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## PREDICTION BY REGRESSION ANALYSIS OF STRETCHABILITY BEHAVIOR FROM UNFINISHED AND FINISHED BLENDED WEFT KNITTED FABRICS

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## ABSTRACT
Stretch, growth, and recovery are essential physical properties of weft-knitted fabrics. These properties may differ between grey and finished fabrics but can be predicted during the grey fabric stage. Laboratory testing, such as fabric stretch, growth, and recovery, can assess these properties. This study aimed to predict the stretch behavior of finished blended knit fabrics based on their grey stage versions. Five different blended CVC fabrics were prepared for the study, consisting of 90% cotton, 5% polyester, and 5% elastane; 90% cotton, 6% polyester, and 4% elastane; 90% cotton, 7% polyester, and 3% elastane; 90% cotton, 8% polyester, and 2% elastane; 90% cotton, 9% polyester, and 1% elastane. Six regression equations covering stretch, growth, and recovery were formulated for the Wales and Course directions. The experimental results showed a decrease in stretch and growth, an increase in recovery in the Wales direction, and a reduction of stretch and growth coupled with an increase in recovery in the Course direction. These findings are of significant practical importance for fabric manufacturers, providing valuable insights into producing fabrics that meet specific buyer requirements.

***Keywords***: *Stretch, growth, recovery, predicting, cotton-polyester-elastane*

## I. INTRODUCTION

Functional fabrics, known for their versatility and practicality, are gaining popularity. Retailers like H&M, C&A, GEORGE, BESTSELLER, MARKS & SPENSER, and ESPRIT favor the 95% cotton and 5% Lycra blend. Our research, aiming to reduce costs while maintaining optimum quality, is designed with this practicality in mind. One area of focus is the stretch behavior of these fabrics. Our study used five different blended cotton, polyester, and lycra fabrics. Tests were carried out on grey and finished fabrics to predict the stretch behavior of the finished fabric based on the stretch data obtained from the grey fabric stage. This research is crucial and groundbreaking for the industry, as it can result in significant cost savings without compromising quality, providing a practical solution for textile manufacturers.

The literature survey showed that most research focused on woven fabrics, with few studies on knit fabrics. Here are some of the findings from previous research: A computer-aided system used for designing knit stretch materials allows designers to optimize their structure based on their functional properties and structural parameters [1]. The researcher researched the correlation between warp count, weft count, greige PPI, greige EPI, greige width, and boil-off by developing an artificial neural network model [2]. Cotton has less stretch and a higher recovery percentage than PC (Polyester-Cotton), with the washing treatment producing higher stretch and less recovery than bleaching, indicating the interdependence of variables [3]. One study revealed that the elastane proportion significantly impacts knitted fabrics' elastic region size [4]. A study showed the effect of elastane linear density, thread density, and weave float on bi-stretch woven fabrics' stretch, recovery, and compression properties. The obtained regression equation's coefficients of determination ($R^2$) indicated the predictability of the formulated statistical models. That experiment analyzed the stretch properties of knit fabrics; it did not predict the stretch behavior of finished fabrics using grey fabric data, which is the primary focus of our research [5]. A study was conducted with 70% polyester 30% cotton, 70% polyester 30% vortex yarn, 70% polyester 30% viscose, 70% polyester 30% cotton ring-spun, and 100% cotton ring-spun to see the effect of the washing cycle on the stretchability of plain knit fabrics [6]. Khalil A. et al. researched weft knitted fabric to improve some physical properties by incorporating elastane yarns that tend to increase fabric thickness and air permeability, finally influencing the geometrical shape of knit fabric using Autocad software. [7]. Chowdhury U. studied the impact of structural attributes on jersey and interlock fabric. Their findings were the different test results obtained lengthwise and widthwise with increased lycra% [8]

The literature survey revealed that most previous research was done on two blended fabrics. In some cases, there was scope to predict the stretchability as elastane was incorporated into the blend, but this still needs to be done. Predicting some quality parameters in advance before going into manufacturing is a modern demand as far as sustainable developmental activities are concerned. However, our study has two main exceptionalities; one uses three different textile fibers, and the other predicts fabric quality parameters (stretchability) in advance.

This study is unique. The fabrics were manufactured in a compliant textile industry using state-of-the-art spinning, knitting, dyeing, and finishing machinery. The novelty of this study offers guidance for new researchers. The study mainly used three fiber types: cotton, polyester, and lycra. The term "king of textile fibers" refers to cotton. In the natural world, plants absorb $CO2$ from the air and water and produce C, H, and O-containing molecules when sunlight is present. Photosynthesis is the name of this process. One of the byproducts of this process is glucose. The fibrillar structure of cotton fiber has three walls: a primary wall, a secondary wall, and a lumen. *Cotton* is a soft, staple fiber that develops around cotton plant seeds in a protective capsule called a boll. Cellulose is the main component of cotton. Each fiber comprises 20-30 cellulose layers coiled on a neat network of natural springs. Cotton fibers have high durability and absorbency due to the arrangement of the cellulose. Cellulose is a significant component of cotton fiber. Plants use $CO2$ from the air and water to form compounds comprising C, H, and O in sunlight. This process is known as photosynthesis. One of the compounds generated this way is glucose [9]. The second fiber, *polyester,* is a long-chain synthetic polymer of at least 85% by weight of an ester of dihydric alcohol (HOROH). Terephthalic acid (p-HOOC-C6H4COOH) is what makes the fibers. Polyester consists of a long-chain polymer. Polyester's filaments and staple forms are strong due to its highly effective Vander wall forces and hydrogen bonds. Consequently, polyester gives higher tensile strength for woven fabrics and higher bursting strength for knit fabrics [10]. The third fiber, *Elastane,* is a non-biodegradable fiber typically used in sportswear and comfort wear. The elastane can stretch up to 500% or even more than 500%. DuPont's laboratory first invented elastane in 1959 in Virginia. Elastane takes 20-200 years to break down but not degrade. After a few years, elastane may break into microplastics. The soft and rubbery segments are responsible for showing stretchability, and hard segments provide rigidity and strength [11].

Fabric stretchability refers to a fabric's ability to elongate in either the length or width direction. The extent of stretch depends on the type of yarns used, fabric structure, and composition. A stretch property is necessary for functional wear or sports clothing. The three significant quality parameters are stretch (extension), growth (unrecovered extension), and recovery. Lycra fiber is known for its superior stretchability compared to synthetic fiber. There are various factors influencing the stretch behavior of blended knit fabrics. Fiber influences stretch property. The higher fiber elongation tends to higher stretch, lower growth rate, and recovery, and vice versa. This phenomenon is slightly different in width direction, meaning that the higher the fiber elongation, the higher the stretch, growth, and recovery. The specimens with higher cotton content exhibit lower tensile and good stretchability [12]. The higher the crystallinity, the higher the stretch% and better mechanical properties [13]. Yarn influences stretch property. Higher yarn elongation tends to higher stretch, lower growth rate, and recovery, and vice versa. The yarn CSP (Count Strength Product) single yarn strength (cN/tex) influences stretch property. The higher the CSP and single yarn strength, the higher the stretch. Coarse and high-elastic yarn typically shows lower fabric growth and higher elastic recovery [14]. Yarn composition also affects knit fabric stretchability [15]. The inlay pre-tension of yarn in the knitting stage tends to change stretchability. However, usually, no change occurs in load elongation behavior [16, 27]. The finer count of core yarn with lycra fiber improves stretchability [17]. Lycra's input tension and cotton yarn's loop length tend to change stretch properties. The higher the loop length, the higher the extension (Senthil Kumar [18, 19]. A filament with a higher initial modulus can improve knit fabric's stretch and recovery properties [20]. The fabric structure, thickness, count, weight, composition, porosity, and tightness influence the stretch property. The higher the fabric thickness, the lower the porosity and the stretch [8, 21]. The fabric's tendency to shrink also affects its stretch properties [22]. The number of washing cycles affects stretch behavior [23]. The test results vary depending on the fabric type and the number of cycles in the test procedure. The stentering and compacting process affects the stretch of knit fabric. The level of compactness percentage inversely affects the level of stretch. The heat-setting process also affects the stretch behavior of knit fabric [24]. The finish types can affect stretchability. The application of wrong test procedures, unskilled technicians, use of non-calibrated lab equipment, inappropriate sample preparation, incorrect handling of samples, and conducting tests not following the international standard atmospheric condition specified in ISO 139 affect stretch behavior [25]. The number of washing cycles affects stretch behavior. The test results vary depending on the fabric type and the number of cycles in the test procedure. When the fabric load is lower, the skin has less stress, allowing more accessible and flexible body movement [15]. The primary goal of this study is to predict the stretchability of finished knit fabrics based on the analysis of grey-stage fabrics.

## II. METHOD & MATERIAL

In the study, the samples are weft-knit blended fabrics. The study used single jersey fabrics with three different fibers: Cotton, polyester, and elastane, with varying percentages of blend ratios. Blended fabrics are popular among the textile community regarding quality and cost. These are widely used in sportswear, functional wear, and activewear. Table 1 shows the names of five blended fabrics used for this study. *Figure 1*. and *Figure 2***.** show the grey fabric and finished fabric.

***Figure 1. Grey fabric***

***Figure 2. Finished fabric***

***Table 1. Types of blended knit fabrics (Sample)***

| Serial No. | Fabric Type | Fabric Composition |
|---|---|---|
| 1 | CVC, Single Jersey Elastane | Cotton 90%, Polyester 5%, Elastane, 5% |
| 2 | CVC, Single Jersey Elastane | Cotton 90%, Polyester 6%, Elastane, 4% |
| 3 | CVC, Single Jersey Elastane | Cotton 90%, Polyester 7%, Elastane, 3% |
| 4 | CVC, Single Jersey Elastane | Cotton 90%, Polyester 8%, Elastane, 2% |
| 5 | CVC, Single Jersey Elastane | Cotton 90%, Polyester 9%, Elastane, 1% |

**Note. CVC stands for Chief Value Cotton**

### 2.1. The preparatory process involved in the study

The BCI (Better Cotton Initiative ) upland cotton is sourced from the United States, along with staple polyester and Lycra. This upland cotton was graded 42-1. Table 2 lists the essential raw cotton test parameters, while Tables 3 and 4 list the important polyester and elastane test parameters.

***Table 2. Quality parameters of cotton***

| Fiber | Tenacity [gm/tex] | Elongation [%] | UHML [mm] | SL [mm] | MIC | SF [%] | SCI | Rd | +b |
|---|---|---|---|---|---|---|---|---|---|
| Cotton | 31.8 | 7.0 | 29.29 | 27.5 | 4.24 | 10.1 | 138 | 71. | 9.8 |

UHML stands for Upper Half Mean Length, SL stands for Staple Length, MIC stands for Micronaire, SCI stands for Spinning consistency index, Rd describes Reflectance, and +b describes the yellowness of cotton

***Table 3. Quality parameters of polyester***

| Fiber | Tenacity [gm/tex] | Elongation [%] | Length [mm] | Fiber Count [Denier] |
|---|---|---|---|---|
| Polyester | 56.7 | 22.0 | 38.0 | 1.30 |

***Table 4. Quality parameters of elastane fiber***

| Fiber | Tenacity [gm/tex] | Elongation [%] | Length [mm] | Fiber Count [Denier] |
|---|---|---|---|---|
| Elastane | 11.25 | 465 | Continuo | 30.0 |

The high-quality yarn was produced using state-of-the-art spinning machines and had a count of 34/1 Ne (17.36 Tex) ring-spun. The grey textiles were made using the latest model knitting machines from Terrot, Germany. Table 5. shows the essential parameters of the knitting process used in manufacturing grey fabrics. The high-quality dispersed dyes of BEZEMA, Germany, with appropriate brand auxiliaries. The blended fabrics were dyed using reactive and dispersion dyes and then processed using Stenter (Monfortis, Germany) and Compactor (Lafer, Italy) equipment to create the final samples.

***Table 5. Quality parameters of Knitting***

| S N | Fabric Type | M/C Dia. | M/C Gauge | M/C RPM | Stitch Length (mm) | Needle Pitch (mm) | Lycra Denier | Reqd GSM |
|---|---|---|---|---|---|---|---|---|
| 1 | 90% C 5% P 5% E | 32 | 24 | 22 | 29.0 | 1.058 | 30 D | 180 |
| 2 | 90% C 6% P 4% E | 32 | 24 | 22 | 29.5 | 1.058 | 30 D | 180 |
| 3 | 90% C 7% P 3% E | 32 | 24 | 22 | 29.0 | 1.058 | 30 D | 180 |
| 4 | 90% C 8% P 2% E | 32 | 24 | 22 | 29.0 | 1.058 | 30 D | 180 |
| 5 | 90% C 9% P 1% E | 32 | 24 | 22 | 29.0 | 1.058 | 20 D | 180 |

C for Cotton, P for Polyester, E for Elastane, and 20 D for 20 Denier.

**2.2. Test standard**

The international test standard for determining the elasticity of fabrics used for the study is ISO 20932-1:2018 [26].

**2.3. Test equipment and apparatus**

The stretch, growth, and recovery tests were performed using the tensile strength tester Titan5 of James Heal and Company, UK.

**2.4. Test procedure**

First, the samples were conditioned for at least 20 hours in the conditioning room following ISO 139 (65% RH±4% RH, and 20°C±2°C for 4 hours). A total of five specimens were taken from both the warp and the weft direction. The specimen size (250 mm – 300 mm long and 50 mm ±1 mm) ensured. The 100 mm benchmark was used. Locate the line clamps in the jaws of the tensile testing machine and set the gauge length to (100±1) mm; the distance was measured with the calibrated rule. Set the Extension and retraction rate of the specimen at 500 mm/min. Set the fixed load (4 N) and a fixed elongation (30%). The test was run to complete the five cycles. After completing five cycles, the measurements were taken for extension/stretch, growth, and recovery after 30 minutes. The same technique was applied to the remaining specimens. Calculate Extension/Stretch, Growth%, and Recovery% using the formula.

**2.5. Calculation of stretch, growth, and recovery by using the formula**

i) Extension/Stretch, S, expressed as a percentage.

$$S = \frac{E}{L} \times 100$$

Where E = is the extension (mm) at maximum force on the fifth cycle.

L = is the initial length (mm)

ii) Growth, G, expressed as a percentage.

$$G = \frac{(Q - P)}{P} \times 100$$

Where Q = is the distance between applied reference marks, the permanent deformation (mm) after a specified recovery period.

P = is the initial distance between applied reference marks, the initial mark.

iii) Recovery, R, expressed as a percentage,

Recovery, R = 100 – G

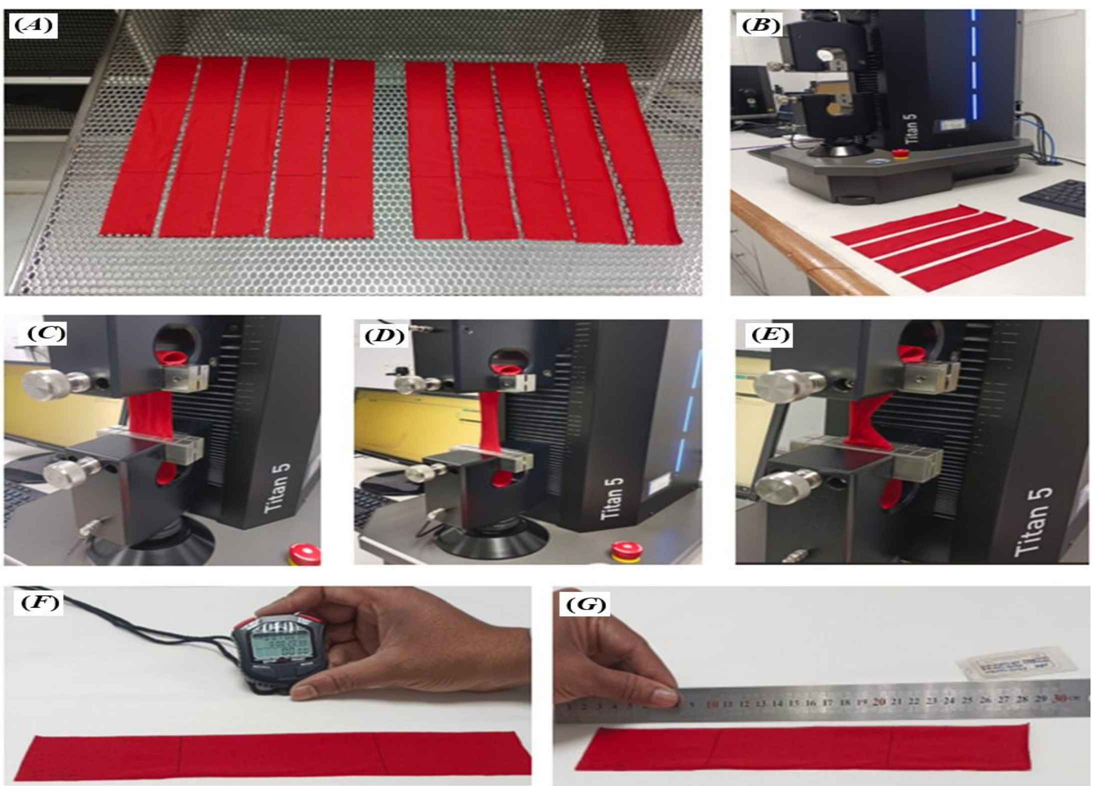


***Figure 3. (A) The specimens are kept for conditioning, (B) the machine is ready for the test, (C) the test specimens are mounted into the machine, (D) the test is in action, (E) the testing cycle completed, (F) the tested specimen is waiting for 30 minutes, (G) the tested specimen is under measurement after 30 minutes.***

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## III. RESULT & DISCUSSION

Blended fabrics' quality parameters or stretch behavior differ from those of grey and finished stage fabrics. Differences in length and width direction were also found in different stretch fabrics. A recent study compared the stretch properties (stretch, growth, and recovery) of finished fabrics to those of grey fabrics. Table 6 represents the comparative stretch data in the Wales direction, and Table 7. represents the comparative data in the course direction. Table 6 shows that the finished fabric stretch and growth decreased, and the recovery increased to an extent compared to the grey stage fabric in the Wales direction. Table 7 shows that the finished fabric stretch and growth decreased, and the recovery increased to an extent compared to the grey stage fabric in the Course direction.

***Table 6. Comparative data (stretch, growth, and recovery) in Wales Direction***

| Fabric Composition | Grey Stretch % | Finished Stretch % | Grey Growth % | Finished Growth % | Grey Recovery % | Finished Recovery % |
|---|---|---|---|---|---|---|
| C 90%, P 5%, E 5% | 114.8 | 88.8 | 15.8 | 5.2 | 84.2 | 94.8 |
| C 90%, P 6%, E 4% | 109.3 | 88.3 | 10.2 | 7.0 | 89.8 | 93.0 |
| C 90%, P 7%, E 3% | 103.9 | 87.7 | 7.6 | 8.2 | 92.2 | 91.8 |
| C 90%, P 8%, E 2% | 74.2 | 87.4 | 6.8 | 7.0 | 93.2 | 93.0 |
| C 90%, P 9%, E 1% | 71.6 | 86.6 | 6.6 | 7.6 | 93.4 | 92.4 |

C for Cotton, P for Polyester, and E for Elastane.

***Table 7. Comparative data (stretch, growth, and recovery) in the course Direction***

| Fabric Composition | Grey Stretch % | Finished Stretch % | Grey Growth % | Finished Growth % | Grey Recovery % | Finished Recovery % |
|---|---|---|---|---|---|---|
| C 90%, P 5%, E 5% | 118.6 | 105.7 | 6.8 | 10.2 | 81.4 | 90.8 |
| C 90%, P 6%, E 4% | 123.3 | 121.3 | 10.8 | 11.8 | 82.2 | 88.2 |
| C 90%, P 7%, E 3% | 124.2 | 123.8 | 11.8 | 12.4 | 88.2 | 87.6 |
| C 90%, P 8%, E 2% | 125.9 | 125.4 | 17.8 | 12.4 | 89.2 | 87.6 |
| C 90%, P 9%, E 1% | 134.2 | 132.0 | 18.6 | 13.4 | 91.4 | 86.6 |

C for Cotton, P for Polyester, and E for Elastane.

The regression analysis was conducted with finished fabric stretch data as an independent predictor and for predicting the response variable or dependent predictor as the finished fabric stretch data.

## IV. FABRIC STRETCH IN WALES DIRECTION

The regression equation for fabric stretch in the length direction is as follows.
Y = 84.19 + 0.03770*X The regression equation can be written as Finished fabric stretch% = 84.19 + 0.03770*Grey fabric stretch%. The slope is 0.03770, which means that when we increase the x = grey fabric stretch by 1%, the Y = finished fabric stretch will increase by 0.03770 times. The y-intercept is 84.19, which means that when x = grey fabric stretch equals 0, the prediction of Y = finished fabric stretch will be 84.19.

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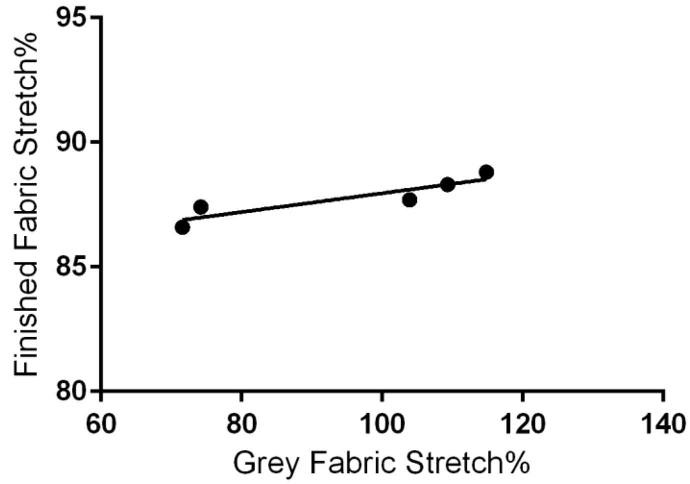


*Figure 4. The regression graph for the stretch in the Wales direction*

**4.2. Fabric Growth in Wales Direction**

The regression equation for fabric growth in the length direction is Y = 9.429 - 0.2584*X. The regression equation can be written as Finished fabric growth% = 9.429 - 0.2584*Grey fabric growth%. The slope is -0.2584, which means that when we increase the x = grey fabric growth by 1%, the y = finished fabric growth will decrease by -0.2584 times. The y-intercept is 9.429, which means that when x = grey fabric growth equals 0, the prediction of Y = finished fabric growth will be 9.429.

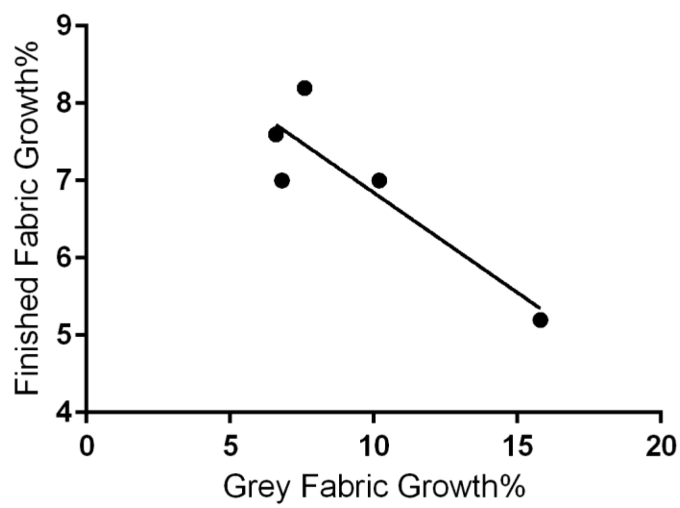


*Figure 5. The regression graph shows the growth in Wales's direction*

**4.3. Fabric Recovery in Wales Direction**

The regression equation for fabric recovery in the length direction is Y = 116.3 - 0.2574*X. The regression equation can be written as Finished fabric recovery% = 116.3 - 0.2574*Grey fabric recovery%. The slope is -0.2574, which means that when we increase the x = grey fabric recovery by 1%, the Y = finished fabric recovery will decrease by

0.2574 times. The y-intercept is 116.3, which means that when x = grey fabric recovery equals 0, the prediction of Y = finished fabric recovery will be 116.3.

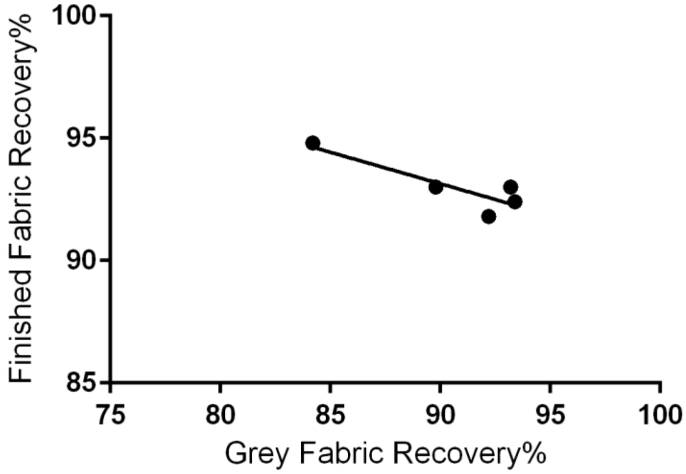


*Figure 6. The regression graph shows the recovery in the Wales direction*

**4.4. Fabric Stretch in Course Direction**

The regression equation for fabric stretch in the length direction is Y = -71.13 + 1.539*X. The regression equation can be written as Finished fabric stretch% = -71.131 + 1.5392*Grey fabric stretch%. The slope is 1.539, which means that when we increase the x = grey fabric stretch by 1%, the Y = finished fabric stretch will increase by 1.539 times. The y-intercept is -71.13, which means that when x = grey fabric stretches equals 0, the prediction of Y = finished fabric stretch will be -71.13.

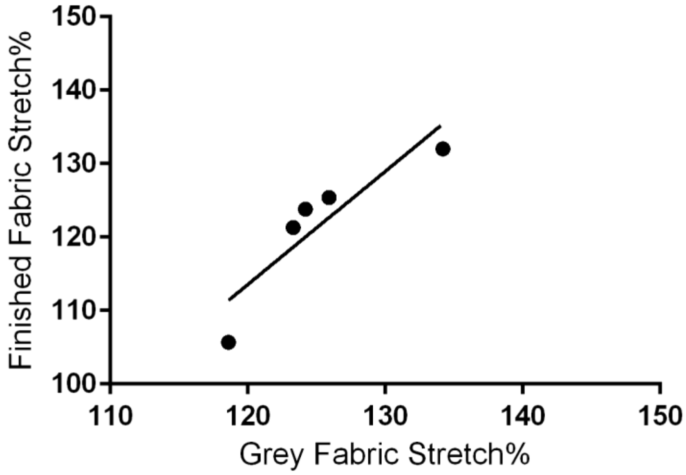


*Figure 7. The regression graph for the stretch in the course direction*

**4.5. Fabric Growth in Course Direction**

The equation for fabric growth in the width direction is Y = 8.223 + 0.2749*X. The regression equation is Finished fabric growth% = 8.223 + 0.2749*grey fabric growth%. The slope is 0.2749, which means that when we increase the x = grey fabric growth by 1%, the y = finished fabric growth will increase by 0.2749 times. The y-intercept is

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8.223, which means that when x = grey fabric growth equals 0, the prediction of Y = finished fabric growth will be 8.223.

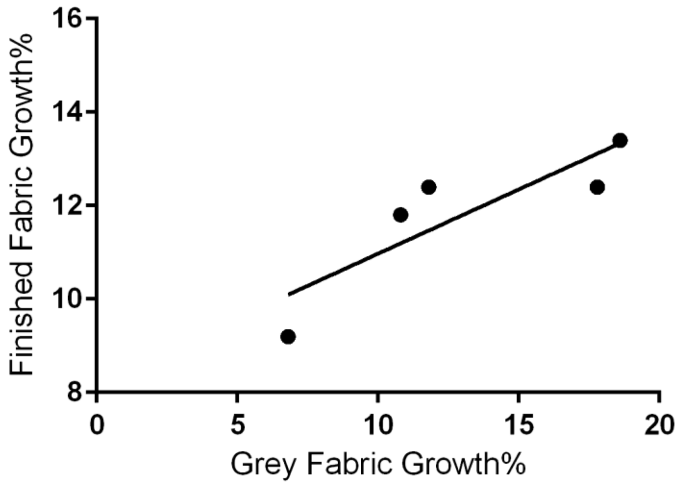


*Figure 8. The regression graph shows the growth in the course direction*

**4.6. Fabric Recovery in Course Direction**

The regression equation for fabric recovery in the length direction is Y = 114.3 – 0.3017*X. The regression equation can be written as Finished fabric recovery% = 114.3 - 0.3017*Grey fabric recovery%. The slope is -0.3017, meaning that when we decrease the x = grey fabric recovery by 1%, the y = finished fabric recovery will decrease by 0.3017 times. The y-intercept is 114.3, which means that when x = grey fabric recovery equals 0, the prediction of Y = finished fabric recovery will be 114.3.

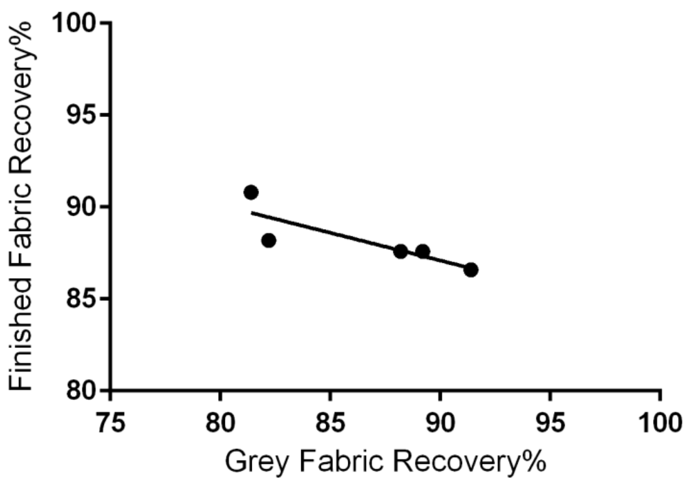


*Figure 9. The regression graph shows the recovery in the course direction*

Considering the facts, the regression predictive equation or model is regarded as the line of best fit.

## V. CONCLUSION

When manufacturing functional apparel, it is crucial to carefully evaluate the stretch, growth, and recovery characteristics of stretch fabrics to ensure optimal performance and comfort for the wearer. This recent study revealed that professionals can predict the stretch properties of finished blended knit fabrics in advance by analyzing the stretch properties of grey fabrics using a suitable regression equation. This predictive capability can significantly enhance functional apparel's design and production process. The study specifically focused on blended weft-knitted fabrics with varying percentages of polyester, highlighting the potential for improved stretch behavior in these fabrics. However, it is essential to note that the study was constrained by the materials used, which included cotton, polyester, and elastane, with varying blend ratios. Despite the promising findings, there remains significant scope for further research. New and advanced researchers have an opportunity to explore additional blend ratios and fabric combinations to enhance further our understanding of stretch fabrics and their application in functional apparel manufacturing. This could develop innovative fabrics with superior stretch, comfort, and performance characteristics. The study provides a clear understanding of the stretch behavior of finished blended knit fabric. This can help the textile manufacturing industry make informed decisions to meet buyer requirements in advance.

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**Data Availability Statement**
The data are available to the researcher based on receipt of the request.

**Conflict of Interest**
The author declares no conflict of interest.

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