Yarn Performance During Weaving

In the traditional approaches to the problem of assessing warp yarn performance on the loom, researchers have investigated tensile strength of sized yarn and attempted to correlate it with weavability [18,19].

However, the use of such tensile strength approach has not shown consistent correlations to weavability because the process
of weaving is far more complex and several authors have raised doubts as to this approach [20,21].
The failure of sized yarns on a loom is attributed to the cumulative damage caused by cyclic fatigue of relatively small forces combined with abrasion [22].

The failure of warp yarns on a loom is caused by repeated cyclic elongation at small stresses well below the breaking point applied under static load [23,24].

The phenomenon commonly known as fatigue [25],is caused by the gradually diminishing resistance of the material, attributable to cumulative damage. Earlier attempts to characterize the fatigue performance of various materials, including textiles, were made in terms of average, median, or logarithmic lifetimes [26-281.
Fatigue behavior of sized staple yam under cyclic loading follows three parameter Weibull distribution [23,26-281.

However, some studies have reported unimodal [29]
distribution whereas other studies have shown bimodal distribution 1301.
This poses a formidable problem in understanding the mechanism of yam failure under tensile loading, since the mechanism involved in bimodal behavior is inherently different from that in unimodal Weibull distribution [23].

Warp Knit Mosquito Net Fabrics

Abstract
The chemical and physical properties of polyester, polyethylene and polypropylene yarn are discussed in relation to their use for the production of long lasting insecticide treated nets (LLINs). Historically, polyester multifilament has been the yarn of choice, but recent interest in insecticide impregnated yarn extrusion has resulted in increased focus on olefin fibers. Potential implications of switching mosquito net fabric production from polyester multifilament yarn to polyethylene and/or polypropylene monofilament yarn are highlighted.
Key Words
Polyester, polypropylene, polyethylene, multifilament, monofilament, mosquito net, LLIN
Introduction
In an effort to reduce the cost and increase the useful life of mosquito nets used for malaria prevention, research organizations, net manufacturers and chemical companies are expanding their selection and use of raw materials to now include polyester (PET), polyethylene (PE) and polypropylene (PP) polymers. Each of these materials has certain advantages and disadvantages that make them more or less desirable for use in manufacturing and by the final consumer. Historically, polyester multifilament yarn has been the market leader for the production of long lasting insecticide treated mosquito nets (LLINs) due to its high strength, relatively low cost, global availability as a commodity product, and compatibility with topical treatments using standard textile processing equipment. Recently however, the use of polyethylene and polypropylene polymers have seemingly gained preference in the mosquito net market with the development of several different monofilament yarns that incorporate insecticide directly into the yarn structure. Polyethylene and polypropylene polymers are preferred for these applications because their low melting temperatures are advantageous for producing yarns containing temperature sensitive insecticides.
This paper 1) details the chemical and physical properties of polyester, polyethylene, and polypropylene polymers; 2) compares and contrasts the differences between
multifilament and monofilament yarn structures; and 3) reviews several important points related to using the different polymer and yarn types for mosquito net fabric production.
Chemical Properties of PET, PE and PP Polymers
Fabric used to sew mosquito bed nets has traditionally been manufactured from warp knitted polyester yarn. Polyester has been used extensively in the textile industry for fiber, yarn, knit, woven and nonwoven fabric production. Polyester has excellent strength and abrasion resistance, has good inherent stability to UV exposure, has good resistance to chemical degradation and can be dyed using disperse dyes. Recent trends in manufacturing mosquito netting from yarns containing insecticide extruded in the fiber have resulted in an increased use of polyolefin polymers due to the lower melting temperature of polyolefin. Both polyester and polyolefin yarns are produced using melt extrusion/spinning.
Polyester

The Federal Trade Commission definition of polyester is a manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalic units, p(-R-O-CO- C_6H_4-CO-O-)x and parasubstituted hydroxy-benzoate units, p(-R-O-CO-C_6H_4-O-)x.
The most common polyester for fiber purposes is poly (ethylene terephthalate), or simply PET. This is also the polymer used for many soft drink bottles and it is becoming increasingly common to recycle them after use by remelting the PET and extruding it as a fiber. This saves valuable petroleum raw materials, reduces energy consumption, and eliminates solid waste sent to landfills.
PET is made by reacting ethylene glycol with either terephthalic acid or its methyl ester in the presence of an antimony catalyst. The reaction is carried out at high temperature and vacuum to achieve the high molecular weights need to form useful fibers [1 1].
Polyester Fiber Characteristics Typically Quoted in Trade Literature [1 1]
· Strong
· Resistant to stretching and shrinking
· Resistant to most chemicals
· Quick drying
· Crisp and resilient when wet or dry
· Wrinkle resistant
· Mildew resistant
· Abrasion resistant
· Retains heat-set pleats and crease
· Easily washed
Some Major Polyester Fiber Uses [1 1]
· Apparel: Every form of clothing
· Home Furnishings: Carpets, curtains, draperies, sheets and pillow cases, wall coverings, and upholstery
· Other Uses: hoses, power belting, ropes and nets, thread, tire cord, auto upholstery, sails, floppy disk liners, and fiberfill for various products including pillows and furniture
Polyethylene and Polypropylene
Polyolefins are fibers in which the polymer is composed of at least 85% by weight of ethylene, propylene, or other olefin units. Olefin is a generic term used to describe fibers made from aliphatic hydrocarbons. Polypropylene and polyethylene are the two most common olefin fibers. The primary characteristic of these fibers that has lead to increased use in mosquito netting is the low melting temperature and low density of the fibers compared to polyester.
Polypropylene is more commonly used as a textile fiber than is polyethylene, however commonly available yarn deniers for both types of polymers are typically much higher denier (i.e. 300, 600, 1000, 1200+ denier) then those used for the production of mosquito nets (75 to 150 denier).
The use of polypropylene in textile applications has grown rapidly over the past ten years primarily driven by its low melting temperature, low density, low moisture regain and low cost. Polypropylene melts at temperatures around 175oC. Although the low melting temperature is a disadvantage in many applications, it is an advantage in nonwoven material production. The largest growth of polypropylene has been in nonwoven material constructions. The melting temperature of polypropylene is substantially lower than the melting temperature of polyester (260-270oC) [12]. Since many insecticides degrade or volatilize at high temperatures the lower melting temperatures of polyethylene (~140oC) and polypropylene (~170 oC) provide an advantage versus polyester for the manufacture of yarns containing insecticide extruded into the fiber.
Olefin Fiber Characteristics Typically Quoted in Trade Literature [12]
· Able to give good bulk and cover
· Abrasion resistant
· Colorfast (because color is from extrusion additives only)
· Quick drying
· Low static (These fibers have significant static unless antistatic agent is added)
· Resistant to deterioration from chemicals, mildew, perspiration, rot and weather
· Thermally bondable (low melting temperature)
· Stain and soil resistant
Sunlight resistant (only if extruded
· with UV inhibitors)
• Dry hand; wicks body moisture from the skin
· Extremely hydrophobic and feel like plastic
· Very lightweight (olefin fibers have the lowest specific gravity of all fibers)
Some Major Olefin Fiber Uses [12]
· Apparel: Activewear and sportswear; socks; thermal underwear; lining fabrics
· Automotive: Interior fabrics used in or on kick panel, package shelf, seat construction, truck liners, load decks, etc.
· Home Furnishings: Indoor and outdoor carpets; carpet backing; upholstery and wall coverings; furniture and bedding

construction fabrics
· Industrial: Carpets; disposable, durable nonwoven fabrics; ropes; filter fabrics; bagging; geotextiles; etc.

Physical Properties of PET, PE and PP Polymers

There are many types of polypropylene, polyethylene and polyester polymers available in the market for the production of yarn and fabric. For direct comparisons between polymer and yarn types the following characteristics for each must be evaluated on a case by case basis:
· Fiber/filament strength,
· Yarn geometry,
· Yarn density,
· Abrasion resistance, and
· Environmental stability.

Fiber/Filament Strength

Filament tenacity is a means of directly comparing the strength of one fiber type to another. Because the tenacity value (the stress at which the fiber breaks) is reported as grams per denier, the effects of disparate fiber sizes is eliminated. Polyester fibers are commercially available in a variety of forms and tenacities, from regular to high tenacity filament yarn, to regular and high tenacity staple fiber. It should be noted that these values are not affected by testing the fiber when wet because all are hydrophobic.

A special note should also be made of the polyethylene values, particularly because several types of polyethylene fibers are available: Linear Low Density PE (LLDPE), Low Density PE (LDPE), High Density PE (HDPE) and Ultra High Molecular Weight PE (UHMWPE). UHMWPE has very high tenacity, but it is a very expensive specialty fiber. Primarily available under the brand names Spectra® and Dyneema®, UHMWPE is primarily used for high performance end uses, such as ballistic vests and is not utilized in commodity grade products. The tenacity values presented in Table I was obtained primarily from the Man-Made Fiber Producers Association, Inc. and the ranges given are related to production process variables.

As shown in Table I, there is much overlap in fiber/filament tenacity between polyester, polypropylene and polyethylene. Therefore, direct comparisons between specific products must be made before conclusions can be drawn regarding the strength of one product versus another.

Yarn Geometry

For a given knit fabric construction, if mesh size and overall weight (GSM) are essentially the same, then the single over-riding factor in fabric properties will be yarn geometry. In some instances, this can trump fiber chemistry. The old adage of making sure to compare “apples to apples” is very true with regard to yarn geometry.

In general, for a specified yarn denier (were denier is equal to the weight in grams of 9000 meters of a material), a continuous filament yarn will be stronger than a staple yarn of the same fiber type. The reason for this is a simple physics problem. When stress is applied to a component, that component will fail at the point least able to sustain that force: the “Weak Link” Theory. Once failure occurs, the totality of the stress is now supported by the remaining structural elements of that component, each of which is now supporting a proportionally larger amount of stress [5]. These incremental failures are observed as “noise” in a stress/strain curve for a material under laboratory test conditions.

With respect to yarns produced from staple (short) fibers, the tensile properties are established by both the mechanical properties of the fibers and by the radial position and packing density of those fibers along the length of the yarn [6]. In the same way, continuous filament yarn properties are affected by fiber type, and by packing density. However, the short fibers in a staple yarn are held in place by a combination of frictional forces and mechanical entanglement. Therefore, fiber slippage is a contributor to staple fiber yarn failure, while the same is not true for continuous filament yarn, where that packing density generally increases in response to a longitudinal stress. This is because the fibers are not free to slip against one another in the direction of the stress, and so will not pull out of the yarn construction. So, for yarns of the same denier and a given fiber type, a continuous filament yarn will be stronger (higher tenacity) than a staple fiber yarn [7].

Turning attention specifically to the continuous filament yarns that are used to produce warp knit mosquito net fabric, the issue of yarn geometry becomes paramount if one wishes to compare two fabric constructions. Yarn size must be considered first if such a comparison is to be valid. For various reasons, it is not correct to compare fabric properties if those fabrics are made with different weights of yarn, even if the fabrics are manufactured in the same manner. For example, if one warp knit fabric is produced with a 100 denier yarn and a second with a 75 denier yarn of the same fiber type, there will be 25% less fiber content in the second fabric (assuming the mesh counts are the same) because denier is a weight per unit length value.

Next one must consider the filament count in the yarn. Once again, for a given fiber type and yarn denier, the size of the filaments in that yarn have a significant impact on the yarn properties. Smaller diameter filaments mean more filaments per yarn denier, which in turn impacts the packing density in the yarn. Because there are multiaxial stresses in a yarn under load – such as longitudinal stress, longitudinal strain, lateral compression, torsion, and surface friction – the proximity of filaments within the yarn cross-section will impact the overall yarn properties. According to the theory of fragmentation, each filament within the yarn essentially behaves mechanically as an independent entity [5]. Therefore, for a selected fiber type, at a given level of twist and a given denier, a yarn with fewer filaments will have strength properties that are higher than those of a similar yarn with more filaments (noting that as the number of filaments increases each of those filaments will have a smaller diameter).

This consideration of yarn geometry is equally important when comparing yarns made from different polymer types. For example, a 100 denier monofilament yarn would be expected to have a higher tenacity value than a 100 denier multifilament yarn with a filament count of 50 or even 25. This would be true even if the monofilament yarn in question was produced from a lower tenacity polymer type. If the uneven filament counts were balanced, the monofilament yarn from the higher tenacity polymer would demonstrate higher strength properties.

Density

Density is the measure of mass (grams) per unit volume (cm 3). As shown in Table II, the density of polypropylene is lower than the density of HDPE and polyester. This means the same volume of one polymer can weigh more or less than the same volume of a different polymer. This is highlighted in Table II with data that illustrates that for monofilament yarns of the same denier (i.e. same weight per unit length), lower polymer density results in yarns with larger diameters. Using the densities stated in Table II for polypropylene, HDPE and polyester, and assuming that a 100 denier monofilament yarn was manufactured from each, the diameter of the polypropylene yarn would be 2.2% greater than the HDPE yarn and 23.1 % greater than the polyester yarn. The HDPE yarn would have a diameter 17.1% higher than the polyester yarn.

Abrasion Resistance

Larger diameter yarns provide more thickness and cover for a given weight of yarn. Larger diameter may also contribute to a perception of higher strength and abrasion resistance than expected from a given polymer type. As shown in Table III, when comparing average properties the yield stress of polyester is 79% and 232% higher than for polypropylene and HDPE respectively.

However, due to the extensive availability of different polymer material variants it is important to directly compare specific products against one another before conclusions can be drawn regarding their absolute physical properties and superiority to other products in the market.

Environmental Stability

When selecting a yarn for a given end use product, polymer chemistry must be considered with respect to environmental conditions and effects of aging. For example, if the end use will involve prolonged exposure to elevated temperatures, particularly when the product will be under compression or strain while at those temperatures, selecting a fiber type with a higher glass transition temperature and melting temperature would be advised. For example, polyester has higher operating temperatures than any of the olefin fibers (except UHMWPE) and would therefore be more resistant to deformation related to elevated temperatures.

Melting temperatures and glass transition temperatures (Tg) for the polymers under discussion are provided in Table IV. Glass transition temperature is the temperature at which a polymer goes from a brittle/hard state to a softened/deformable state. This is opposed to the melting temperature at which a solid material becomes liquid. Glass transition temperature can be used to determine the relative hardness of a polymer and of fibers produced from those polymers.

While thermoplastic polymers tend to have sensitivity to UV radiation exposure, some perform better than others. It is necessary to add UV-stabilizers to olefin fibers to reduce degradation of physical properties caused by exposure to sunlight, while polyester fiber generally performs better under conditions of UV exposure. Note that the effects of UV-radiation damage are additive, such that repeated short doses have the same cumulative effect as a single prolonged exposure, and that reflected light is also detrimental to the physical properties of UV sensitive polymers.

Other Factors

Depending on the end use application, there are other factors to consider when specifying fiber type. Olefins are not dyeable, and coloration is limited to pigments which are extruded with the polymer as the yarn is produced. While this does have some advantage with regard to fading and color-fastness, the color palate is very limited and colored olefin yarns carry a price premium. On the other hand, polyester is readily dyed by chemical baths, and color specification is more simple and varied.

If any surface treatment, such as an insecticide, is to be applied to the yarns or finished fabric, olefins should be viewed with caution. Polypropylene is difficult to coat or bind with any chemistry other than polypropylene based chemistry – the industry saying is that “PP only likes PP”. Some affinity for polyethylene exists, but formulations must be carefully considered.

Most chemicals extruded into polymer fibers must migrate to the surface of the fiber before they are effective for their intended purpose. This is true for insecticides extruded into polyolefin fibers. As a result, after washing it is typical that some period of regeneration time (i.e. 3 to 7 days) is required before extruded fiber products regain their biological efficacy against mosquitoes. The regeneration time and surface functional properties must be evaluated for each material and chemical being used in an extruded fiber. If the insecticide is not available on the surface of the netting then the efficacy of the insecticide toward mosquitoes is poor, resulting in a mosquito net that functions only as a physical barrier during the regeneration period.

Polyester is known to be highly resilient. Polyester yarns and fabrics resist compression and will return to their original state with little distortion. Conversely, polypropylene and particularly commodity fiber grade polyethylene are softer polymers and the yarns and fabrics tend to “remember” a shape when they have been compressed. Polyethylene and polypropylene yarns and fabrics also tend to exhibit a condition known as “creep” where under its own weight the fiber tends to grow and elongate.

Potential Implications for Warp Knit Fabric Manufactures Desiring to Convert Production from Polyester to Polyethylene or Polypropylene Fabric

There are several important issues that warp knit fabric manufactures must consider when contemplating the switch from producing polyester to polypropylene or polyethylene netting fabrics. These include:

1. Availability of raw material (yarn)
2. Suitability of existing warping equipment (i.e. designed for polyester multifilament) for processing polyethylene or polypropylene yarn (monofilament)
3. Impact on warping and knitting productivity by changing from 75-100 denier multifilament polyester to 100-150 denier multi or monofilament polypropylene or polyethylene
4. Impact on knitting by changing from current mesh size (156 mesh produced on 28 gauge tricot machines) to that required when using 100-150 denier polyethylene/polypropylene monofilament (56-136 mesh)

Availability of Raw Material

Polyester multifilament yarn is a global textile commodity widely available from numerous sources around the world. It is commonly available in 70, 75, 100 and 150 denier, and as both flat and textured filament. Multiple filament counts are also widely available ranging from 18 to 72 filaments per yarn bundle.

Polypropylene monofilament and multifilament yarn is also available globally, although much more difficult to find in the yarn deniers typically used to produce mosquito bed net fabrics (75 to 150 denier). The reason for this is that the extrusion/spinning speed for low denier polyethylene yarn is substantially slower (i.e. 1200 meters per minute) than for low denier polyester (i.e. 2800 to 3200 meters per minute) yarn, and the economics of spinning low denier polypropylene yarns are difficult to justify. In addition, because the physical properties of similar type and denier polyester yarn generally far outperform polypropylene, it has been difficult for polypropylene to gain favor at this end of the market.

There is much less polyethylene yarn produced than either polyester or polypropylene, and the vast majority is produced as coarse denier (300, 600, 1000, 1200+)
monofilament. As with polypropylene, the economics of producing commodity grade low denier polyethylene are difficult to justify, and the physical properties of polyester far outperform that of similar type and denier polyethylene.

Suitability of Existing Warping Equipment for Processing of Polyethylene and/or Polypropylene Yarns

All WHOPES approved polyester warp knit mosquito nets are currently being produced from either flat or textured 75 or 100 denier multifilament yarn (i.e. 36 filaments per yarn cross section). This yarn type is warped on conventional direct filament warpers and knit on tricot warp knitting machines (Karl Mayer and Liba being the two most prominent brands of equipment). Conventional direct filament warpers use a creel type that allows for the yarn to be drawn over the end of the package imparting one turn of twist in the yarn for each revolution of yarn coming off the package. Imparting twist in flat or textured multifilament yarn does not present a problem since these yarns generally have some small amount of twist inherent to the filament bundle.

According to representatives from Karl Mayer North America, this same type of warping arrangement would be acceptable for processing both polyethylene and polypropylene multifilament yarn. However, should it be necessary to use monofilament polypropylene or polyethylene yarn similar to that used for the production of Olyset, NetProtect, and Duranet, it may be necessary to use a roll-off creel that is specially designed to allow each yarn package to turn as the yarn is withdrawn from the side of the package. This technology results in zero twist being added to the yarn. Note that monofilament yarns inherently have zero twist and process better through the knitting process when no or little twist is added [9-10].

According to Karl Mayer representatives the cost of a conventional creel is approximately $100 per position, while roll-off creels can cost from $350 to $450 per
position [9-10]. A typical creel used to produce beams for a 28 gauge tricot warp knitting machine running off 43 inch beams requires 1190 positions. Therefore, should a manufacturer need to purchase a new roll-off creel in order to convert their production from polyester multifilament to polyethylene or polypropylene monofilament an investment of $416,500 to $535,500 per creel would be required. Furthermore, roll-off creels limit production speeds to 400-600 meters per minute, whereas conventional direct warper creels allow for production speeds between 1000-1200 meters per minute [9-10]. As a result, roll-off creels limit warper capacity to only approximately half that which is achieved when a conventional creel can be used. Therefore, should it be necessary to use a roll-off creel for the production of monofilament warp knit fabrics additional warping capacity (both headstock and creels) would need to be purchased as well. This could very easily result in a required capital investment of $1.1 - 1.3M per set of warpers. Granted, lesser quality Asian or Indian equipment could be substituted for Karl Mayer equipment at about one third the cost. This however would still result in a sizable investment for many companies.

Impact on Warping and Knitting Productivity by Increasing Yarn Denier

As stated previously, all WHOPES approved polyester mosquito nets are produced from 75 or 100 denier flat or textured multifilament yarn. As shown in Table V, these yarns have nominal yarn diameters of 0.088 and 0.101 mm respectively. Changing yarn type from polyester to either polypropylene or polyethylene results in an average increased yarn diameter of 22.2%. As a result, warp beam capacity would be decreased on average by 17.7% if using the same denier yarn before and after the raw material change was made (i.e. 75 denier polyester to 75 denier PP/PE). Assuming the same fabric construction (i.e. mesh count, yarn run-in/rack, etc.) and machine runtime efficiency the knitting room will incur 17.7% more warp-outs due to the reduced length of yarn on each warp beam. Ultimately, this will require either higher labor content for the warp change crew, or acceptance by plant management that production capacity (linear yards per machine hour) will be lost.

Given that the current crop of polyethylene LLINs (NetProtect, Duranet and Olyset) are produced from 100 – 150 denier yarns, and it is very doubtful that the reported increased durability of these type products can be maintained with 75 denier yarns, the resulting impact on warp out efficiency loss is foreseen to be substantially greater. For example, assuming a change from 75 denier polyester to 150 denier PP/PE yarn, the loss in warp beam capacity is calculated to be 41.3%. This will dramatically affect production capacity in knitting (41.3% more warp outs), as well as in the warping area (less yards per warp beam means more beam changes, and efficiency loss in that area as well). As a result, substantial capital investment may be required in order for a plant to maintain production output (linear yards) and mill balance.

Impact on Knitting by Changing Fabric Construction (156 mesh to other larger mesh sizes)

All WHOPES approved polyester mosquito nets are made from warp knit 156 mesh fabrics. According to Karl Mayer North America, the standard machine type for the production of this type fabric is a 28 gauge 2-bar tricot warp knitting machine. After reviewing an Olyset net sample representatives of Karl Mayer North America indicated that Olyset like fabric (56 mesh, produced from 150 denier monofilament polyethylene) could likely also be produced using the same machine type and gauge, although some limitations could apply pending machine age and exact specification. In the event it becomes necessary to change machine gauge in order to produce acceptable quality

netting from higher denier PP/PE yarns it was estimated by Karl Mayer to cost approximately $22,000 per machine to convert a 170 inch 2-bar tricot warp knitting machine to a different gauge (new needle bar and slider bar pre-loaded with new knitting elements).

According to Karl Mayer, one should anticipate 10-15% increased wear on the knitting elements (needles, guides, sliders and sinkers) when changing from multifilament to monofilament yarn. The estimated cost of replacing these elements is $10,000 - $12,000. For budget purposes, one should plan on 10-15% higher expenditures for these items [9- 10].

Summary

The following bullet points summarize the data presented in this paper:

· Durability of warp knit fabrics and mosquito nets made from warp knit fabric is significantly influenced by monofilament versus multifilament yarn choice.

· The yarn structure (monofilament versus multifilament) likely has more influence on net durability than does the polymer type (polyester, polypropylene, polyethylene)

· Polyolefin fibers are gaining in popularity because their lower melt temperatures allow insecticides to be included into the yarns during extrusion.

· Most chemicals extruded into polymer fibers must migrate to the surface of the fiber before they are effective for their intended purpose. This is true for insecticide extruded into fibers. As a result, after washing it is typical that some period of regeneration time (i.e. 3 to 7 days) is required before extruded fiber products regain their biological efficacy against mosquitoes.

· Polyester fibers typically have higher tenacity (grams/denier) than polyolefin fibers.

· For yarns without UV stabilizers added, the UV stability of polyester is superior to that of polypropylene and polyethylene.

· Low denier multifilament polyester is a global textile commodity.

· Low denier polyethylene and polypropylene (multi and monofilament) is difficult to source in significant volumes and therefore generally more expensive.

· Warping equipment designed to process 75-100 denier multifilament polyester may not be suitable for higher denier, monofilament polyethylene or polypropylene. Therefore, any manufacturer contemplating to switch raw material types may need to invest in new warping equipment.

• The yarn diameter of polyethylene and polyethylene yarn is significantly larger than the same denier polyester yarn – this means much less yarn can be put on a warp beam and therefore significantly higher efficiency losses in warping and knitting for beam changes. In addition, any manufacturer contemplating to switch raw material types may need to invest in additional warping capacity in order to maintain mill balance.

· Use of larger denier monofilament yarns increases the expense of knit fabric production due to greater wear and tear on all knitting elements.

· Use of insecticide impregnated extruded fiber products will likely reduce the market competition of LLIN production because:

· Yarn availability will be limited versus current supply of polyester yarns available in the global textile market,

· Special/additional equipment and processing conditions are required in warping and knitting,

· Special equipment and safety measures must be implemented to reduce worker exposure to insecticide during all stages of net production.

Roselon Knit Extension Tester2

Barré produced by knitting machinery is relatively common, is the easiest to see in the greige, and is the easiest to correct. Often uneven yarn tension during knitting may be a cause. To test for uneven tension, the Roselon Knit Extension Tester can be used. For this test, a fabric sample is cut and raveled to yield yarn samples from light and dark streak areas. The yarn ends are taped and clamped to the tester. As each yarn is stretched to the maximum extension point, the points are plotted on graph paper. Comparisons are usually made visually rather than mathematically.

2 Source: Spinlon Industries Incorporated, 18 S. Fifth Street, Quakertown, Pennsylvania 18951