum Weavability Curve of an 8-Harness Weave ULS Weft Yarn

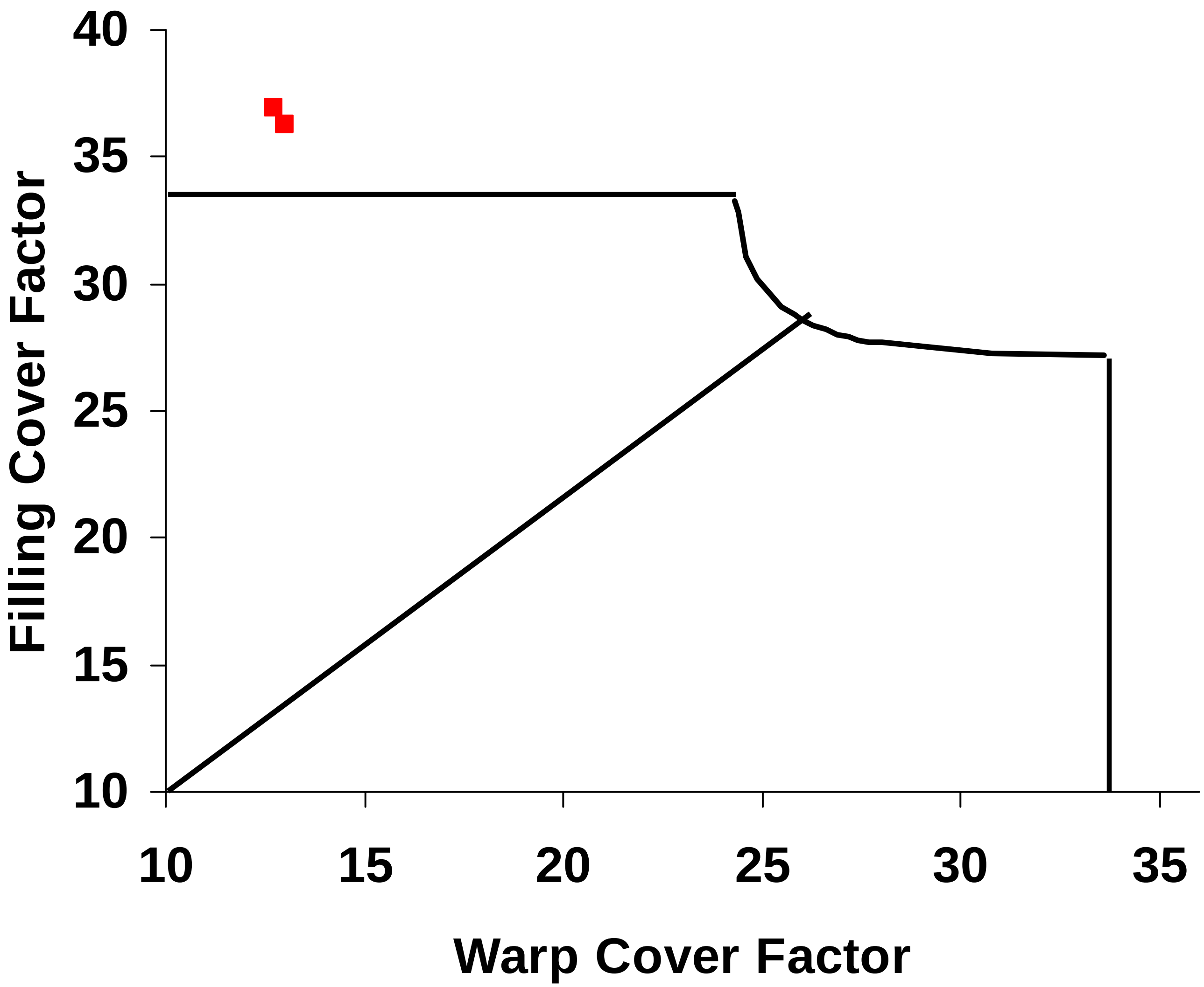

Figure 4.2B Maximum Weavability Curve for an 8-Harness Weave Type 400 Weft Yarn