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Title: RELATION OF SELECTED SEAMING METHODS AND THREADS TO THE BREAKING STRENGTH AND ELONGATION OF SEAMS IN A POLYESTER DOUBLE-KNIT FABRIC

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The major purposes of the research were to determine whether there were significant differences in breaking strength and elongation of the following types of seams in a polyester double-knit fabric:

1. seams stitched with threads of (a) mercerized cotton, (b) core-spun polyester/cotton, and (c) bonded nylon monocord.

2. seams stitched with (a) a narrow zigzag stitch, (b) a lock-stitch made while stretching the fabric, and (c) an elastic straight stitch.

3. seams stitched (a) parallel to the wales and (b) parallel to the courses.

4. seams stitched with settings of (a) 9 stitches per inch, (b) 12 stitches per inch, and (c) 15 stitches per inch.

Results indicated that the polyester/cotton core-spun thread produced seams with greater breaking strength and elongation than

mercerized cotton thread for all comparable sets of specimens. Seams constructed with polyester/cotton core-spun thread also tended to exhibit greater seam breaking strength and elongation than those seamed with bonded nylon monocord thread. The nylon thread, in turn, tended to produce stronger and more extensible seams than did mercerized cotton thread.

The elastic straight stitch (a triple lockstitch) produced seams with greater breaking strength and elongation than either of the other stitch types. Most seams stitched with the lockstitch with stretch had a higher mean seam breaking strength and elongation than comparable seams stitched with the zigzag stitch.

Stitch length affected seam breaking strength and elongation to a greater extent with the zigzag than with the lockstitch with stretch. For most comparable sets of zigzag specimens, increases in the number of stitches per inch were accompanied by increases in seam breaking strength and elongation. With the lockstitch, those differences which were significant indicated that the shorter stitches were related to greater breaking strength and elongation.

Seams parallel to the courses were related to greater seam breaking strength and elongation than seams parallel to the wales.

Relation of Selected Seaming Methods and Threads to the Breaking Strength and Elongation of Seams in a Polyester Double-Knit Fabric

by

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RELATION OF SELECTED SEAMING METHODS AND THREADS TO THE BREAKING STRENGTH AND ELONGATION OF SEAMS IN A POLYESTER DOUBLE-KNIT FABRIC

INTRODUCTION

During the last decade there has been a spectacular rise in the quantity of knitted apparel on the market. Knits have entered the realms of high fashion, and the fashion-conscious home sewer has followed the lead of the couturier. Dominated by the polyester fiber and the double-knit structure, knits were considered by American Fabrics to be "hardly a factor" in home sewing just two years ago (48).

Because the rise in the amount of knitted yardage has been so sudden, the home sewer is often faced with sewing on an unfamiliar construction. The discrepancies in the literature complicate her problem, as do the varied construction techniques she may observe on ready-to-wear. She may ponder the merits of the new sewing machines with stitches which their manufacturers advocate for knitted fabrics. She must decide whether to use conventional garment patterns or those designed specifically for knits. That she seeks help in making these decisions is evidenced by the attendance at classes in sewing with knits held in fabric stores, sewing machine centers, and community college adult education programs.

Published research on seams in knitted fabrics is inadequate, particularly for double knits. The present study was undertaken to provide answers to some of the questions commonly raised regarding construction techniques on double-knit fabrics. It is hoped that additional variables will be studied by other researchers and that results will be made available to those in a position to guide the home sewer.

Statement of the Problem

The specific purposes of the research were to determine whether there are significant differences in breaking strength and elongation of:

1. seams stitched with threads of (a) mercerized cotton, (b) core-spun polyester/cotton, and (c) bonded nylon monocord.

2. seams stitched with (a) a zigzag stitch, (b) a straight lockstitch made while stretching the fabric, and (c) an elastic straight stitch.

3. seams stitched (a) parallel to the wales and (b) parallel to the courses.

4. seams stitched with settings of (a) nine stitches per inch, (b) 12 stitches per inch, and (c) 15 stitches per inch.

Hypotheses

The hypotheses tested were:

1. A zigzag stitch will produce seams with greater strength and elongation at break than will either a straight lockstitch made while stretching the fabric or an elastic straight stitch.

2. There will be no significant differences in strength or elongation at break between seams constructed with an elastic straight stitch and those constructed with a straight lockstitch while stretching the fabric.

3. Seams stitched with polyester/cotton core-spun thread will have greater strength and elongation at break than will seams stitched with bonded nylon monocord thread.

4. Seams stitched with bonded nylon monocord thread will have greater strength and elongation at break than will seams stitched with mercerized cotton thread.

5. Seams stitched with shorter stitches will have greater strength and elongation at break than will seams constructed with longer stitches.

6. Seams stitched parallel to the courses will exhibit greater strength and elongation at break than seams stitched parallel to the wales.

Delimitations and Assumptions

The writer felt that the choice of a fabric with a basic knitted structure would yield results with greater possibilities of application than would the use of a more novel structure. Thus, a polyester double-knit fabric in a Ponte di Roma stitch was used for all tests.

Thread size was chosen on the basis of the size which was available in colors in the retail market, since most home sewing is done with colored thread. White thread was used for all final tests to eliminate differences which might result from different dyes and to contrast with the red fabric.

Seams constructed with a zigzag stitch were limited to a single width of stitch.

Stitch length was varied for the straight lockstitch and zigzag stitch, but it was held constant for seams made with the elastic straight stitch because proper stitch formation was possible only at 15 stitches per inch.

The research was based on the assumption that results of seam breaking strength and elongation obtained by laboratory techniques would reflect relative differences in actual use. Although there was no standard procedure designed specifically for seam breaking strength and elongation in knitted fabric, it was assumed that methods designed for use on woven fabrics could be adapted.

Definitions

Cut is the number of needles per inch on certain knitting machinery.

Stitch length setting is the number of stitches per inch when a seam of a given stitch type is made through two plies of fabric in a relaxed state.

Elastic stitch or elastic straight stitch is a triple lockstitch in which the sewing machine takes two stitches forward followed by one stitch back.

Lockstitch refers to the 300 series of stitches in the Federal standards (44). Unless further qualified, lockstitch shall hereafter refer to stitch 301, the most common stitch on home sewing machines.

Zigzag stitch refers to stitch 304 in the Federal standards, in which alternate stitches are to the right and to the left of the center of the line of stitching (44).

Lengthwise specimens are those in which the test seams are parallel to the wales and the long dimension of the specimens.

Widthwise specimens are those in which the test seams are parallel to the courses and the long dimension of the specimens.

REVIEW OF THE LITERATURE

A review of the literature revealed that little research concerning the load-extension behavior of seams has been performed on knitted fabrics. Published reports of the geometry and properties of double-knit fabrics are almost non-existent. Other writers have noted the lack of scientific investigation related to knitted fabrics. Innes stated that, although more people are usually employed in the making-up operations than in knitting the fabrics, few studies had been done on seams in knitted fabrics (27). Grosberg indicated that load-extension behavior had been studied in more detail than any other mechanical property of knitted fabrics, but he also stated:

> However, even this aspect of the mechanics of knitted fabrics has been treated rather sketchily, basically because the geometry of the knitted structure is relatively complex and does not allow of the simple solutions that apply to woven fabrics (24, p. 439).

Double-Knit Fabrics

Construction

Knitted fabrics are constructed in rows of interlocking loops, forming wales and courses. The loops are interlocked in various ways to produce the different knit stitches.

Double-knit fabrics are filling knits made on circular knitting machines, and may be classed as a special variety of rib knits (37). The loops are interlocked in such a manner that the fabric has the appearance of a double-faced plain jersey (38, p. 11). Double-knit fabrics usually are more closely knitted than single knits, with a minimum of 16 needles per inch (37).

Double-knit fabrics are divided into non-jacquard, intermediate jacquard, and rib-jacquard fabrics (37). Ponte di Roma is classified as a non-jacquard structure, along with other common structures such as interlock, single piqué, and double piqué. Interlock is the basic double-knit structure to which the other double-knit fabrics are closely or distantly related (38, p. 11). It is the equivalent of a double 1 x 1 rib fabric (38, p. 12; 20, p. 350).

Properties

Knitted fabrics display wide variations in initial extension and initial modulus (24, p. 439). They exhibit an average modulus which is rather low, but which varies greatly with the direction of pull (13). Extensibility is dependent on the stable shape of the unit cell. The loop configuration of knitted fabrics makes them more elastic than their woven counterparts (13; 20, p. 349; 30; 37). One source compared the knitted loop to a tiny spring which returned to its normal position after each stretch (20, p. 351). This elasticity contributes to the comfort of the wearer (30).

The loop structure tends to make knitted fabrics more resilient than wovens (37). Knitted fabrics will not wrinkle easily, and wrinkles tend to hang out. These properties make knitted garments particularly suitable for travel.

The porosity of knitted fabrics is also a function of the loop construction (37). Knits tend to be relatively porous, allowing air to move rather freely through the fabric.

Properties of a knitted fabric are influenced by the fiber content, as well as the knit configuration. Compared with wool knits, textured polyester double-knit fabrics tend to be more slippery on the cutting table, to snag more readily, and to more easily retain markings from staples or tacks used in laying-up operations (36, 37).

Fletcher and Roberts compared the load-extension behavior of cotton single and double-knit fabrics (21). Their findings revealed that the double-knit fabric neither extended as much under a given load nor exhibited as much growth after removal of the load as the single knit.

An additional advantage of double over single knits is that they do not have the tendency to curl at the edges, simplifying the cutting operation (38).

Importance

Knitted fabrics have gained great popularity during recent years. Between 1962 and 1967 the proportion of apparel made of knits rose from 9 to 35 percent (29). One source estimates that, by 1972, knitted garments will comprise 50 percent of manufactured apparel (19).

Within the knitting industry, the largest growth has been in double knits (22). In 1962, only 33 million yards of double-knit fabrics were produced, but by 1968, the quantity had risen to 160 million yards (41). It is anticipated that double-knit production will reach 300 million yards by 1972.

When double-knit fabrics were first produced, wool was the predominant fiber in this new market, but more recently polyester has taken the lead (19). In 1968, 125 million pounds of fiber went into double-knit production, 40 million pounds of which was polyester. Three-fourths of this polyester was in filament form; the remainder in staple. Together, the two forms of polyester clearly led the nearest competitors in the double-knit market, acetate and acrylic fibers. Forecasts for 1974 give polyester an even greater lead.

Not only are knits a rapidly growing sector of the ready-to-wear market, but they have also made a spectacular appearance on the yardage market. According to American Fabrics, "Today knits are considered the fastest growth sector of the retail fabric market with growth limited only by the availability of the knitting machines" (48). Because the pattern companies are aware of this trend, they are including directions for the use of wide knitted fabric.

The knitted fabrics have brought about the rapid development of stores specializing in knits (48). Companies have been formed which specialize in supplying patterns and findings specifically for knitted fabrics, as well as the fabrics, to knitted fabric retail stores. The popularity of classes in sewing knitwear has been so great that centers have been formed to train instructors in sewing techniques for knitted fabrics.

Sewing Threads

General Requirements

Functional requirements for sewing threads fall into two broad classifications: (1) sewability and (2) serviceability in the seam (4; 8; 31, p. 281).

Sewability. Sewability of a sewing thread has been defined by Kropf as "the ability of a thread to perform efficiently on the sewing machine" (31, p. 281). A thread with good sewability performance is characterized by a balanced stitch, no skipped stitches, and few, if any, thread breaks (8). In the home, a thread with poor sewability becomes an annoyance to the sewer, as well as lowering the quality of the seam. In the apparel industry, the additional factors of costs of labor and overhead place emphasis on sewability.

Abrasion resistance is an important factor in sewability of threads. Bernier states that "'abrasion resistance' includes influences of breaking strength and breaking elongation, along with construction, elastic properties, surface properties, and the effect of the sewability finish" (4).

Serviceability. A sewing thread with good serviceability performance in the seam will fasten securely and permanently, and should remain unchanged by normal methods, temperatures, and numbers of cleanings (4). It should produce a neat seam without seam pucker. If the thread is intended for decorative purposes it should retain such value for the life of the item. In garments, threads are also expected to form seams which achieve desired levels of appearance and comfort. The thread should be resistant to degradation by sunlight and perspiration and should be sufficiently abrasion resistant so that normal wear does not greatly affect seam strength (8).

Adequate stretch of the seam is an important functional requirement on synthetic fabrics, especially in stretch garments (4). Although the type of stitch will influence stretch, threads of synthetic fibers are required for adequate stretch.

Properties

Properties of sewing threads depend upon fiber and yarn properties, although these may be modified in processing (4).

Fiber Properties. The cotton fiber has a tenacity of 3. 0 to 5. 0 grams per denier, and an elongation at break between 5 and 10 percent (11, p. 57).

The tenacity and elongation at break of the polyester fiber can vary greatly, depending upon the amount of drawing (33, p. 344). Higher degrees of drawing result in yarns with higher tenacity and lower elongation than when yarns have been drawn less. Cook places the tenacity and elongation of regular tenacity polyester filament at 4. 5 to 5. 5 grams per denier and 20 to 30 percent (11, p. 281-282). High tenacity polyester has a tenacity of 6. 0 to 7. 0 grams per denier and an elongation of 7 to 15 percent (11, p. 282).

One source indicates that the tenacity of nylon varies from 4. 3 to 8. 8 grams per denier, and the elongation at break ranges from 18 to 45 percent (33, p. 303). A second source distinguishes between regular tenacity and high tenacity nylon, placing tenacity for standard filament nylon at 4. 6 to 5. 8 grams per denier with 26 to 32 percent elongation at break (11, p. 237). Comparable data for high tenacity nylon are tenacity up to 8. 8 grams per denier and elongation of 19 to 24 percent.

From these fiber properties we might expect that, other things being equal, differences in breaking load and elongation between polyester and nylon threads would depend upon the type of each fiber used. Both polyester and nylon threads would be expected to be greater in breaking load and elongation than corresponding cotton threads.

Yarn Properties. In yarns of natural fibers a certain amount of twist is necessary for fibers to cohere (43). In spun yarns tensile strength is dependent upon the amount of friction between fibers and, thus, upon the degree of twist. In yarns of continuous filament fibers twist reduces, rather than increases, tensile strength. However, twist in such yarns is necessary to resist damage from stresses other than tensile stresses.

A single yarn is in balance only in the presence of a tensile stress (43). Under certain conditions the yarn will untwist or snarl. By twisting two or more yarns into a ply, with the twist in the ply in the direction opposite from the original, a structure that is roughly balanced can be achieved.

Synthetic filaments, available in long continuous lengths, can produce threads with few knots or other defects which reduce sewability (4, p. 100).

The plied construction presents problems in sewability when yarns are composed of synthetic filaments (31, p. 284). Although the plied yarn is in balance while the thread is at rest, the helical configuration results in an unbalanced condition when the thread is in motion in the sewing machine. An additional problem associated with the plied construction is its lower resistance to abrasion as compared with some other constructions. Because each of the plies appears on top of the thread, abrasion over a very short distance will cut or greatly weaken all plies. Both of these problems are considerably lessened with the use of bonded monocord synthetic threads.

In the manufacture of bonded monocord threads, a number of parallel filaments are bonded together, with little or no twist in the bundle (31, p. 284). A maximum of three turns per inch is allowed this thread type in the Federal specifications for nylon thread (45). The low twist of the bonded monocord construction results in threads of improved strength by eliminating the problem of the unbalanced condition caused by the helical configuration of plied yarns (31, p. 284). The low twist of bonded monocord thread also produces improved abrasion resistance, because a much greater area must be abraded to cut all filaments than in the conventional plied construction.

The bonding material used to weld the fibers together in bonded monocords is a plastic resin (17, p. 1). While grouping the filaments into a thread, the bonding does not completely restrain the individual filaments, but allows transverse accommodation (4). This effect permits the filaments to conform to the shape of the stitches, reducing the possibility of seam pucker.

In core-spun threads each ply is made of a continuous filament synthetic fiber core which is coated with spun fiber before two or more of these yarns are plied (17, p. 2). The strength and elongation of this type of thread is determined by the properties of the synthetic core (4). The spun covering, usually cotton, adds bulk and helps to protect the synthetic filament from heat. It also contributes to the surface properties of the thread, including its sewability characteristics (8).

Comparisons of Threads. One report indicated that for comparable sizes, loop strength of threads in decreasing order were: nylon filament, polyester filament, polyester/cotton core spun, spun polyester, mercerized cotton, and unmercerized cotton (17, p. 2). This relationship existed for all thread sizes included in the test. A second source indicated that mercerized cotton thread had less than 60 percent of the loop breaking strength of polyester/cotton core-spun thread of equivalent diameter (8).

Flex abrasion resistance of continuous filament nylon thread is about six times as great as that of an equivalent size of polyester/ cotton core-spun thread (17, p. 5). The core-spun thread is, in turn, much more resistant to flex abrasion than mercerized cotton thread.

Threads Recommended for Seaming Knitted Garments

There is obviously no universal thread suitable for seaming all garments. The choice of thread depends upon such factors as fiber content and weight of fabric, the location of the seam, and the anticipated cleaning method (34, p. 682).

One manufacturer recommends either its polyester thread in filament, core, or spun form, or its nylon thread in filament or core form for seaming polyester double-knit fabrics (16, p. 7). A second manufacturer recommends its polyester sewing threads for seaming men's knitted polyester suits on the basis of the higher tensile strength and extensibility, greater dimensional stability, and greater resistance to degradation by perspiration of these threads as compared to cotton (7, p. 3). The recommended threads included both spun polyester and polyester/cotton core spun.

Seams

A properly constructed seam is characterized by strength, elasticity, durability, security, and satisfactory appearance, according to the Federal Standards for Stitches, Seams and Stitchings (44). The standards further indicate that the seam should be as strong, elastic, and durable as the fabric.

Research by Tagawa indicated that the most important factor influencing seam strength was thread strength, though seam type and stitch type were contributing factors (42). He also concluded that seam elongation was dependent upon the elongation of the thread and upon sewing procedures. The source did not indicate whether a woven or a knitted fabric was used in this research.

To the garment maker, the major difference between seaming knitted and woven fabrics is the greater extensibility of the knits (14, p. 1; 15, p. 2). Seams should be at least as extensible as the fabrics on which they are used (7, p. 1; 27). Therefore, selecting seams with sufficient extensibility would seem to be one of the major problems in sewing with knitted fabrics.

Stitch Type and Length

In 1933 Davis reported an investigation of seams stitched with cotton thread on a plain knitted cotton fabric (12). He found that, for seams stitched with comparable stitch lengths, the load required to break the chainstitch was considerably greater than that required to break the lockstitch. Elongation at break was also greater for chain-stitched than for lockstitched seams, though not as markedly. Seams stitched with two-thread and three-thread overlock stitches had considerably greater breaking strength and elongation than either chain-stitched or lockstitched seams. He concluded that the lockstitch was entirely unsuitable for seaming selvaged knitted fabrics.

Davis also found that, for both the lockstitch and the chainstitch, increased stitch density was associated with decreased breaking load. With the lockstitch, elongation at break increased between 12 and 18 stitches per inch, but decreased greatly between 18 and 20 stitches per inch.

Commercial Methods. Most authorities recommending seaming methods to manufacturers of knitted apparel concur with Davis in recommending some form of chainstitch or overlock stitch.

In an article on seaming knitted fabrics, Atkinson emphasizes the greater extensibility of the two-thread chainstitch and the overlock stitches as compared with the lockstitch (2). P. J. Kennedy recommends a two-thread chainstitch or three-thread overedge stitch for seaming polyester double knits on the basis of the extensibility of these seams (28). He suggests that the lockstitch be used only on fabrics with little stretch or in locations where stretch is limited, such as zipper applications. He recommends 12 to 18 stitches per inch.

A Du Pont publication recommends the chainstitch for seaming men's polyester or polyester-blend double-knit apparel (16, p. 5). The superiority of the chainstitch is attributed to the stitch configuration and the amount of thread which enters each stitch. Recommended stitch length is 14 to 16 stitches per inch. If a test seam fails when extended to a maximum, the number of stitches per inch should be increased. The lockstitch is suggested only for knitted fabric with little stretch or for taped seams. A minimum of 10 stitches per inch is recommended when seams are constructed with the lockstitch. If a chainstitch is not available for the inseam of trousers, 14 or more stitches per inch should be used with the lockstitch (16, p. 10).

A Celanese publication recommends the use of the chainstitch for tailored double-knit garments, particularly for the trouser inseam (9). The publication also recommends 8 to 10 stitches per inch for inside seams, 10 to 14 stitches per inch for outside seams, and 6 to 7 stitches per inch when the serging stitch is used. A second publication from this company states that stitch length should be no longer than 14 stitches per inch, and under some circumstances it may need to be 18 to 20 stitches per inch, for seams in men's polyester knit suits (7, p. 5). The shorter stitches may be necessary on very extensible fabrics. According to this source, stretching of the fabric during seaming should be avoided (7, p. 4).

Solinger states that the regular lockstitch is less desirable than either the one- or two-thread chainstitch for any application where the seam is subjected to high tensile strain with little fabric support (40, p. 710). He also indicates that the standard zigzag stitch is more elastic than either the one- or two-thread chainstitch, with the degree of elasticity dependent upon the length-width ratio of the stitch. The overedge or serging stitches have extensibilities which are equal to or exceed that of the regular zigzag stitch (40, p. 711). The overedge class of stitches is used most frequently on knitted fabrics because the seam elasticity can match that of the fabric.

Home Methods. Literature recommending home methods of seaming knitted fabrics generally suggests methods other than the chainstitch or overedge, since these stitches are not available to most home sewers. Barrier and Miller imply the use of a lockstitch, but suggest that a fine zigzag may also be used (3). They recommend 16 stitches per inch. A Coats and Clark publication also implies a lockstitch in recommending 12 stitches per inch except in areas of strain, where 15 stitches per inch are suggested (10, p. 5).

A Simplicity publication recommends 12 to 15 regular lockstitch or small zigzag stitches per inch (39). According to Vogue Pattern Book International, the seam should be stretched slightly while stitching 12 to 15 straight or slightly zigzag lockstitches per inch (26). An alternative is to use one of the stretch stitches available by means of some of the newer machines.

According to Ann Person, knits should be stitched with a lockstitch while stretching the seam (35, p. 2). The amount of stretch depends upon the fabric and the required extensibility of each seam. She suggests that most knits be seamed with two rows of stitching one-eighth inch apart, with the seam allowance one-fourth inch in width. On double knits, however, a single row of stitching with the regular seam allowance may be used.

For general knitwear seaming, Black suggests the use of the so-called "overlock" stitch available on some home sewing machines (5, p. 3). When this stitch is not available, she recommends two rows of regular lockstitching spaced one-fourth inch apart, with the stitch length set at 12 stitches per inch (5, p. 2). Black suggests other methods for specific applications. For skirt side seams on firm knits including double knits, she recommends a single row of stitching with the seam five-eighths inch from the cut edge (5, p. 5). For the folded edge at the top of an elastic-band skirt, she suggests stretching the fabric while stitching with the lockstitch, using a slight zigzag, or stitching with one of the special stretch stitches (5, p. 6).

Cameron recommends the lockstitch for seaming double knits, but suggests that the stitch be lengthened slightly (6, p. 18). "In fact," she states, "most home craftsmen have a tendency to sew with too short a stitch."

Adjustment and Condition of the Sewing Machine

For proper stitch formation, upper and lower thread tensions must be balanced. Research by Davis showed that unbalanced stitches had considerably less strength than properly balanced stitches, a result of a greater strain falling on one thread than the other (12).

There is general agreement in the literature that, in seaming knitted fabrics, thread tensions should be kept to the minimum which will form secure stitches (7, p. 1; 9; 16, p. 5; 28). The results of Nemeth's research on polyester sewing threads indicates that breaking strength and elongation both decrease when high sewing tensions are used (18).

Solinger states that the elasticity of the lockstitch varies inversely with the tension (40, p. 710). Since each thread has some degree of elasticity, the more thread that enters each stitch, the greater the elasticity of the stitch. When tension is decreased elasticity and the possibility of seam slippage increase.

In sewing fabrics containing synthetic fibers on a lockstitch machine, the tension on the upper thread should be approximately 150 grams (40, p. 681). This approximate tension can be obtained by loosening the bobbin tension until the bobbin and bobbin case barely glide down the thread when suspended by the thread alone. The upper thread tension is then adjusted to balance the lower. This method is also advocated for use in sewing knitted fabrics of any fiber content and for applications which require the use of synthetic threads (4; 14, p. 2; 16, p. 6; 46, p. 32). One source stated that the bobbin and case unit should almost, but not quite, glide down the thread under its own weight (7, p. 4).

In seaming knitted fabrics, pressure on the pressure foot must be kept at a minimum to prevent differential feeding of the plies (7, p. 5; 9; 10, p. 5; 16, p. 6; 26; 28, p. 61). An additional reason for the low pressure is to reduce abrasion caused by the feed dog (16, p. 6).

A single point on a thread may pass through the machine needle up to 50 times (23, p. 113). Thus, it seems apparent that the needle and other machine parts which come in contact with the thread must be smooth and free from sharp edges. This is especially important in using synthetic threads, since they are much more susceptible to shearing from sharp edges than is cotton thread (46, p. 30-32).

Machine adjustments are more critical for synthetic than for cotton threads. Since synthetic threads tend to form smaller loops, the hook should be set more closely than for cotton thread (46, p. 32). Adjustment of the check spring is also more critical.

METHODS AND MATERIALS

Wherever standard procedures existed, thread, fabric, and seam properties were measured in accordance with the standards established by the American Society for Testing and Materials (hereafter referred to as A. S. T. M.). Specimens were brought to moisture equilibrium in the standard atmosphere for testing textiles of 70° ± 2° F. at 65 ± 2 percent relative humidity and tested under those conditions, unless stated otherwise.

Selection and Description of Fabric and Threads

A knitted fabric of 100 percent polyester was chosen for the experiments. According to a representative of the manufacturer, yarns used in the manufacture of the fabric were 150 denier, 34 filament polyester (25). They were knit in a Ponte di Roma stitch on an 18-cut double-knit machine.

The selection of threads was based on the results of a preliminary investigation. As many brands as could be found on the local market were purchased, and relative differences in breaking load and elongation were determined. The brand of thread with the highest mean breaking load and elongation within a given thread type was chosen to represent that type in the final tests.

Two 325-yard spools of mercerized cotton, two 200-yard spools of nylon, and three 100-yard spools of polyester/cotton core-spun thread were purchased on the open market. Labels on the spools indicated that the threads were the following sizes: mercerized cotton, size 50; polyester/cotton core-spun, size 60; and nylon, size A. The mercerized cotton and polyester/cotton threads contained three plies; the nylon thread was a bonded monocord based on multifilament yarn.

Each spool of a given thread type was purchased at a different store to increase the chance that no two spools represented the same lot. White thread was selected for the final tests because it contrasted with the red fabric sufficiently so that seam breaks were more easily detected.

Thread Properties

Twist, breaking load, and breaking elongation of sewing threads were determined according to methods described in A. S. T. M. procedure D 204-57T (1, p. 64-72). A t-test was done to identify significant differences between thread types for each property.

Twist

Twist was determined on a standard twist tester with clamps set ten inches apart. On the plies, a tension was applied through a ten-gram weight on the non-rotating clamp, and the twist was determined through a direct count. Two plies were then snipped away, and the twist of the remaining single yarn was determined by the standard deflection method. The yarn was adjusted between the clamps so that a deflection of 0.125 inch was obtained when a load of three grams was applied in the center. The twist was removed and reinserted in the opposite direction through the rotatable clamp until a deflection of 0.125 inch was again obtained. Twist was read from the counter and calculated in turns per inch.

Counts were made on twenty specimens for each of the mercerized cotton and polyester/cotton core-spun thread types. The number of specimens from each spool was proportional to the number of seams stitched from that spool. Bonding prevented determination of twist in the nylon thread.

Breaking Load and Elongation

Breaking load and elongation of the sewing threads were determined on a constant-rate-of-load machine with a 2000-gram capacity. Clamps were set ten inches apart. Specimens were drawn directly from the spool and inserted between the clamps with a uniform amount of tension. Twenty specimens of each thread type were tested, with the number taken from each spool proportionate to the number of seams stitched from that spool. Breaking load and elongation were recorded on an automatic recording chart and read to the nearest ten grams and 0.05 inch, respectively.

Fabric Properties

Fabric properties were measured according to the procedures established in A.S.T.M. procedure D 231-62, Standard Methods of Testing and Tolerances for Knit Goods (1, p. 76-78). Width was determined under prevailing atmospheric conditions. Wale and course counts and weight of conditioned specimens were determined in the standard atmosphere.

Width

The fabric was laid on a smooth, horizontal surface without tension, and allowed to relax for 24 hours. This procedure was based on a recommendation in the literature that a relaxation period be allowed to relieve uneven tensions (15, 36, 37). Five measurements of width were taken with a yardstick and recorded to the nearest 1/16 inch. Measurements were taken in the center and in two-yard intervals from the center.

Wale and Course Count

The number of wales and courses in distances of two inches were counted in five places with the aid of a thread counter. Mean wale and course counts per inch were calculated.

Weight

Ten specimens, each measuring two inches square, were cut out by means of a die. The areas from which the specimens were taken were distributed throughout the length and width of the fabric. The ten specimens were weighed collectively to the nearest 0.001 gram, and the weight per square yard was calculated and reported in ounces.

Seam Properties

Seam breaking strength and elongation were determined from lengthwise and widthwise specimens with seams constructed of selected thread types, stitch types, and stitch lengths. Methods were adapted from A.S.T.M. procedure D 1683-68, Seam Breaking Strength of Woven Textile Fabrics, since there was no standard procedure for seams in knitted fabrics (1, p. 371-375).

Preliminary Investigations

Preliminary investigations were undertaken to determine methods of preparing and testing seam specimens and to determine which variable should be included in the final study.

Specimens with seams at five different angles with respect to the wales and courses were tested, but it was felt that the exact point of break on bias specimens was too difficult to determine to yield accurate results. Therefore, only specimens with seams parallel to the wales and to the courses were included in the final study.

It was determined that to prevent jaw breaks the direction of load should be parallel, rather than perpendicular, to the seam. Size of the jaw faces, method of pressing seams, size and type of sewing machine needle, and number of specimens were also determined on the basis of preliminary tests.

Sampling

The fabric was laid on a smooth surface without tension and allowed to relax for 24 hours before cutting. After the fabric was divided into five blocks, each block was further divided into lengthwise- and widthwise-specimen areas. Correction was made for skew between the two areas of the block to increase the degree to which the direction of test paralleled the wales or courses. No correction was made for bow.

Two replicates of each combination of variables were cut from each block, producing a total of ten replicates. No more than one lengthwise replicate nor more than two widthwise replicates were cut on the same wales, and no two replicates were cut on the same courses. With these exceptions, specimens within each block were randomly arranged. No specimen was cut nearer the edge than one-tenth the width of the fabric. Specimens were coded for thread type, stitch type, and stitch length.

Each specimen was cut to measure 8 ± 0.1 inches in length and 5.25 ± 0.1 inches in width. Before seaming, specimens were cut in half lengthwise and the two sections placed in the same relative position as they were before cutting. After seaming, the specimens measured the recommended four inches in width.

Seaming

Seam specimens were stitched with a zigzag home sewing machine.[1] A size 14 needle and a zigzag presser foot and throat plate were used for all seams. Pressure on the presser foot was set at the minimum.

The lower tension was adjusted so that when a full bobbin was placed in its case and the unit held by the thread, it required only a slight jar to make the unit ride down the thread.

Upper tension was adjusted to balance the lower. A balanced tension was determined by an adaptation of the measurement of thread crimp method described by Whitlock, et al. (47, p. 44). A seam was stitched through two plies of the knit fabric. A cut was made through the fabric and threads near one end of the stitching, and a mark was made on the stitching line three inches from the cut. The stitching

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[1] A Viking model 6010 sewing machine was used for all stitching.

was carefully removed up to the mark, and the upper and lower threads smoothed out between the thumb and forefinger perpendicular to the row of stitching. When the length of the threads differed by no more than one-eighth inch, the tension was considered balanced. Tension was adjusted at twelve lockstitches per inch and re-adjusted for each change in thread type.

Stitch length was adjusted by stitching through two plies of the knit fabric with the fabric relaxed. The adjustment was made until three one-inch counts taken one inch apart were each within one-half stitch from the desired number. The stitch length setting was re-adjusted for each change in stitch type or stitch length desired.

Ten replicates were made of each combination of fabric direction, thread type, stitch type, and stitch length. Within each group of replicates approximately equal numbers of specimens were stitched from each spool of a given kind of thread.

Seams were stitched 5/8 inch from the cut edge at stitch length settings of 9, 12, and 15 stitches per inch for the lockstitch and zigzag stitch, and at 15 stitches per inch for the elastic straight stitch.

Seams stitched with the zigzag and elastic stitches were guided gently through the machine without placing the fabric under tension. Seams stitched with the lockstitch were given considerable stretch by stretching them approximately three-fourths of the amount possible to stretch them without mechanical assistance. This resulted in actual stitch lengths shorter than is indicated by the stitch length settings.

The zigzag stitch was adjusted for a narrow width. The setting on the machine was placed at 0.75, producing a stitch about 1/32 inch wide.

Occasional skipped stitches occurred with nylon thread, particularly with the zigzag stitch. Although adjustments improved the stitching slightly, they did not eliminate skipped stitches, and many of the seams stitched with nylon thread included at least one skipped stitch. Not all skipped stitches, however, were in the three-inch portion of the seam to be tested.

Pressing

Each seam was pressed open for five seconds with a dry iron at a temperature between 300° and 350° F., as indicated by Tempilsticks which melt at those temperatures.

Seam Breaking Strength and Elongation

Specimens were conditioned and tested in the standard atmosphere. A line was drawn on each specimen 1/2 inch from the seam and parallel to it. A second line was drawn perpendicular to the seam and 1 1/2 inches from the upper edge. These lines were used in aligning the seams squarely in the jaws of the testing equipment.

Seam breaking strength and elongation were tested on a constant-rate-of-traverse machine. Maximum capacity was 100 pounds except that specimens stitched with the elastic stitch and nylon and polyester/cotton core-spun threads were tested at a maximum capacity of 400 pounds. The front jaw face measured one inch square; the back one measured two inches in the direction of load and three inches perpendicular to direction of load. Clamps were set three inches apart. A weight was attached to the lower end of the specimens to remove slack before the lower jaw was tightened. The weight for pre-tensioning was based on the A. S. T. M. recommendation of approximately 0. 5 percent of the breaking load (1, p. 365). The anticipated low breaking load of eight pounds was used in determining the pre-tensioning load of 22. 1 grams, which was used for all specimens.

Breaking strength and elongation were recorded on an automatic recording chart. Strength was read to the nearest pound; elongation to the nearest 0. 1 inch. Seam rupture was caused by the breakage of the sewing thread in all cases included in the analysis. If the point of break was questionable the specimen was discarded. Therefore, a good many means were based on fewer than ten specimens. The exact point of seam break was questionable for many specimens with high breaking strength, resulting in fewer acceptable specimens from such sets than from those with lower breaking strength. The number of specimens of each set included in the statistical analysis is listed in the Appendix.

Three sets of specimens were completely eliminated from statistical analysis because they contained specimens which had not broken when removed from the testing equipment. Inclusion of the specimens remaining from those sets in the analysis would have produced biased results.

Statistical Analysis

An analysis of variance for the entire sample was performed by computer, but because of uneven sample size, only treatment means and mean square for error were used in comparing sets of samples. The least significant difference between treatments was calculated for each comparison at the 0.05 and 0.01 levels of significance, based on the sample size of the respective treatments.

RESULTS

Properties of Sewing Threads

Twist per inch was significantly higher in the polyester/cotton core-spun thread than in the mercerized cotton thread (Table 1). This difference was observed in both the singles and the plies. Mean twist of the polyester/cotton singles was 25.7 per inch, compared with 22.5 turns per inch for the mercerized cotton thread. Mean twist per inch in the plies was 22.1 for polyester/cotton thread and 19.2 for mercerized cotton.

Table 1. Properties of Sewing Threads

Thread	Mean twist per inch (number) Plies		Mean twist per inch (number) Singles		Mean breaking load (grams)			Mean elongation at break (percent)		
Mercerized cotton	19.2		22.5		1134			5.0		
						***			***	
Nylon	-	***	-	***	923		***	17.8		***
						***			n. s.	
Polyester/cotton	22.1		25.7		1514			19.0		

*** Significant at the 0.005 level.
n. s. Not significant.

There was a considerable difference in breaking load between the three threads tested (Table 1). The polyester/cotton core-spun thread had a significantly higher mean breaking load than the mercerized cotton thread, although the polyester/cotton was sold as size 60 and the mercerized cotton as size 50. The polyester filaments within each ply undoubtedly contributed the additional strength. Polyester/cotton and mercerized cotton threads both exhibited significantly greater mean breaking load than the nylon thread. The low strength of the nylon thread, sold as size A, might be partially attributed to its finer diameter. The construction of the bonded thread, with its characteristic low twist and monocord nature, may also have contributed to its low strength.

Both nylon and polyester/cotton threads exhibited considerably more elongation at break than the mercerized cotton thread (Table 1). This might be anticipated because of the inherent properties of the fibers. Differences in elongation at break between polyester/cotton thread and nylon thread were not significant.

Properties of the Fabric

The mean width of the fabric was 65. 6 inches. Bow was 1. 1 percent and skew 2. 3 percent. Most of the skew appeared to be present on only half of the width. The fabric had 26 wales and 25 courses per inch. The weight of the fabric was 7. 06 ounces per square yard.

Properties of Seams

Effects of Thread

Seam Breaking Strength. A high relationship existed between the choice of thread and strength of seams. In the majority of cases the use of polyester/cotton thread resulted in stronger seams than use of nylon thread, and seams stitched with nylon thread were generally stronger than those stitched with mercerized cotton (Table 2).

The mean seam breaking strength was significantly greater for seams stitched with polyester/cotton thread than for corresponding seams stitched with mercerized cotton thread. Seams stitched with nylon thread had a higher mean breaking strength than the corresponding seams stitched with mercerized cotton thread. These differences were significant in all but three cases. The mean seam breaking strength was greater for specimens stitched with polyester/cotton thread than for corresponding seams stitched with nylon thread except for widthwise specimens stitched with 9 straight or 15 elastic stitches per inch. These differences were significant in all but two cases.

The difference in strength between seams of mercerized cotton and polyester/cotton threads might have been anticipated from the higher single strand breaking load of the latter. Seam strengths of mercerized cotton and nylon threads, however, were inversely related to their respective sewing thread breaking loads. In fabrics which

Table 2. Seam Breaking Strength According to Type of Thread

Seaming Variables			Mean seam breaking strength (pounds)			Mean difference in breaking strength (pounds)		
Stitch type	Stitches per inch (number)	Direction of seam	C[a]	N	P	C vs N	C vs P	N vs P
Zigzag	9	lengthwise	7.3	8.4	14.5	1.1	7.2**	6.1*
		widthwise	7.7	9.9	14.8	2.2	7.1**	4.9
	12	lengthwise	11.3	14.4	19.2	3.1	7.9**	4.8
		widthwise	13.4	21.2	27.0	7.8**	13.6**	5.8*
	15	lengthwise	13.2	22.0	36.0	8.8**	22.8**	14.0**
		widthwise	12.0	35.6	54.4	23.6**	42.4**	18.8**
Lockstitch	9	lengthwise	11.2	22.0	32.7	10.8**	21.5**	10.7**
		widthwise	12.9	32.3	31.2	19.4**	18.3**	1.1
	12	lengthwise	12.4	26.6	44.3	14.2**	31.9**	17.7**
		widthwise	15.1	-	53.3	-	38.2**	-
	15	lengthwise	12.1	23.9	-	11.8**	-	-
		widthwise	18.7	32.8	-	14.1**	-	-
Elastic	15	lengthwise	33.6	66.0	81.3	32.4**	47.7**	15.3**
		widthwise	45.0	108.7	105.6	63.7**	60.6**	3.1

* Significant at the 0.05 level.
** Significant at the 0.01 level.
a C, N, and P indicate mercerized cotton, bonded nylon, and polyester/cotton core-spun threads.

exhibit a high degree of stretch, such as the knit in this study, thread elongation may be of greater importance to seam strength than thread breaking load. Loop strength of the sewing threads might have been a better indicator of seam strength than the single strand breaking load of thread used in this study.

Seam Elongation at Break. Differences in elongation at break of seams according to thread were similar to differences in mean seam breaking strength (Table 3). In general, seams stitched with polyester/ cotton thread had the greatest mean elongation at break, followed by seams stitched with nylon thread. Seams stitched with mercerized cotton thread had the lowest elongation at break. Similar differences in elongation between threads occurred in single strand sewing thread tests, although the difference in elongation between threads of polyester/cotton and nylon were not significant.

Seams stitched with polyester/cotton or nylon thread had significantly greater mean elongation at break than corresponding seams stitched with mercerized cotton. Most of these differences were significant at the 0.01 level.

Mean elongation at break was significantly greater for seams stitched with polyester/cotton thread than for those stitched with nylon thread in all cases except widthwise specimens stitched with 9 lock-stitches or 15 elastic stitches per inch.

Table 3. Seam Elongation at Break According to Type of Thread

Seaming variables			Mean elongation at break (inches)			Mean difference in elongation (inches)		
Stitch type	Stitches per inch (number)	Direction of seam	C[a]	N	P	C vs N	C vs P	N vs P
Zigzag	9	lengthwise	1.14	1.32	1.76	0.18*	0.62**	0.44**
		widthwise	1.19	1.44	1.68	.25**	.49**	.24**
	12	lengthwise	1.63	1.84	2.08	.21*	.45**	.24**
		widthwise	1.71	2.07	2.25	.36**	.54**	.18*
	15	lengthwise	1.80	2.26	2.69	.46**	.89**	.43**
		widthwise	1.65	2.48	2.80	.83**	1.15**	.32**
Lockstitch	9	lengthwise	1.53	2.20	2.38	.67**	.85**	.18*
		widthwise	1.65	2.39	2.27	.74**	.62**	.12
	12	lengthwise	1.66	2.30	2.75	.64**	1.09**	.45**
		widthwise	1.71	-	2.66	-	.95**	-
	15	lengthwise	1.67	2.20	-	.53**	-	-
		widthwise	1.96	2.33	-	.37**	-	-
Elastic	15	lengthwise	2.54	3.07	3.40	.53**	.86**	.33*
		widthwise	2.55	3.57	3.56	1.02**	1.01**	.01

* Significant at the 0.05 level.
** Significant at the 0.01 level.
a C, N, and P indicate mercerized cotton, bonded nylon, and polyester/cotton core-spun threads.

Effects of Stitch Type

Seam Breaking Strength. In general, seams stitched with the elastic stitch were the strongest, and the lockstitch with stretch produced stronger seams than did the zigzag stitch.

With settings of 15 stitches per inch, the elastic straight stitch produced seams with significantly greater breaking strength than did either the lockstitch or the zigzag stitch (Table 4).

Seams constructed with the lockstitch had significantly greater breaking strength than seams with the zigzag stitch when stitched with polyester/cotton thread at settings of 9 or 12 stitches per inch. With nylon thread, the lockstitch was significantly stronger than the zigzag at settings of 9 and 12 stitches per inch but not at 15 stitches per inch. With cotton thread the lockstitch was significantly stronger than the zigzag only for widthwise seams stitched with 15 stitches per inch.

Seam Elongation at Break. Significant differences in mean elongation at break for the three stitch types corresponded with the significant differences in mean seam breaking strength, except that elongation was also significantly greater for lockstitched than for zigzag seams stitched with cotton thread at nine stitches per inch (Table 5). Therefore, the breaking strength of the seams according to stitch type was directly related to elongation at break, high breaking strength being associated with high elongation at break.

Table 4. Seam Breaking Strength According to Type of Stitch

Seaming variables			Mean seam breaking strength (pounds)			Mean difference in breaking strength (pounds)		
Thread type	Stitches per inch (number)	Direction of seam	Z[a]	L	E	Z vs L	Z vs E	L vs E
Mercerized cotton	9	Lengthwise	7.3	11.2	-	3.9	-	-
		Widthwise	7.7	12.9	-	5.2	-	-
	12	Lengthwise	11.3	12.4	-	1.1	-	-
		Widthwise	13.4	15.1	-	1.7	-	-
	15	Lengthwise	13.2	12.1	33.6	1.1	20.4**	21.5**
		Widthwise	12.0	18.7	45.0	6.7**	32.0**	26.3**
Nylon	9	Lengthwise	8.4	22.0	-	13.6**	-	-
		Widthwise	9.9	32.3	-	22.4**	-	-
	12	Lengthwise	14.4	26.6	-	12.2**	-	-
		Widthwise	-	-	-	-	-	-
	15	Lengthwise	22.0	23.9	66.0	1.9	44.0**	42.1**
		Widthwise	35.6	32.8	108.7	2.8	73.1**	75.9**
Polyester/ cotton	9	Lengthwise	14.5	32.7	-	18.2**	-	-
		Widthwise	14.8	31.2	-	16.4**	-	-
	12	Lengthwise	19.2	44.3	-	25.1**	-	-
		Widthwise	27.0	53.3	-	26.3**	-	-
	15	Lengthwise	36.0	-	81.3	-	45.3**	-
		Widthwise	54.4	-	105.6	-	51.2**	-

** Significant at the 0.01 level.
a Z, L, and E indicate zigzag, lockstitch, and elastic stitches.

Table 5. Seam Elongation at Break According to Type of Stitch

Seaming variables			Mean elongation at break (inches)			Mean difference in elongation (inches)		
Thread type	Stitches per inch (number)	Direction of seam	Z[a]	L	E	Z vs L	Z vs E	L vs E
Mercerized cotton	9	Lengthwise	1.14	1.53	-	0.39*	-	-
		Widthwise	1.19	1.65	-	.46**	-	-
	12	Lengthwise	1.63	1.66	-	.03	-	-
		Widthwise	1.71	1.78	-	.07	-	-
	15	Lengthwise	1.80	1.67	2.54	.13	0.74**	0.87**
		Widthwise	1.65	1.96	2.55	.31**	.90**	.59**
Nylon	9	Lengthwise	1.32	2.20	-	.88**	-	-
		Widthwise	1.44	2.39	-	.95**	-	-
	12	Lengthwise	1.84	2.30	-	.46**	-	-
		Widthwise	2.07	-	-	-	-	-
	15	Lengthwise	2.26	2.20	3.07	.06	.81**	.87**
		Widthwise	2.48	2.33	3.57	.15	1.09**	1.24**
Polyester/ cotton	9	Lengthwise	1.76	2.38	-	.62**	-	-
		Widthwise	1.68	2.27	-	.59**	-	-
	12	Lengthwise	2.08	2.75	-	.67**	-	-
		Widthwise	2.25	2.66	-	.41**	-	-
	15	Lengthwise	2.69	-	3.40	-	.71**	-
		Widthwise	2.80	-	3.56	-	.76**	-

* Significant at the 0.05 level.
** Significant at the 0.01 level.
a Z, L, and E indicate zigzag, lockstitch, and elastic stitches.

Effects of Stitch Length

Seam Breaking Strength. Seam breaking strength was more closely related to stitch length for seams stitched with a zigzag than for those seamed with a lockstitch.

Fifteen zigzag stitches per inch produced seams with a significantly greater mean seam breaking strength than nine zigzag stitches per inch for all corresponding sets of specimens except widthwise specimens stitched with cotton thread (Table 6).

With polyester/cotton and nylon threads, 15 zigzag stitches per inch produced significantly stronger seams than corresponding seams with 12 zigzag stitches per inch, but differences were not significant when mercerized cotton thread was used.

A greater mean seam breaking strength resulted from seams stitched with 12 than with 9 zigzag stitches per inch for all corresponding sets of specimens. These differences were significant for all widthwise specimens and for lengthwise specimens stitched with nylon thread.

Twelve lockstitches per inch produced seams with a significantly greater mean seam breaking strength than nine lockstitches per inch when stitched with polyester/cotton thread.

Only for widthwise specimens stitched with mercerized cotton thread did 15 lockstitches per inch produce seams with a significantly

Table 6. Seam Breaking Strength According to Length of Stitch

Seaming variables			Mean seam breaking strength (pounds)			Mean difference in breaking strength (pounds)		
Stitch type	Thread	Direction of seam	9 stitches per inch	12 stitches per inch	15 stitches per inch	9 vs 12 stitches per inch	9 vs 15 stitches per inch	12 vs 15 stitches per inch
Zigzag	Mercerized cotton	Lengthwise	7.3	11.3	13.2	4.0	5.9*	1.9
		Widthwise	7.7	13.4	12.0	5.7*	4.3	1.4
	Nylon	Lengthwise	8.4	14.4	22.0	6.0*	13.6**	7.6*
		Widthwise	9.9	21.2	35.6	11.3**	25.7**	14.4**
	Polyester/cotton	Lengthwise	14.5	19.2	36.0	4.7	21.5**	16.8**
		Widthwise	14.8	27.0	54.4	12.2**	39.6**	27.4**
Lockstitch	Mercerized cotton	Lengthwise	11.2	12.4	12.1	1.2	0.9	0.3
		Widthwise	12.9	15.1	18.7	2.2	5.8*	3.6
	Nylon	Lengthwise	22.0	26.6	23.9	4.6	1.9	2.7
		Widthwise	32.3	-	32.8	-	0.5	-
	Polyester/cotton	Lengthwise	32.7	44.3	-	11.6**	-	-
		Widthwise	31.2	53.3	-	22.1**	-	-

* Significant at the 0.05 level.
** Significant at the 0.01 level.

greater mean seam breaking strength than nine lockstitches per inch. Differences in strength between seams constructed with 12 and 15 lockstitches per inch were not significant.

Seam Elongation at Break. Differences in stitch length were associated with a greater number of significant differences in elongation for zigzag than for lockstitched seams. A similar result was observed for seam breaking strength.

With only one exception, the mean elongation at break increased with an increasing number of zigzag stitches per inch (Table 7).

There were few significant differences in the elongation at break of seams with lockstitching. With polyester/cotton thread, a significantly greater mean elongation resulted with 12 than with 9 lockstitches per inch. Widthwise seams stitched with cotton thread showed a significantly greater elongation at 15 than at either 9 or 12 lockstitches per inch.

Effects of Direction of Seam with Respect to Wales and Courses

Seam Breaking Strength. Mean breaking strength was greater for widthwise seams than for corresponding lengthwise seams for all except two sets of specimens (Table 8). These differences were significant in 11 of the 19 comparisons.

Widthwise seams were significantly stronger than corresponding lengthwise seams stitched with nylon thread except those stitched

Table 7. Seam Elongation at Break According to Length of Stitch

Seaming variables			Mean elongation at break (inches)			Mean difference in elongation (inches)		
Stitch type	Thread	Direction of seam	9 stitches per inch	12 stitches per inch	15 stitches per inch	9 vs 12 stitches per inch	9 vs 15 stitches per inch	12 vs 15 stitches per inch
Zigzag	Mercerized cotton	Lengthwise	1.14	1.63	1.80	0.49**	0.66*	0.17*
		Widthwise	1.19	1.71	1.65	.52**	.46**	.06
	Nylon	Lengthwise	1.32	1.84	2.26	.52**	.94**	.42**
		Widthwise	1.44	2.07	2.48	.63**	1.04**	.39**
	Polyester/ cotton	Lengthwise	1.76	2.08	2.69	.32**	.93**	.61**
		Widthwise	1.68	2.25	2.80	.57**	1.12**	.55**
Lockstitch	Mercerized cotton	Lengthwise	1.53	1.66	1.67	.13	.14	.01
		Widthwise	1.65	1.78	1.96	.13	.31**	.18*
	Nylon	Lengthwise	2.20	2.30	2.20	.10	.00	.10
		Widthwise	2.39	-	2.33	-	.06	-
	Polyester/ cotton	Lengthwise	2.38	2.75	-	.37**	-	-
		Widthwise	2.27	2.66	-	.39**	-	-

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 8. Seam Breaking Strength According to Direction of Seam with Respect to Wales and Courses

Seaming variables			Mean seam breaking strength (pounds)		
Thread	Stitch type	Stitches per inch (number)	Lengthwise seams	Widthwise seams	Mean difference in breaking strength (pounds)
Mercerized cotton	Zigzag	9	7.3	7.7	0.4
		12	11.3	13.4	2.1
		15	13.2	12.0	1.2
	Lockstitch	9	11.2	12.0	.7
		12	12.4	15.1	2.7
		15	12.1	18.7	6.6*
	Elastic	15	33.6	45.0	11.4*
Nylon	Zigzag	9	8.4	9.9	1.5
		12	14.4	21.2	6.8*
		15	22.0	35.6	13.6**
	Lockstitch	9	22.0	32.3	10.3**
		12	26.6	-	-
		15	23.9	32.8	8.9**
	Elastic	15	66.0	108.7	42.7**
Polyester/ cotton	Zigzag	9	14.5	14.8	.3
		12	19.2	27.0	7.8**
		15	36.0	54.5	18.4**
	Lockstitch	9	32.7	31.2	1.5
		12	44.3	53.3	9.0**
		15	-	-	-
	Elastic	15	81.3	105.6	24.3**

* Significant at the 0.05 level.
** Significant at the 0.01 level.

with nine zigzag stitches per inch. With polyester/cotton thread, differences were significant for corresponding seams except those stitched with nine lockstitches or zigzag stitches per inch. Differences in strength were significant for seams stitched with cotton thread only with 15 lockstitches or elastic stitches per inch.

Seam Elongation at Break. The mean elongation at break was greater for widthwise than for lengthwise seams in 15 of the 19 comparisons (Table 9). In six cases these differences were statistically significant. The majority of significant differences occurred when seams were stitched with nylon thread.

Table 9. Seam Elongation at Break According to Direction of Seam with Respect to Wales and Courses

Seaming variables			Mean elongation at break (inches)		
Thread	Stitch type	Stitches per inch (number)	Lengthwise seams	Widthwise seams	Mean difference in elongation (inches)
Mercerized cotton	Zigzag	9	1.14	1.19	0.05
		12	1.63	1.71	.08
		15	1.80	1.65	.15
	Lockstitch	9	1.53	1.65	.12
		12	1.66	1.78	.12
		15	1.67	1.96	.29**
	Elastic	15	2.54	2.55	.01
Nylon	Zigzag	9	1.32	1.44	.12
		12	1.84	2.07	.23**
		15	2.26	2.48	.22*
	Lockstitch	9	2.20	2.39	.19*
		12	2.30	-	-
		15	2.20	2.33	.13
	Elastic	15	3.07	3.57	.50**
Polyester/ cotton	Zigzag	9	1.76	1.68	.08
		12	2.08	2.25	.17*
		15	2.69	2.80	.11
	Lockstitch	9	2.38	2.27	.11
		12	2.75	2.66	.09
		15	-	-	-
	Elastic	15	3.40	3.56	.16

* Significant at the 0.05 level.
** Significant at the 0.01 level.

CONCLUSIONS AND RECOMMENDATIONS

The major purposes of the research were to determine how breaking strength and elongation of seams in a polyester double knit fabric were affected by the choice of sewing thread, stitch type, stitch length, and direction of the seams with respect to the wales.

The study indicated that the choice of thread greatly influenced both breaking strength and elongation of seams. Relative differences in seam breaking strength and elongation between seams stitched with the three thread types were more closely related to thread breaking elongation than to thread breaking load.

The seams stitched with polyester/cotton core-spun thread exhibited significantly greater breaking strength and elongation than seams stitched with mercerized cotton thread. The hypothesis which stated that bonded monocord thread would produce seams with greater breaking strength and elongation than would mercerized cotton thread was supported by the experimental results. Significant differences resulted from all comparisons of the two threads with regard to breaking elongation of seams and from most comparisons with regard to seam breaking strength. The hypothesis which stated that polyester/cotton core-spun thread would produce seams with greater breaking strength and elongation than bonded nylon monocord was partially supported by the findings. In seven of the eleven comparisons of seam breaking strength and in nine of the eleven comparisons of seam elongation at break, seams stitched with polyester/cotton thread were significantly stronger and more extensible than those stitched with nylon thread. Thus, it would seem that the recommendations in the literature that a thread containing polyester be used to seam knitted fabrics is well founded. However, great differences in strength were found between brands of thread in the preliminary experimental work. More research is needed to determine whether such differences are sufficient to affect the relative strength of the three thread types.

Seam breaking strength and elongation were related to stitch type. The hypothesis which stated that a zigzag stitch would produce seams with greater strength and elongation at break than either of the other stitch types was rejected. On the contrary, the investigation indicated that the zigzag stitch produced seams definitely weaker and less extensible than did the elastic stitch and, for a good many comparisons, weaker and less extensible than the lockstitch with stretch.

The hypothesis which stated that there would be no significant differences in strength or elongation at break between seams constructed with the elastic straight stitch and those constructed with the lockstitch with stretch was rejected. With either nylon or mercerized cotton thread, seams stitched with 15 elastic stitches per inch exhibited greater breaking strength and elongation than comparable lockstitches.

The results seem to indicate that the elastic stitch would be desirable for use where seams would be subject to high loads or extreme extension. The lockstitch with stretch can produce seams with strength and extensibility which are probably sufficient for most purposes if thread with high elongation at break is used. The writer would hesitate to recommend the slight zigzag stitch for use on action garments or for other seams which might be subjected to high stress.

Research which indicates the amount which seams in various garment locations might be expected to extend would be helpful in determining the seam type to use for a given purpose. Additional research is also needed to establish the relationships which may exist between stretching the fabric during seaming and fabric growth. It is possible that fabric growth would render the lockstitch with stretch unacceptable for some fiber-construction combinations of knitted fabrics and acceptable for others. The zigzag stitch used in this study was very narrow. Whether wider zigzag stitches would be sufficiently strong and extensible to compare with the lockstitch with stretch would have to be determined by further study.

One of the hypotheses was that shorter stitches would produce seams with greater strength and elongation than longer stitches. This hypothesis was accepted for seams stitched with the zigzag stitch and either nylon or polyester thread and for seams stitched with the lockstitch and polyester/cotton thread. It also applied to certain seams stitched with mercerized cotton thread and either the zigzag stitch or the lockstitch. For most comparisons in which seams were constructed with a zigzag stitch, 15 stitches per inch resulted in stronger, more extensible seams than 12 stitches per inch, and 12 stitches per inch produced stronger, more extensible seams than 9 stitches per inch. With the lockstitch only a few significant differences in stitch length existed.

The hypothesis which stated that seams stitched parallel to the courses would exhibit greater strength and elongation at break than seams stitched parallel to the wales was accepted. Although less than half of the comparisons were statistically significant, all but 4 of the 38 comparisons were in the direction indicated. Thus, widthwise seams, such as yoke seams, might be expected to require a greater stress or strain before seam breakage than would lengthwise seams especially when stitched with nylon or polyester/cotton thread.

A review of the literature revealed that much more research is needed with regard to fabric geometry, load-extension behavior, and seaming methods for double-knit fabrics. A method for more precisely determining the point of seam breakage would greatly aid further research into seam behavior of knitted fabrics.

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APPENDIX

NUMBER OF ACCEPTABLE SPECIMENS

Seaming Variables			Number of Specimens	
Thread	Stitch Type	Stitches per inch (number)	Lengthwise	Widthwise
Cotton	Zigzag	9	10	10
		12	10	10
		15	10	10
	Lockstitch	9	10	10
		12	10	9
		15	10	9
	Elastic	15	7	2
Nylon	Zigzag	9	10	10
		12	10	10
		15	7	10
	Lockstitch	9	9	10
		12	7	0
		15	7	6
	Elastic	15	3	3
Polyester	Zigzag	9	10	10
		12	10	10
		15	9	9
	Lockstitch	9	10	10
		12	8	10
		15	0	0
	Elastic	15	3	5