ABSTRACT

Jones, Jeremy. Abrasion Characteristics of Ring-Spun and Open-End Yarns. (Under the direction of Dr. Pam Banks-Lee and Dr. William Oxenham.)

In the early 1980s, widespread claims in the knitting industry suggesting that the use of open-end yarns significantly increased the wear of mechanical components, especially knitting needles. Since then, many studies have attempted to explain this phenomenon and have yielded widely varying results.

A study was conducted to compare the yarn properties of open-end yarn to ring-spun yarn. Identical yarns of varying parameters including yarn type, yarn count, and twist multiple were produced from the same raw cotton stock to eliminate variability in raw material. These yarns were tested for abrasiveness on a Lawson-Hemphill CTT (Continuous Tension Transport) tester. The device passes the yarn over a wire and records the length of yarn required to sever the wire.

For this study the CTT was encoded to abrade a fixed length of yarn over the wire. The wire was then observed with both a Hitcahi ESEM (Environmental Scanning Electron Microscope) and a digital imaging microscope. The resultant images were examined for attrition and the abrasion values were evaluated using statistical analysis.

It was confirmed that an increase in yarn count corresponded to a decrease in abrasion. Twist multiple had a noticeable effect on abrasion although the trends between yarn types, and yarn counts were inconsistent. Open-end yarn abrasion values were only slightly greater than their ring-spun counterparts, contradicting the claims of the knitting industry.

Abrasion Characteristics of Ring-Spun and Open-End Yarns

By

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DEDICATION

This thesis is dedicated to my father Chris, who is always there to support me, my mother Anita who selflessly devotes her life to helping children, and my wonderful new wife Jessica who truly inspires me to follow my dreams.

BIOGRAPHY

Jeremy Jones was born in Cumberland, Maryland on December 27, 1975. He was raised in Clayton, NC and graduated from W. G. Enloe High School in 1993. He entered North Carolina State University and received a Bachelor of Science degree with a major in Textile Material Science in May 1999.

In August 1999, the author entered graduate school at the North Carolina State University's College of Textiles to pursue a Master of Science degree in Textile Management and Technology.

ACKNOWLEDGEMENTS

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1 Introduction

The basis for this research resulted from widespread claims from the knitting industry that the use of open-end (OE) yarns significantly increases wear on mechanical components, specifically knitting needles components. In the early 1980s there was "a degree of panic in the US knitting industry, with reports of needle failure in 4-10 weeks when working with OE spun yarns, as compared to a replacement life of 6-12 months when knitting conventional ring spun yarns" [1]. Many attempts to explain this phenomenon have been made with the most popular explanation faulting the abrasiveness of open-end yarns in comparison to their ring-spun counterparts.

The root cause of this increased mechanical wear is of considerable interest to textile machinery manufacturers and fabric producers since the margin of profit in the textile industry is quite small. The expense of prematurely re-needling knitting machines can noticeably impact the operational cost of the facility. Equipment manufacturers continuously strive to develop machinery to reduce mechanical wear and increase profitability [2].

The goal of this research is to determine how the characteristics of yarn type, yarn twist and yarn count influence yarn abrasiveness. In order to ascertain the characteristics of yarn that affect abrasion of a surface, a study was conducted to compare open-end and ring-spun yarns made from identical cotton stock. The twist multiple varied from 3.5 to 5.5 in increments of 0.5 and cotton counts (Ne) of 10, 20 and 30 were selected.

This research endeavors to illustrate the abrasion characteristics of different yarn types, sizes and twist levels. The open-end yarn type was expected to be more abrasive than ring spun yarn.

This is due to the bulky, stiff nature of open-end yarns as well as the coarse hand, or feel, of the fabric produced from these stiff yarns.

As the level of twist was increased, the level of abrasion was also expected to increase. The increase in abrasion was expected since the stiffness of a yarn increases as twist increases. A maximum level of twist was expected to be revealed since an indefinite increase in yarn twist will cause the fibers in the yarn to break, considerably weakening the yarn and decreasing its stiffness.

Finally, finer yarns were expected to wear more quickly than larger yarns. This was anticipated since finer yarn was expected to have a small, focused, and well-defined area of abrasion whereas the larger yarn would simply ride over the wire resulting in much less attrition.

2 Literature Review

Abrasion is defined as “the process of wearing down or rubbing away by means of friction” [3]. The issue of yarn abrasion has been defined both as the attrition of yarn upon itself or another surface, and the resistance of yarn to suffer damage when abraded upon a surface. Factors believed to affect yarn attrition include the following:

- Yarn Friction [4, 5]
- Yarn Type [2]
- Twist multiple [4]
- Hairiness [4]
- Contaminants [2, 6, 7]

2.1 Yarn Friction

Yarn friction is a property which influences yarn abrasion. Friction is “the rubbing of one object or surface against another” [8]. There are several different types of abrasion that occur in yarn. These include yarn-to-yarn and yarn-to-surface friction [5, 9, 10]. Jeddi and Sheikhzadeh [9] performed a study that examined the wear of a yarn against an abrading material (latch needle). They concluded, “that when the friction between the yarn and the abradant increases the abrasion resistance decreases” and that their results are “in line with findings of El Gaiar and Cusick, who found that abrasion resistance is high for a fabric with a low coefficient of friction” [9].

In comparing yarn-to-yarn self abrasion Chattopadhyay and Banerjee found that ring-spun yarns have the lowest yarn-to-yarn friction value regardless of the type of fiber used in the yarn construction or the speed of the yarn passing over itself [5]. The reason for the lower level of friction in ring-spun yarns, “may be ascribed to their smooth surface character” [5]. Rotor-spun yarns, “with a predominance of belts on the rotor yarn surface, being perpendicularly disposed, are likely to enhance friction” [5].

In considering friction versus linear density, “the increase in friction for all types of cotton yarn with a decrease in linear density can be attributed to a larger area of contact between the yarns or between the yarn and the guide” [5]. This larger area of contact is a result of a reduction in the flexural rigidity of the yarn, causing it to bend more [5]. Chattopadhyay and Banerjee state, “as far as friction between yarn and a guide is concerned, *ring-spun yarns show the highest friction*, followed by rotor- and friction-spun yarns for cotton and viscose fibers” [5] (Emphasis Added).

When studying cotton blend yarns, Barella et. al.state as the proportion of cotton in the blend increases, the loss of matter during abrasion appears to affect mainly the cotton [4]. “In addition, the ring-spun yarns are affected most by this phenomenon” [4]. It can be stated that ring-spun cotton yarns are most likely to lose matter during abrasion.

Although many studies have been performed that focus on the resistance of yarn to abrasion [4, 9, 10], relatively few studies have focused on the actual abrasion of the yarn on another surface [1, 5]. Those that have broached the topic yield variable results. Some cite impurities in OE yarns as the culprit [3, 8].

2.2 Yarn Type

Different processes can be used to create yarns that have the same linear density. The method used to twist the fibers into yarns can vary dramatically. Two popular processes for producing yarns are ring spinning and open-end spinning. These yarns may have the same linear densities and twist multiples, but differ significantly in fiber orientation within the yarn.

2.2.1 Ring-spun yarns

The ring-spun yarn production method has been in use for over "150 years and comprises the greatest share of yarns manufactured today" [11]. The method used to produce ring-spun yarns is "a series of operations in which a mass of entangled fibers is transformed into a rope-like structure in which the fibers are more aligned than in the entangled mass; the rope-like structure is twisted to bind the fibers" [11].

Modern machinery creates the yarn by drafting a roving of cotton fibers to a preset linear density, twisting the yarn with a spindle and a traveler. The result is a yarn with a relatively parallel core, increasing in twist level as the surface of the yarn is reached. The structure of the yarn "may be characterized as an assembly of helically arranged, well-aligned fibers with a hairy surface" [5]. An illustration of this process is shown in Figure 1.

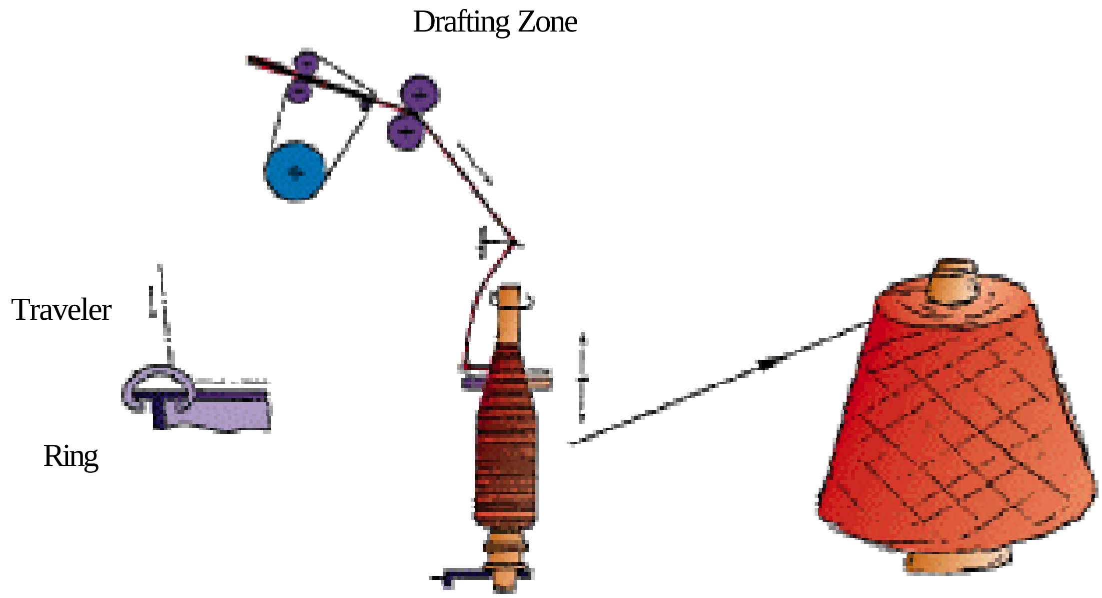


Figure 1 - Ring spinning Technique [13]

The Roving enters the ring-spinning frame from the top left corner of the figure. It is then drafted to a preset linear density by three sets of rollers and twisted through the rotating action of the yarn cop and the traveler. The yarn is subsequently wound onto a larger package illustrated by the yarn cone in this figure.

2.2.2 Open-end spun yarns

Open-end or rotor-spun yarns are created through a process that is fundamentally different from ring spinning. The sliver is completely disassembled into individual fibers, which are fed into a rotating chamber. The fibers are individualized “by means of a small feed roller to a rapidly rotating beater that is covered with wire points. This beater detaches fibers individually from the sliver and projects them into the airstream flowing down the delivery duct. The fibers are deposited in a V-shaped groove along the sides of a lightweight rotor. Fibers from the side of the rotor are “peeled off” to join the “open-end” of a previously formed yarn. As the fibers join the yarn, twist is conveyed to the fibers from the movement of the rotor. A constant stream of individual fibers enters the rotor, is distributed in the groove, and is removed after becoming part of the yarn itself” [11].

A much thinner strand of fibers collect in the perimeter of the chamber via centrifugal force. One end of the strand of fibers is pulled from the rotating chamber, which imparts twist into the strand of fibers, creating the yarn. As the yarn is pulled from the chamber, more fibers are randomly laid in the perimeter of the chamber. A percentage of these fibers become trapped in the yarn as it is pulled from the chamber. Because these fibers are added to the yarn after it has been partially twisted, fibers on the surface of the yarn contain less twist than those in the center of the yarn. As the yarn is pulled through the navel of the rotor, there is a great potential for the loose fiber to wrap circumferentially around the yarn. The result is a highly-twisted yarn core covered with fibers of widely varying twist angles, partially covered by tightly bound by “wrapper” fibers. An illustration of this process is shown in Figure 2.

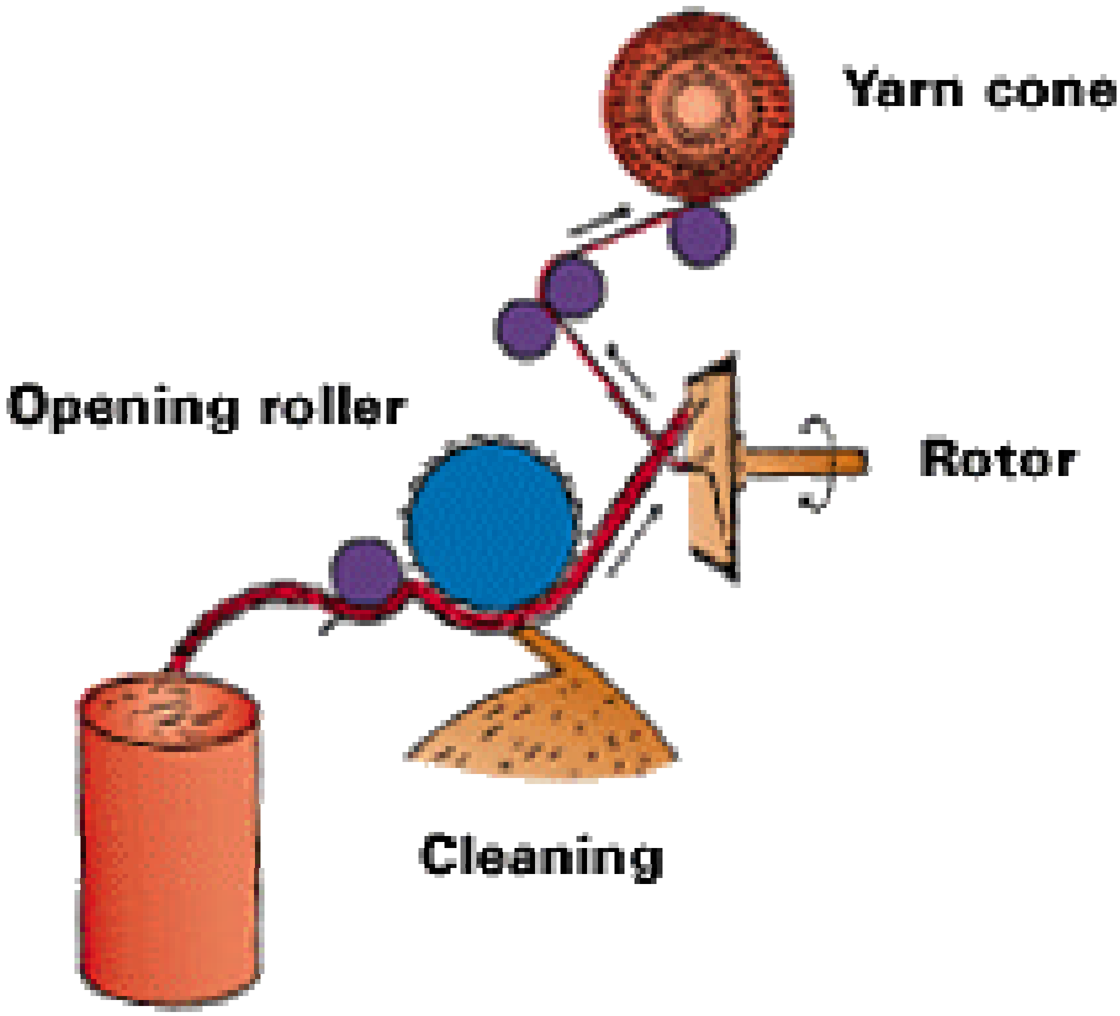


Figure 2 - Rotor spinning technique [13]

Sliver is pulled from the orange can and passes through the feed mechanism in the OE spinning frame. The fibers are individualized by the opening roller and are fed to the rotor through a tapered duct. The newly created strand of fiber is pulled from the rotor and wound onto the yarn cone.

Chattopadhyay and Banerjee define the structure of rotor yarn as “an assembly of disorderly arranged twisted fibers…the yarn surface contains many wrapper fibers in the form of sheaths and belts (i.e. tightly wrapped perpendicularly disposed fibers)” [5]. Because of the random placement of the fibers added after the yarn is partially constructed, the level of twist in the surface fibers along the length of the yarn is inconsistent. The yarn is characterized by regions of highly-twisted "wrapper" fibers along with regions of much more parallel fibers.

The abrasion resistance of open-end spun yarn has been examined in both yarn and fabric structures. Chand concluded that as a yarn, "The abrasion-resistance of rotor-spun yarn must be lower than that of ring-spun yarn because of the poor wrapping of the fibers in the outer layer of rotor-spun yarn" [12].

2.3 Twist Multiple and Hairiness

Generally, the hairiness of ring-spun yarns decreases with increasing twist multiple [5]. The English twist multiple (TM_e) and hairiness are discussed in the same section because these characteristics are interrelated. Also, Chattopadhyay and Banerjee confirm, "the hairiness of [rotor] yarns is less than that of ring-spun yarn" [5]. This observable fact is illustrated in Figure 3.

Figure 3 - Comparison of OE yarn (left) and ring yarn (right) [2].

The OE yarn is identified by the wrapper fibers that randomly cover the surface of the yarn. The fibers in ring-spun yarn, in comparison, are helically arranged and are not subjected to the wrapper fiber phenomena.

As far as friction and twist are concerned, "it is well known that twist changes the surface character of yarn. Hence, yarns were spun at different levels of twist to study its influence on frictional behavior. With the increase of twist, a reduction in [yarn-to-yarn] frictional force for both ring- and rotor-spun yarns is observed" [5].

A study by Barella, et al. [4] examined yarn attrition by self-abrasion. They attributed their results to yarn hairiness. The yarns in the study consisted of ring and open-end spun 70/30 and 50/50 polyester/cotton blend yarns. The "hairs" were separated into two categories of greater or less than 3 mm as shown in Table 1. Barella, et al. observed, "for ring-spun yarns, when the twist increases, the number of hairs longer than 3 mm decreases rapidly. The corresponding decrease is less marked for rotor-spun yarns. The number of hairs shorter than 3 mm is also affected by the twist increase, but the change is more gradual and depends on the degree of order existing in the yarn. Rotor-spun yarns are proportionally less affected than the more-ordered ring-spun yarns" [4].

Table 1 – Effect of Twist on Yarn Hairiness [4].

This is an illustration of one of several studies concerning yarn twist and hairiness. The yarn used was a 50/50 cotton/polyester yarn with a linear density of 40 tex. Hairiness values decreased as twist increased, for all the yarns in the experiment.

Spinning Process	Twist Multiplier turns/cm $(tex)^{1/2}$	28.7	33.5	38.3	45.3
Ring Spinning	hairs <3mm	227	223	185	
	hairs >3mm	25	16	9	
Rotor Spinning	hairs <3mm	-	93	75	68
	hairs >3mm	-	18	15	12

Table 2 - Effect of twist on Yarn Hairiness converted to units of TM_e.

Converting the values of twist multiple to the English system allows a direct comparison between the values of twist used in this study. A 40 tex yarn is equivalent to 14.76 Ne.

Spinning Process	Twist Multiplier turns/in	3.0	3.5	4.0	4.73
Ring Spinning	hairs <3mm	227	223	185	

	hairs >3mm	25	16	9	
Rotor Spinning	hairs <3mm	-	93	75	68
	hairs >3mm	-	18	15	12

The results of Barella's work demonstrate the general trend that as twist multiple increases, hairiness decreases. In general the total number of hairs in ring yarns are nearly double that of open-end yarns. A graph of these results is shown in Figure 4 and illustrates the fewer number of hairs present in open-end yarns. This graph also shows how the number of hair is the rotor yarn is decreasing at a much lower rate than that of the ring-spun yarn.

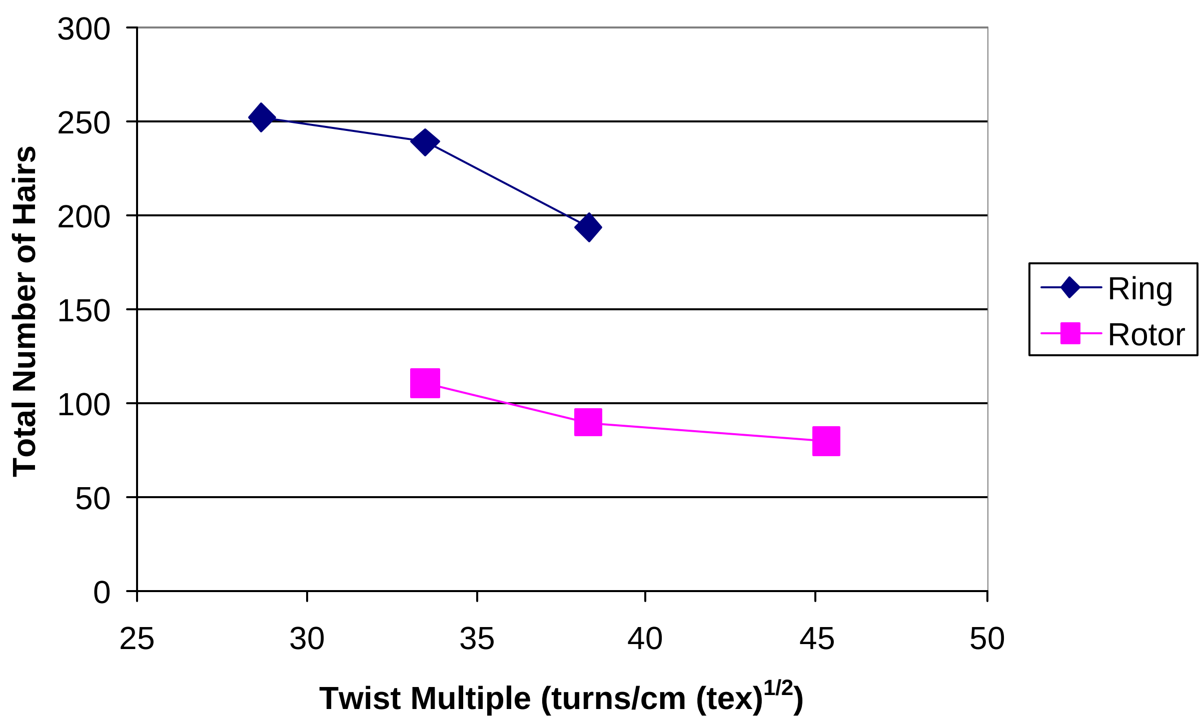


Figure 4 - Graph of number of hairs vs. yarn twist [4]

A graphical representation of the data shown in Table 1. The hairiness of both yarn types is decreasing although the overall number of hairs on the rotor yarn is approximately half that of ring yarn.

Jeddi and Sheikhzadeh [9] examined yarn-to-surface abrasion resistance and the influence of yarn twist and stated “the results of twist multiplier as an internal factor show an increase in resistance to abrasion when this factor increases. The trend of this increase is first slow and then rapid, and from a certain twist multiplier onwards the increase in abrasion resistance slows down.” They suggest “that the construction of yarn with twist less than a certain region of twist multiplier, as a result of abrasion forces, will suffer deformation, and the yarn rupture will be caused by slippage of fibres through the body of the yarn, but rupture of the yarn which has a twist multiplier more than the certain region will occur by breakage of fibres in the yarn construction” [9]. Jeddi and Sheikhzadeh [9] applied the term “twist limits” to this region.

2.4 Knitting Needle Wear Effects

In this study the effects of yarn wear on knitting needles is of primary interest. On a typical knitting needle, the most visible signs of wear are at the hook tip, latch spoon, latch hole and rivet [6]. Groz-Beckert has performed extensive research in the area of knitting needle wear [13] effects. Some effects of their research is provided.

2.4.1 Contaminants

Evans [1] states that the problem of substandard OE yarn is due to “the ability of the OE system to spin yarn from lower grade cotton containing relatively short fibres to produce an acceptable yarn. The contaminants in OE spun yarns were reported by W. J. Naarding in 1976 to consist of ‘fibre fragments, vegetable particles and microdust’. Once these are incorporated into the yarn it becomes very abrasive and accelerated wear occurs [1].

Groz-Beckert also cites yarn contamination as a major contributor to needle wear [13]. An illustration of the service life of needles is shown in Figure 4. Open-end and ring-spun yarns containing no impurities result in little needle wear whereas impurities cause open-end yarns to be more abrasive than ring yarns by a factor of four [13].

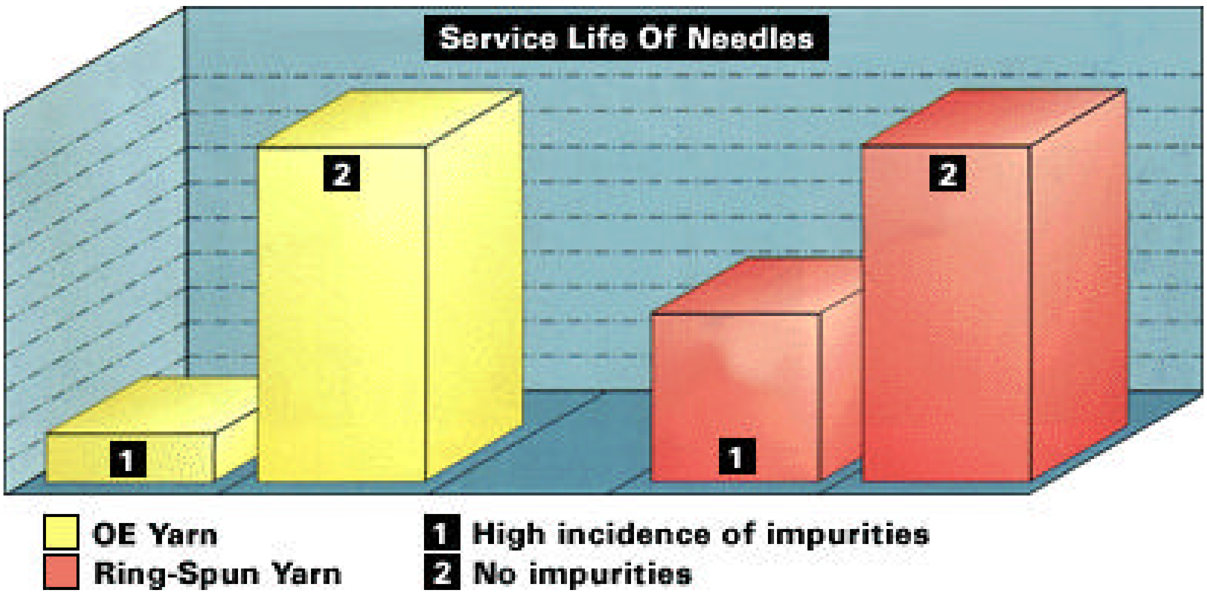


Figure 5 - Groz-Beckert evaluation of impurities and needle wear [13]

Groz-Beckert determined that the service life of needles is nearly identical between ring and rotor yarn samples that have no yarn impurities. The addition of impurities to the yarn shows a dramatic decrease in needle life for the OE yarn. The needle life of OE yarn with impurities is approximately one-fourth that of ring-spun yarn with the same level of impurities.

"The position of the abrasive particles in the yarn is of decisive importance in determining the degree of wear. A particle attached to the surface of the yarn will clearly exercise the most serious abrasive effect. Yarns manufactured using the OE spinning method tend to demonstrate a greater degree of dust on the yarn surface" [13]. The increased number of abrasive particles on the yarn surface of open-end yarn directly relates to the decreased service life of needles.

Groz-Beckert states that yarns with "a large number of mineral and vegetable particles on the surface of the yarn cause a large number of impurities to act on the stitch-forming elements resulting in a high degree of needle abrasion and shorter needle life [13].

2.4.2 Wear on needle hook and latch groove

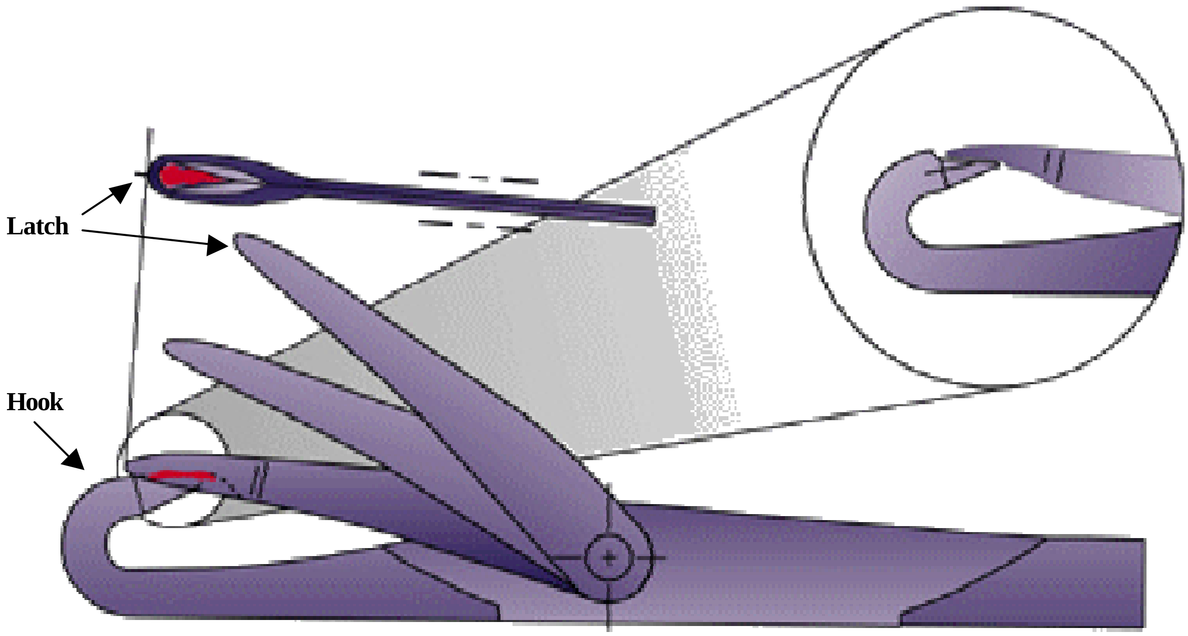


Figure 6 - Wear on needle hook and latch groove [13].

The area shown in red is subject to wear when the latch closes. After a significant number of repetitions, the needle will wear to the point that the latch will slip beneath the hook. When this situation occurs, yarn can no longer slide over the hook and will continue to accumulate beneath the hook.

Groz-Beckert [13] states that abrasive particles can play a major role in the wear on needle hooks and latch grooves. Cotton fibres can contain varying degrees of impurity "depending on where they are cultivated, the harvesting method, weather conditions and gin treatment (cleaning process after harvesting). Some cotton is contaminated by sand dust which is not eliminated by the preparations for spinning and during the spinning process itself, the inevitable result is wear, not only of needles but also of yarn carriers, sinkers, cylinders and cams" [13].

"This abrasive effect can be minimized by careful selection of raw materials and intensive purification and dust removal during preparation for spinning and during the spinning process. Where particles such as oxides or silicates which are harder than needle steel are carried on the surface of a spun yarn, the needle surface will become scratched, inevitably resulting in abrasion of the needle material" as shown in Figure 7 [13].

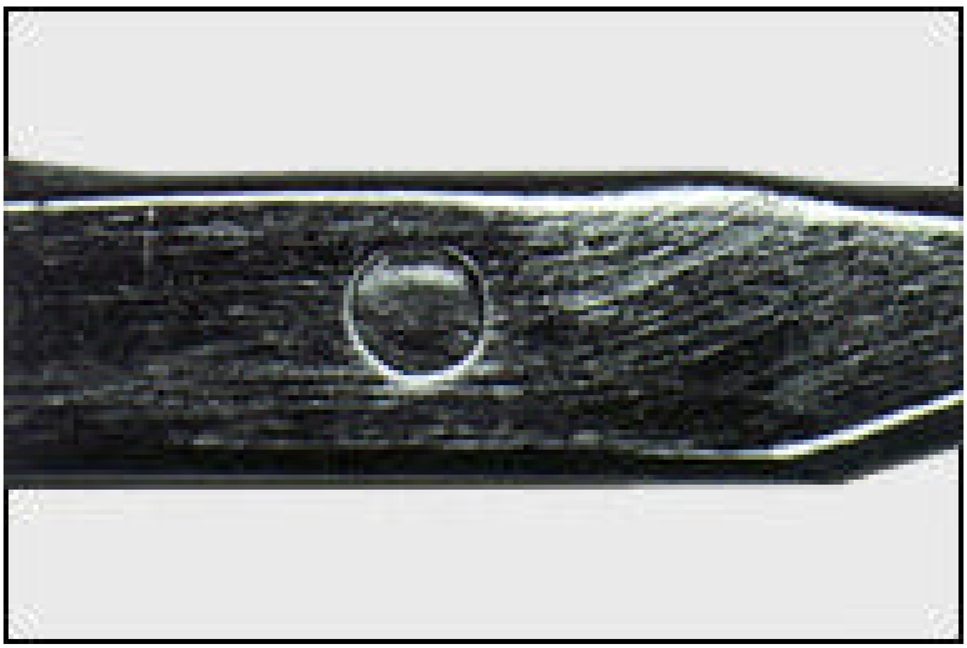
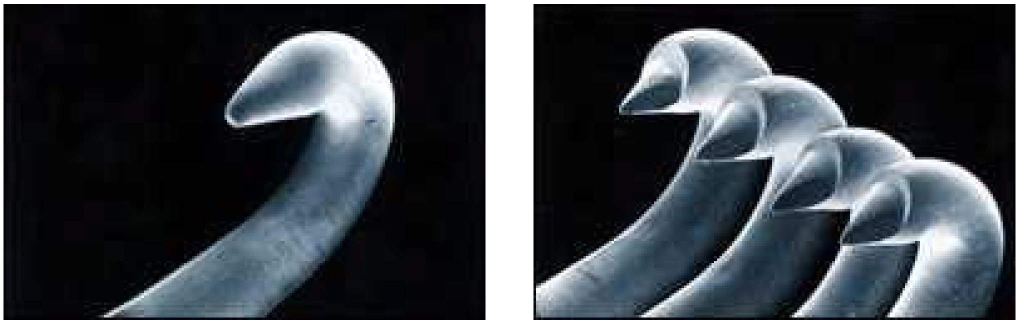


Figure 7 - Abrasion of Needle Material [13]

Particles in the yarn, which are harder than the needle, scratch the needle surface. Yarns with the greatest number of these particles yield the greatest needle wear.

"Abrasive particles accumulate at the points marked in red. In this example these are the latch groove and the hook. With every closing movement the latch makes impact with the hook. As a result of the applied pressure level and the friction, the needle steel is worn by the particles as illustrated below" [13].



New hook   Worn hooks

Figure 8 - Groz-Beckert hook wear effects

The hook of a new needle is almost perfectly conical at the tip. As the latch wears the tip of the hook, the area of the needle tip is reduced.

2.4.3 Abrasion on the back of the latch and latch seat

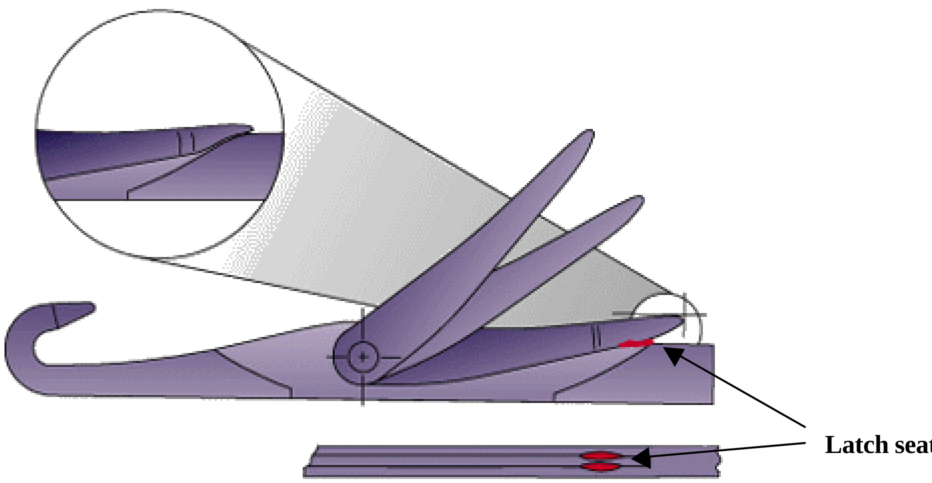


Figure 9 - Abrasion on back of latch and latch seat [13]

"The same effect is incurred when the latch opens and impacts the latch seat" [13]. Abrasive particles remaining on the back of the latch or in the latch seat are forced into the metal in the locations indicated in red. The particles wear the metal resulting in either a latch or seat failure.

Once the latch becomes level with the seat, the yarn cannot slide the latch back into the hook. The result is dropped ends, which appear as lines in the fabric.

2.4.4 Abrasion on the latch guide and latch bearing

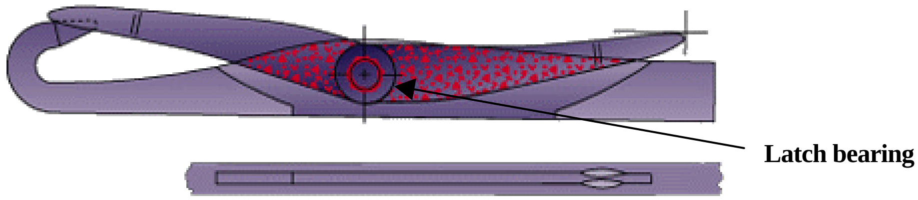


Figure 10 - Abrasion on the latch guide and latch bearing [13]

"Dirt particles are also able to gain access to the slot between the latch shank and the cheek, and also between the rivet and latch hole" [13]. The combined action of the latch movement and the abrasive particles causes the wear of the rivet and latch hole [13]. This wear can cause the latch to slip past the hook or below the latch seat resulting in ends down or unintentional stripes in the fabric.

2.4.5 Summary

Groz-Beckert [13] attributes the wear of latch needles to abrasive particles that grind the metal surfaces of the needles. Yarns containing more abrasive particles are responsible for needle wear. The particles responsible for needle wear are the oxides or silicates carried on the surface of the yarn, which are harder than needle steel and scratch the surface of the needle. This scratching results in the inevitable abrasion of needle material [13].

3 Methodology

3.1 Objective

The objective was to study the effect of various yarn parameters on needle wear. The parameters that were studied include ring and open-end yarn types, twist levels within the yarns and yarn size.

3.2 Materials

Yarns were produced from cotton grown in North Carolina. The average upper quartile length (UQL) of the four cotton bales was 1.14 inches. The short fiber content (SFC) was 30.8% (by number). The experiment required 15,000 meters of the 22 different combinations of yarn shown in Table 3. The cotton stock was identical for both the open-end and ring-spun yarns.

Table 3 - Yarn Parameters

The yarns in this study were selected to determine the effects of abrasion over a wide range of variables. In this case, three different yarn counts, five different twist multiples and two distinct yarn types are under evaluation.

Spinning Method	Yarn Count (Ne)	Twist Multiple (TM_e)				
Ring-Spun	**10**		**4.0**			
	20	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**
	30	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**
Open-End Spun	**10**		**4.0**			
	20	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**
	30	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**

3.3 Equipment and Procedure

Both fiber processing and analytical equipment were used to complete this research. In order to produce yarns for the experiment, equipment in North Carolina State University Short Staple Fiber Processing facility was used. Analytical equipment was used to measure yarn abrasion and surface wear.

3.3.1 Yarn Processing

The cotton bales were hand opened and placed in the Rieter B3/3R mixing opener. The Rieter ERM cleaner model B5/5 opened the fiber and a Rieter C4 card processed it into sliver. The sliver was subjected to two passes on a Rieter RSB851 drawframe and equal masses of fiber were evenly split between the open-end and ring-spinning processes.

The sliver allocated to the ring-spun yarn was processed into roving using a Saco-Lowell roving frame. A Saco-Lowell ring-spinning frame with SKF drafting produced the ring-spun yarn. The remaining 50% of sliver was used to produce yarn on the Rieter R1 open-end spinning frame.

3.3.2 Analytical Equipment and Procedure

The equipment used in the experiment consisted of a Lawson-Hemphill CTT (Continuous Tension Transport) equipped with Belden® 8057 34 AWG Hookup-Lead Magnet copper wire (Full specifications are available in Appendix B). Experiments were performed on a Lawson-Hemphill CTT (Continuous Tension Transport) tester. A yarn was threaded through the machine and passed over a metal wire until the attrition suffered by the wire caused it to sever. The distance of yarn required to sever the wire was recorded, indicating the amount of abrasion between the yarn and wire. A diagram of the yarn path is shown in Figure 11.

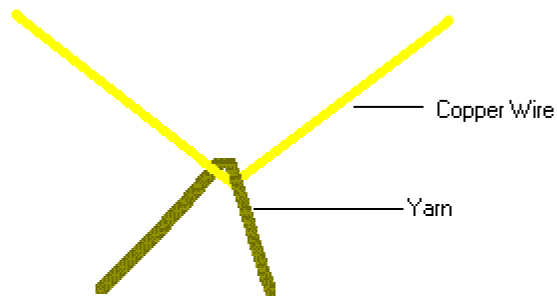


Figure 11 - Yarn path over copper wire

The copper wire is initially horizontal. The yarn is passed over the wire and tension is applied. As tension increased, the copper wire bows down into the shape of a "V". The yarn also assumes the shape of a "V". The yarn is then placed into motion and rubs over the copper wire for either a preset length, or until the wire severs.

Initially the wire was entirely horizontal. The experimental yarn was threaded over the wire and tension was applied. The tension caused the wire to droop and the yarn rested in the "v" of the wire. The yarn was subsequently passed over the wire and remained in the same position on the wire throughout the entire experiment.

Although the experiment can be designed to run either until the wire breaks or a preset length of yarn is exhausted, the initial experimental design required continuous operation of the CTT until the wire was severed. Seventy-two attempts at achieving a suitable wire break yielded only 26 suitable data points, most of which were not reproducible. The entire set of initial experimentation is available in Appendix A.

The most common cause of error was due to individual fibers wrapping around the wire, resulting in artificially inflated abrasion lengths. The second most common problem was slubs or thick places in the yarn that would snap the weakened wire rather than sever it, prematurely terminating the experiment.

The buildup of fiber during the yarn-wire abrasion increased as the wear of the wire increased. In order to circumvent the problem, the experimental design was revised to subject the wire to a fixed length of attrition, which was significantly shorter than the length required to sever the wire. The wire would then be analyzed for abrasion with an electron microscope. The abrasion length initially chosen was 1000 meters (m). Viewing the wire with the SEM illustrated the need to substantially increase the abrasion length. A length of 3000 m was subsequently selected.

Once each sample of wire was produced, a Hitachi ESEM (Environmental Scanning Electron Microscope) was used to investigate the abrasion. An image of the wire produced by the SEM is shown in Figure 12. The image appears as a long cylinder of dark, non-reflective material with a small bright, white region. The dark material is a nylon polymer coating, which does not reflect the electrons to the viewer and makes the region appear dark. The exposed copper wire is metallic and highly reflective. This region appears bright white in the viewer. The abrasion observed consists of coating stripped from the wire as well as metal stripped from the copper core. Wire attrition is indicated by the concavity of the copper surface.

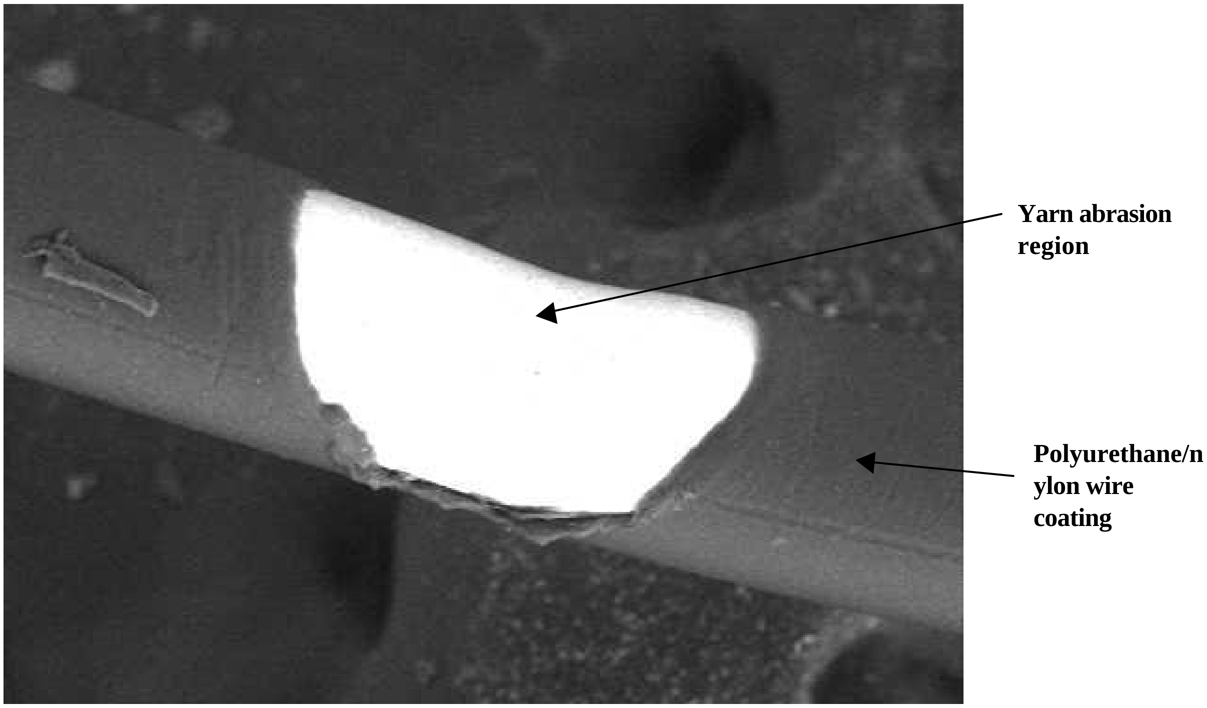


Figure 12 - Typical Result of Yarn-to-Wire Abrasion

The cylinder in this picture is the copper wire as seen with the SEM. The dark part of the wire is a polyurethane/nylon coating which does not reflect the electron beam to the detector. The bright white region is the copper that has been exposed through yarn abrasion. There is an impression in the copper that indicates wear. Note the coating has not been removed from the bottom of the wire since this region does not contact the yarn.

In order to determine whether the type of attrition suffered by the wire was related to the type of attrition suffered by a needle, actual samples of needles were collected from a 16-needle circular knitting machine. The knitting machine was to be operated for a standard period of time and the needle was to be removed and observed for wear with the SEM. An image of a new knitting needle is shown in Figure 13.

The length of time in which to operate the knitting machine was to be determined experimentally. A 1986 Master's Thesis by Steve Ward stated the number of hours a knitting needle was expected to last in a Union Underwear plant was 2880 [6].

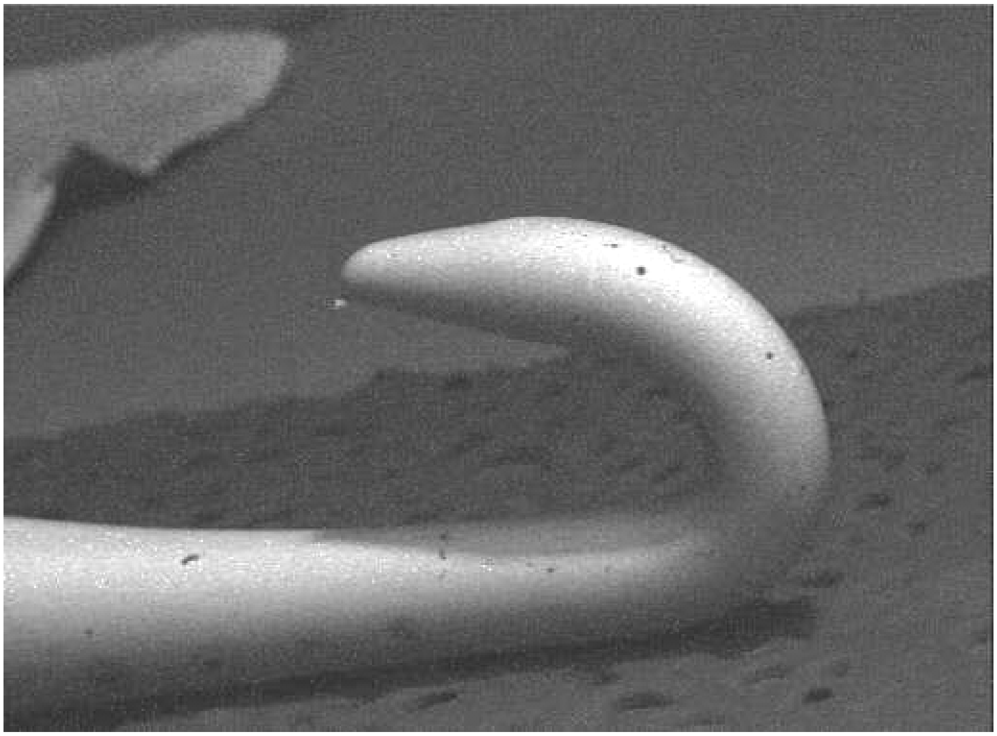


Figure 13 - SEM image of an unused knitting needle

A new knitting needle has a very smooth surface and a conical tip. As the needle is used, a ridge forms in its tip as the latch strikes its surface.

Although the SEM images provided a means to qualitative identify yarn abrasion, a quantitative method of examining the wires was desired. A revised study was developed to obtain a greater number of data points in the set. Since the yarns produced for the first analysis were exhausted, an additional set of yarns were produced from the same cotton bales and tested on the CTT. Five repeats at 3000 meters per data point were tested. The repeats were required to develop statistically significant values.

The abraded wires were then examined with a digital microscope known as a Microwatcher®. The length of wire was placed under the lens and rotated until a minimum cross-section was observed. The image was captured with a digital video card and an example is shown in Figure 14

The length of the minimum cross-section was measured in units of pixels. The original width of the wire was also measured in order to determine the ratio of the abraded wire width to the original width of the wire. This value is referred to as the percent remaining. Subtracting this value from unity (1) yielded the percent of wire abraded, which is the value reported on the charts and graphs. Ultimately, five of these values were obtained for each yarn and the averages were reported.

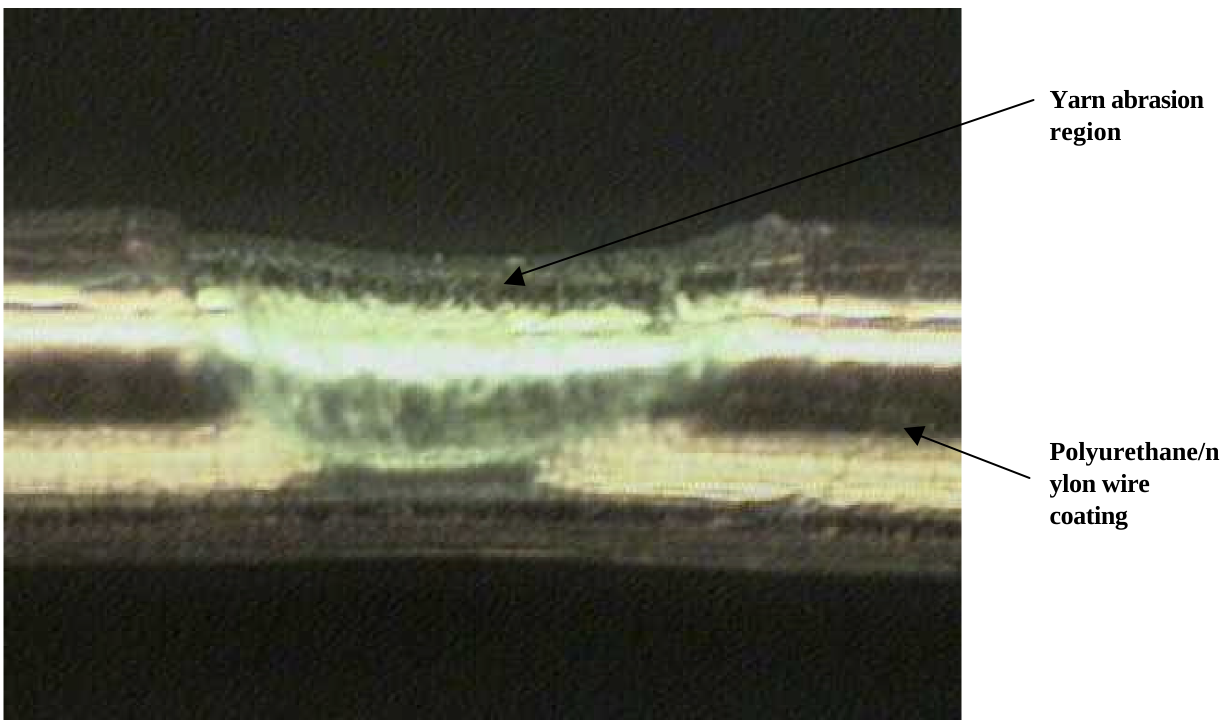


Figure 14 - Typical image observed from the Microwatcher ®

The Microwatcher® is a light microscope combined with a video camera. The image shows the gold-colored polyurethane/nylon coating and a bright silver region representing the abraded copper metal beneath the coated surface.

3.3.3 Statistical Analysis

Once the level of abrasion was recorded for each sample of each yarn type, the data was analyzed on Minitab® Statistical Software, Release 13.1 [16]. The yarn type, yarn count and yarn twist were inserted into the program. Since the software requires numerical data, the yarn type was changed from OE to “1” and from ring-spun to “2.” This convention will follow throughout the data analysis.

The first analysis that was performed was a to determine the normality of the data using the mean, standard deviation, and confidence. These values were calculated using Microsoft Excel®. Points that fell outside the confidence were eliminated.

Once the data was refined, a linear regression was performed. The p-value of yarn type, yarn count and twist as well as the R-square values were obtained from the analysis. P-values that exceeded a 95% confidence were removed from the analysis and the regression was repeated. Also, since ring-spun and open-end yarn has widely varying structures, regressions were individually performed for each group.

Additionally, Minitab® provides an equation that calculates the expected, or “fit” values based on the data. These values were recorded and plotted against the mean of the actual values to determine how closely the actual data fits the expected values.

4 Results and Discussion

The intended operation of the CTT requires a package of yarn to run over a wire until the wire is severed. In order to assess the variability in the process, the procedure was standardized with 10 Ne, 4.0 TM_e open-end yarn. Once an acceptable level of variability was obtained, the test was repeated for the entire set of experimental yarns. Recorded for each test was the following:

- trial number
- date
- time
- yarn type
- Ne
- TM_e
- test velocity
- room temperature
- relative humidity
- input tension
- output tension
- length required to break
- comments

4.1 Original Experimentation

Complete results of the original experimentation are available in Appendix A

. Initial experimentation revealed a fatal flaw in testing yarns with a high SFC using the CTT. Yarn constructions wherein fibers easily separated, such as those with a low TM_e, allowed fibers to become tightly wrapped around the wire. This impenetrable layer of wrapped fibers insulated the wire from subsequent abrasion by the yarn. An image of this phenomenon can be seen in the SEM micrograph of the 10 Ne, 4.0 TM_e yarn in Figure 15.

In order for wire abrasion to continue, the yarn must abrade through the layer of wrapped fibers. In many cases the extra layer of wrapped fibers was never penetrated. This occurrence appeared most prominent in heavier count ring-spun yarns with a low TM_e.

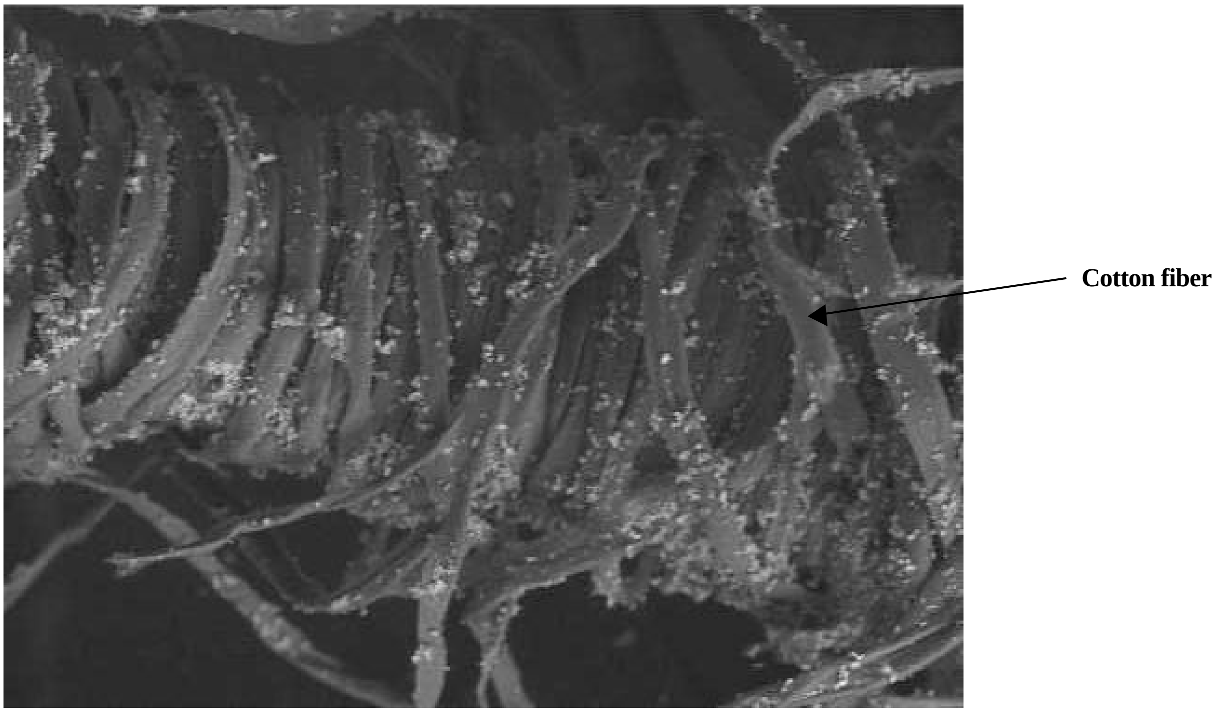


Figure 15 - 10 Ne, 4.0 TM_e yarn encircled with fiber during testing

During initial testing, the greatest detriment to severing the copper wire was cotton fibers that wrapped around the surface of the wire and ceased further abrasion. Shown here is a severe example of this phenomenon.

An example of the entangled mass of fibers wrapped around the wire is shown in Figure 15. This layer of fiber, formed between the yarn and wire, is essentially impermeable and causes wire attrition to cease. Initially no fibers were wrapped around the wire. As testing progressed, hairs on the bottom of the yarn followed a path under the wire. These hairs attracted those that passed over the wire. As the base of the hair reached the wire, the tip of the hair was pulled in an opposite direction to the movement of the yarn. This reversal of direction hooked the fiber around the wire and initiated the wrapping process.

The images in Figure 16 illustrate how a small number of fibers are required to insulate the wire from yarn abrasion. In each case the image appears to contain only one fiber, which wraps around the white area of abrasion approximately three times. The addition of only a few more fibers would completely encircle the abrasion region, rendering the experiment void.

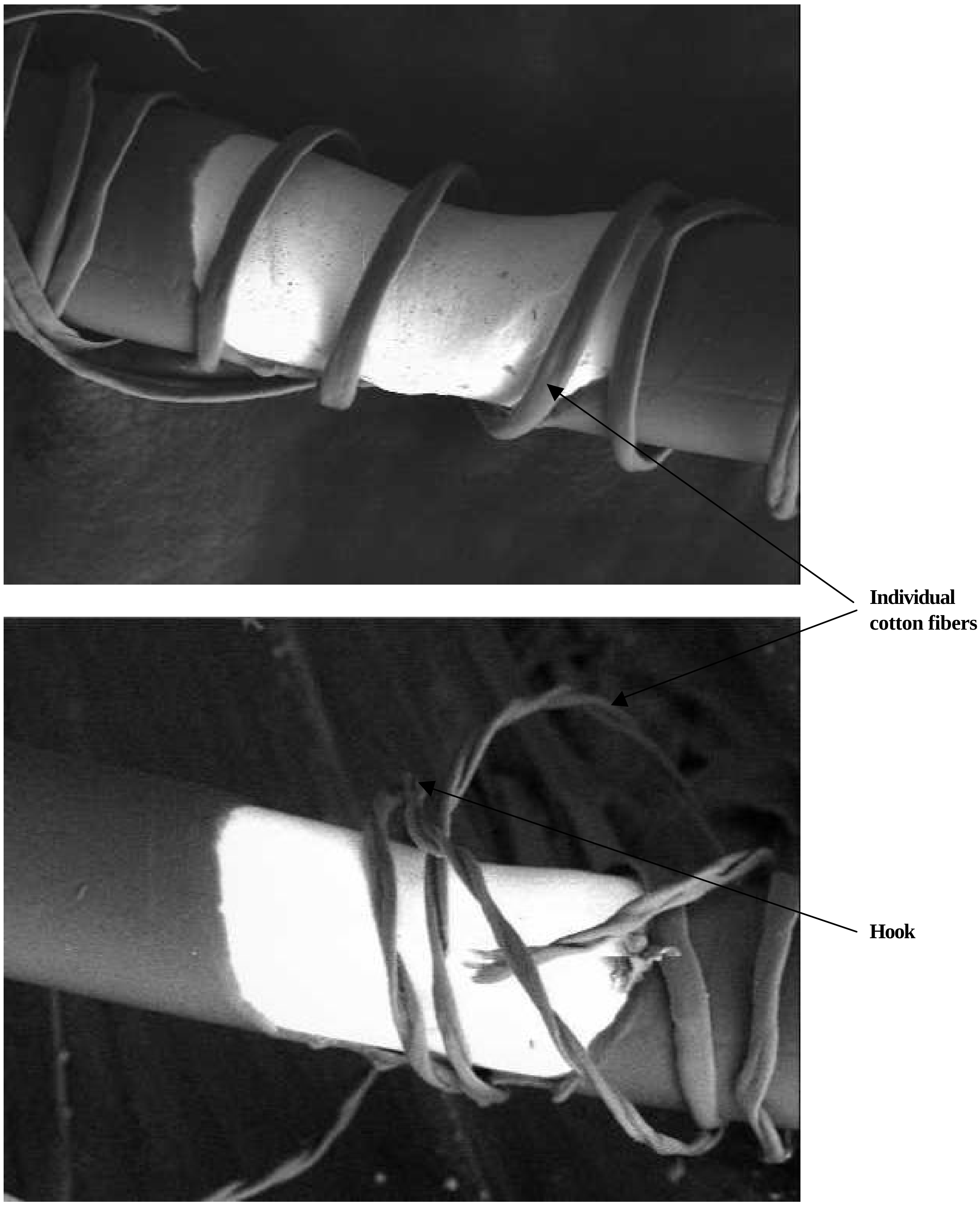


Figure 16 - Fiber wrapping: Relation of fiber to yarn

Shown are two images of abraded wire that are wrapped with at least one fiber. Even one fiber between the yarn and the wire can negatively impact abrasion, returning a superficially low yarn abrasion value.

Although the layer of fiber wrapping around the wire was a significant problem in the wire experiment, the situation was not observed in the operation of the knitting machine. The yarn in a weft knitter travels in both tangential as well as transverse directions across the needle. The relatively complex motion of the yarn on the needle allows the yarn to slide any wrapped fibers off the needle before fiber buildup can occur. An experiment was devised to confirm this observation as well as to determine the location of attrition suffered by a knitting needle.

The experiment required the operation of the circular weft knitter for a fixed period of time. A needle would subsequently be removed and examined under the SEM for attrition. In order to determine the appropriate runtime an initial evaluation was performed. The initial evaluation required examination of the needle after one hour of knitting machine operation. Once a suitable level of attrition was achieved the needle could be examined for wear using the SEM.

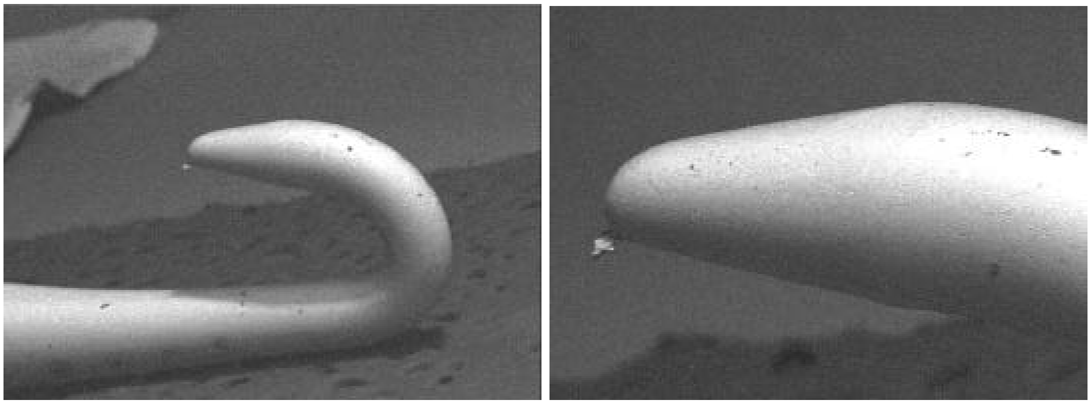
Three needles, shown in

Figure 17, were examined with the SEM:

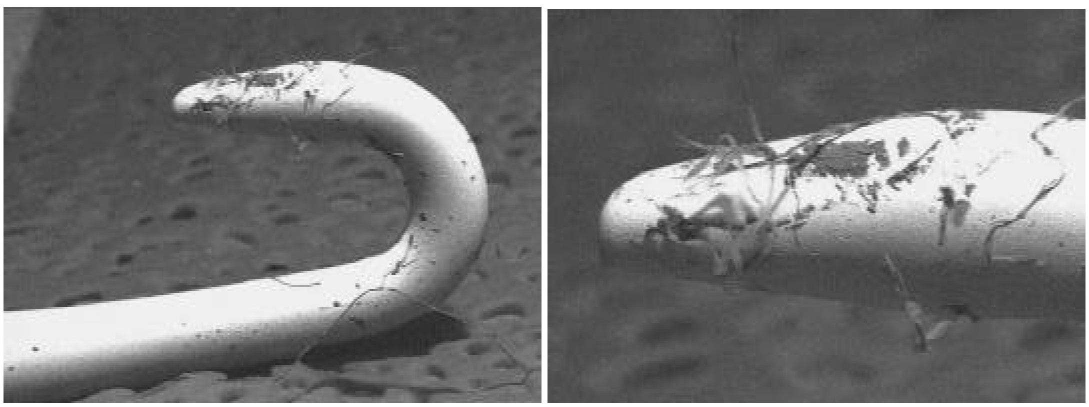
1. A new needle
2. A needle with 1 hour of knitting abrasion
3. A needle with a larger, unknown amount of abrasion

The new needle had no signs of abrasion on the hook. It appeared very smooth and contained a small particle of dirt on its tip. The needle containing one hour of abrasion time was very dirty, covered with the vegetable matter that separated from the yarn. No visible wear was apparent on the hook surface. The needle with unknown abrasion time was nearly as clean as the new needle. It revealed a very small indentation in the surface of the hook as the only visible sign of attrition.

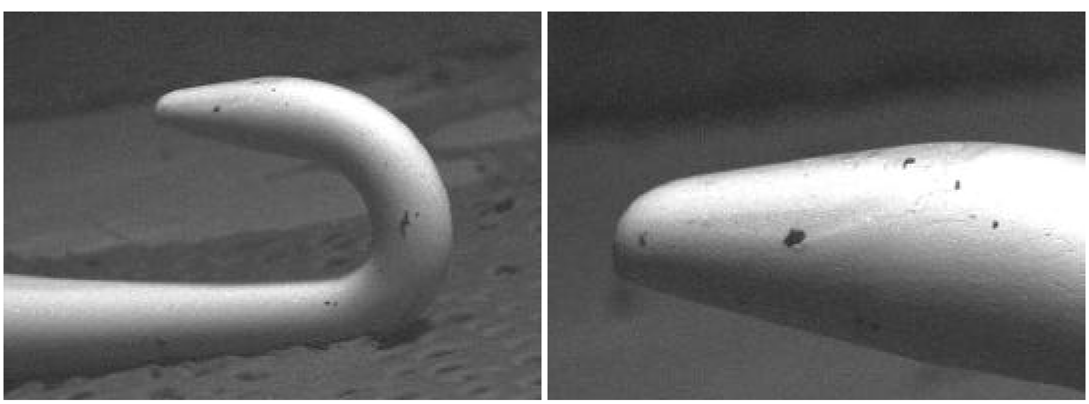
The amount of attrition suffered by the needle was visibly insignificant after one hour of knitting time. Even if the knitting time was substantially increased, the level of abrasion between needle samples would require a very precise measuring method to determine differences in attrition. Such a measuring method could not be produced for this study. In addition, the knitting time and yarn supply required to produce statistically significant needle samples were prohibitive. In order to give an indication of the amount of time required to wear out a needle, a Master's Thesis by Steve Ward states that a Union Underwear plant expects their Groz-Beckert needles to last 2,880 hours [6].



(a) New knitting needle (0 hrs knitting time)



(b) Experimental knitting needle (1 hr. knitting time with OE spun 100% cotton yarn)



(c) Knitting needle with extended (unknown) number of knitting hours.

Figure 17 – SEM micrographs of needle hook wear

The new needle (a) shows no signs of wear. After one hour of abrasion, needle (b) also shows no signs of wear although hook is covered in vegetable matter and one can see the location where the latch strikes the hook. Even a needle with an extended number of knitting hours (c) has only a very slight impression where the latch contacts the hook.

4.2 Revised Experimentation

Since it was revealed that abrasion comparisons on actual knitting needles would be prohibitive, a revised experiment employing the CTT was devised. While the CTT was in operation, it was observed that the buildup of fiber was most severe after the groove in the wire became prominent. Fiber buildup remained a problem preventing abrasion indefinitely. A new experimental procedure was developed to minimize this phenomenon. The revised procedure reduced the length of yarn required for the test to 3000 m. This length was sufficient to obtain visible variances in wire abrasion and significantly decreased the condition of fibers wrapping around the wire.

For the revised experiment, there were five repeats per test and twelve unique yarn combinations. This required the use of sixty lengths of 3000 m yarn, totaling 180,000 m. The percent wire abrasion for the sixty yarn lengths is given in Table 4. Missing cells in Table 4 represent samples for which abrasion could not be measured.

Table 4 – Percent depth of yarn abrasion recorded from the wire

The ratio of the original and final widths of the copper wire were recorded, representing the amount of wire remaining after abrasion. This value was subtracted from one to determine the amount of wire abraded by the yarn.

	TM	20 Ne	30 Ne
Open-End	3.5	0.1074	0.1188
		0.1235	0.1625
		0.1292	0.1352
		0.1199	0.1078
		0.1170	
	4.0	0.1017	0.1455
		0.1169	0.1355
		0.1053	0.1279
			0.1402
			0.1423
	4.5	0.0964	0.0866
		0.1245	0.1393
		0.1053	0.2337*
		0.1040	0.1163
			0.1339

	TM	20 Ne	30 Ne
Ring-Spun	3.5	0.0802	0.0875
			0.1102
			0.1097
		0.1319	0.0951
		0.1100	0.0717
	4.0	0.1022	0.1345
		0.1010	0.1185
		0.0990	0.1356
		0.1084	0.1447*
		0.0766	0.0926
	4.5	0.0825	0.0793
		0.1199	0.0992
		0.1232	0.1237
		0.1456	0.1288
		0.0592	0.0633*

The mean ($\overline{X}$), standard deviation (s) and 95% confidence for each of the 12 sample groups is shown in Table 5. The means are also plotted in Figure 18. From Table 5, it can be seen that three abrasion values fall outside of the individual group confidence. Since these yarns were created and tested using identical procedures, there was no known reason for the abrasion values to fall outside the 95% confidence limits. These values are indicated by a star (*) in Table 4 and were eliminated from future statistical analysis. Removing the initial missing data (6 points) and the three outlying values leaves a final data set of 51 data points.

Table 5 - The Mean, Standard Deviation and 95% Confidence for each of the 12 groups

The mean, standard deviation and 95% confidence are tools that can be used to determine the quality of the data that has been recorded as well as the values that exceed preset specification limits.

	TM		20 Ne	30 Ne
Open-End	3.5	$\overline{X}$ =	0.119405	0.13108
		s =	0.008079	0.023787
		Confidence	0.007081	0.023311
	4.0	$\overline{X}$ =	0.107956	0.138283
		s =	0.007957	0.006823
		Confidence	0.009004	0.005981
	4.5	$\overline{X}$ =	0.107535	0.141966
		s =	0.011954	0.055268
		Confidence	0.011714	0.048443

	TM		20 Ne	30 Ne
Ring-Spun	3.5	$\overline{X}$ =	0.10738	0.094857
		s =	0.025932	0.016166
		Confidence	0.029344	0.01417
	4.0	$\overline{X}$ =	0.097442	0.125167
		s =	0.01217	0.02048
		Confidence	0.010668	0.017951
	4.5	$\overline{X}$ =	0.106072	0.098865
		s =	0.034639	0.028119

		Confidence	0.030362	0.024647

Table 6 - Mean abrasion data after normalization

The mean abrasion data is useful for visually representing each group as compared to their expected values. It helps to illustrate any trends that exist.

	TM		20 Ne	30 Ne
Open-End	**3.5**	$\overline{X}$ =	0.119405	0.13108
		s =	0.008079	0.023787
	4.0	$\overline{X}$ =	0.107956	0.138283
		s =	0.007957	0.006823
	4.5	$\overline{X}$ =	0.107535	0.119023
		s =	0.011954	0.023735
	TM		**20 Ne**	**30 Ne**
Ring-Spun	**3.5**	$\overline{X}$ =	0.10738	0.094857
		s =	0.025932	0.016166
	4.0	$\overline{X}$ =	0.097442	0.125167
		s =	0.01217	0.02048
	4.5	$\overline{X}$ =	0.096198	0.107758
		s =	0.030819	0.022955

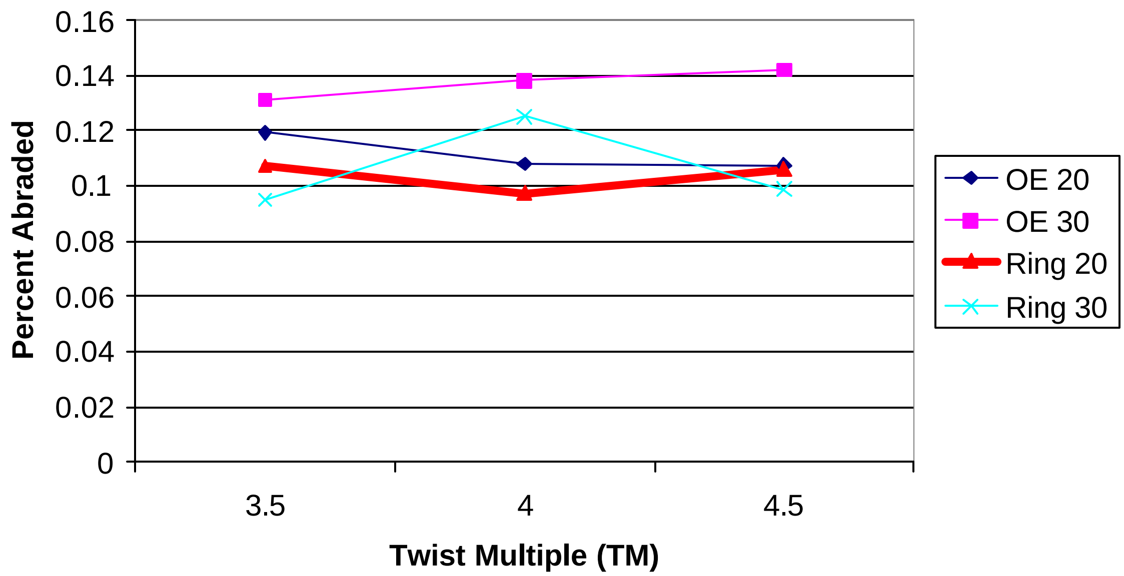


Figure 18 – The means of the percents of wire attrition versus twist multiples

The means of the percent abrasion values generally follow an increasing or decreasing trend. The 30 Ne ring-spun yarn, however is notably more concave down than the rest of the samples.

No clear trend can be seen when considering all the data represented in Figure 18. The wire abrasion data in Figure 18 was expected to reveal trends regarding yarn type, yarn twist and yarn count. One would expect an increase in abrasion as twist increases. Also, as yarns decrease in count, or increase in fineness, the expected trend is an increase in wire abrasion. Furthermore, one would expect greater wire abrasion from open-end yarns than ring-spun yarns.

In general, the data did not easily lend itself to explicit trends. It appeared that the 30 Ne, OE yarn was most abrasive and abrasion increased slightly as twist multiple increased. Any trends from the remaining yarn types are substantially less obvious. It is possible that the resultant abrasion value of the 30 Ne ring-spun yarn at 3.5 TM was inaccurate due to the propensity of fibers wrapping around the wire. The 3.5 TM_e point is believed to be artificially low due to the lack of abrasion resulting form wrapper fibers that insulated the wire from the yarn.

Regression analysis was used to further study the data. “Linear regression is used to make predictions about a single value. Simple linear regression involves discovering the equation for a line that most nearly fits the given data. That linear equation is then used to predict values for the data” [14]. Or simply, “regression models are used to predict one variable from one or more other variables” [15]. The single predicted value in this case is the abrasion value. The variables that can be used to assess abrasion include: yarn type, yarn count and twist multiple. The regression analysis was performed using Minitab Statistical Software version 13.1 [16]. For the purposes of software analysis, the OE yarn was relabeled type “1” and ring-spun yarn was type “2.” The complete set of data relating yarn type, count and twist to observation number is provided in Table 7.

Table 7 - Yarn Type, Yarn Count and Twist based on Observation Number

Observation	Type	Count	Twist	Abrasion
1	1	20	3.5	0.107438
2	1	20	3.5	0.123482
3	1	20	3.5	0.129167
4	1	20	3.5	0.119919
5	1	20	3.5	0.117021
6	1	20	4	0.101695
7	1	20	4	0.11691
8	1	20	4	0.105263
11	1	20	4.5	0.096436
12	1	20	4.5	0.12449
13	1	20	4.5	0.105263
14	1	20	4.5	0.10395
16	1	30	3.5	0.11875
17	1	30	3.5	0.1625
18	1	30	3.5	0.135246
19	1	30	3.5	0.107822
21	1	30	4	0.145492
22	1	30	4	0.135524
23	1	30	4	0.127932
24	1	30	4	0.140206
25	1	30	4	0.142259
26	1	30	4.5	0.086598
27	1	30	4.5	0.139293
29	1	30	4.5	0.116327
30	1	30	4.5	0.133874
31	2	20	3.5	0.080247
34	2	20	3.5	0.131915
35	2	20	3.5	0.10998
36	2	20	4	0.102249
37	2	20	4	0.10101
38	2	20	4	0.098969
39	2	20	4	0.108384
40	2	20	4	0.076596
41	2	20	4.5	0.082474
42	2	20	4.5	0.119919
43	2	20	4.5	0.123203
44	2	20	4.5	0.14557
45	2	20	4.5	0.059197

46	2	30	3.5	0.0875
47	2	30	3.5	0.110187

Table 7, Continued

48	2	30	3.5	0.109731
49	2	30	3.5	0.095137
50	2	30	3.5	0.07173
51	2	30	4	0.134454
52	2	30	4	0.118503
53	2	30	4	0.135593
55	2	30	4	0.092632
56	2	30	4.5	0.079332
57	2	30	4.5	0.099156
58	2	30	4.5	0.123711
59	2	30	4.5	0.128834

An initial regression analysis was performed on the abrasion values using type, count, and twist as model predictors. The following results were obtained from this initial regression analysis.

Table 8 - Actual abrasion, Expected abrasion, and Residual for the initial regression

The observation number corresponds to a specific yarn abrasion sample number. The actual column represents measured abrasion. The fit value was calculated by Minitab® from the abrasion equation it created and the residual is the difference between the actual and fit values.

Obs	Actual	Fit	Residual
1	0.10744	0.11697	-0.0095
2	0.12348	0.11697	0.00651
3	0.12917	0.11697	0.0122
4	0.11992	0.11697	0.00295
5	0.11702	0.11697	0.00005
6	0.10169	0.11629	-0.0146
7	0.11691	0.11629	0.00062
8	0.10526	0.11629	-0.011
11	0.09644	0.11561	-0.0192
12	0.12449	0.11561	0.00888
13	0.10526	0.11561	-0.0103
14	0.10395	0.11561	-0.0117
16	0.11875	0.12735	-0.0086
17	0.1625	0.12735	0.03515
18	0.13525	0.12735	0.00789
19	0.10782	0.12735	-0.0195
21	0.14549	0.12667	0.01882
22	0.13552	0.12667	0.00885
23	0.12793	0.12667	0.00126
24	0.14021	0.12667	0.01354
25	0.14226	0.12667	0.01559
26	0.0866	0.12599	-0.0394
27	0.13929	0.12599	0.0133
29	0.11633	0.12599	-0.0097
30	0.13387	0.12599	0.00789
31	0.08025	0.10037	-0.0201
34	0.13191	0.10037	0.03154
35	0.10998	0.10037	0.00961
36	0.10225	0.09969	0.00256
37	0.10101	0.09969	0.00132
38	0.09897	0.09969	-0.0007
39	0.10838	0.09969	0.00869
40	0.0766	0.09969	-0.0231
41	0.08247	0.09901	-0.0165

Table 8, Continued

42	0.11992	0.09901	0.02091
43	0.1232	0.09901	0.02419
44	0.14557	0.09901	0.04656
45	0.0592	0.09901	-0.0398
46	0.0875	0.11075	-0.0233
47	0.11019	0.11075	-0.0006
48	0.10973	0.11075	-0.001
49	0.09514	0.11075	-0.0156
50	0.07173	0.11075	-0.039
51	0.13445	0.11007	0.02438
52	0.1185	0.11007	0.00843
53	0.13559	0.11007	0.02552
55	0.09263	0.11007	-0.0174
56	0.07933	0.10939	-0.0301
57	0.09916	0.10939	-0.0102
58	0.12371	0.10939	0.01432
59	0.12883	0.10939	0.01944

Table 9- Inital table of predictors, coefficients, t-values and p-values

Predictor	Coef	SE Coef	T	P
Constant	0.11757	0.03218	3.65	0.001
Type	-0.0166	0.005564	-2.98	0.005
Ne	0.001038	0.000556	1.87	0.068
Twist	-0.00136	0.006819	-0.2	0.842

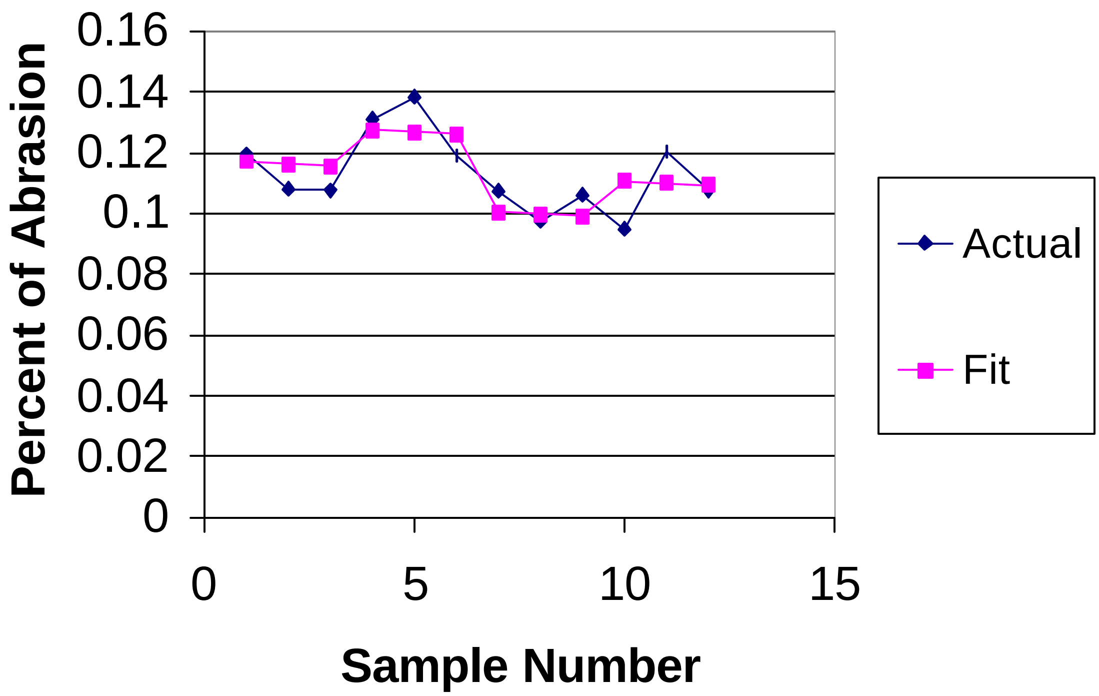


Figure 19 - Initial comparison of mean actual abrasion and mean fit values

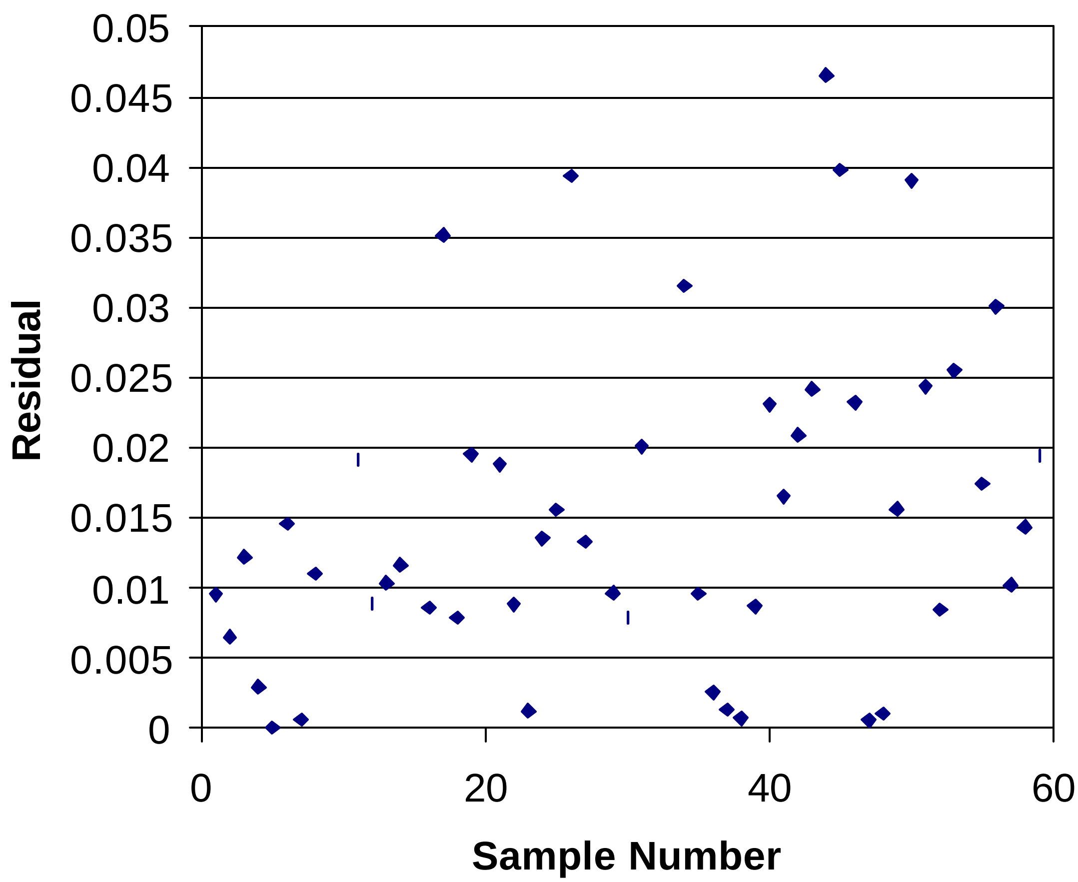


Figure 20 - Initial plot of residuals recorded for the entire data set

The initial regression equation, from Table 9, is: Abrasion = 0.118 - 0.0166 Type + 0.00104 Ne - 0.00136 Twist. The r-square value is 21.4%.

The term that indicates the ability of the equation to predict the abrasion values is the r-squared value (R-sq). It is known that an R-square value of 100% is difficult to obtain in the textile industry because of the inherent variability in spun yarns; therefore values from approximately 75% are desirable.

After producing the linear model to predict future abrasion values, the equation of the line can be evaluated as to how well it fits actual data. This is accomplished by measuring the difference between the predicted values and the actual values. Since this difference may be either positive or negative, the sum of the squares of the differences between the predicted abrasion value and the actual abrasion value is calculated. This method, the Least Squares Method, can be represented using a scatter diagram of the residuals. A residual is the difference between the actual and predicted value. A plot of the residuals of the initial linear regression is shown in Figure 20.

Such scatter in the residuals implies little fit between the actual and predicted values, thus giving a low R-square value. As can be seen in Figure 19, the fit values do not predict the actual value. This is to be expected when a statistical model shows a low R-square value. For these results the R-square value was 21.4%. R-square values that show a good prediction of actual data are generally much higher (>75%).

Also, from the statistical results, the twist appears to be insignificant in abrasion. This is shown by its high p-value of 0.842. P-values of 0.5 or less are required for a 95% confidence. One would expect twist to have a very prominent role in predicting abrasion. This lack of significance might be associated with the limited twist ranges selected for study and the use of mechanical twist level rather than the actual yarn twist level. Also notable is the level of significance of yarn type and yarn count p-values, which are 0.005 and 0.068, respectively. Values less than 0.05 represent a 95% confidence. P-values in this range normally imply that the variables being investigated are significant predictors of the dependent variables being investigated.

The actual and predicted abrasion values were incorporated into Table 10. Separate plots for the open-end and ring-spun yarn types were created using the actual and predicted abrasion values. The open-end data is shown in Figure 21 and the ring-spun data is shown in Figure 22.

Visually, the data for the OE, 20 Ne yarn in Figure 21 illustrates a more accurate fit between the actual and predicted abrasion values. The 20 Ne abrasion value demonstrates a slightly decreasing trend as twist increases. The 30 Ne yarn abrasion increases slightly from 13.1% to 13.8% abrasion before decreasing to 11.9% at 4.5 TM. The 30 Ne yarn is more accurately described as a curved line. Because of the nature of linear regression, an estimate of abrasion based on curvilinear data is much less precise.

Table 10 - Table of Predicted Values

Spinning Method	Count: 20 Ne			Count: 30 Ne		
	3.5 TM	4.0 TM	4.5 TM	3.5 TM	4.0 TM	4.5 TM
Open-End	0.1166	0.1139	0.1111	0.1300	0.1272	0.1245
Ring-Spun	0.1009	0.0981	0.0953	0.1143	0.1115	0.1087

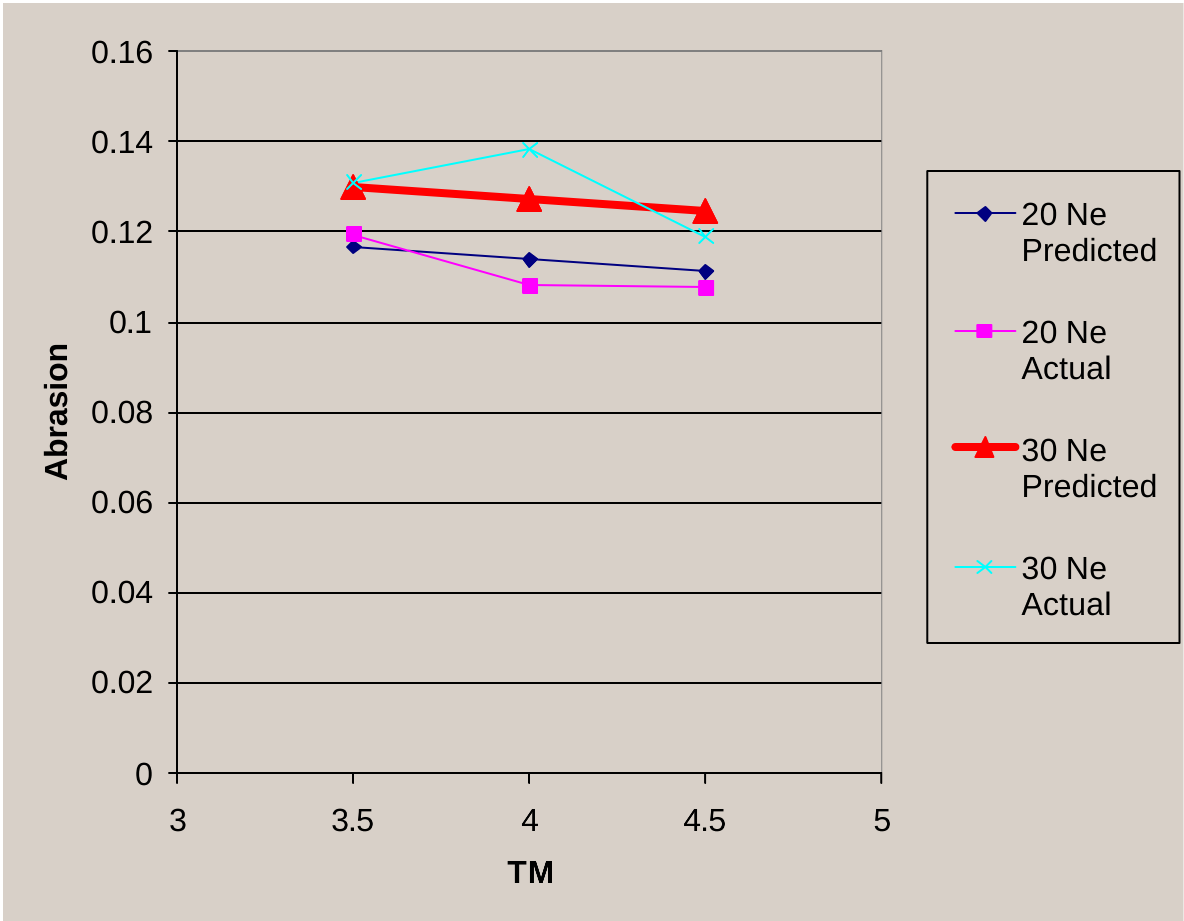


Figure 21 - Open-End Fit Comparison

Visually, the data for ring-spun, 20 Ne yarn in Figure 22 illustrates a more accurate fit between the actual and predicted abrasion values than the 30 Ne yarn. The 20 Ne abrasion value demonstrates a slightly decreasing trend as twist increases, which falls very closely to the actual abrasion value. The 30 Ne yarn abrasion increases significantly 9.5% to 12.5% abrasion before settling to 10.7% abrasion at 4.5 TM. The 30 Ne yarn in both the open-end and ring-spun figures suggests curvilinear abrasion data that is not accurately captured by linear regression analysis.

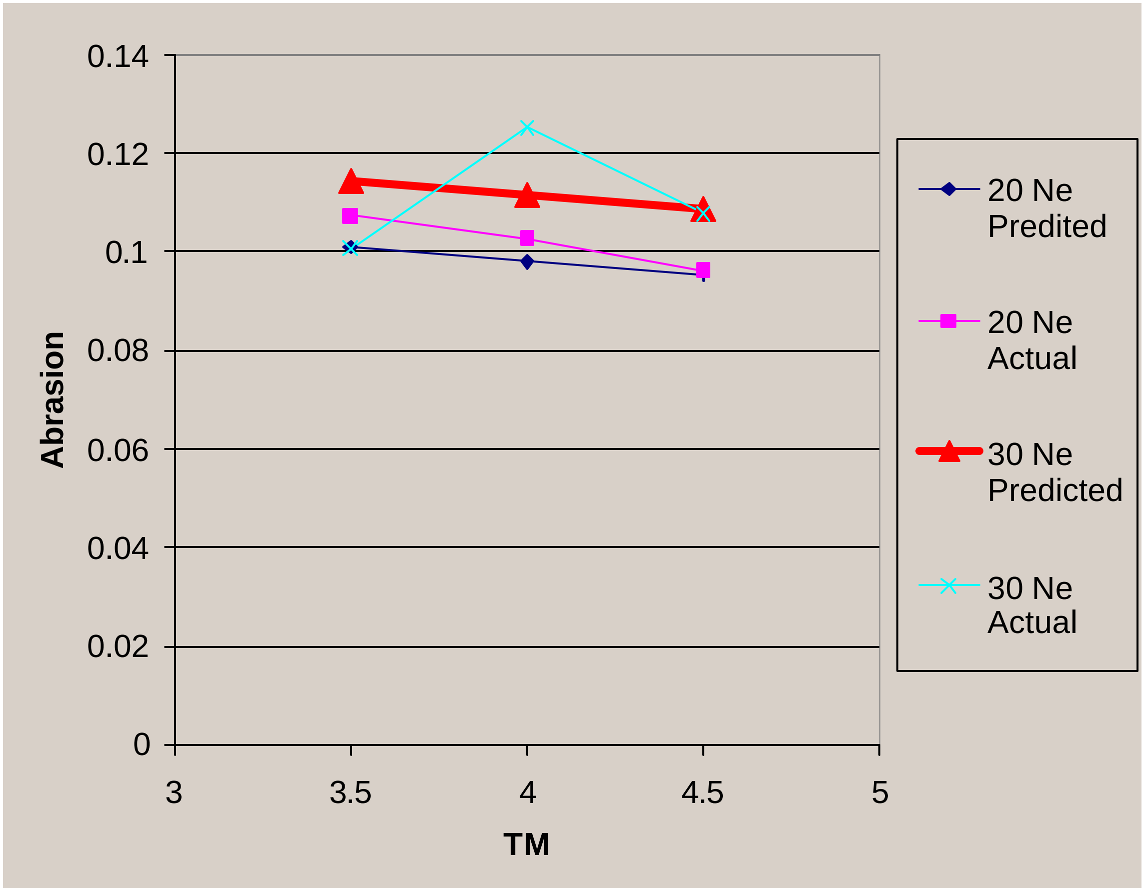


Figure 22 - Ring-Spun Fit Comparison

Based on the forecasted values using the regression equation, comparisons can be made based on twist and count. The predicted values indicate that as count increases, abrasion also increases. By comparing the values in each of the cells with corresponding twist, but different count, each of the cells with the higher count, have a higher abrasion level. Comparing the predicted values of abrasion for the same count, but varying twist, the abrasion level decreases as twist increases for both 20 and 30 count.

To determine the accuracy of the predicted values to actual data, the percent error was calculated and is provided in Table 11 and Table 12. The greatest error occurred with a twist of

4.0 with either the 20 Ne or 30 Ne yarns. However, the average value of a yarn with 30 Ne and twist multiple of 4.0 does not follow the predicted trend of decreasing abrasion as twist decreases. Upon graphing the predicted values versus the actual values, it appears the abrasion value for the 30 Ne yarn with a twist multiple of 4.0 seems skewed. However, it may be in fact that the 30 Ne yarn with a twist multiple of 3.5 is actually the culprit, as it provided the most difficulty during testing.

Table 11 – Percent Error Values of Abrasion for Open-End Yarn

OE		20			30	
	3.5	4.0	4.5	3.5	4.0	4.5
Predicted	0.11761	0.11163	0.10565	0.13544	0.12946	0.12348
Average	0.11941	0.10796	0.10754	0.13108	0.13828	0.11902
% Error	1.50	7.73	1.75	3.33	6.38	3.74

Table 12 - Percent Error Abrasion Values for Ring-Spun Yarn

Ring		20			30	
	3.5	4.0	4.5	3.5	4.0	4.5
Predicted	.09991	.10034	.10077	.10883	.10926	.10969
Average	0.10738	0.102653	0.096198	0.100639	0.125167	0.107759

It is likely that one linear regression equation cannot accurately represent both ring-spun and open-end yarn abrasion, since characteristics of the yarn types including surface and core fiber orientation vary significantly. This is a possible explanation for the low R-square value. Therefore, individual regressions were performed separately for the open-end and ring-spun abrasion data.

4.2.1 Open-End Data Analysis

The initial data set for the open-end yarn samples contained thirty data points. Of those, four did not run and two were outside the 95% confidence interval. Statistical models were run by sorting based on yarn type and doing the analysis only on type “1” yarns. Results are shown in Table 13, Table 14, Figure 23 and Figure 24.

From Table 14, the regression equation is Abrasion = 0.124 + 0.00181 Ne - 0.0121 Twist. The r-square value for this data is 33.7%. The r-square value has increased from 21.4% from the combined ring-spun and open-end data. This, combined with the very low p-value of 0.007 for yarn count, signifies the increase in abrasion predictability based on yarn count. The yarn twist p-value exceeds the accepted p-value limit of 0.05. The p-value of 0.112 shows twist to be significant with only 88.8% confidence.

Since twist was not significant at the 95% confidence level, it was removed from the model in an attempt to increase model accuracy. This generated a model having yarn count as the only independent variable. Results form this model are shown in

Table 15, Table 16, Figure 25, and Figure 26.

Table 13 - Regression Analysis of Open-End Data

Obs	Actual	Fit	Residual
1	0.10744	0.11814	-0.0107
2	0.12348	0.11814	0.00534
3	0.12917	0.11814	0.01102
4	0.11992	0.11814	0.00178
5	0.11702	0.11814	-0.00112
6	0.10169	0.11208	-0.01039
7	0.11691	0.11208	0.00483
8	0.10526	0.11208	-0.00682
11	0.09644	0.10602	-0.00958
12	0.12449	0.10602	0.01847
13	0.10526	0.10602	-0.00076
14	0.10395	0.10602	-0.00207
16	0.11875	0.1362	-0.01745
17	0.1625	0.1362	0.0263
18	0.13525	0.1362	-0.00096
19	0.10782	0.1362	-0.02838
21	0.14549	0.13014	0.01535
22	0.13552	0.13014	0.00538
23	0.12793	0.13014	-0.00221
24	0.14021	0.13014	0.01007
25	0.14226	0.13014	0.01212
26	0.0866	0.12408	-0.03748
27	0.13929	0.12408	0.01521
29	0.11633	0.12408	-0.00775
30	0.13387	0.12408	0.00979

Table 14 - Coefficients, T-values, and P-values for the Open-End Regression

Predictor	Coef	SE Coef	T	P
Constant	0.12445	0.03235	3.85	0.001
Ne	0.001806	0.000604	2.99	0.007
Twist	-0.01212	0.007329	-1.65	0.112

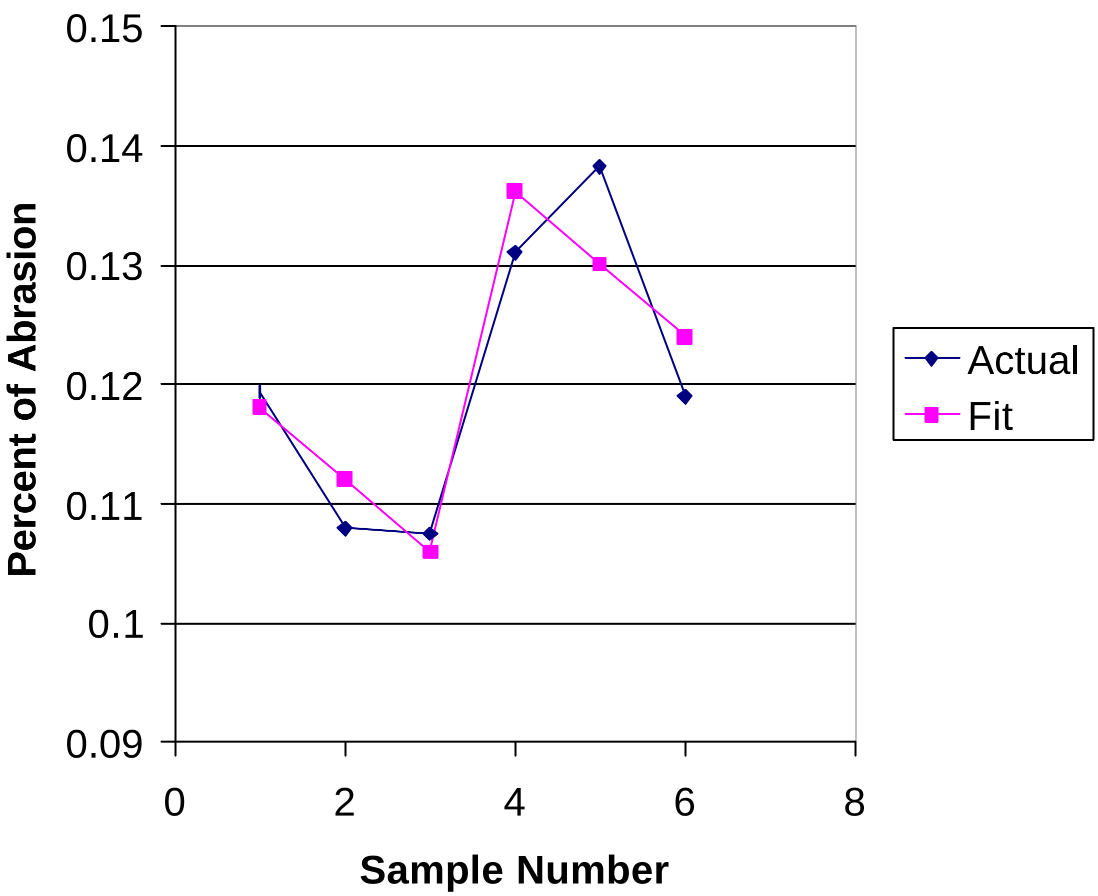


Figure 23 – Mean Abrasion Values versus the Fit Abrasion Value for Open-End Linear Regression Model with Yarn Count and Yarn Twist as Predictors

The Actual and Fit values in the initial open-end regression are shown in the figure. Although the lines share similar shape, the R-square value of 33.3% indicates the regression equation could be improved.

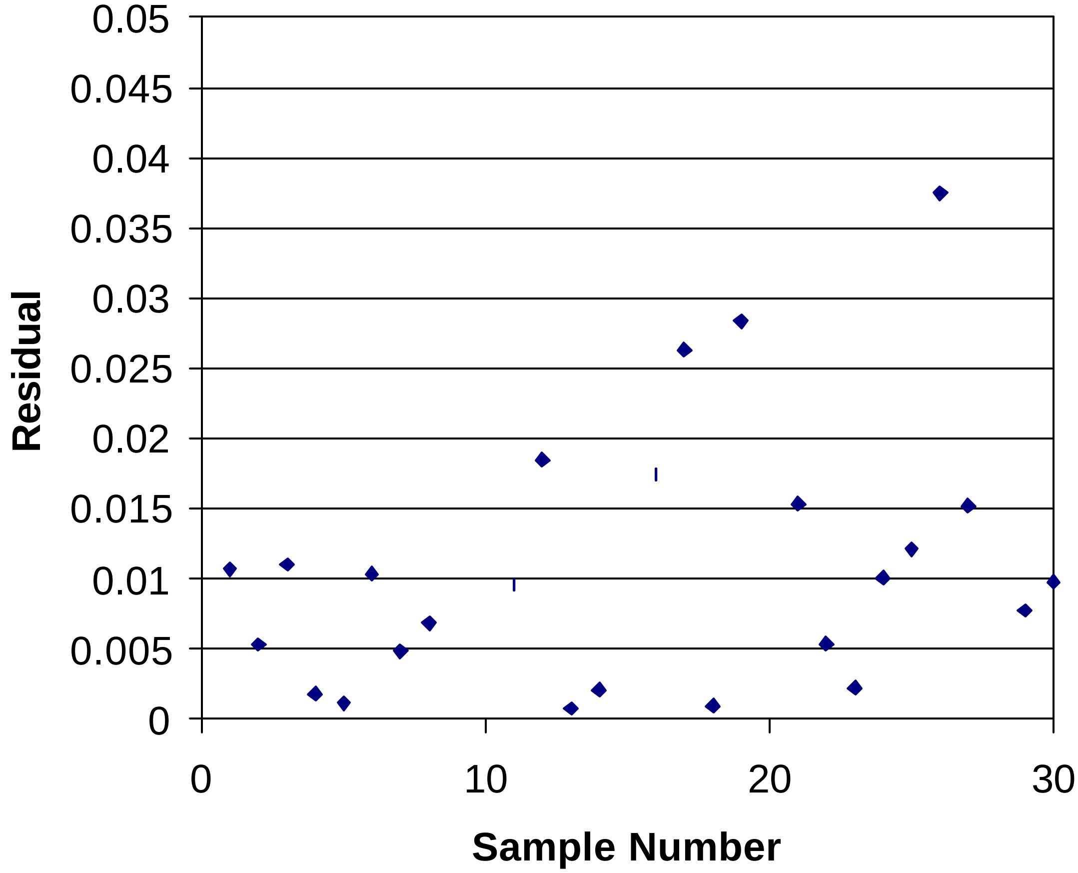


Figure 24 – Initial Regression Plot of OE Values for the Abrasion Model with Yarn Count and Yarn Twist as Predictors

The random dispersion of the regression values do not indicate trends that could improve the regression equation.

Table 15 - Open-End Regression Analysis of Count

Obs	Actual	Fit	Residual
1	0.10744	0.11259	-0.00515
2	0.12348	0.11259	0.0109
3	0.12917	0.11259	0.01658
4	0.11992	0.11259	0.00733
5	0.11702	0.11259	0.00444
6	0.10169	0.11259	-0.01089
7	0.11691	0.11259	0.00432
8	0.10526	0.11259	-0.00732
9	*	0.11259	*
10	*	0.11259	*
11	0.09644	0.11259	-0.01615
12	0.12449	0.11259	0.0119
13	0.10526	0.11259	-0.00732
14	0.10395	0.11259	-0.00864
15	*	0.11259	*
16	0.11875	0.13014	-0.01139
17	0.1625	0.13014	0.03236
18	0.13525	0.13014	0.00511
19	0.10782	0.13014	-0.02232
20	*	0.13014	*
21	0.14549	0.13014	0.01535
22	0.13552	0.13014	0.00538
23	0.12793	0.13014	-0.00221
24	0.14021	0.13014	0.01007
25	0.14226	0.13014	0.01212
26	0.0866	0.13014	-0.04354
27	0.13929	0.13014	0.00915
28	*	0.13014	*
29	0.11633	0.13014	-0.01381
30	0.13387	0.13014	0.00373

Table 16 - Coefficients, T-Values, and P-Values for Open-End Analysis of Count

Predictor	Coef	SE Coef	T	P
Constant	0.07748	0.01607	4.82	0
Ne	0.001755	0.000626	2.81	0.01

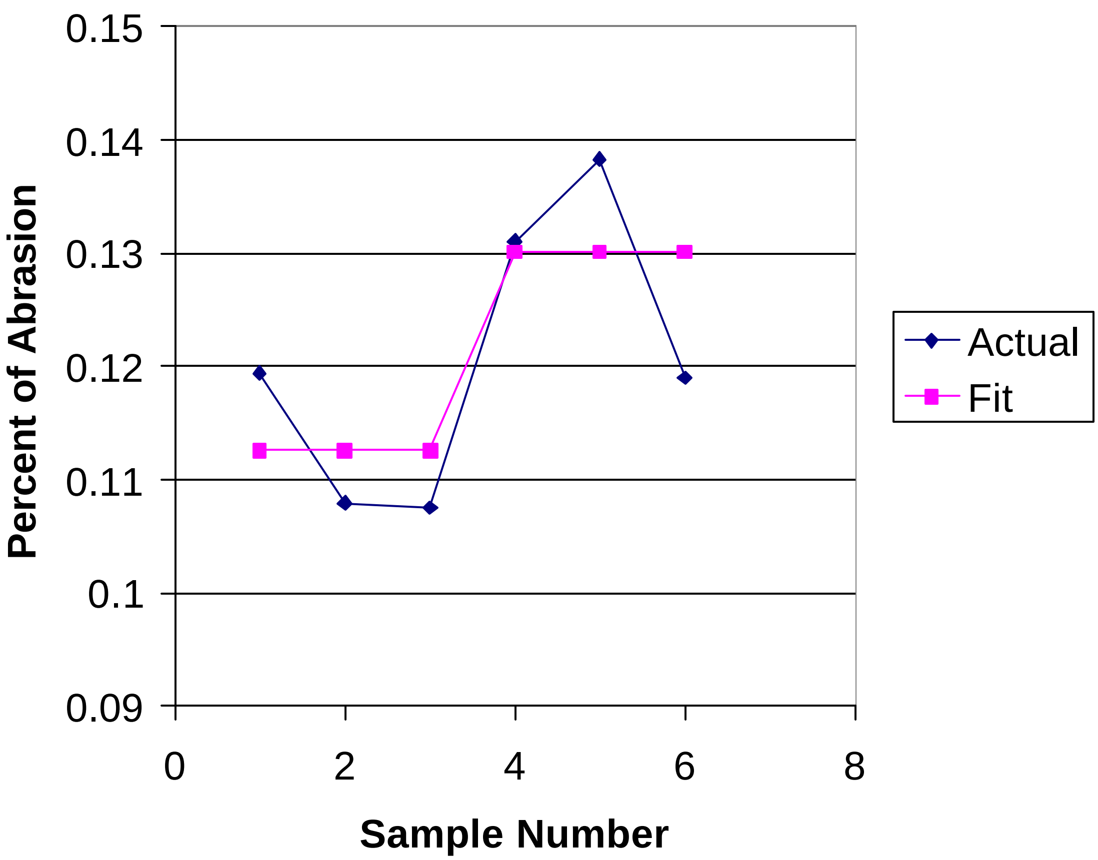


Figure 25 – The Mean Abrasion Value versus the Fit Value using Yarn Count as the Predictor for Open-End Yarns

The Actual and Fit values have a weaker correlation once twist is removed from the regression equation. Therefore, twist is an important predictor of abrasion.

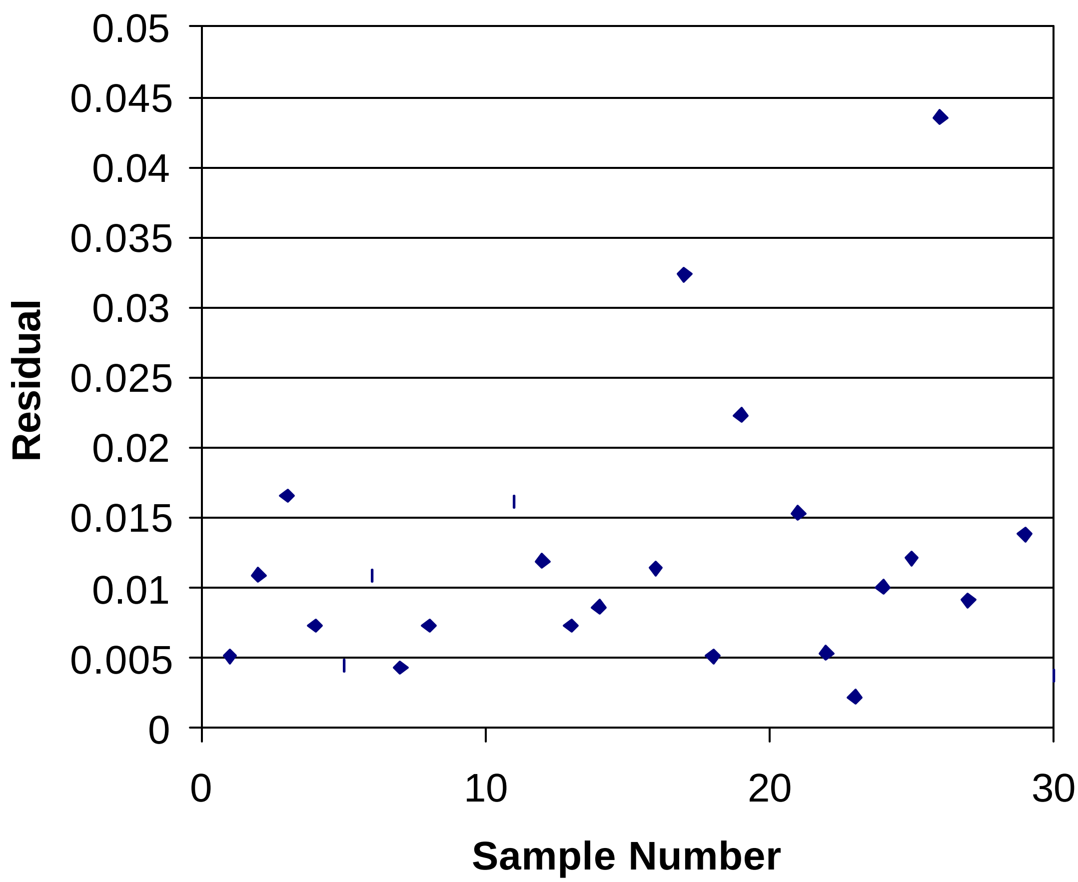


Figure 26 – Initial Regression Plot of OE Values for the Abrasion Model with Yarn Count as the Predictor

The regression equation is Abrasion = 0.0775 + 0.00176 Ne. The r-square value is 25.5%. The p-value of count remains essentially unchanged when the predictor of yarn twist is removed from the regression analysis. Also, the r-square value decreases from 33.7% to 25.5%, showing that a regression model based solely on yarn count is less accurate. This can also be concluded by comparing Figure 23 and Figure 25.

A graph of the residuals is plotted in Figure 27. The residual values for the residual plot that incorporates both yarn twist and yarn count as predictors appears to be a better fit than using yarn count as the only predictor. This is evident by the values of "twist and Ne" that are oriented more closely to the x-axis.

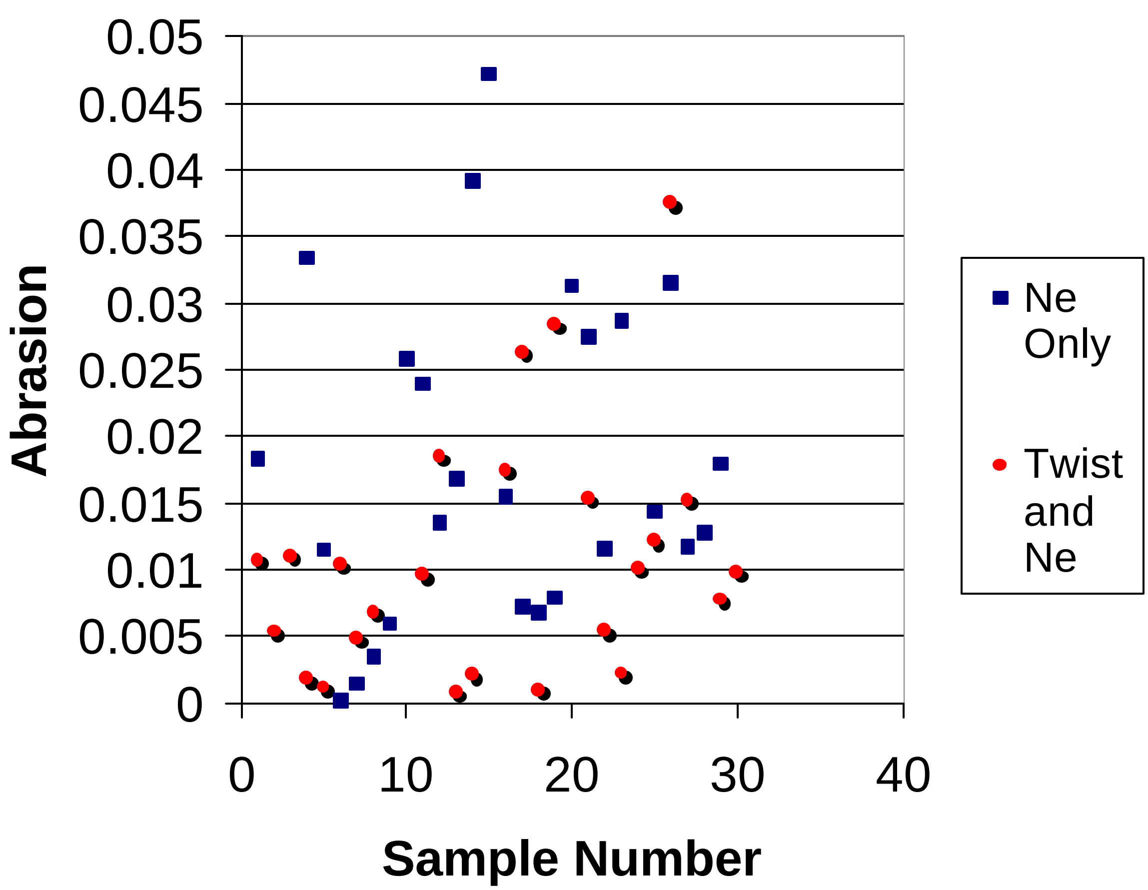


Figure 27 – Combination of Two OE Residual Plots with Twist and Ne as one predictor and "only Ne" as the other

The model in Figure 23 fits the data better than that of Figure 25. The fact that twist did not prove to be significant in the previous model, but its removal tends to degrade the model, implies that twist may have a nonlinear relationship to abrasion.

4.2.2 Ring-Spun Data Analysis

Of the original thirty samples in the data set, two did not run and two others were outside of the confidence interval. Statistical models were run on these type "2" yarn abrasion values and the results are shown in

Table 17, Table 18, Figure 28 and Figure 29.

The regression equation for the ring-spun data is Abrasion = 0.0619 +0.000451 Ne + 0.0079 Twist. The s-value and r-square value are 0.02285 and 2.8%, respectively. These values, combined with the p-values of 0.623 for yarn count and 0.489 for and yarn twist, show the profound lacking ability to accurately predict ring-spun yarn abrasion based solely on yarn count and twist.

Based on these results, it may be concluded that either none of the predictors for predicting the abrasion of ring-spun yarns have been analyzed, or yarn count and yarn twist have a nonlinear relationship to abrasion. A nonlinear relationship to abrasion would not appear in a linear model.

Table 17 - Regression Analysis for Ring-Spun Data

Obs	Actual	Fit	Residual
1	0.08025	0.09851	-0.01826
4	0.13191	0.09851	0.03341
5	0.10998	0.09851	0.01147
6	0.10225	0.10245	-0.0002
7	0.10101	0.10245	-0.00144
8	0.09897	0.10245	-0.00348
9	0.10838	0.10245	0.00594
10	0.0766	0.10245	-0.02585
11	0.08247	0.10639	-0.02392
12	0.11992	0.10639	0.01353
13	0.1232	0.10639	0.01681
14	0.14557	0.10639	0.03918
15	0.0592	0.10639	-0.04719
16	0.0875	0.10301	-0.01551
17	0.11019	0.10301	0.00717
18	0.10973	0.10301	0.00672
19	0.09514	0.10301	-0.00788
20	0.07173	0.10301	-0.03128
21	0.13445	0.10696	0.0275
22	0.1185	0.10696	0.01155
23	0.13559	0.10696	0.02864
25	0.09263	0.10696	-0.01433
26	0.07933	0.1109	-0.03157
27	0.09916	0.1109	-0.01174
28	0.12371	0.1109	0.01281
29	0.12883	0.1109	0.01793

Table 18 - Coefficients, T-values, and P-values for Ring-Spun Regression

Predictor	Coef	SE Coef	T	P
Constant	0.06189	0.05343	1.16	0.259
Ne	0.000451	0.000906	0.5	0.623
Twist	0.00789	0.01121	0.7	0.489

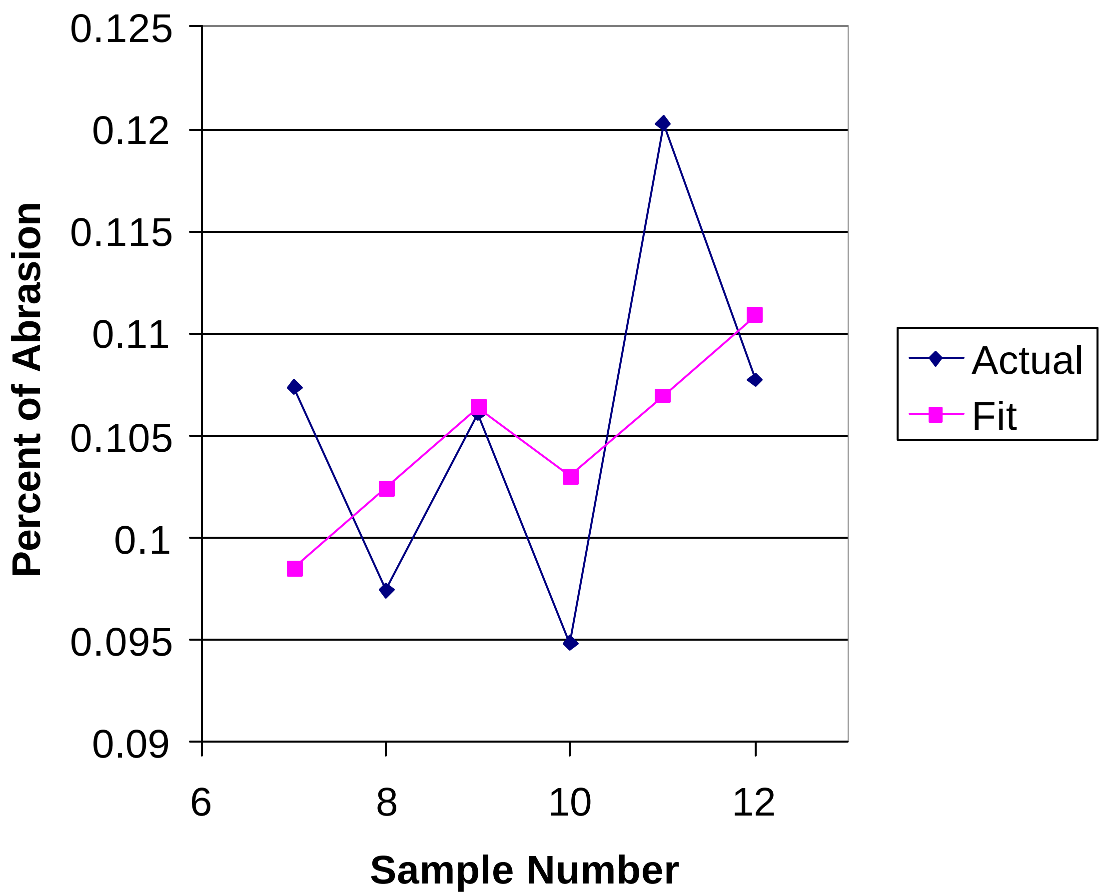


Figure 28 – The Mean versus the Fit Values for the Ring-Spun Yarn Linear Regression

The Actual and Fit values for the ring-spun linear regression do not coincide at all, supporting the 2.8% R-square value yielded by the linear regression equation.

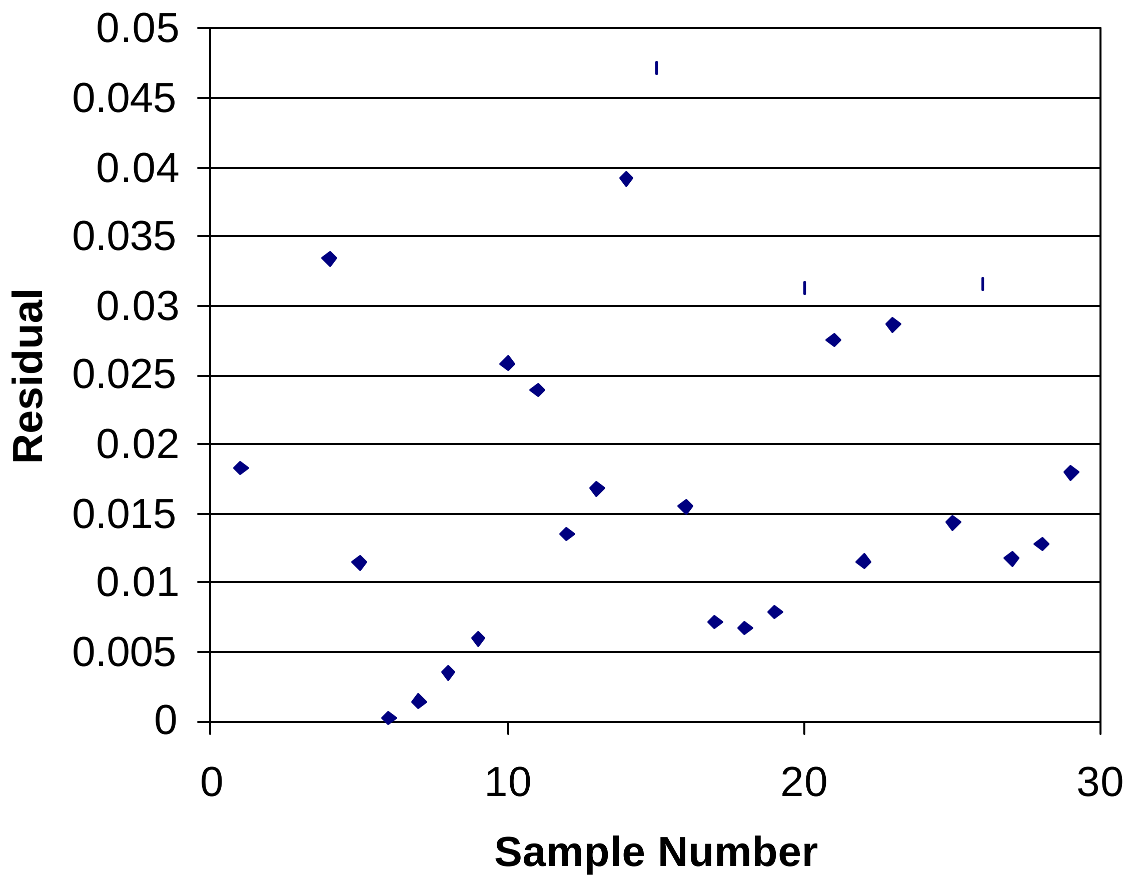


Figure 29 – Plot of the Ring-Spun Yarn Regressions

4.2.3 Summary of Ring-Spun and Open-End Statistical Analysis

Throughout the entire statistical analysis, the highest R-square value was achieved by the open-end regression equation that analyzed only type “1” data and used yarn twist and yarn count as predictors. No model was found that predicted the abrasion of ring-spun yarns with any accuracy. Since both ring-spun and open-end models have very low R-square values, this statistical analysis leads to the conclusion that either inappropriate levels of twist and count were selected or independent variables selected have a nonlinear relationship to abrasion.

Although the statistical analysis was inconclusive, there were some obvious differences in the abrasion characteristics of the yarns in this research. These differences, though not significant, were associated with type of yarn, yarn count and yarn twist level.

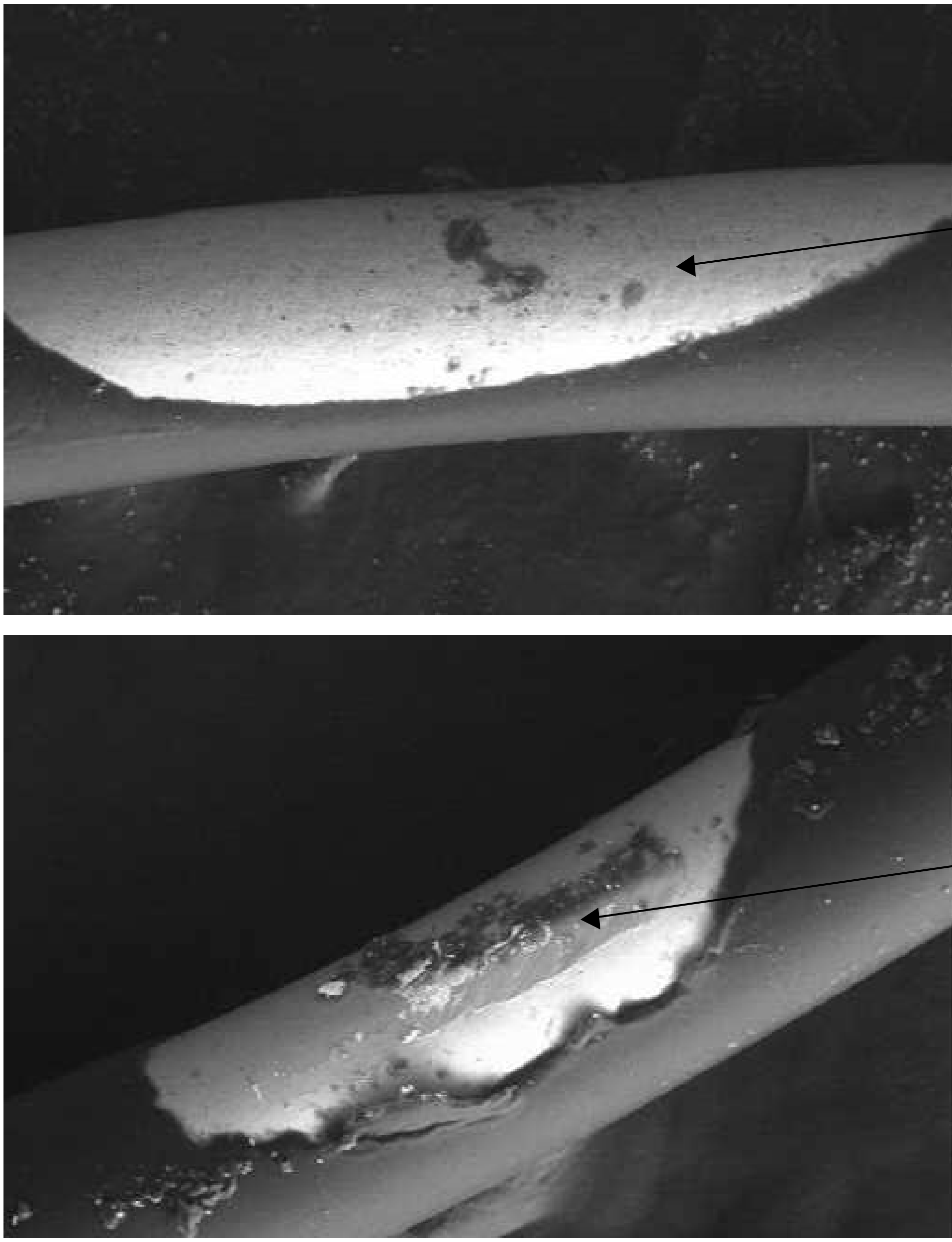
4.3 Yarn Type vs. Abrasion

The disparity in abrasion among yarn types was the primary basis for this research. Historically, ring-spun yarn was the major yarn type that was produced and converted to fabric. When the supply of yarn shifted from ring-spun to open-end yarns, an important change occurred in the knitting industry. Knitting needles were wearing out much more quickly. Evans [1] illustrated how the life of knitting needles was reduced to approximately 16%-20%. The results presented in this research address the observation in the U.S. knitting industry that open-end spun yarns are more abrasive than ring spun yarns.

In order to assess the difference in open-end and ring-spun yarn abrasion, several different evaluations were performed. The first evaluation was a visible comparison of open-end and ring-spun yarn abrasion using the SEM. In the initial experiment, a 1000 m length of each yarn type passed over a segment of wire. Each abrasion zone was viewed and captured using the SEM. The images shown in Figure 30 visualize the effect of yarn type on wire attrition.

The cylindrical wire in the SEM image is covered with a polyurethane/nylon coating, which is nonconductive and appears as a dark black surface. Below the coating is solid, bare copper wire. Its strong conductivity is highly reflective and appears bright white color in the image. During the CTT experiment, the polyurethane/nylon coating was worn away by the yarn, exposing the bright copper surface beneath. The flecks of dark matter on the copper surface are believed to be shards of the coating that are superficially attached to the wire.

A comparison of wire attrition by ring and open-end yarn types is shown in Figure Figure 30. The image of the open-end yarn illustrates how the yarn has completely worn away the wire coating. Conversely, a portion of the wire coating is still affixed to the wire in the abrasion region of the ring-spun image. This is a visible confirmation that ring-spun yarn resulted in a lower level of wire attrition than open-end yarn.



The open-end yarn has completely worn away the wire coating, revealing the bright copper surface below.

The less abrasive ring-spun yarn is more gentle to the wire. Even a portion of the wire coating remains on the wire surface.

Figure 30 - 10 Ne, 4.0 TM_e open-end yarn (top), ring spun yarn (bottom)

This is a visual comparison of the different abrasion characteristics of ring-spun and open-end yarn. The transition from metal to coating in the open-end yarn abrasion image is very smooth, indicative of a solid, abrasive interaction. The jagged coating of the ring-spun abraded wire shows how pieces of coating have been pulled away from the wire, leaving the transition from metal to coating relatively unscathed.

A visual confirmation that the open-end yarn is more abrasive than ring-spun yarn, has been observed. A qualitative evaluation of the level of abrasion was desired since previous experimentation by Bryan [10] concluded that "rotor-spun yarns are *less* abrasive than ring-spun yarns" (Emphasis added).

The data in Figure 18 qualitatively reveals the differences in abrasion between the yarn types in the experiment. The open-end 30 Ne yarn appeared to be the most abrasive with abrasion values of approximately 14%. The open-end 20 Ne yarn fell between the abrasion values of the 30 Ne open-end yarn and the 20 Ne ring-spun yarn with abrasion levels of 11%-12%. The 20 Ne ring yarn appeared to be the least abrasive as its values remained near 10%. The data for the 30 Ne ring-spun yarn was too imprecise to draw an accurate conclusion.

There are several different reasons why open-end yarns appear more abrasive than ring-spun yarns. The reason attributed to increased abrasion by open-end yarns is their yarn structure. The individual fibers in ring yarns possess greater mobility than those in open-end yarns. This mobility allows the fibers ring yarn to bend and spread out more easily, thus distributing the force on the wire. Open-end yarn is characterized by a solid, highly twisted core of fibers, which possess very limited mobility. This lack of mobility is believed to contribute to the greater level of attrition caused by open-end yarns. An illustration of this concept is provided in Figure 31.

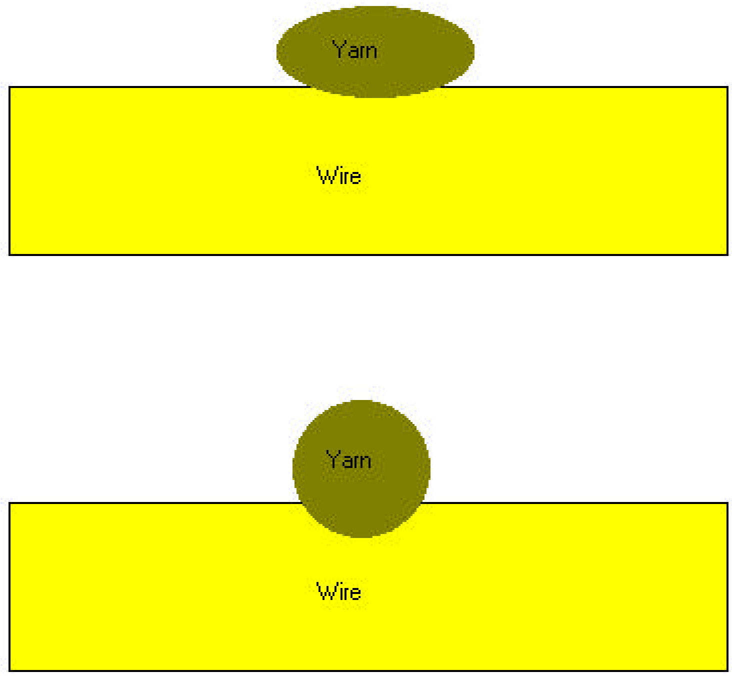


Figure 31 - Comparison of wire abrasion with high fiber mobility (top) and low fiber mobility (bottom)

The yarn in Figure 31 (top) is a representation of typical ring-spun yarn. As the yarn crosses over the wire it fans out over the surface of the wire. The greater surface area reduces the force per area or stress (ó) on the wire surface. The lower level of stress on the wire results in a lower level of wire attrition.

4.4 Yarn Twist vs. Abrasion

Yarn twist was believed to be a significant factor in yarn abrasion. An increase in yarn twist results in increased yarn stiffness and decreased fiber mobility. The yarn twist test results in Figure 31 showed that there was little difference between the greatest and lowest wire abrasion value. The set of results range in value from 9.7% +/- 1.2% to 14.2% +/- 5.5%. More importantly, the trends for each of the experiments vary between positive and negative concavity, challenging the straightforward idea that abrasion increases as twist increases.

The addition of error bars exhibits a greater similarity between abrasion levels of various yarn twist values. The wire abrasion data suggests that the 30 Ne open-end yarn supports the claim that increasing twist yields and increase in wire attrition. The yarn abrasion values of the remaining yarns disprove this theory.

4.4.1 Ring Spun Yarn Twist vs. Abrasion

A characteristic believed to result in increased abrasion is yarn twist. Historically, a high twist multiple was thought to result in increased abrasion since the outermost layer of yarn becomes more perpendicular to the surface it abrades against. The more perpendicular orientation of the fibers was expected to increase yarn abrasiveness. A visual representation of the effect of yarn twist of 30 Ne ring-spun yarn, with TM_e's of 3.5 and 5.5 is illustrated in Figure 32. The images illustrate the effect of increasing yarn twist resulting in increased abrasion. The 3.5 TM_e yarn has a similar area of abrasion as the 5.5 TM_e yarn, but very little copper has been removed by its surface, illustrated by the full, round shape of the exposed copper. The higher twist ring-spun yarn has promoted a greater level of attrition, illustrated by the significant quantity of copper removed from the body of the wire. This is illustrated by the significant indention visible in the surface of the copper wire. The copper that has not been worn off the wire has been rubbed away from the top of the wire and onto its side. This can be seen by the waves in the copper surface of the wire in the bottom image.

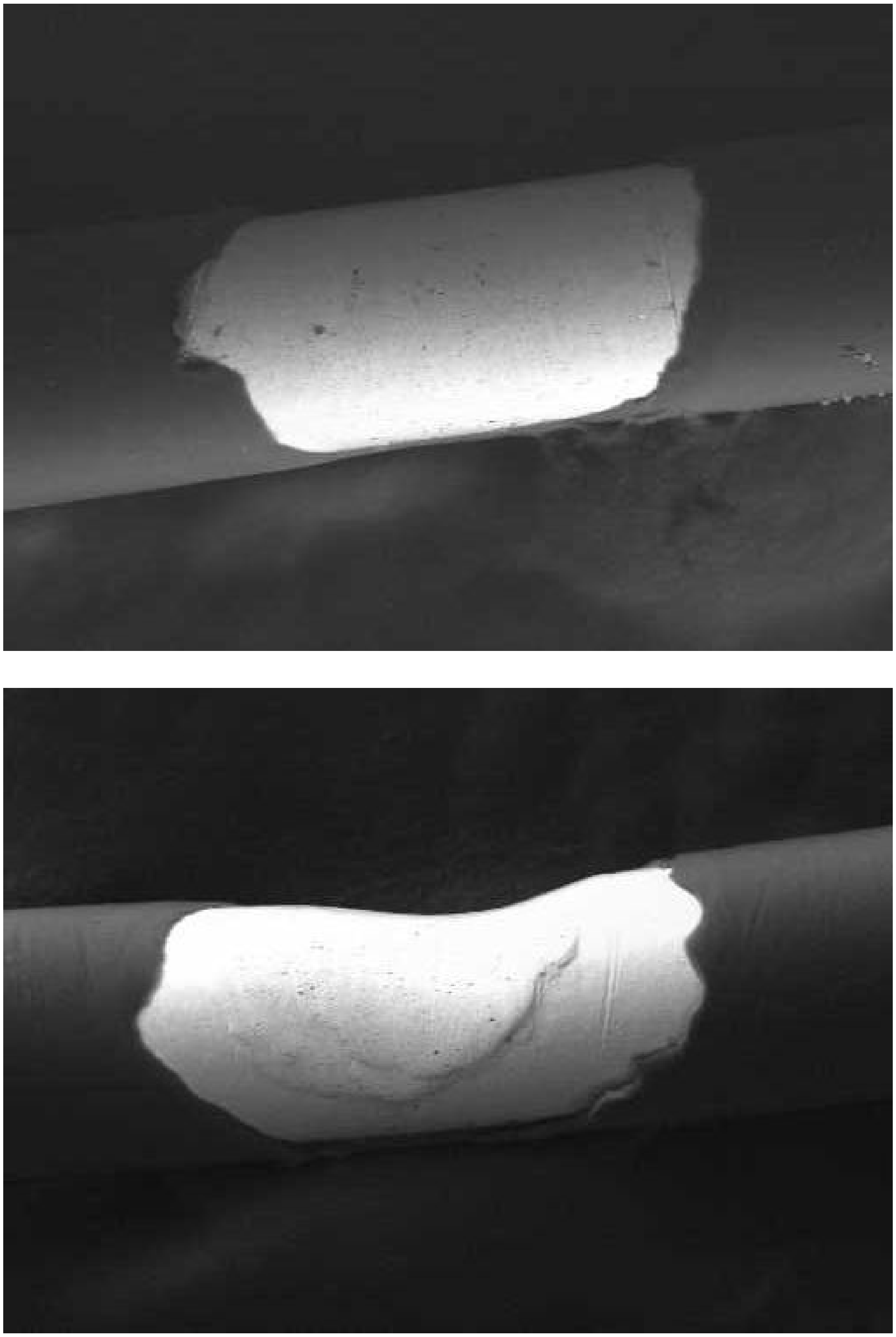


Figure 32 - Copper wire attrition of 30 Ne ring-spun yarn 3.5 TM_e (top) and 5.5 TM_e (bottom)

The difference in the attrition suffered by the wire is attributed to the stiffness of the yarn. A flexible, yielding yarn will be more likely to bend around the surface of the wire. The greater area of contact reduces the stress imposed on the wire, which results in decreased abrasion.

The stiffness of ring spun yarn increases as twist increases. The 3.5 TM_e ring spun yarn has low twist and therefore has low flexural rigidity. As the twist increases, so does the flexural rigidity to the point that the individual fibers have essentially zero mobility. In this situation, a much smaller contact region is created between the yarn and the wire. The force of contact is significantly higher and more abrasion occurs. This situation is very similar to the difference in yarn type and the same mechanics apply to this example. This situation is illustrated in Figure 31.

The fibers in the less rigid yarn have greater mobility, which allow the force on the wire to be distributed more evenly. This situation results in a much lower level of abrasion as the yarn passes over the wire. The opposite is true for the yarn with low fiber mobility. Since the fibers do not have the mobility to spread across the surface of the wire, a deep valley forms in the wire as the yarn crosses over it.

4.4.2 Open-End Yarn Twist vs. Abrasion

The effect of yarn twist of open-end yarn abrasion is comparably less apparent than that of ring-spun yarn. The reason for this difference is due to the inherently rigid structure of open-end yarn. The center of open-end yarn is highly twisted unlike that of ring-spun yarn. This highly twisted core gives the open-end yarn great flexural rigidity. Since open-end yarn already has high flexural rigidity, it is less affected by changes in twist level. The concentration of abrasion is nearly identical between the 3.5 TM_e and 5.5 TM_e samples as shown in Figure 33. Both twist levels cause the wire to be cut deeply.

The effect of increasing abrasion with increasing twist is essentially indiscernible in open-end yarns.

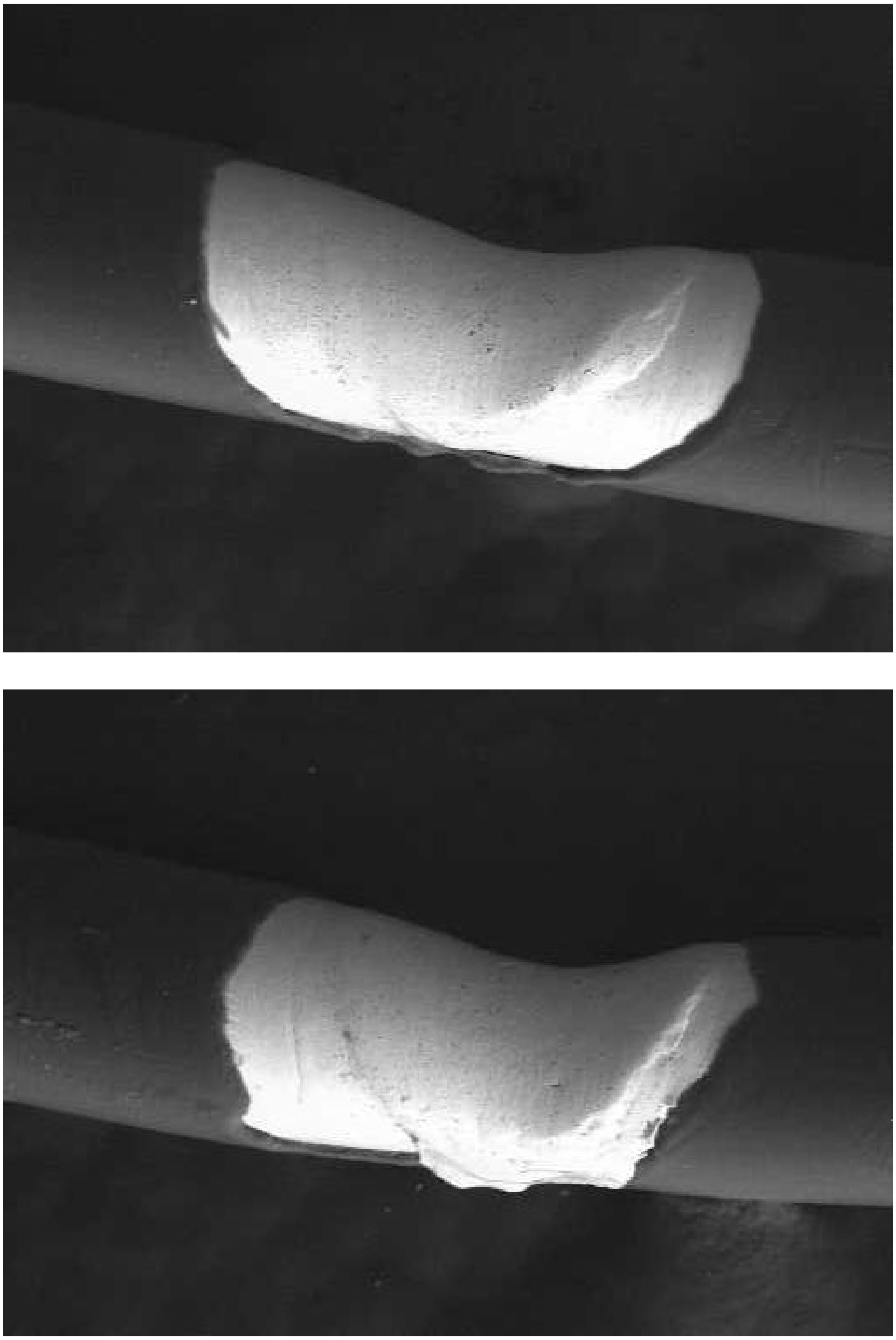


Figure 33 - Copper wire attrition by 30 Ne, open-end yarn with 3.5 TM_e (top), and 5.5_e TM (bottom)

4.5 Yarn Count vs. Abrasion

The relationship between yarn size and abrasion was expected to show that finer yarns were more abrasive than coarser yarns. The 20 Ne and 30 Ne open-end yarns illustrated this point well.

4.5.1 Yarn Count vs. Abrasion in Open-End Yarns

The images shown in Figure 34 illustrate the significant difference in attrition due to yarn count. The polyurethane/nylon coating is worn away by both the 10 Ne and 30 Ne yarn samples. The 10 Ne sample has a much wider area of abrasion. It is believed that the yarn does not slide longitudinally on the wire but remains in the “v” created by the tension of yarn on the wire illustrated in Figure 11. The greater area of attrition suffered by the wire is attributed to the larger diameter of the 10 Ne yarn. This phenomenon is explained in Figure 35.

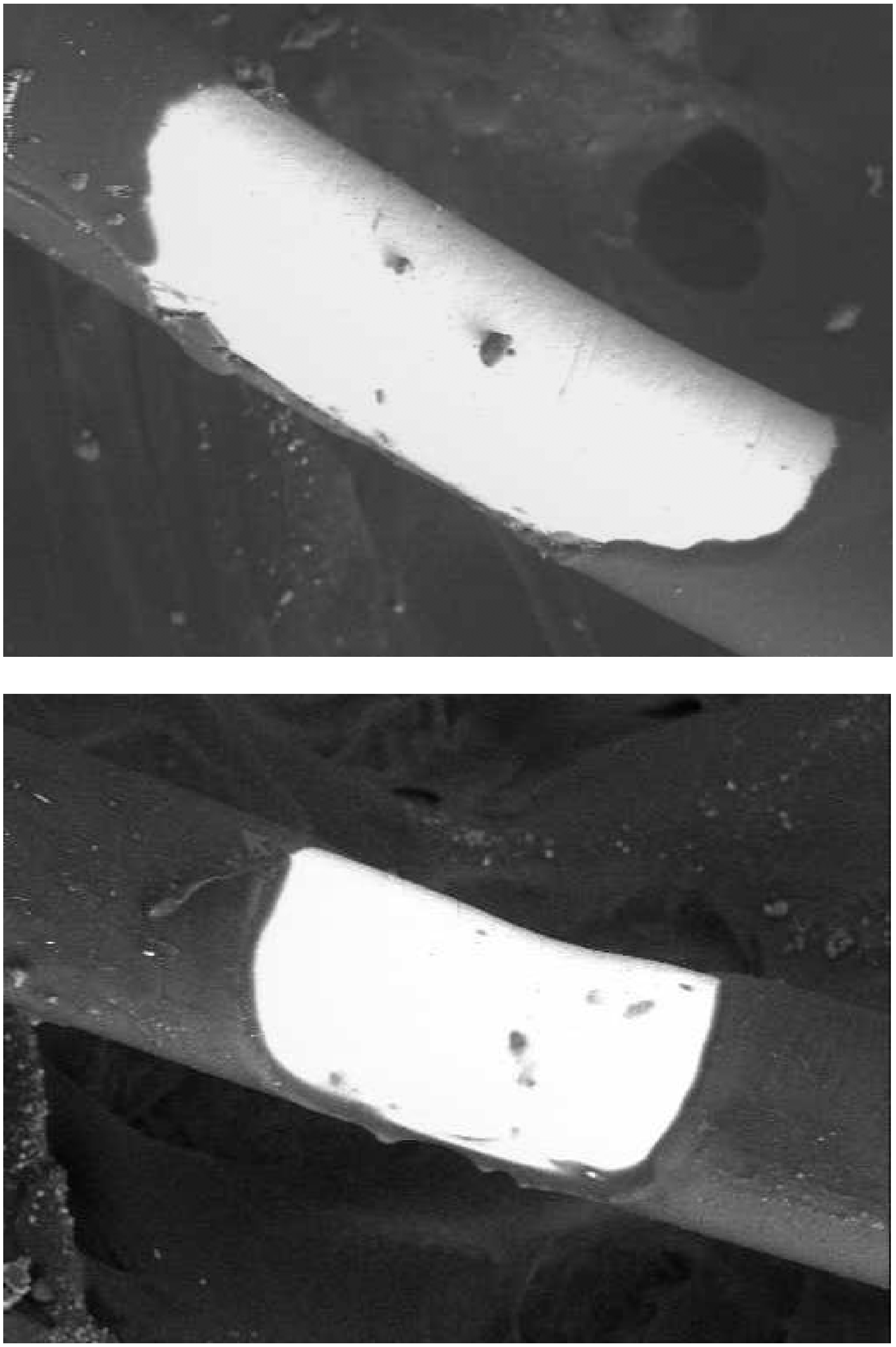


Figure 34 - Attrition of wire by OE yarn, 4.0 TM_e, 10 Ne (top) and 30 Ne (bottom)

The wider yarn in Figure 35 (left) has a much larger area of contact with the wire than the thinner yarn on the right. The tension is an equal 25 grams of force (g-f) for both yarns. Since all other properties are equal, the yarn with the greater stress (ó) will sever the yarn more quickly. The only property that varies is the contact area between the yarn and wire. The smaller contact area of the yarn on the right of Figure 35 results in increased force imposed on the wire, increasing the stress and abrasion between the wire and the yarn.

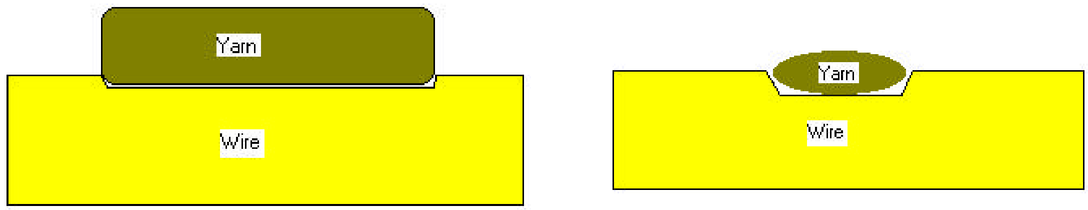


Figure 35 - Wear of wire due to different yarn size

4.5.2 Yarn Count vs. Abrasion in Ring-Spun Yarns

In open-end yarns, the copper wire suffered a greater level of attrition by the 30 Ne yarn than its 10 Ne counterpart. The same situation applies to ring-spun yarns. The 30 Ne yarn was more abrasive than the 10 Ne yarn. Surprisingly, the area of abrasion is similar in the ring-spun yarn experiment. Figure 36 shows the attrition of a copper wire by ring-spun yarn whose TM_e is identical and whose yarn count varies from 10 Ne to 30 Ne.

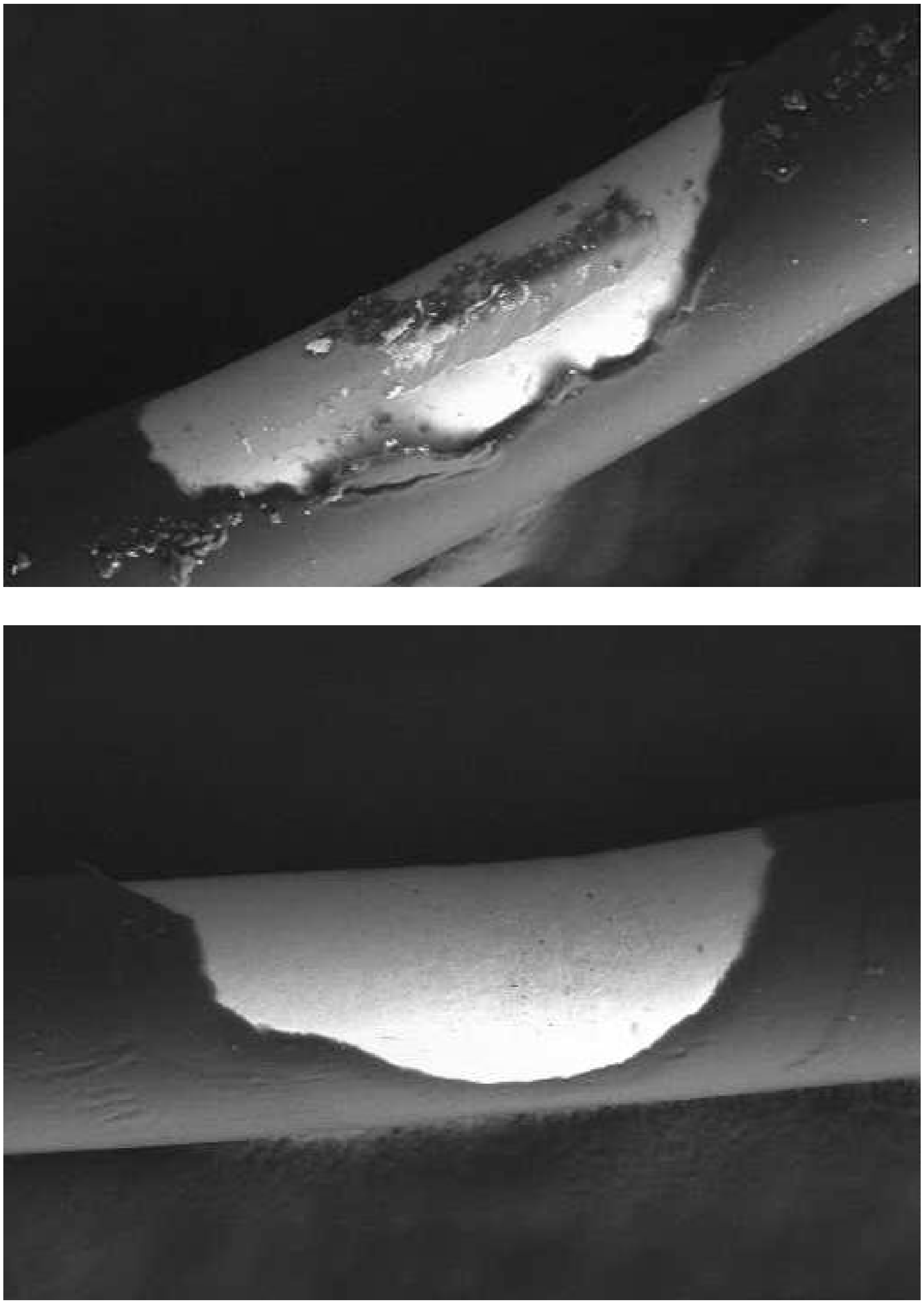


Figure 36 - Attrition of wire by ring-spun yarn, 4.0 TM_e, 10 Ne (top), 30 Ne (bottom)

Although the area of attrition is similar for both yarns, the depth of abrasion is decisively greater for the 30 Ne yarn. The dark segment of wire coating, which has not been worn away from the copper surface, illustrates the lack of abrasion by the 10 Ne yarn. The wire coating in the abrasion region of the 30 Ne sample has completely worn away and additional abrasion has occurred into the copper surface. The wear, indicated by the slight concavity in the surface of the wire, is greater for the 30 Ne sample.

4.5.3 Yarn Count vs. Abrasion Summary

For both open-end and ring-spun yarns, as yarn size decreases, the level of wire attrition increases. The open-end yarn, with its lower fiber mobility, wears an abrasion region on the wire that widens as the yarn count increases. Conversely, ring-spun yarn had greater fiber mobility, resulting in a similar abrasion width as the yarn count varied.

5 Conclusions

In the early 1980s there was "a degree of panic in the US knitting industry, with reports of needle failure in 4-10 weeks when working with open-end spun yarns, as compared to a replacement life of 6-12 months when knitting conventional ring spun yarns" [1]. However, the research conducted comparing the abrasion of both open-end and ring-spun yarns contradicted these claims. Although the data supported the condition that open-end yarns are more abrasive than ring-spun yarns, the magnitude of this difference did not coincide with the claims of the knitting industry in the 1980s.

In addition to yarn type, the abrasion resulting from differences in twist and count were examined. Historically, a high twist multiple was believed to result in increased abrasion. This trend was generally supported by the findings of this study for open-end yarns. Although the magnitude of the abrasion level was significantly more profound in ring-spun yarns, the trends associated with this abrasion were practically nonexistent. The difference in the effect of twist on ring-spun vs. open-end yarn may be explained by the inherently rigid structure of open-end yarn over a range of twist multiples.

The effect of twist is more significant to ring-spun yarn, although it is much more random for the yarn samples tested in this study. While the expected trend of an increase in abrasion with an increase in twist was supported by this research, the data was inconsistent. Statistical analysis suggests that a nonlinear relationship between yarn twist and abrasion may exist for ring-spun yarns. The effect of twist on ring-spun yarn must be more carefully examined in order to resolve its relationship with abrasion.

Historically, an inverse relationship exists between abrasion and count. As count increases, the abrasion of the yarn on the knitting needles decreases. This study conclusively confirmed the relationship between count and abrasion.

With all other factors being equal, open-end yarns are more abrasive than ring-spun yarns, but not nearly to the degree observed by the knitting industry in the early 1980s. The data in this study revealed that the level of abrasion is not significantly greater between yarn types, counts, and twists. This is confirmed by the fact that the highest and lowest abrasion level of the yarns varied no more than 10%.

The data in this study still does not answer the question of why the knitting industry experienced such a rapid decline in needle life when knitting with open-end yarns. This may be due to a combination of inherent differences in the cotton stock used to produce each yarn type, as well as the position of these impurities in the yarn structure. Both Evans and Groz-Beckert cited contaminants in open-end yarns as the major culprits of accelerated needle wear. Since Groz-Beckert reports the greatest gradient in the abrasion of knitting needles appears when the yarns contain an incomparable level of impurities, research should be conducted to examine this phenomenon.

6 Future Research

The results of this study imply a slight difference in the abrasion characteristics of different yarn types, counts, and twists. The error associated with these results, however is significant enough to require a more accurate method to measure abrasion. The use of actual knitting needles may suggest different levels of wear and therefore was attempted in this study. Unfortunately, the hard nickel coating on the needles prevented the appearance of a significant level of abrasion. Attempts were made to coat the needle with a sputtercoater. The needles could not be properly oriented in the sputtercoater in order to consistently coat the hook and latch. The wear of the needle is of particular interest because it most closely resembles the wear experienced by the needle in practice. It may be possible to coat the needle with a chemical that is worn away by the yarn.

The dynamics of the yarn over the wire were of great interest. Several experiments may shed light onto the motion of the yarn. These include the filming of the yarn running over the wire with a high-speed camera, and the measurement of the "bounce" of the yarn on the wire with a high-speed tension meter.

The gauge of the wire may need to be revised to more closely resemble the shape of a knitting needle. The wire used in this study was a fine, 34 gauge wire. It was suggested that the hairs of the yarn were subjected to a force against the wire that sheared the hairs from the yarn. Although this was not concluded to occur, any alteration of yarn structure can negatively impact the reliability of the tests.

Ideally, the experiment would be reproduced in a real-time, actual factory setting using open-end and ring-spun yarns produced from identical cotton stock. The yarns would need to be knitted on two identical knitting machines under comparable conditions in order to effectively monitor the abrasion of each yarn type on the needles of each machine. The needles could then be examined using a SEM for a visible assessment of wear. An accurate and precise method of measurement would be required to determine the degree of needle wear. This accuracy and precision would be necessary since the level of abrasion would likely be small. In this experiment, abrasion varied by approximately 3% overall.

The yarn property that should receive the greatest priority in further examination of yarn abrasion is the quantity of abrasive particles in and on the yarn surface. These particles, claim Evans and Groz-Beckert, are primarily responsible for needle wear. Therefore, focusing on yarn contaminants as a major link in the statistical design will be useful in gaining an understanding of the effect of yarn parameters on needle wear. Since yarn type, twist and count were nearly insignificant with regard to yarn abrasion, the abrasive impurities in yarn should be examined in the future. This would most likely shed new light in the area of open-end and ring-spun yarn abrasion.

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Appendix A

		Material Properties			Test Conditions					
Trial Number	Date/Time	Yarn Type	Ne	TM_e	Test Veolcity (m/min)	Temp/RH%	Input Tension (cN)	Output Tension (cN)	Length to break (m)	Comments
1	5/24 11:20 AM	OE	10	4.0	100	80/33	10.4	23.2	~~2367~~	300g wire tension. The wire did not break. It elongated an activated a shut-off sensor.
2	5/24 11:45 AM	OE	10	4.0	100	80/33	10.3	24.1	-----	Reduced to 200g yarn tension. Yarn entangled around output rolls.
3	5/24 12:05 AM	OE	10	4.0	100	80/33	10.6	23.9	-----	Preset length—test terminated at 3600 m.
4	5/24 1:00 PM	OE	10	4.0	100	80/33	10.0	22.9	~~1916~~	Yarn became hung on feed mechanism and snapped. Fibers had a tendency to wrap around the copper wire.
5	5/25 1:35 PM	OE	10	4.0	360	80/36	10.2	25.6	~~3616~~	Increased airflow over wire. Preset length tripped.
6	5/25 1:55 PM	OE	10	4.0	360	80/36	10.0	25.0	3423.5	Wrapping fiber problem appears resolved. Clean break.
7	5/25 2:07 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	~~3616~~	Preset length tripped.
8	5/25 2:20 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	3715	Clean break.
9	5/25 2:32 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	~~3376~~	Yarn break.
10	5/25 2:45 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	3718	Good break.
11	5/25 3:08 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	~~3469~~	Yarn supply expired.
12	5/25 3:20 PM	OE	10	4.0	200	80/36	10.0	23.0-26.0	5543	
13	5/25 3:53 PM	OE	10	4.0	360	80/36	10.0	23.0-26.0	3916	
14	5/30 12:10 PM	OE	10	4.0	360	80/25	10.0	21-26	3191	Clean break.
15	5/30 12:23 PM	OE	10	4.0	200	80/25	10.0	21-23	~~10000+~~	Fibers wrapped around wire. Friction decreased. Test was aborted at 10,000 m
16	5/30 1:18 PM	OE	10	4.0	200	80/25	10.0	21-23	5231	Test repeated at higher air pressure across wire.
17	5/30 1:50 PM	OE	10	4.0	200	80/25	10.0	21-24	5858	Clean break.
18	5/30 2:22 PM	OE	10	4.0	360	80/25	10.0	21-25	2802	Clean break.
19	5/30 2:32 PM	OE	10	4.0	360	80/25	10.0	20-26	3093	Clean break.

20	6/01 11:20 AM	OE	10	4.0	100	80/26	10.0	20-23	-----	Yarn break.
21	6/08 1:26 PM	OE	10	6.0	360	80/26	10	22+	-----	Yarn wrapped around output rolls. Pressure too low.
22	6/08 1:39 PM	OE	10	6.0	360	80/26	10	21+	~~5280~~	Yarn wrapped around output rolls again. Pressure increased.
23	6/08 2:05 PM	OE	10	6.0	360	80/26	10	25+	-----	Yarn supply expired.
24	6/08 2:26 PM	OE	10	6.0	360	80/26	10	24+	-----	Fibers wrapped around wire.
25	6/08 2:42 PM	OE	10	6.0	360	80/26	10	24+	~~9280~~	Yarn expired. Fibers wrapped around wire.
26	8/09 4:05 PM	OE	10	4.0	360	80/26	50	98	~~392~~	New “wire guide.” Yarn break—wire sagged.
27	8/09 4:20 PM	OE	10	4.0	360	80/26	50	111	~~787~~	Bad break
28	8/09 4:30 PM	OE	10	4.0	360	80/26	50	107	1097	Good break
29	8/09 4:35 PM	OE	10	4.0	360	80/26	50	101-107	1128.1	Good break
30	8/10 4:40 PM	OE	10	4.0	360	80/26	50	103	912	Good break
31	8/10 1:35 PM	OE	10	4.0	360	80/26	50	99-105	~~859~~	Yarn break
32	8/10 1:45 PM	OE	10	4.0	360	80/26	25	54	1417	Good break
33	8/10 1:50 PM	OE	10	4.0	360	80/26	25	55	1731	Good break
34	8/10 1:56 PM	OE	10	4.0	360	80/26	25	56	1181	Good break
35	8/10 2:02 PM	OE	10	4.0	360	80/26	25	52-60	1633	Good break
36	8/10 2:08 PM	OE	10	4.0	360	80/26	25	52-60	1737	Air adjusted to reduce wrapping. No improvement.
37	8/10 2:15 PM	OE	10	4.0	360	80/26	25	52-60	1955	Fiber wrapping around wire
38	8/10 2:30 PM	OE	10	4.0	360	80/26	25	52-60	1669	Air adjusted again. Tangential airflow improved wrapping problem.
39	8/10 2:35 PM	OE	10	4.0	360	80/26	25	52-60	1837	Airflow adjusted and increased. Problem significantly reduced.
40	8/10 2:45 PM	R	20	5.5	360	80/26	25	52-60	6106	No wrapping fibers detected on wire.
41	8/18 1:28 PM	OE	10	4.0	360	80/26	25	52-60	2366	Wrapping fiber problem
42	8/18 1:35 PM	OE	10	4.0	360	80/26	25	52-60	3865	Wrapping fiber problem
43	8/18 1:45 PM	OE	10	4.0	360	80/26	50	52-60	-----	Yarn break
44	8/18 1:55 PM	OE	10	4.0	360	80/26	25	52-60	3810	
45	8/18 2:12 PM	OE	10	4.0	360	80/26	25	52-60	2201	Good clean break. Used hook to keep wire free of wrapping fibers.
46	8/18 2:20 PM	OE	10	4.0	360	80/26	25	52-60	2221	Good clean break. Used hook to keep wire free of wrapping fibers.
47	8/18 2:30 PM	OE	10	4.0	360	80/26	25	52-60	~~2793~~	Bad break—pulled on wire with hook
48	8/18 2:45 PM	OE	10	4.0	360	80/26	25	52-60	2797	Looked like a good break
49	8/18 3:00 PM	OE	10	4.0	360	80/26	25	52-60	2519	Looked like a good break
50	8/18 3:25 PM	OE	20	4.5	360	80/26	25	65	6654	Looked like a good break
51	8/18 3:55 PM	OE	10	4.0	360	80/26	25	68	14000 +	Yarn expired
52	8/18 4:35 PM	R	30	4.0	360	80/26	25	60	5934	Good break
53	8/21 11:15 AM	OE	10	4.0	360	80/26	25	60	2411	Good break
54	8/21 11:20 AM	R	10	4.0	360	80/26	25		-----	Too much wrapping
55	8/21 11:45 AM	OE	30	4.0	360	80/26	25	55	6668	Good break

	AM									
56	8/21 12:05 PM	R	20	4.5	360	80/26	25	57	~~3166~~	Too much fiber wrapping
57	8/23 11:00 AM	OE	10	4.0	360	80/26	25	58	2875	
58	8/23 11:25 AM	R	20	5.0	360	80/26	25	58	~~1529~~	Fiber wrapping problem
59	8/24 1:05 PM	OE	10	4.0	360	80/26	25	58	2991	Slight fiber wrapping
60	8/24 1:16 PM	OE	20	3.5	360	80/26	25	60	4656	Slight fiber wrapping
61	8/24 1:31 PM	R	20	5.5	360	80/26	25	60	~~4616~~	Bad break—fiber wrapping
62	8/24 1:50 PM	R	20	5.5	360	80/26	25	60	8503	Fiber wrapping problem
63	9/06 12:40 PM	OE	10	4.0	360	70/65	25	?	~~1018~~	New environment—Cotton Incorporated laboratory. Auto-stop was on.
64	9/06 12:45 PM	OE	10	4.0	360	70/65	25	?	~~1018~~	Auto-stop was on
65	9/06 12:50 PM	OE	10	4.0	360	70/65	25	?	1428	Looked like a good break
66	9/06 1:05 PM	OE	10	4.0	360	70/65	25	?	1912	Looked like a good break
67	9/06 1:10 PM	OE	10	4.0	360	70/65	25	?	1643	Looked like a good break
68	9/06 1:15 PM	OE	10	4.0	360	70/65	25	?	1560	Looked like a good break
69	9/06 1:20 PM	OE	10	4.0	360	70/65	25	?	1422	Looked like a good break
70	9/06 1:25 PM	R	10	4.0	360	70/65	25	?	?	Wrapping fiber problem
71	9/28 2:11 PM	R	30	3.5	360	80/26	25	47-48	~~1400~~	Return to COT Lab. Wire lost tension
72	9?28 2:17 PM	R	30	3.5	360	80/26	25	48-50	~~2490~~	Yarn break

Appendix B

http://bwccat.belden.com/cgi-bin/ncommerce3/ExecMacro/BELDEN/frames.d2w/report

Description

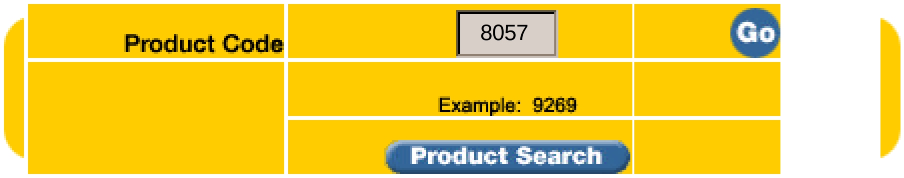
Special Application, Single Beldsol Solderable, 1/2 pound spool, 34 AWG. Beldsol Magnet Wire is a dual insulated Magnet Wire that combines the excellent dielectric characteristics of polyurethane and the known toughness and solvent resistance of a nylon overcoat. This wire is rated by IEEE tests for 270 deg.F usage and will solder without insulation removal at 750 deg.F. Complies with J-W-1177/9 specifications. MW 28-C (single).

Disclaimer: Great effort is made to ensure the accuracy of the information presented, but errors or omissions may occur. This listing of information is presented as a courtesy and does not ensure that a product with these specifications is available. Specification and availability should be confirmed with a call to our sales representative or to Customer Service. Have a question? Call us at 1-800-BELDEN-1 or send us a comment

07/16/01

http://ecom.belden.com/static/ZZBLDNTD01FROMCATA.HTM?P0=8057

To display Technical Data, enter a Product Code and press Go.



TECHNICAL DATA

07/28/98 REV. 0 8057

I. DESCRIPTION:

MAGNET WIRE - SINGLE BELDSOL SOLDERABLE

II. ELECTRICAL CHARACTERISTICS:

UL STYLE: NONE

UL RATING: NONE

CSA TYPE: NONE

CSA RATING: NONE

MIL STANDARD: J-W-1177/9

MIL SPEC. RATING: 130C

OTHER: NEMA MW 28-C (SINGLE)

III. PHYSICAL CHARACTERISTICS:

AWG SIZE: 34 AWG

STRANDING: 34 AWG SOLID BARE COPPER

INSULATION MATERIAL: POLYURETHANE WITH NYLON OVERCOAT

INSULATION THICKNESS: .0005" MIN. INCREASE IN OD

DIAMETER: .0072" MAX.

TEMPERATURE RATING: 130C