Elastane fabrics – A tool for stretch applications in sports

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Elastane fibres show rubber like behavior and are highly stretchable. Basically these fibres contain polyurethane bonds. Elastic garments used in athletics and sports may improve the athlete’s performance in cycling, swimming and so on. A great deal of research is reported on elastane structure, yarn formation and fabric production. Testing of elastane and its fabric has given new dimensions in terms of results. New attempts are being made to produce the yarn with blends and subsequent conversion into woven and knits, in order to improve garment elastic behaviour and productivity. This paper reports the elastane fibre characteristics, elastane yarn production method, new attempts in yarn production, commercial ways of fabric manufacturing techniques, fabric properties, new testing methods to test the elastic products and its application.

Keywords: Core-spun yarn, Elastane, Elastic recovery, Elastic yarn, Relaxation, Spandex

1 Introduction

Elastane fibres, better known under their trade names such as lycra, spandex and dorlastan, represent a further high point in the development of man-made fibres. Invented in 1937 in Germany, elastane has properties not found in nature, the most important having an extraordinary elasticity. Spandex is a generic term used to designate elastomeric fibres which have an extension-at-break greater than 200 % and also show rapid recovery when tension is released. These fibres exhibit rubber like behavior with high reversible extension as high as 400 - 800 %. The name Spandex is an anagram of the word expands and is known as Elastane.

In chemical terms, elastane is a synthetic linear macromolecule with a long chain containing at least 85 % of segmented polyurethane along with the alternating hard and soft segments linked by urethane bonds – NH – CO – O –. Soft chain segment gives elasticity (recoverable stretch ability) to fibre, while hard chain segment gives molecular interaction force to fibre and which ensures a certain level of strength of fibre and long term stability.

Elastane is used in all areas where a high degree of permanent elasticity is required, for example, in tights, sportswear, swimwear, corsetry, and in woven and knitted fabrics. Elastane is a prerequisite for fashionable or functional apparel which is intended to cling to the body, while at the same time remaining comfortable.

Spandex (approved by Federal Trade Commission, USA) is a man-made, organic synthetic base fibre. It could be produced from dry spun, reaction spun and melt spun techniques. In general, spandex fibres are spun from polyurethane spinning solution. The spinning process is conducted using dry method by blowing hot air through the spun filaments with simultaneous evaporation of the solvent from them.

Kielty et al. have explained that the structure of elastic fibres is extracellular matrix macromolecules comprising an elastane core surrounded by a covering of fibrillin-rich microfibrils. The structure of elastic fibres is complex because they have multiple components, tightly regulated developmental depositions, a multi-step hierarchical assembly and
unique biochemical functions. Lee et al. studied the internal structure and orientation behavior of two series of elastane fibres, which were made with different spinning methods using different soft and hard segment types by Fourier Transform Infrared Spectroscopy (FTIR), polarizing light microscopy and Instron. The results conclude that dry spun fibres exhibit better elastic recovery than melt spun fibres. The mechanical hysteresis gave consistent results with those of FTIR and birefringence measurements.

Spandex fibre is used in both woven and knit forms for sports underclothes and tights wear. Spun spandex fibre is usually used in weaving for fabrication of ribbons, tapes, medical stockings, and bandages.

It can be noted that worldwide spandex consumption and growth is 30 - 40 % per year and is expected to grow high. Asian countries have a share of nearly 60 % of world consumption and contribute 25% of world wide spandex growth per year. Spandex is readily compatible with other common fibres including nylon, polyester, acetate, polypropylene, acrylic, cotton, wool and rayon. In general, breaking strength of spandex fibre is 0.7 g / den and elongation before break ranges from 520 % to 610 %. Spandex fibre is white in colour and dyeable with disperse and acid dyes. It has good resistance to chemicals and withstands the action of perspiration. It may degrade and turn yellow when it is treated with chlorine. It can be washed at 60 °C and tumble dried at 80 °C. The fibre has moisture regain of about 0.3 % with melting point 250 °C, but starts sticking at 175°C (ref. 8).

Walter listed the following as potential developments in spandex, In order to enhance the commercial value of the products, following may be used (i) completely chlorine resistant polyether spandex for swimwear (ii) chemically modified spandex (iii) union dyeable spandex, and (iv) high modulus spandex (with medical applications).

This paper reviews about the elastane fibre characteristics, elastane yarn production method, new attempts in yarn production, commercial ways of fabric manufacturing techniques, fabric properties, new testing methods to test the elastic products and its application. Elastic garments have tremendous scope in the field of tight fit sportswear application.

2 Commercial Methods of Elastane Yarn Production

Elastane yarns contribute significant elastic properties to all types of fabrics like circular knits, warp knits, flat knits, wovens, nonwovens, lace and narrow fabrics. The elastane yarn preparation is discussed hereunder.

2.1 Spandex Core Spun Yarn

Singh reported production of two way stretch woven fabrics for apparel use, which can be efficiently produced from natural fibres by using elastic core-spun yarns. He found that the fabric structure influences stretch characteristics. An open weave fabric offers higher stretch than a close weave. The thread count distribution significantly varies fabric stretch. The finished fabric stretch reduces with an increasing ends and / or picks per inch. Generally, core-spun and siro-spun yarns are produced on regular ring spinning machines with special feeder rollers and guiding devices. These spun yarns are difficult to produce with better covering effect.

In order to produce better cover effect to fine elastomeric yarn and best dynamic elastic recovery, Ching Iuan and Hsiao-Ying studied the cross-sections of the core-spun yarns produced from three different fineness of spandex and the migration of the spandex inside the core yarn. They optimised the spandex fineness, draw ratio and twist factor to achieve the better covering effect.

Covered elastic yarns are usually wrapped with hard fibres like nylon or rayon. Generally, two layers of the hard fibres are wound on the elastomeric yarn in opposite directions while the spandex is moving through the covering machine under controlled tension.

Core-spun yarn, covered yarn, elasto twist yarn, two for one twisted yarn, air-covered yarn and siro-spun yarn are the common elastic yarn production methods and these yarns are used to produce outer wear, leisure wear and sportswear.

2.2 Elastane Plated Cotton Fabric

Bayazit produced the spandex plated cotton single jersey knitted fabric, as plating technique is an easy way to produce stretch properties in the fabric. Spandex bare yarn is directly back plated with hard yarn in knitting machine itself, whereas stretch yarn produced by core-spun technique can be further converted into either woven or knitted fabrics.

Egon studied the production feasibility of core-spun yarn consisting of modal and lyocell with spandex yarns of different counts. The study was aimed to improve the thermo physiological comfort of
the wearer. Ke and Zhang developed the moisture comfort elastic plated fabric with cotton yarn outside, superfine polypropylene fibre inside and lycra at center. The fabric was produced on a special feed weft knitting machine.

3 Modified Elastic Yarns and Fabrics

New dimensions explored in the manufacture of elastic yarns and fabrics in order to enhance the product value and productivity are discussed hereunder.

3.1 Modification in Ring Frame

Lou et al. produced a polyester core-spun yarn containing spandex fibres using a self-designed, multi-section drawing frame and a ring spinning frame. The mechanical properties of the core-spun elastic yarns were examined under various processing conditions. They optimized the draw ratio to enhance the breaking tenacity and elongation of the core-spun elastic yarns.

3.2 Modified Rotor Spinner

Jia-Horng et al. developed a novel method to prepare highly elastic complex yarns using a self-designed multi-sectional draw frame and rotor twister. They examined the mechanical properties of the elastic complex yarns by optimizing the machine speed and twist to acquire higher breaking strength of the yarn.

3.3 Air Vortex Spinner with Special Device

Hüseyin and Sukriye produced core-spun yarns containing spandex using air vortex spinner with special attachments for bare spandex feed. The yarn properties were compared with normal vortex-spun yarn. They concluded that the yarn properties of elastic core-spun vortex yarns are significantly affected by spandex and yarn count. Core-spun vortex yarns containing spandex showed lower tenacity and higher breaking elongation than normal vortex-spun yarn.

3.4 Woolen Spinning with Special Device

Min et al. stated that the spandex can be used on modified worsted spinning system to produce spandex core-spun yarn and studied the influence of spandex drafting ratio and yarn twist factor on tensile properties and elasticity of the core-spun yarn. The yarn twist and spandex drawing ratio have influence on yarn properties. Elastic recovery of core-spun yarns increases with increasing the yarn twist and spandex draw ratio.

4 Elastic Fabric

There exists a number of ways to produce elastic fabrics. The elasticity of the fabrics is much lower than that of the elastomeric fibre because of the restrictions of the hard fibre structure. Stress and strain curves show a combination of the elastic power of the fibre and the effect of the hard fibre assembly recovering from the compression. Elastane yarns are very efficient in this field of sports application. It is sufficient to provide the desired stretch properties of a woven and knitted fabric even with lower percentages like 2 – 3 % of elastane.

Normally, elastic knitted fabrics in grey stage are relaxed and further the fabric is heat set, bleached, dyed and compacted in the wet processing treatment. For normal fabric, heat setting is not recommended. Heat setting process is the key step to lock the desired fabric properties like width, weight, stretch and power. Spandex inter molecules are broken and reformed, and the polymer chains can rearrange during heat setting. If the spandex in the fabric is under stretch during heat setting, the chains disorient and the retractive force reduces. The fibre fineness is reduced to that at the extension during heat setting, and the similar process with steam can reduce the fibre fineness in core-spun yarns. Heat setting is preferably done early in the textile process rather than at the end in order to reduce yellowing on drying. But it can be done anytime if the time and temperature of heat setting are optimized. Under-setting results in eventual loss of fabric dimensions, while over heat setting lowers power and can discolor the spandex and companion fibres.

Relaxation treatment is used to reduce potential distortion or deformation of the fabric from residual uneven tension. It develops the power and recovery of the fabric. The fabric should be relaxed prior to heat setting to avoid rope marks and puckering during dyeing, and ensure good dimensional stability in the final garment.

Bleaching agents such as hydrogen peroxide can be used for elastic fabric. Chlorine containing bleaches may cause yellowing in spandex fibres and hence should be avoided. Disperse dyes and acid dyes have good affinity to elastane and no affinity with direct dyes. Right matching of spandex and hard yarn dye shades in the fabric may not be necessary. Because, generally the spandex is hidden in the fabric.
Mercerisation process is also used to improve dye ability of the elastic fabric. Compacting process is used to physically rearrange the yarn geometry in the fabric. In woven fabrics, weft yarns can be forced close together, thus preshrinking the fabrics. In the knit fabrics, the loops can be rearranged to overcome distortion in the length to width caused by stretching tensions.

4.1 Dimensional and Physical Characteristics of Elastic Fabrics

Bayazit investigated the dimensional properties of spandex plated cotton single jersey fabrics and compared the results with fabrics knitted from cotton alone. The loop length and amount of spandex are used to determine the dimensional properties of the knits. It is apparent that as the amount of spandex increases, loop length values remain nearly the same and the course and wale spacings decrease. Spandex containing fabrics tend to be tighter. The weight and thickness of the fabrics are higher, but spirality is lower. Spandex containing fabrics were lower in air permeability. Further, he claimed that the power of recovery in single jersey fabrics that have been stretched is generally inadequate, and therefore spandex is increasingly used to impart a greater level of stretch and more dimensional recovery can be achieved with cotton alone.

Chathura and Bok studied the dimensional stability of core-spun cotton / spandex single jersey structures with high, medium and low tightness factors, under dry, wet and full relaxation conditions. Results were compared with those of similar fabrics knitted from 100% cotton. Course, wale and stitch density found to increase with progression of relaxation and higher values were reported with cotton/spandex structures. Course, wale and stitch density were linearly and positively correlated with inverse of loop length. They concluded that yarns with elastomeric components increase tightness factors, giving better dimensional stability to single jersey fabrics. Yarn linear density was found to be insignificant to treatments.

Chathura and Bok also studied the dimensional characteristics of 1 × 1 rib knitted structures made from cotton/spandex core-spun yarns. Cotton/spandex rib structures assumed more stable state after 10th laundering cycle under the experimental conditions. But, the same was not in case of normal cotton fabric. Fabric relaxation procedures had a significant effect on dimensional characteristics of cotton/spandex and cotton rib structures. However, area shrinkage variations was unaffected by treatment. They also analysed the dimensional characteristics of core-spun cotton / spandex interlock structures with high, medium and low tightness factors under dry, wet and full relaxation conditions. Results were compared with those for similar knitted fabrics from 100% cotton. Dimensional characteristics of core-spun cotton/spandex and cotton samples were measured by varying course, wale and stitch densities under dry, wet and full relaxation conditions. Higher U % was reported with cotton / spandex interlock fabric than with 100% cotton fabric. Under full relaxation, cotton / spandex shows the U % values with lower CV%. Stitch density growth is linearly correlated with tightness factor at machine off state during relaxation states. Cotton / spandex interlock structures show more prominent co-relationship with their tightness factors on their dimensional parameters.

Elizabeth et al. investigated the effect of drying on the aesthetics and performance of stretch fabrics to determine the best care procedures for cotton / spandex blends. For 100% cotton and 92:8 cotton / spandex fabrics, the amount of stretch was roughly twice as much when evaluated by the ASTM D6614 method. For 100% cotton samples, a high correlation between the amount of stretch in both D6614 and D2594 test methods was noticed. When stretch fabric (92:8 cotton/spandex) was tested, no correlation was found between the stretch results of the two methods. In addition, D6614 method showed that the fabrics respond well beyond their yield points and no correlation is noticed between growth results. This raises question about the test method to be used in industry.

Tezel et al. studied the dimensional and physical properties of cotton/spandex single jersey fabrics using plating technique. The effects of spandex brand and the tightness factor of the cotton and spandex yarn on dimensional and physical properties of cotton/spandex single jersey fabrics were investigated. In order to examine effects of the tightness factor of cotton and spandex yarns, fabric samples were knitted by feeding both cotton and spandex yarns with three different adjustments of positive yarn feeding mechanisms to knit tight, medium, and loose cotton/spandex single jersey fabrics. Four different spandex yarns were used. The fabrics knitted with spandex yarns with largest tension values under a constant draw ratio gave highest weight, courses per cm, stitches per cm and thickness,
and lower air permeability and bursting strength. Spandex yarns with similar elongation % also followed similar trend. Increase in thickness and decrease in fabric width with shorter loop length is mainly due to greater stretched strength.

4.2 Comfort Characteristics of Elastic Fabrics

Verdu et al. 28 analysed effect on comfort by introducing DOW XLA ™ fibre in woven polyester / cotton fabrics meant for professional wear. The comfort parameters such as thermal, moisture, tactile and pressure sensations were analyzed. A fabric elasticized with polybutylene terephalate (PBT) elastic fibre was also studied for comparison purpose. Further, the effect of fabric mechanical and comfort properties on repeated laundry washes was also investigated. The results indicated that the use of new fibre inside a core-spun yarn to elasticize fabrics for professional wear provided additional comfort than non elasticized fabrics. The thermo physiological and sensorial comfort of fabrics was found to be invariant with washing cycles. However, the differences in performance were noticed on comparison with traditional non-elasticized and PBT elasticized fabrics. 

Salopek et al. 29 studied the influence of different yarns (100 % cotton and 100% cotton elastane) and the finishing treatment on physical and mechanical properties (KES - F system) of knitted fabrics. The presence of elastane component in single jersey fabrics knitted from cotton affects the properties of knitted fabrics like increase in tensile resilience on termination of force, shear rigidity, bending rigidity and compressional energy during compression. Among the investigated yarn characteristics, yarn evenness significantly affected geometrical roughness. Finishing process (optical bleaching, softening and dyeing) lowered tensile energy during stretching, bending rigidity, compressional energy and geometrical roughness while it significantly increases fabric thickness and compressional resilience.

Bartels 30 reported that the usage of elastic yarns and their fabrics has some limitations. They cannot absorb moisture within their structure and are non wettable by liquid sweat, thus reducing the thermo physiological wear comfort. These yarns are very flat and smooth, which reduces the skin sensorial wear comfort. But in the literature, there is no mention about any experimental trials to arrive to such decision.

4.3 Elastic Properties of Elastic Fabrics

In ancient days, mercerisation and texturisation processes were used to improve the elasticity of woven fabrics. Donald 31 claimed improvement in stretch properties of normal cotton fabrics by slack mercerization with sodium hydroxide. However, the study is silent about elastic recovery nature.

Mukhopadhyay et al. 32 developed the air-jet textured yarn to acquire stretch properties of woven fabric by analysing fabric extension and recovery characteristics. It was observed that the spun yarn fabric shows better dimensional stability and shape retention property in terms of higher immediate recovery and resiliency, and lower delayed recovery and permanent set as compared to the textured yarn fabric. Single yarn fabric possesses greater recovery and resiliency along weft direction as compared to doubled yarn fabric. The finer filament textured yarn fabric shows lower immediate recovery and resiliency than coarser filament textured yarn woven fabric.

Kentarou and Takayuki 33 studied the relationship between stretch properties of weft knit fabrics and their geometrical parameters. The comparison was made on stress strain behavior of similar fabrics made from spun yarn by false texurising. Stretch of these fabrics was affected by cover factor only. It is known that stress-strain behaviour depends on raw material and knit construction, irrespective of the density of knitted fabrics.

Few attempts were reported on elastic properties of elastic fabrics produced with spandex. Mukhopadhyay et al. 34 studied the effect of lycra filament on the extension-at- peak load, immediate recovery, delayed recovery, permanent set and resiliency of cotton–lycra blended knitted fabric. It is observed that the immediate recovery, extension and resiliency are higher for lycra blended fabric, but its delayed recovery and permanent set are lower than 100 % cotton fabric.

Dunja and Vili 35 investigated the behavior of woven fabric with elastane yarn during stretching. The study reported the viscoelastic part of the stress-strain curve and behaviour of fabrics with elastane yarn after one hour stretching above the yield point. Research results on viscoelastic part of stress-extension curve show low values of stress and extension at yield point (extension at the yield point ranges 0.25% - 0.75 %), which indicates that a larger area of the viscoelastic behaviour of the fabrics is analysed. Further the results also show greater differences in viscoelastic properties on stress-extension curve beyond the yield point, which means that the elastane in yarn affects viscoelastic
properties, with an extension which is higher than one at the yield point.

Cooper et al. observed that means of reducing the inter fibre frictional properties should also significantly improve the stretch and recovery properties of all cotton stretch woven fabrics.

5 Testing of Elastic Materials

Testing for elastane yarn and fabric is not similar to that used for hard yarn and its fabric. Because, the slight variation in spandex yarn tension affects its properties. Linear density of elastomeric yarns is tested using linear density apparatus following the ASTM D2591-01 method. In measuring stress – strain behavior of elastomeric fibres, special clamps or bench marks are to be used to avoid false readings from necking out of threads as a result of the large reduction in yarn size which occurs at high extensions. Similarly, Elastic stretch and recovery of core-spun fabric is tested using ASTM D 4964 -96 method. Fabric slippage will be more for elastic fabrics which will affect the end results. It can be controlled by using band clamps at both the edges. Cooke and Assimakopoulos attempted the fabric specimen - symmetrical folding method to avoid the edge effect during testing of fabric extension and recovery. The method of sample placement in the machine has significant effect on test performance. Similarly, Kiely et al. recommended that the stretch properties are better tested by deformation of a sample clamped all around, as in a burst tester.

Elastic properties of the fabric are normally assessed by parameters like fabric immediate and delayed recovery, and permanent set. This static measurement helps to analyse only the fabric dimensional stability, whereas dynamic elastic properties of the fabric are used to analyse the garment response to body movement which will help to improve power during sports activity. It can be indirectly measured using ASTM Method D 2594-99A with Instron tester.

Even though a number of methods are available to test suitability of elastic yarn and their fabrics characteristics for a specific end use the facilities to quantify the characteristics are scanty in literature. For example, some times the sports wear made up of good elastic fabric may not serve the purpose. The testing of its elastic properties with the existing methods may be unsuitable. Elastic properties of elastic fabrics are generally tested in uniaxial direction but in real time performance, the garment stretch and recovery is in multi-directional way (horizontal, vertical direction and also in lateral direction). Hence, new test methods are thus required to assess the specific end use applications of elastic garments.

Hazel et al. developed a device that can be used for measuring the stretch and elastic recovery of knitted materials in lengthwise, crosswise or in both directions simultaneously when various loads are applied. It is possible to determine the combined instantaneous and delayed recovery.

Ryan and Postle stated that the dynamic elastic modulus is one of the fundamental properties of textile materials and also equally difficult to quantify. Sonic methods are now developed to test the dynamic elastic modulus. The tests are not only simple but also non destructive in nature.

The use of compression garments is becoming increasingly more common among athletes as the garments have been shown to promote everything from an increase in oxygenation to a decrease in recovery time. Measurement of lactic acid, creatine kinase and other intra cellular fluid is used to assess the performance of the sportsmen.

Salim Ibrahim developed several new test methods to provide a quantitative definition of performance of form-persuasive fabrics and garments. Some of them are (i) pressure indicator which continuously measures garment pressure on the body, the instrument consists of a pressure transducer which is inserted between garment and body to measure the garment pressure, (ii) contour meter which measures the static response with help of contour gauge to provide quantitative and qualitative measurement of change in body geometry with pressure; and (iii) an accelerometer to measure the extent of dynamic control or the control of seat vibration during walking, afforded by foundation garments.

The length and/or shape variations in tight-fitting garment of a person can be measured using dipole resonator adapted with the garments.

6 Application of Elastic Garments in Sports

Elastic fabrics are an important route to achieve comfort by freedom of movement for body fitted with sports and outdoor wear. Elastic garments used in athletics and sports may improve the athlete’s performance in cycling, swimming and so on. They are also important for inner wear. This type of fabric enables freedom of body movement by reducing the
fabric resistance to body stretch. A simple body movement may extend the body skin by about 50% and the fabric must easily accompany the stretch and recover on relaxation. Strenuous movements involved in active sports may require even greater garment stretch. Drastic differences between skin and fabric movements result in restrictions of movement to the wearer. Elastic fibre, yarn and fabric provide the necessary elasticity to a garment. Brandon et al. determined the effect of custom-fit compression shorts on athletic performance and examined the mechanical properties of the shorts. The compressive garment significantly reduced impact force by 27% as compared to American football pants alone.

Compression garments may offer several ergogenic benefits for athletes across a multitude of sporting backgrounds. In particular, some studies have reported that compression garments improve muscular power, strength, enhance recovery following intense exercise and improve proprioception. However, caution should be taken while choosing the correct compression garment for the right sports and ensuring that the garment provides enough pressure to promote venous return.

Rob and Marc have conflict opinion that no benefit is observed while wearing compression garments for repeat-sprint or throwing performance. However, the use of these garments as a recovery tool, while doing exercise, may be beneficial to reduce post-exercise trauma and perceived muscle soreness. They also reported that the effect of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise is negligible. Similarly, William observed that these garment has no effect on maximal force or power of the highest jump. But, it has significant effect on repetitive vertical jumps by helping to maintain higher mean jumping power. Though there are some conflicts about the benefit of compression garments, the spandex and their fabrics have tremendous scope in the field of sports applications. Research towards improvement in the elasticity of fibre, yarn and fabrics and development in testing methods for elastic garments, is the current requirement for the industrial product development.

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