A Model for Predicting the Stretch and Recovery Test Results of Single Jersey Fabric

Submitted by

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Declaration

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Table of Content

List of Keywords

ANalysis Of VAriance (ANOVA)

Constant Rate of Extension (CRE)

Elongation

Elongation

Elustane

Extension

Fabric

Growth

Modulus

Recovery

Single Jersey

Stitch

Stretch and Recovery

Tensile Testing

Visual Studio (VS)

Warp

Weft

List of Tables

List of Figures

Abstract

In the Textile Testing field fabrics are tested based on the international standards recorded in test methods. The stretch and recovery test is one of the important textile tests used to measure the extension and recovery of a fabric under a target load. This test is performed using a tensile testing machine, usually of the Constant Rate of Extension (CRE) type. The time allocated to complete the test is considerably high due to the high time requirement for preconditioning, conditioning, sample preparation and testing. The stretch and recovery test report results are very critical and urgent most of the time. However, due to the time constraint, it may not be possible to deliver the reports to the customers on time. Therefore, this research has been carried out to predict the stretch and recovery test results for single jersey fabric without performing the physical test procedures.

This research aims to design a mathematical model to predict the stretch and recovery for single jersey fabric. In achieving this objective, the quantitative method was applied. A theoretical framework was constructed grounded on a comprehensive analysis of the related literature. Resultant models derived during the analysis stage, then validated, and a simple tool has been implemented to be used by the laboratory staff. The model has shown more than 76% of accuracy, but it could be further validated by increasing the sample size and by revising the assumptions made during the study.

This research has a great benefit to textile laboratory staff since they can utilize minimum resources for Stretch and Recovery Test. As the CRE machine requires more duration for the test specimen preparation and more time to complete the test, testing staff will be able to use the simple application developed based on the model derived as the result of this study.

Chapter 1: Introduction

1.1 Background

Single jersey is a weft-knitted which is formed by interlooping yarns by one set of needles (Asit G, 2020). Single jersey manufacturing is significantly more rapid and cost effective than woven (Catarino et al., 2004). The appearance of the two sides of the single jersey fabric is different. The vertical columns of loops are called wales, and horizontal lines of loops are called courses (Abdessalem S.B et al., 2009). Single jersey structures are commonly light in weight, comfortable to wear at any event and require less effort to keep neat and presentable. The tendency of single jersey fabric to recover quickly after wrinkling is one of the other factors which boost its popularity. Single jersey sewn structures are utilized for planning dynamic attire, for example, sports garments. The elastic nature permits for rich physical activity.

Single jersey fabrics have many uses and applications since they are generally light in weight, comfortable to wear, soft, flexible and stretchable. The properties of single jersey fabric are; (1) low dimensional stability, (2) higher elasticity, (3) comfort in wearing, (4) less labor cost in manufacturing, (5) simple finishing process than other fabrics such as woven, (6) softness of the fabric, (7) some of the fabrics do not require ironing since fold (crease) marks do not remain in the fabric.

The single jersey fabrics have high preference over other fabrics for different purposes mainly due to the elastic properties which allow the fabric to stretch significantly, even under small stresses, and however later it returns to the original shape (Eltahan and Eman, 2016). Since stretch and elastic recovery are very important in single jersey fabrics, evaluation of them is valuable (Olena Kyzymchuk and Liudmyla Melnyk, 2018). The results of such evaluations will be useful for the technologists who want to create fabrics for special purposes and to the consumer to purchase single jersey fabrics for a definite need.

The rest of the segments of this chapter are arranged as follows. In the section 1.2; the motivation of the study is clarified. The purpose of the study, primary and the secondary questions are introduced in the next section. The section 1.4, discusses the method followed in the study and finally, in section 1.5, the structure of the thesis is introduced.

1.2 Motivation for the research

The stretch and recovery test under BS.EN.ISO 14704 -1 was performed to measure the extension and the recovery of a fabric. This is a very sensitive and an important test done in a standard atmospheric conditioned environment of which the temperature has to be 20 +/- 2 °C and the Relative Humidity (RH) has to be 65 +/- 4%. The fabric samples shall be conditioned for minimum of 20 hours in a tension free state. Then the prepared specimen shall be conditioned in the same state for a further 4 hours after preparation. Accordingly, 24 hours will be taken for the conditioning in an ISO17025 certified laboratory. Then, the stretch and recovery test is carried out using a Constant Rate of Extension (CRE) machine and it requires nearly two hours for the test. There are some situations where the customers expect immediate test results. The laboratory staff is unable to satisfy such requirements since the test needs more time specially for conditioning and testing specimens.

This motivated the researcher to initiate this study to implement a model to predict the stretch and recovery test results of single jersey fabric without carrying out the test in a physical laboratory.

1.3 Aims and Research Questions

As discussed in chapter 1, the time and the cost to perform the stretch and recovery test is high with compared to the other textile tests. However, there is no proper approach suggested to overcome this limitation by the existing research studies. Therefore, a requirement for an alternative method to derive the test results without performing the test in a real laboratory was raised.

Accordingly, the primary objective of this research is set to design a mathematical model to predict the stretch and recovery for single jersey fabric. The sub objectives of the research are:

- Identify the properties of extension and recovery of single jersey fabric based on the results of the stretch and recovery test.
- Identify the suitable analysis method to construct the mathematical model to represent the relationship between stretch and recovery with the elastane percentage of the fabric.

To satisfy these purposes, the main research question is constructed as "How to design a mathematical model to predict the stretch and recovery for single jersey fabric?". Once the main research question is formed, the sub questions are listed as follows:

a. What are the properties of extension and recovery of single jersey?
b. What is the suitable analysis method to construct the mathematical model to represent the relationship between stretch and recovery with the elastane percentage of the fabric?

1.4 Methodology of the Research

The primary objective of this research is set to design a mathematical model to predict the stretch and recovery for single jersey fabric. To satisfy this point, a quantitative research technique is embraced. A quantitative Methodology of the research empowers evaluating explicit hypotheses to address the research questions (Neuman, 2007). Specifically, a quantitative system is valuable for inspecting how hypotheses are supported to the prediction (Creswell et. al, 2011). The quantitative approach is selected due to two reasons. It is suitable for enormous population and for drawing solid decisions from information gain in the analysis (Landman, 2003, Steckler et al., 1992). Thereby, following the quantitative research approach, the data is gathered from the results generated by the CRE machine for the stretch and recovery test of single jersey fabric.

As appeared in Figure 1.1, the flow of the research has segregated to eight stages to carry out the tasks of the research. Firstly, the research is initiated with a plan. In the second phase, the related literature on the research topic were gathered. The review of related literature prompts a better comprehension of the research space, the current investigations, apparatuses and advancements utilized by researchers etc. Such an understanding prompts the improvement of a theoretical framework for the model fabricated. In this stage, hypotheses are created dependent upon the connections among the theories built in the theoretical framework. Research instrument is illustrated in the fourth section of the research. The data collection is performed by conducting stretch and recovery test for single jersey fabric using CRE machine. In the fifth phase of the research, the hypotheses are generated. In the next step, the data analysis is performed and the mathematical models are developed. Hypotheses were tested in the seventh step and in eighth step the model is evaluated and finalized. Finally, the conclusions were made by answering the research questions.

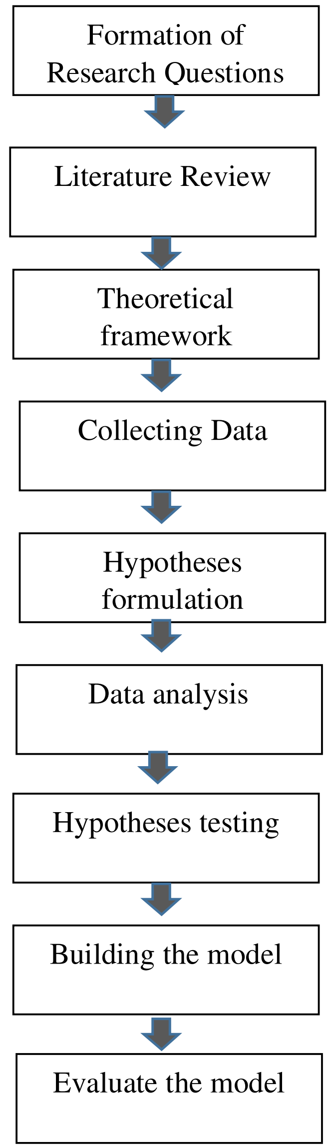


Figure 1.1 Methodology of the Research

1.5 The Thesis Structure

Chapter 1: Introduction; This chapter provides a prologue about the research including a short portrayal of the foundation of the research, the motivation to initiate the research, purpose of the research and the method applied to achieve the objectives.

Chapter 2: Literature Review; illustrates the findings of a thorough survey of the literature data of the research in three steps. First, the research setting is talked about with an accentuation on the Single jersey fabric. Secondly, the properties of the single jersey fabric are discussed in detail. Finally, the stretch and recovery test for single jersey fabric is discussed.

Chapter 3: Theoretical framework; this chapter illustrates the theoretical framework proposed in modeling the stretch and recovery test. Grounded on the theoretical framework, hypotheses are proposed in this chapter.

Chapter 4: Research Methodology; this chapter proves the validity of the selected research methodology. An impression of different research methods are discussed in chapter. The usage of the research methodology in achieving the objectives is also explained including the collection of data and the data analysis.

Chapter 5: Results of the Data Analysis; this chapter illustrates the method followed in data analysis in detail. The descriptive statistics of the in the samples is potted. Finally, the validity of the hypotheses are also discussed in this chapter.

Chapter 6: Conclusion; this chapter provides an overall conclusion of the study including the findings, limitations, the contribution of the study to the textile industry and finally, the future directions.

Chapter 2: Literature Review

This part gives a thorough discussion on the literature appropriate to this research in three stages. Firstly, the details about the single jersey fabric. Secondly, the stretch and recovery property and testing stretch and recovery of a single jersey fabric is discussed in detail. Then an account of similar studies is presented.

2.1 Single Jersey Fabric

When compared to woven fabric, knit fabric is easier to deform or stretch by compressing or elongating each stitch that from the fabric. Therefore, mainly the single jersey fabrics are used to construct underwear and outerwear. The main properties of knitted fabric are; air permeability, comfort in wearing, extensibility, and heat insulation. Knit fabrics are constructed of 100% cotton. However, the knit stitches reach to original dimensions when the force on the fabric is removed. The single-knit fabrics may experience permanent deformation. In order to improve the recovery performance of circular single-knit fabrics, the fabric is co-knit with spandex fiber or cotton yarn.

Single jersey stitch: at the point when the needle is raised successfully high by the camming action to obtain the yarn in the snared partition if the needle and the old circle is beneath the latch, a Single jersey stitch will be framed as the needle plummets (Sadek et. al., 2012).

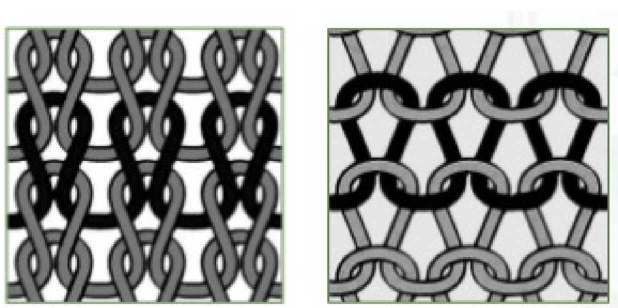


Figure 2.1 Single jersey Stitch

Tuck stitch: A tuck stitch is made of a held loop with single or multiple knitted loops (Fig. 9.4). It is constructed when a needle is holding its loop also receives a new loop. The side limbs not restricted at their feet by the head of an old loop, so they can open outwards towards the two adjoining needle loops formed in the same course. The tuck loop thus assumes an inverted V or U-shaped configuration (Sadek et. al., 2012).

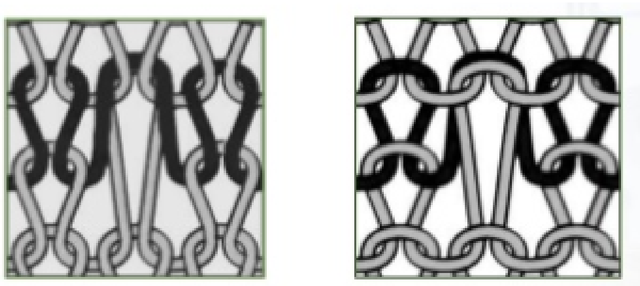


Figure 2.2 Tuck Stitch

2.2 Stretch and Recovery Test for Single Jersey Fabric

Stretch and recovery test is one of the most popular textile tests. It utilized to compute the maximum stretchability of a single jersey fabric at a required force and recovery of the fabric after a specific time. The CRE machine could be used to fulfill this requirement. The buyers require an acceptable extension range and a recovery value. The stretch and recovery test is used to check whether the fabric is inclusive of the buyers' requirements. A sample image of the CRE machine is shown in the figure 2.3.

Figure 2.3 CRE Machine

There are common terms used in stretch and recovery test for single jersey fabric. They are extension, elongation, elastic limit, un- recovered elongation/ growth recovered elongation, gauge length, stitch length and course length. Following section discusses about these terms.

Extension: The increase of the length of a test specimen produced by special force. This expressed in the unit call millimeters.

Elongation: The ratio of the extension to the initial length of a test specimen is called as the elongation.

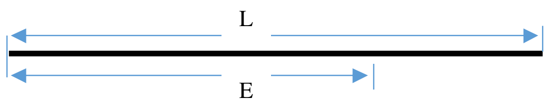


Figure 2.4 Elongation Property

Let, L = initial length of the specimen

E = Extended length of the specimen after a specific force.

Then, Elongation (%) = (L-E)/E * 100

Elastic limit: It is defined as the value of stress up to and within which the material returns back to their original position in both shape and size on the removal of external force.

Un- recovered elongation/ growth: the ratio of un- recovered extension of the test specimen to its initial length after a defined loading – unloading cycle, expressed as a percentage.

Let,

Q = distance between applied reference marks after a specified recover period

P = initial distance between applied reference marks

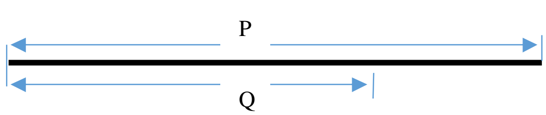


Figure 2.5 Un- recovered Elongation Property

Un-recovered elongation, C (%) = (P-Q)/ Q * 100

Recovered elongation: This is obtained by subtracting unrecovered elongation from 100%.Therefore, recovered elongation = (100- C) Where, C is the un- recovered elongation

Gauge length: The original length of a specimen over the strain length is determined by the Gauge length.

Stitch length: The length of a yarn which confined in a single jersey loop is known as stitch length or loop length. This includes the needle loop and half the sinker loop on either side of it.

Stitch length = Course length / No of needle Single jerseyting

Course length: The straight length of a yarn single jersey by all or a portion of the needles in the construction of a specific course.

Course length = No of needle Single jerseyting * Stitch length

Stretch and Recovery Test Procedure

The stretch and recovery test procedure is shown in following figure 2.5.

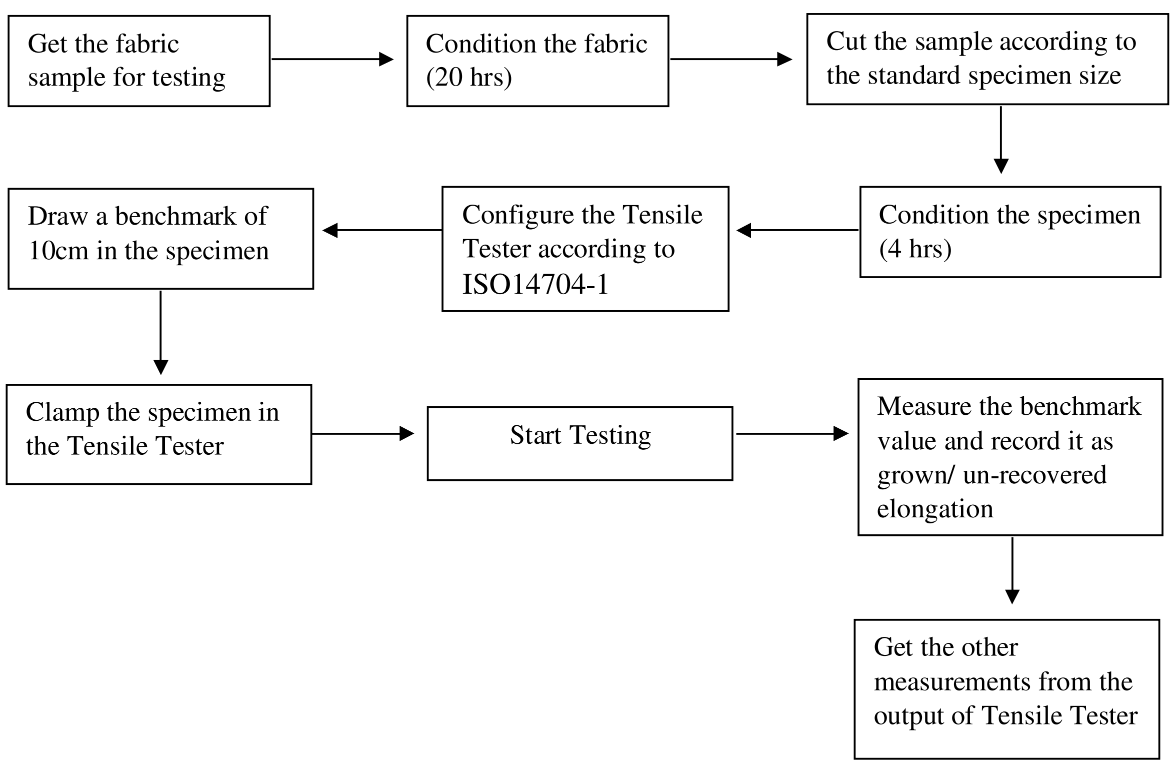


Figure 2.5 Tensile Testing Test Procedure

The tensile tester is used to perform the stretch and recovery test. As illustrated in the above figure, when the fabric sample is received for the test, it has to be kept in a standard atmospheric conditioned environment. Then the fabric samples are cut according to the standard specimen size. Next, the specimens are conditioned for about 4 hours. During this time, the tensile tester is configured according to the ISO14704-1 standard. Then draw a benchmark of 10cm in the test specimens. Clamp the specimen in the tensile tester. Then the test is started. Once the testing is over, again measure the benchmark value in the specimen and record. This is known as the growth/ un- recovered elongation. The tensile tester produces different values in the output. They are for stitch density, yarn count, loop length, machine gadget, machine diameter, the modulus at 2nd load curve, the modulus at 5th load curve and extension at 15N.

2.3 Related Studies

The stretch and recovery test is considered as an important fabric test and many researchers have conducted various studies in this domain. A study on finding the effect of elastane usage on plated plain knitted fabric features was carried out by many researchers and they formed a sequence of five cotton/Lycra plated plain knitted fabrics via a manufacturing single jersey circular knitting machine. They gathered all the measurements, 24 hours after the knitting of fabric, so as to let the fabric to relax, and keep the standard textile testing conditions of 21°C ± 1°C and 65% ± 2% relative humidity. They utilized seven specimens and each sample was tried for mean value of width and weight. According to the results, it's indicated that the amount of elastane substantially affects dimensional and elastic properties of cotton/Lycra plated plain knitted fabric. Fabric width rises while the fabric weight get decreases with Lycra use when utilizing a large- diameter circular knitting machine with a positive Lycra yarn delivery (Abdessalem S.B et al., 2009).

The Dorlastan product information technical report produced by Asahi Kasei Spandex Europe GmbH has indicated that the elastane yarn proportion is a very important parameter of single jersey plated fabric. It has concluded that the proportion of elastane influences the characteristics of the fabric (Asahi Kasei (2008). In another research, the authors were assessed the knitted fabric performance properties such as shrinking, laundering and elastic properties like breaking extension, maximum extension at cyclic loading upto defined load/ extension. Accordingly, they reduced the area density of a Lycra plain knitted fabric based on the product specification and able to optimize the knitting and after-treatment process. (Cuden, A. P. et al.). The authors of another study have investigated the effect of extension increase percent of bare Lycra yarns during looping. Their results claimed that according to the increases of extension increase percentage, there exists a sharp increase in the courses density, the thickness and weight per unit area of the fabric. The air permeability of both half and full plating fabrics decreased. Also, they mentioned that a comparison between half and full plating methods contributes to improving fabric quality by determining optimal Lycra percentage (Sadek et. al., 2012).

The researches of another study have mentioned that the shrinkage and bursting strength decreases with the decrease of lycra percentage, Spirality decreases and Pilling quality increases with the increase of lycra percentage and vice versa in investigating the effect of lycra percentage to the properties of single jersey knitted fabric (Rahaman H et. al, 2014).

In another study about the investigation of the suitability of cotton - spandex core spun yarn for circular knitting, the researchers clearly indicated that the yarn is suitable for circular knitting and change in stitch length values since they do not have any significant impact on wale density values. Also, they claimed that there exists an inverse proportion to the stitch length values (V. Kumar and V. R. Sampath, 2013).

There is a study about investigation of the elastic recovery and elastic elongation of elastic warp knitted fabric made of polyethylene terephthalate and polybutylene terephthalate filament. According to their finding they have mentioned that the dyeing temperature, heat setting time and temperature has a better relationship with elastic elongation and recovery. (Qing CHEN, et al, 2017).

There was another key study done by a group of researchers and they used woven fabrics for the study. The recovery and elongation properties of stretch woven fabric were measured on the latest Titan Universal Test Equipment with different rates of extension. After the sample data had been gathered Machine learning algorithms were used (Feed Forward Neural Network and Multiple Linear Regression) to measure the most accurate test results in the tests and selected the best model. The authors have mentioned the actual test results and the predicted results in their paper. According to their findings, they were able to use these two machine learning algorithms to correctly predict the results of the test (Noyan Ogulata et. al, 2006).

There was another study with statistical methods to demonstrate the cotton fabrics which containing diverse rates of spandex by illustrating the actual relationship among them (Elshakankery M.H and , Alsaid Ahmed Almetwally, 2012).

There was a study about forecasting the tensile properties of cotton spandex core-spun yarns using Artificial Neural Network (ANN) and Linear Regression algorithms by a gang of researchers. Further, the yarn breaking elongation, breaking strength, and work of rupture of the core-spun yarns were studied by them. Accordingly, they evaluated the accuracy with the root mean square error, mean bias error, and the coefficient of determination in the two models and concluded that the ANN outperforms the linear regression (Almetwally, 2014).

An ANN approach for prediction of bursting strength of knitted fabrics has carried out in another study. The researchers used three parameters named; elastomeric yarn count, basic yarn count and elastomeric yarn ratio as inputs to the ANN model with nine neurons in single hidden layer. According to their outcome, they suggested that the ANN model they trained will be able to predict the bursting strength behavior of a knitted fabric (Bahadir M.C et al, 2012).

There was another study which used an ANN model based on rotor speed, rotor diameter, navel type, ginning waste proportion, opener roller speed, and yarn linear density as inputs to the ANN algorithm, the outcome of the research has shown that the breaking strength and the mass irregularity of rotor spun yarns could be forecasted by ANN with a higher accuracy (Shanbeh M et al., 2011).

As per the understanding about the existing research studies conducted in the same domain, there were no research based on predicting the stretch and recovery for single jersey fabric. Further, no research has been carried out to derive the results of the stretch and recovery test without performing the test in a physical laboratory. Therefore, there exist a clear gap between the research idea and the existing studies.

In the next chapter, the theoretical baseline for predicting the stretch and recovery for single jersey fabric is discussed using a theoretical framework.

Chapter 3: Theoretical Framework

This chapter presents the Theoretical framework for predicting the stretch and recovery for single jersey fabric. Such a framework is useful since its structure can support a theory of a research study (Abend, 2013).

This chapter is organized as follows. Firstly, the important properties and results of stretch and recovery test are discussed. Then, the theoretical framework of the research is presented. Next, a comprehensive depiction of the theories of the theoretical framework and the research hypotheses constructed conforming to the relationships between those hypotheses are presented. Finally, the conclusion of the chapter is presented.

3.1 Selection of Stretch and Recovery Test Results for the Implementation of Theoretical Framework

As discussed in chapter 2, the stretch and recovery test is performed using the tensile tester known as CRE machine. The output of stretch and recovery test which is given by the CRE machine consists of different components. They are stitch density, yarn count, loop length, machine gadget, machine diameter, the modulus at 2nd load curve, the modulus at 5th load curve, extension at 15N and the growth.

The stitch density, yarn count, loop length, machine gadget and machine diameter are considered as constant since they are not going to change while performing the test. However, the modulus at 2nd load curve, the modulus at 5th load curve, extension at 15N and the growth values are measured and recorded. In most of the circumstances, the customers are concerning and requesting these parameter values as the results of the test. Therefore, these test output parameters are included to the theoretical framework to carry out the research.

Modulus at 2nd load curve

Modulus is the force measured at 40% elongation during the movement of the clamp of the CRE machine towards the upper direction at 2nd curve.

Modulus at 5th load curve

Modulus is the force measured at 40% elongation during the movement of the clamp of the CRE machine towards the upper direction at 5th curve.

Extension at 15N

Extension is the increase in length of a test specimen produced by 15 N force as a result of testing, expressed in units of length in millimeters.

Growth

This is known as the unrecovered elongation as well. It is the ratio of un- recovered extension of the test specimen after cycling to a specified force or extension, to its initial length, expressed as a percentage.

3.2 Development of the Theoretical Framework

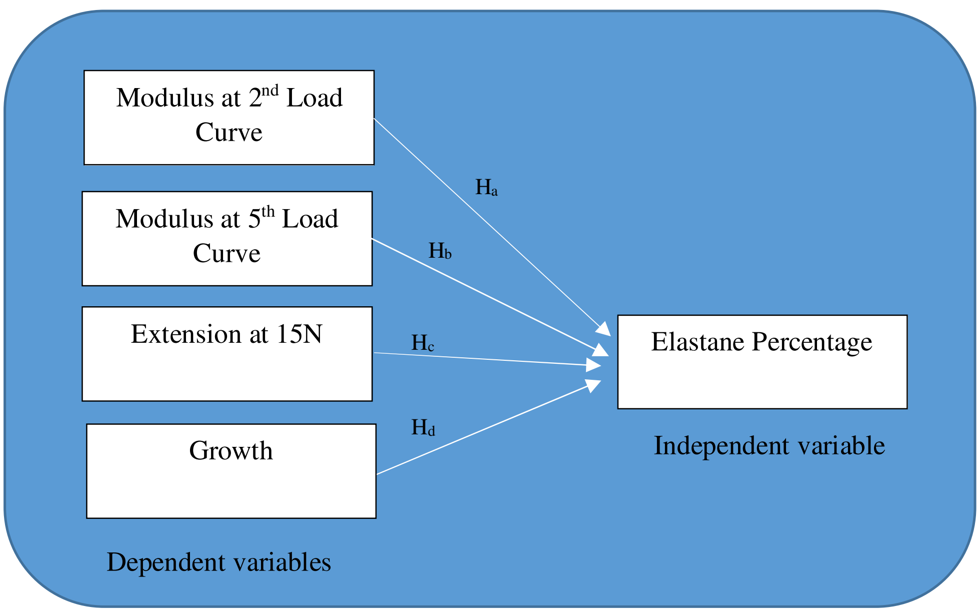


Figure 3.1: Theoretical Framework of the Research

According to the Theoretical framework illustrated in figure 3.1, modulus at 2nd load curve, Modulus at 5th load curve, extension at 15N and the growth values determine the stretch and recovery of a fabric when the above-mentioned parameters remain unchanged.

Based on the theoretical framework, four hypotheses are set.

H_a: There exists a relationship between the modulus at 2nd load curve and the elastane percentage of the fabric.

H_b: There exists a relationship between the modulus at 5th load curve and the elastane percentage of the fabric.

H_c: There exists a relationship between the extension at 15N and the elastane percentage of the fabric.

H_d: There exists a relationship between the growth and the elastane percentage of the fabric.

H_a: There exists a relationship between the modulus at 2nd load curve and the elastane percentage of the fabric.

In this hypothesis, it analyses whether there is a relationship between the modulus results at 2nd load curve has a relationship with the elastin percentage of the fabric.

H_b: There exists a relationship between the modulus at 5th load curve and the elastane percentage of the fabric.

The hypothesis H_b determines whether there is a relationship between the modulus results at 5th load curve has a relationship with the elastin percentage of the fabric.

H_c: There exists a relationship between the extension at 15N and the elastane percentage of the fabric.

In this hypothesis, it checks the relationship between the extension at 15N and the elastane percentage of the fabric.

H_d: There exists a relationship between the growth and the elastane percentage of the fabric.

The hypothesis H_d determines whether there is a relationship between the growth value and the elastane percentage of the fabric.

This chapter presented the theoretical framework developed to gather the theoretical support to the research through four hypotheses. The framework considers four theoretical constructs called modulus at 2^{nd} load curve, modulus at 5^{th} load curve, extension at 15N and the growth values which could be measured during the stretch and recovery test. Based on them four hypotheses were formed.

The next chapter discusses the methodology followed in the research.

Chapter 4: Methodology of the Research

In order to achieve the goal of this study a confirmatory approach is applied. The hypotheses developed to distinguish the connection between yield parameters of the stretch and recovery test and the elastane level of the single jersey fabric are identified. Then the hypotheses are validated by analyzing the information gathered by performing stretch and recovery test for chosen test specimens. This chapter presents the research method followed in this study.

First, the details of the research strategy is presented to meet its aims. Accordingly, this chapter enlightens how stretch and recovery test was performed to collect test data, the data analysis procedure and the techniques followed at each step of the research.

The chapter is prepared as follows. Initially, the two main research strategies are discussed. Next, the methodology of the research adopted in this research is discussed. Finally, the conclusion of the chapter is presented.

4.1 Research Strategy Followed in the Study

The quantitative research method is trailed in this study to reaches its target. This research follows the confirmatory method to confirm the priori hypotheses created on the yield properties of the stretch and recovery test against the elastane percentage of the fabric. A quantitative approach is identified as appropriate for the study as it is observing the strength of the proposed hypotheses on distinguishing the relationship between the parameters. The methodology of the research performed in this study is illustrated in the Figure 4.1 and the research methodology is executed in six steps, namely; define the aims of the research and research questions, reviewing associated literature, developing a theoretical framework and building hypotheses, data collection, data analysis, model and evaluate the results, illustration of conclusions and proposing recommendations.

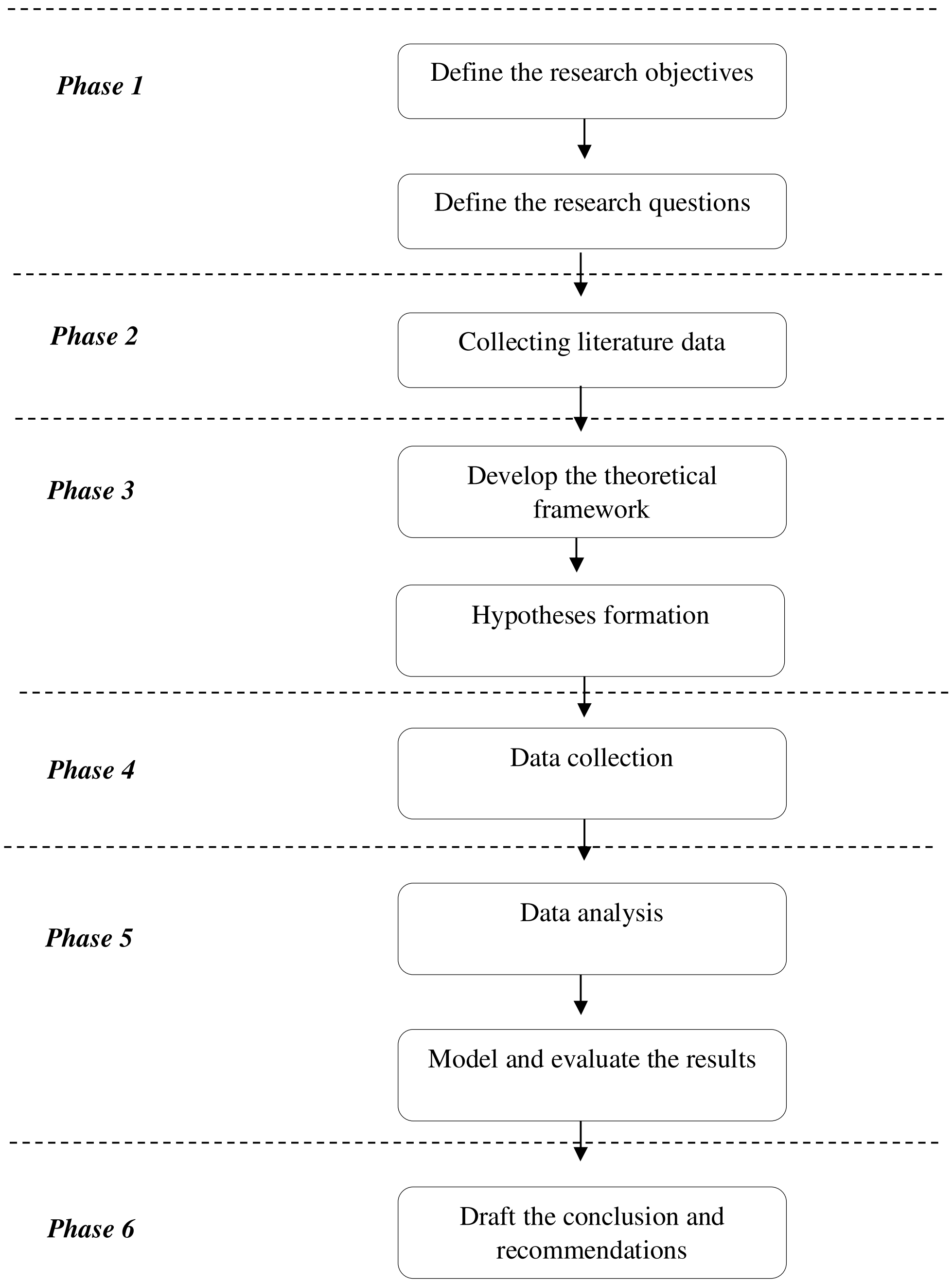


Figure 4.1. Flow of the Research

In the first stage, the aims/ and research questions were drafted based on the initial data and the ideas. Then the quantitative research strategy is adopted to achieve the purposes of the research. The research objectives are discussed in chapter 1.

In the second stage, an evaluation of the literature was conducted. A wide-range of literature data associated to the concepts useful to the research was shown, and the outcomes of prior research germane to this research were reviewed. Different research studies conducted in similar capacity were discussed with their aims, their procedure, the results and the conclusions they made in the study in chapter 2.

In the third phase, a theoretical framework of the study was constructed based on the results of the literature study. Four hypotheses were established grounded on the relations in theoretical framework. Also, the independent variables contributing to the theoretic constructs in the theoretical baseline were also recognized from the literature review.

In the fourth phase, data collection was carried out. The data was gathered by performing stretch and recovery test using the tensile tester (CRE machine).

In the fifth phase, the data was analyzed using a data mining algorithm and a prediction model was developed. Then, the model was evaluated and the mathematical formula to calculate the predictor values based on the input elastane percentage were derived.

During the final phase, the research questions were answered, and the conclusions and recommendations were drafted.

4.2 Construction of the Research Instrument

As mentioned in above, the data collection was done by performing the stretch and recovery test using a tensile tester under the specified standard conditions.

4.2.1 Measuring Equipment

The tensile tester is used to perform the stretch and recovery test for single jersey fabric. A ruler is needed to mark the benchmark measurements in the test specimen.

4.2.2 Sample Preparation

Five types of single jersey fabrics are used for the stretch and recovery test for both warp and weft directions.

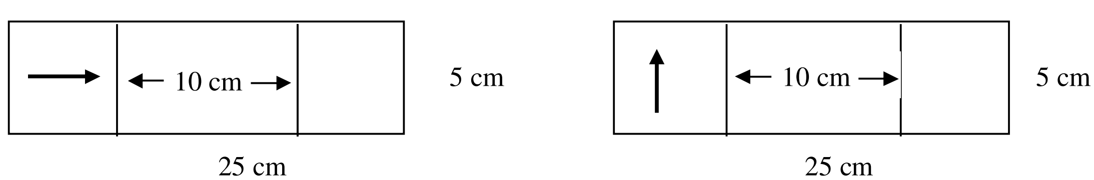


Figure 4.2. Fabric Specimen for warp and weft

The details about the sample fabric are illustrated in table 4.1.

Table 4.1: Details of single jersey fabric used for the sample

Composition	Machine Gauge	Machine Diameter	Loop length	Yarn count
95% cotton 5% Spandex	28	30	3.2mm	30Ne cotton & 20D Spandex
92% cotton 7% Spandex	28	30	3.0mm	30Ne cotton &20D Spandex
90% cotton 10% Spandex	28	30	3.0mm	30Ne cotton & 20D Spandex
88% cotton 12% Spandex	28	30	3.3mm	30Ne cotton & 20D Spandex
87% cotton 13% Spandex	28	30	3.3mm	30Ne cotton & 20D Spandex

According to the fabric samples considered in this study, it can be seen that the loop lengths are varying from 3.3mm to 3.0mm. Usually, the loop lengths of the fabric samples that are commercially available with suppliers to have different values. However, since the loop lengths of fabrics considered in this study are closer to 3.0mm, an assumption is made as its unique.

According to a researcher, (Eltahan E, 2016) the output of stretch and recovery test results depend on several parameters of the sample fabric, named; yarn composition, Knitted fabric structure type, gauge, elastane yarn linear density, yarn count, fabric GSM, elastane fiber proportion (%) and fabric thickness. The thickness and fabric GSM were not considered in this study and except for yarn composition all other parameters were unique.

4.2.3 Data Collection

The stretch and recovery test is performed under the ISO14704-1 standard laboratory with the required conditioning and humidity factors. Once the test is over, 300 test results were recorded for the analysis. The growth of the specimens are manually measured after the test. Other measurements such as elastane, modules at 2nd load curve, modulus at 5th load curve, and extension are taken from the tensile tester.

Table 4.2 illustrates the details about the data set.

Table 4.2: Details of the Data Set

Name of the variable	**Description**
Elastane (%)	Elastane percentage of the fabric
Modulus at 2nd (N)	Modulus value at 2nd load curve
Modulus at 5th (N)	Modulus value at 5th load curve
Extension (%)	Extension percentage of the fabric
Growth (%)	Growth of the fabric

A. Independent Variables

The elastane percentage of the single jersey fabric (Elastane) is considered as the independent variable of this study.

B. Dependent Variables

Modulus at 2nd load curve (Modulus2), Modulus at 5th load curve (Modulus5), extension at 15N (Extension) and the growth (Growth) are defined as the dependent/ target variables in the study.

The tensile tester result sheets are attached in the Appendix section of this thesis.

4.2.4 Data Cleaning and Pre-processing

Since the dataset is generated from tensile tester, there were no missing values, null values and incomplete values in the data set. Therefore, a special task in preparing the data is not required. However, the data is transformed into numeric type to analyse using R statistical software package.

4.2.5 Data Analysis

The task of the analysis was to identify the relationship between the predictor variable with each target variable and come up with a model to predict the stretch and recovery test results. Since this model needs to utilize for easy calculation of the test results without the real test, it has to be a mathematical model. Therefore, the linear regression analysis technique was undertaken.

Initially, the dataset was separated into training and testing set to start the analysis task. 80% of the records were incorporated into the training set and the remaining 20% of the data is included into the testing set.

Next, open source R statistical software was selected to derive the regression model and to evaluate the accuracy of the models. This contains several packages and libraries to analyze data efficiently. However, the user has to remember and type program lines in the R editor to get results of the analysis. As the first step of the analysis, descriptive statistics were analysed. Then a correlation analysis was done to identify the strength of the relationships among the variables. Then the simple linear regression is used to build the analytical model since a mathematical formula is also incorporated into the final outcome. Then the regression model was built and tested the fitness of the model the future forecasting. The training data set was analyzed and the model was developed. The model was evaluated using testing data set and the residual distribution is also evaluated for making the finalized model.

This chapter illustrated how the research is structured with the research approach to reach its target. The quantitative approach is applied in the study and the main intuition of this chapter was to explain the preparation of the research instrument, data gathering and data analyzing steps followed in this study. The complete analysis procedure with the assumptions and the hypotheses is discussed in detail in the next chapter.

Chapter 5: Data Analysis and Results

5.1 Introduction

The main drive of chapter 5 is to demonstrate how preliminary data analysis is done and explain the analysis results. Therefore the analysis was initiated by conducting the identification of descriptive statistics of the data. During the analysis stage, first a correlation analysis was conducted. Next, the regression model was built. Then, based on the model details, further transformations were applied if necessary. Next, based on the results of the regression analysis the regression equation was built. Finally, the accuracies of the models were tested by performing an ANOVA test.

This chapter has organized as follows. Initially, the section 5.2 represents descriptive statistics derived in the preliminary data analysis. Next, section 5.3 presents the results obtained in the regression analysis. Next, section 5.4 discusses the model by revisiting the hypotheses. Finally, the section 5.5 drafted the conclusion of the chapter.

5.2 Descriptive Statistics

As discussed in chapter 4, the data set is cleaned and transformation of all values into numeric was carried out. Results taken from performing the test to warp direction and weft direction are separately considered. As the major step of primary analysis of the data in the research, the basic descriptive statistical details of the respondents is summarized through tables. This would be helpful for understanding the characteristics of the sample.

The descriptive statistics of each variable are represented in table 5.1 and 5.2.

Table 5.1: Descriptive Statistics of Variables of Warp Direction Test

Variable	**Min**	**Max**	**Mean**	**Median**	**Std. dev.**	**Coefficient of variance**
Elastane (X)	0.04	0.137	0.0939	0.1	0.0365	0.3826
Modulus2 (Y1)	0.54	1.04	0.611	0.6	0.7529	0.6285
Modulus5 (Y2)	0.5	5.59	0.867	0.519	1.1487	0.9538
Extension (Y3)	98.2	101.8	99.57	99.9	1.1129	0.0111
Growth (Y4)	5	11	7.63	8	2.0265	0.2654

Table 5.2: Descriptive Statistics of Variables of Weft Direction Test

Variable	**Min**	**Max**	**Mean**	**Median**	**Std. dev.**	**Coefficient of variance**
Elastane (X)	0.04	0.137	0.09	0.1	0.0365	0.3826
Modulus2 (Y1)	0.24	3.015	0.78	0.87	0.6543	0.8335
Modulus5 (Y2)	0.15	0.84	0.46	0.42	0.2854	0.6154
Extension (Y3)	101.6	249	160	133.1	61.887	0.3867
Growth (Y4)	7	8	7.71	8	6.4357	0.4035

5.3 Data Analysis

The dataset is segregated into two parts named training set and the testing set. The training set contains 80% of the data of the entire dataset and the testing dataset contains 20% of the data. The analysis has carried out using R statistical software.

5.3.1 Analysis of the Test Results of Modulus2 (Y1) in Warp Direction

- **Correlation Analysis between Modulus2 (Y1) and Elastane (X)**

The Modulus2 variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
Pearson's product-moment correlation

data:  Y1 and X
t = 8.9274, df = 73, p-value = 2.548e-13
alternative hypothesis: true correlation is not
equal to 0
95 percent confidence interval:
 0.5926648 0.8156668
sample estimates:
      cor
0.7224485
```

Figure 5.1: Correlation Analysis of Elastane (X) variable and Modulus2 (Y1)

According to the correlation output, the *P*-value is 2.548e-13 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

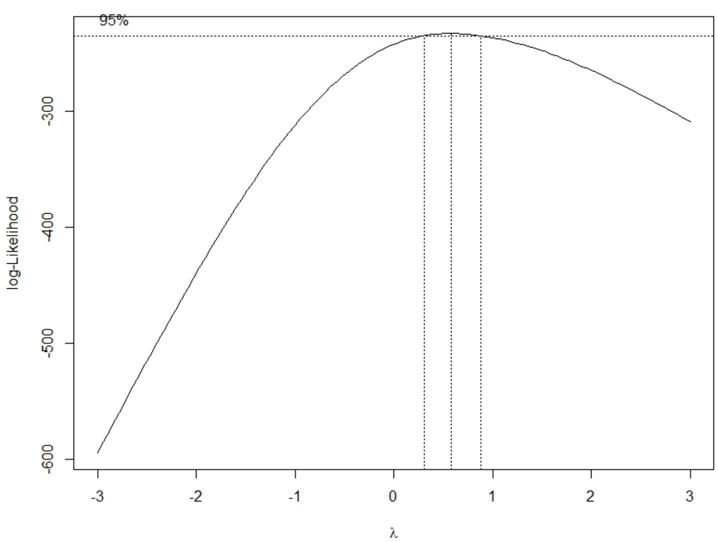
- **Regression Analysis between Modulus2 (Y1) and Elastane (X)**

The linear regression output is shown in Figure 5.2.

```
Call:
lm(formula = Y1 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.5013 -0.1916  0.2445  0.5985  0.8183 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  -0.4583     0.2558  -1.792   0.0773 .  
X            21.9980     2.4641   8.927 2.55e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7604 on 73 degrees of freedom
Multiple R-squared:  0.5219,	Adjusted R-squared:  0.5154 
F-statistic:  79.7 on 1 and 73 DF,  p-value: 2.548e-13
```

Figure 5.2: Regression output of Modulus2 – Warp variable

According to the above result, the multiple R- squared value is on average. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.6

Figure 5.3: Boxcox Transformation for Modulus2

Then the best lambda value given by boxcox transformation is applied with Y1 variable and again applied the regression analysis as Y1^0.6 ~ X. the X and Y1^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y1)^0.6 ~ (X), data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-0.6772 -0.4437 -0.2225  0.5866  0.6694

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.30334    0.23630   1.284    0.202
 (X)         2.0101     0.06526  -4.043 9.61e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error:  0.331  on 114 degrees of freedom
Multiple R-squared: 0.8243 ,    Adjusted R-squared:  0.8011
F-statistic: 16.35 on 1 and 114 DF,  p-value: 9.609e-05
```

Figure 5.4: Regression output of Modulus2 – Warp variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y1} = \widehat{\beta 0} + \widehat{\beta 1}X$$

$$\widehat{Y1} = 0.30334 + 2.0101X \tag{1}$$

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.5

```
Response: (Y1)^0.6
           Df  Sum Sq Mean Sq F value    Pr(>F)
(X)         1  3.6102  3.6102  16.349 9.609e-05 ***
Residuals  14 25.1730  0.2208
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 5.5: Anova Test of Modulus2 – Warp variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.36032 , p-value = 0.4531
```

Figure 5.6: Normality Test of Residuals in Modulus2 – Warp variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 0.4531 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2 Analysis of the Test Results of Modulus5 (Y2) in Warp Direction

- **Correlation Analysis between Modulus5 (Y2) and Elastane (X)**

The Modulus5 variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y2 and (X)
t = -1.6282, df = 114, p-value = 0.0165
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.32415935  0.03245651
sample estimates:
       cor
 0.1507521
```

Figure 5.7: Correlation Analysis of Elastane (X) variable and Modulus5 (Y2)

According to the correlation output, the *P*-value is 0.0165 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

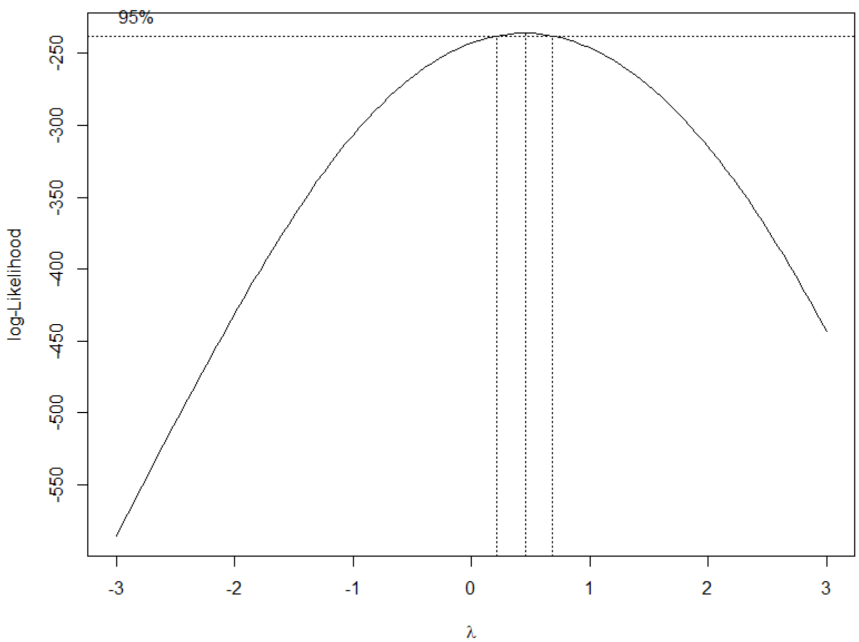
- **Regression Analysis between Modulus5 (Y2) and Elastane (X)**

The linear regression output is shown in Figure 5.8.

```
Call:
lm(formula = Y2 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.2631 -0.1409  0.2515  0.4925  0.6261 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  -0.5922     0.2135  -2.773  0.00704 ** 
X            20.1512     2.0572   9.796  6.1e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6348 on 73 degrees of freedom
Multiple R-squared:  0.5679,	Adjusted R-squared:  0.562 
F-statistic: 95.95 on 1 and 73 DF,|  p-value: 6.096e-15
```

Figure 5.8: Regression output of Modulus5 – Warp variable

According to the above result, the multiple R- squared value is on average. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.5

Figure 5.9: Boxcox Transformation for Modulus5

Then the best lambda value given by boxcox transformation is applied with Y2 variable and again applied the regression analysis as Y2^0.5 ~ X. the X and Y2^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y2)^0.5 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.6309 -0.3615  0.1483  0.3875  1.2604 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)   1.934     0.09583  13.061   <2e-16 ***
X             1.45634   0.95553  -1.524     0.13    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3762 on 114 degrees of freedom
Multiple R-squared:   0.7825 ,   Adjusted R-squared:  0.766 
F-statistic: 2.323 on 1 and 114 DF,  p-value:  0.013
```

Figure 5.10: Regression output of Modulus5 – Warp variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y2} = \widehat{\beta 0} + \widehat{\beta 1}X$$

$$\widehat{Y2} = 1.934 + 1.4563X$$

(2)

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.11

```
Response: (Y2)^0.5
           Df  Sum Sq Mean Sq F value Pr(>F)
X           1  0.3288 0.32883  2.3229  0.013
Residuals  14 16.1376 0.14156
```

Figure 5.11: Anova Test of Modulus5 – Warp variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.89899, p-value = 0.3875
```

Figure 5.12: Normality Test of Residuals in Modulus5 – Warp variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 0.3875 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.3 Analysis of the Test Results of Extension (Y3) in Warp Direction

- **Correlation Analysis between Extension (Y3) and Elastane (X)**

The Extension variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y3 and X
t = 7.3976, df = 114, p-value = 2.534e-11
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.4320577 0.6811089
sample estimates:
     cor
0.569513
```

Figure 5.13: Correlation Analysis of Elastane (X) variable and Extension (Y3)

According to the correlation output, the *P*-value is 2.534e-11 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

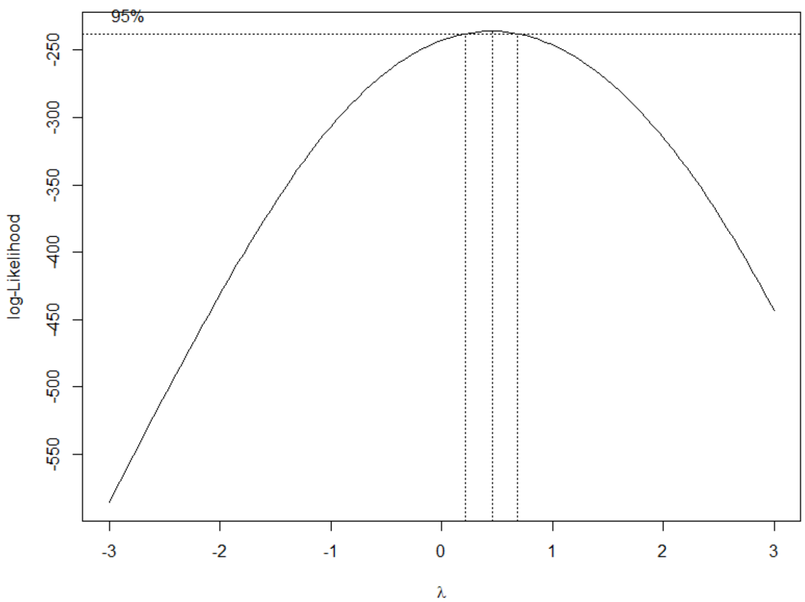
- **Regression Analysis between Extension (Y3) and Elastane (X)**

The linear regression output is shown in Figure 5.14.

```
Call:
lm(formula = Y3 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-39.087 -33.463 -22.807  -2.929 113.429

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   143.93      17.77   8.102 9.07e-12 ***
X             -93.61     171.15  -0.547    0.586
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 52.82 on 73 degrees of freedom
Multiple R-squared:  0.004081, Adjusted R-squared:  -0.009562
F-statistic: 0.2991 on 1 and 73 DF,|  p-value: 0.5861
```

Figure 5.14: Regression output of Extension – Warp variable

According to the above result, the multiple R- squared value is low. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.5

Figure 5.15: Boxcox Transformation for Extension

Then the best lambda value given by boxcox transformation is applied with Y3 variable and again applied the regression analysis as Y3^0.5 ~ X. the X and Y3^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y3)^0.5 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-1.2144 -1.0887 -0.6788  0.6878  2.1948

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   98.041     0.3282  26.092  < 2e-16 ***
X            19.6930     3.2727   6.017  2.2e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.3034 on 114 degrees of freedom
Multiple R-squared: 0.726 .,     Adjusted R-squared:  0.6971
F-statistic: 36.21 on 1 and 114 DF,  p-value: 2.201e-08
```

Figure 5.16: Regression output of Extension – Warp variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y3} = \widehat{\beta 0} + \widehat{\beta 1}X$$

$$\widehat{Y3} = 98.041 + 19.693X$$

(3)

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.17

```
Analysis of Variance Table

Response: (Y3)^0.5
          Df  Sum Sq Mean Sq F value    Pr(>F)
X          1  60.126  60.126  36.208 2.201e-08 ***
Residuals 14 189.309   1.661
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 5.17: Anova Test of Extension – Warp variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.78655, p-value = 1.079
```

Figure 5.18: Normality Test of Residuals in Extension – Warp variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 1.079 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2.4 Analysis of the Test Results of Growth (Y4) in Warp Direction

- **Correlation Analysis between Growth (Y4) and Elastane (X)**

The growth variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y4 and X
t = 0.96256, df = 114, p-value = 0.0378
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.09406893  0.26772163
sample estimates:
       cor
0.08978756
```

Figure 5.19: Correlation Analysis of Elastane (X) variable and Growth (Y4)

According to the correlation output, the *P*-value is 0.0378 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

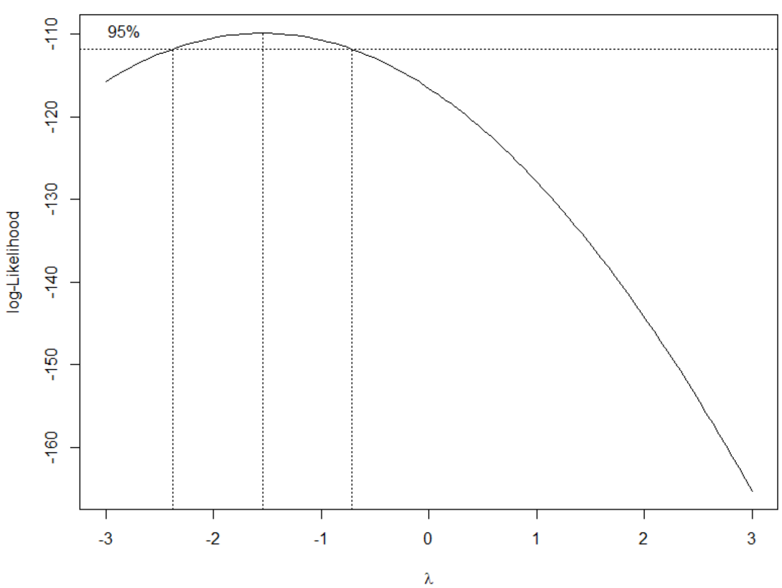
- **Regression Analysis between Growth (Y4) and Elastane (X)**

The linear regression output is shown in Figure 5.20.

```
Call:
lm(formula = Y4 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-14.170  -3.170  -2.625   0.345  11.860 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)   17.190      1.858   9.251 6.32e-14 ***
X            -50.496     17.901  -2.821  0.00617 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.524 on 73 degrees of freedom
Multiple R-squared:  0.09828,	Adjusted R-squared:  0.08593 
F-statistic: 7.957 on 1 and 73 DF,  p-value: 0.006166
```

Figure 5.20: Regression output of Growth – Warp variable

According to the above result, the multiple R- squared value is low. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



$\lambda = 0.5$

Figure 5.21: Boxcox Transformation for Extension

Then the best lambda value given by boxcox transformation is applied with Y4 variable and again applied the regression analysis as Y4^0.5 ~ X. the X and Y4^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y4)^0.5 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-0.4733 -0.2599 -0.2049  0.1361  0.6412

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  5.70232    0.09034  30.243   <2e-16 ***
X            0.56645    0.90075  -0.629    0.531
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3547 on 114 degrees of freedom
Multiple R-squared:  0.8234   ,  Adjusted R-squared:   0.7977
F-statistic: 0.3955 on 1 and 114 DF,  p-value: 0.0372
```

Figure 5.22: Regression output of Growth – Warp variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y4} = \beta_0 + \beta_1 X$$

$$\widehat{Y4} = 5.70232 + 0.56645X \quad (4)$$

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.5

```
Analysis of Variance Table

Response: (Y4)^0.5
          Df  Sum Sq  Mean Sq F value Pr(>F)
X          1  0.0497 0.049747  0.3955 0.0372
Residuals 14 14.3404 0.125793
```

Figure 5.23: Anova Test of Growth – Warp variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.83681, p-value =  0.3486
```

Figure 5.24: Normality Test of Residuals in Growth – Warp variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 0.3486 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2.5 Analysis of the Test Results of Modulus2 (Y1) in Weft Direction

- **Correlation Analysis between Modulus2 (Y1) and Elastane (X)**

The Modulus2 variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y1 and X
t = 9.3391, df = 117, p-value = 7.854e-16
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5366493 0.7457869
sample estimates:
      cor
0.6535186
```

Figure 5.25: Correlation Analysis of Elastane (X) variable and Modulus2 (Y1)

According to the correlation output, the *P*-value is 7.854e-13 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

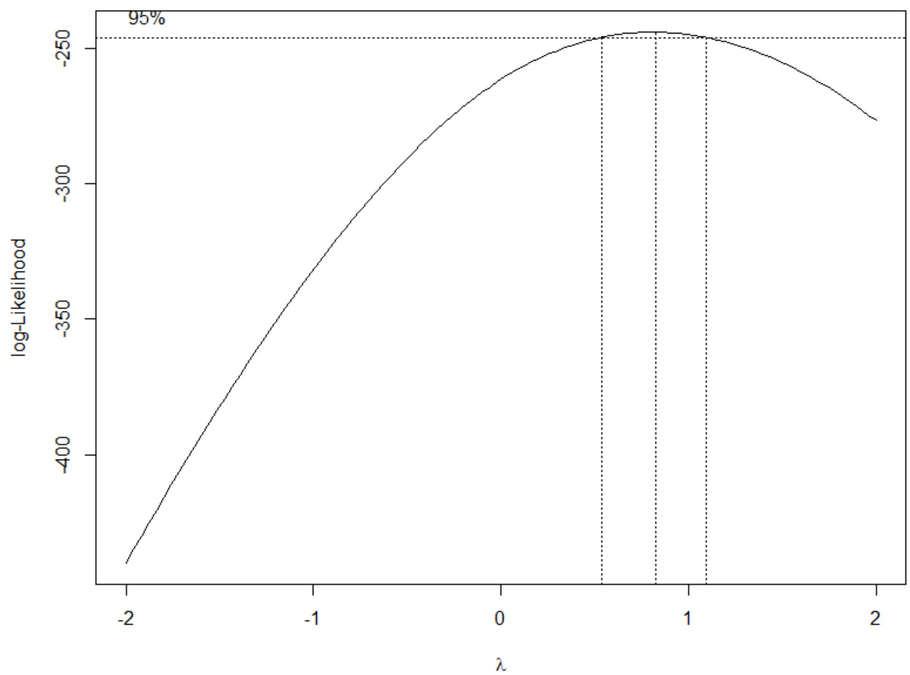
- **Regression Analysis between Modulus2 (Y1) and Elastane (X)**

The linear regression output is shown in Figure 5.26.

```
Call:
lm(formula = Y1 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-1.4338 -0.2394  0.4572  0.6352  0.8913

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -0.2413     0.2077  -1.162    0.248
X            19.1542     2.0510   9.339 7.85e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8184 on 117 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.4271,	Adjusted R-squared:  0.4222
F-statistic: 87.22 on 1 and 117 DF,  p-value: 7.854e-16
```

Figure 5.26: Regression output of Modulus2 – Weft variable

According to the above result, the multiple R- squared value is on average. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.4

Figure 5.27: Boxcox Transformation for Modulus2

Then the best lambda value given by boxcox transformation is applied with Y1 variable and again applied the regression analysis as Y1^0.4 ~ X. the X and Y1^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y1)^0.4 ~ X, data = Training)

Residuals:
     Min       1Q   Median       3Q      Max
-0.57753 -0.04906  0.18752  0.22296  0.28529

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.63513    0.07938   8.001 9.97e-13 ***
X            5.07696    0.78402   6.476 2.31e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.3128 on 117 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.81017 ,    Adjusted R-squared: 0.80019
F-statistic: 41.93 on 1 and 117 DF,  p-value: 2.314e-09
```

Figure 5.28: Regression output of Modulus2 – Weft variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y1} = \widehat{\beta 0} + \widehat{\beta 1} X$$

$$\widehat{Y1} = 0.63513 + 5.07696X$$

(5)

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.29

```
Analysis of Variance Table

Response: (Y1)^0.4
          Df  Sum Sq Mean Sq F value    Pr(>F)
X          1  4.1037  4.1037  41.933 2.314e-09 ***
Residuals 17 11.4499  0.0979
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 5.29: Anova Test of Modulus2 – Weft variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.72614, p-value = 1.331
```

Figure 5.30: Normality Test of Residuals in Modulus2 – Weft variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 1.331 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2.6 Analysis of the Test Results of Modulus5 (Y2) in Weft Direction

- **Correlation Analysis between Modulus5 (Y2) and Elastane (X)**

The Modulus5 variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y2 and X
t = 8.0202, df = 118, p-value = 8.633e-13
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.4641436 0.6988132
sample estimates:
      cor
0.5939703
```

Figure 5.31: Correlation Analysis of Elastane (X) variable and Modulus5 (Y2)

According to the correlation output, the *P*-value is 8.633e-13 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

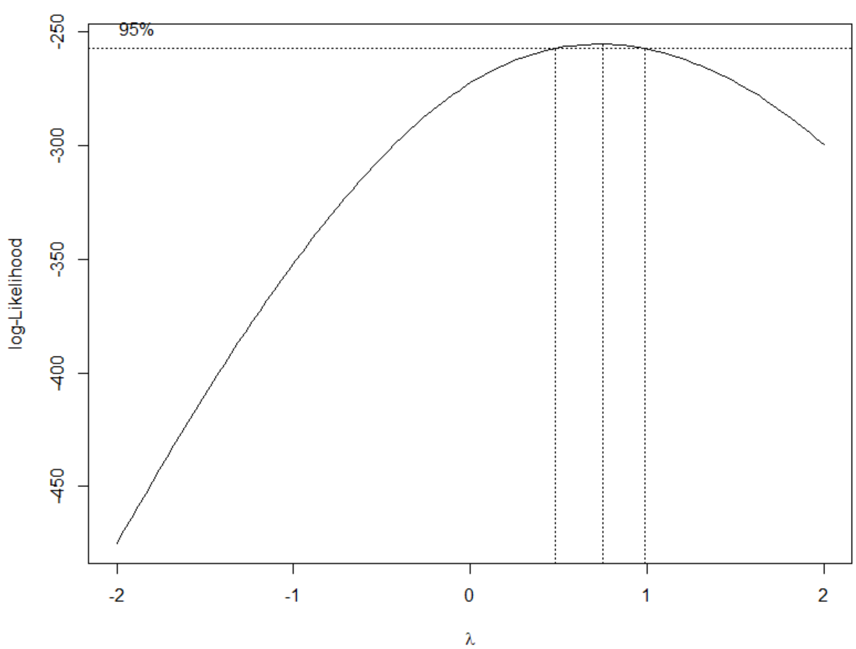
- **Regression Analysis between Modulus5 (Y2) and Elastane (X)**

The linear regression output is shown in Figure 5.32.

```
Call:
lm(formula = Y2 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.2098 -0.1687  0.3732  0.5123  0.7094 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  -0.4336     0.1723  -2.516   0.0132 *  
X            18.0317     1.6971  10.625   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6798 on 118 degrees of freedom
Multiple R-squared:  0.4889,   Adjusted R-squared:  0.4846 
F-statistic: 112.9 on 1 and 118 DF,  p-value: < 2.2e-16
```

Figure 5.32: Regression output of Modulus5 – Weft variable

According to the above result, the multiple R- squared value is on average. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



$\lambda = 0.5$

Figure 5.33: Boxcox Transformation for Modulus5

Then the best lambda value given by boxcox transformation is applied with Y2 variable and again applied the regression analysis as Y2^0.4 ~ X. the X and Y2^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y2)^0.5 ~ X, data = Training)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.67532 -0.04648  0.21059  0.25419  0.32728 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  0.35433    0.09193   3.854 0.000189 ***
X            7.20796    0.90556   7.960 1.19e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3627 on 118 degrees of freedom
Multiple R-squared:  0.7952 ,    Adjusted R-squared:  0.7429 
F-statistic: 63.36 on 1 and 118 DF,  p-value: 1.187e-12
```

Figure 5.34: Regression output of Modulus5 – Weft variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y2} = \beta_0 + \beta_1 X$$

$$\widehat{Y2} = 0.35433 + 7.20796X$$

(6)

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.35

```
Analysis of Variance Table

Response: (Y2)^0.5
          Df  Sum Sq Mean Sq F value    Pr(>F)    
X          1  8.3369  8.3369  63.356 1.187e-12 ***
Residuals 18 15.5273  0.1316                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 5.35: Anova Test of Modulus5 – Weft variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.72353, p-value =  0.3571
```

Figure 5.36: Normality Test of Residuals in Modulus5 – Weft variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 0.3571 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2.3 Analysis of the Test Results of Extension (Y3) in Weft Direction

- **Correlation Analysis between Extension (Y3) and Elastane (X)**

The extension variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  Y3 and X
t = 1.4872, df = 118, p-value = 0.01398
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.04468429  0.30741074
sample estimates:
      cor
0.1356435
```

Figure 5.37: Correlation Analysis of Elastane (X) variable and Extension (Y3)

According to the correlation output, the *P*-value is 0.01398 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

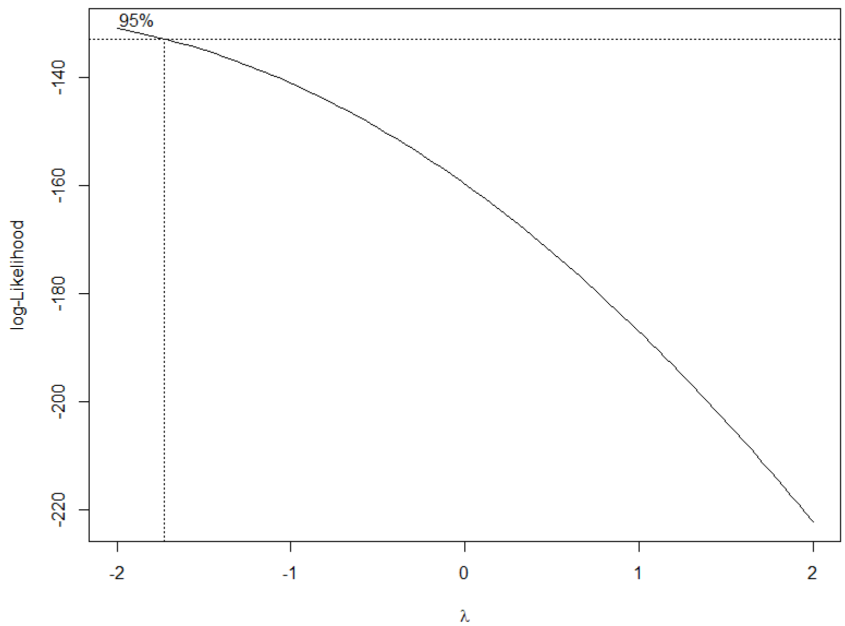
- **Regression Analysis between Extension (Y3) and Elastane (X)**

The linear regression output is shown in Figure 5.38.

```
Call:
lm(formula = Y3 ~ log(X), data = Training)

Residuals:
    Min      1Q  Median      3Q     Max
-50.035 -40.814 -23.866  -0.877 105.866

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   180.75      28.11   6.429 2.84e-09 ***
log(X)         16.77      11.28   1.487     0.14
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 56.64 on 118 degrees of freedom
Multiple R-squared:  0.0184,    Adjusted R-squared:  0.01008
F-statistic: 2.212 on 1 and 118 DF,  p-value: 0.1396
```

Figure 5.38: Regression output of Modulus5 – Weft variable

According to the above result, the multiple R- squared value is low. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.5

Figure 5.39: Boxcox Transformation for Modulus5

Then the best lambda value given by boxcox transformation is applied with Y3 variable and again applied the regression analysis as Y3^0.4 ~ X. the X and Y3^λ gives the best model with highest accuracy.

```
Call:
lm(formula = (Y3)^0.5 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.8056 -1.4715 -1.2257  0.0305  4.1334 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 180.5666     0.5608  20.624   <2e-16 ***
X             0.4799     5.5241   0.087    0.931    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.213 on 118 degrees of freedom
Multiple R-squared:  0.769    , Adjusted R-squared: 0.723 
F-statistic: 0.007549 on 1 and 118 DF,  p-value: 0.0093
```

Figure 5.40: Regression output of Extension – Weft variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y3} = \widehat{\beta 0} + \widehat{\beta 1}X$$

$$\widehat{Y3} - 180.5666 + 0.4799X$$

(7)

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.41.

```
Analysis of Variance Table

Response: (Y3)^0.5
           Df Sum Sq Mean Sq F value Pr(>F)
X           1   0.04  0.0370  0.0075 0.0093
Residuals  18 577.81  4.8967
```

Figure 5.41: Anova Test of Extension – Weft variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.68505, p-value = 1.062
```

Figure 5.42: Normality Test of Residuals in Extension – Weft variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 1.062 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.3.2.8 Analysis of the Test Results of Growth (Y4) in Weft Direction

- **Correlation Analysis between Growth (Y4) and Elastane (X)**

The growth variable in the warp direction dataset is considered to check the correlation coefficient with the Elastane variable. First, following two hypotheses were formed.

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0$$

Where, H_0 denotes that the correlation between the two variable is 0 and H_1 denotes that the correlation between the two variables is not equals to 0.

```
        Pearson's product-moment correlation

data:  ElastaneDataWeft$Y4 and ElastaneDataWeft$X
t = -3.5544, df = 148, p-value = 0.000509
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.4217485 -0.1258361
sample estimates:
       cor
0.2804421
```

Figure 5.43: Correlation Analysis of Elastane (X) variable and Growth (Y4)

According to the correlation output, the *P*-value is 0.000509 which is less than 0.05. Then, H_0 can be rejected at 95% of a confidence level. Therefore, it can be said that there exists a significant linear relationship between the two variables.

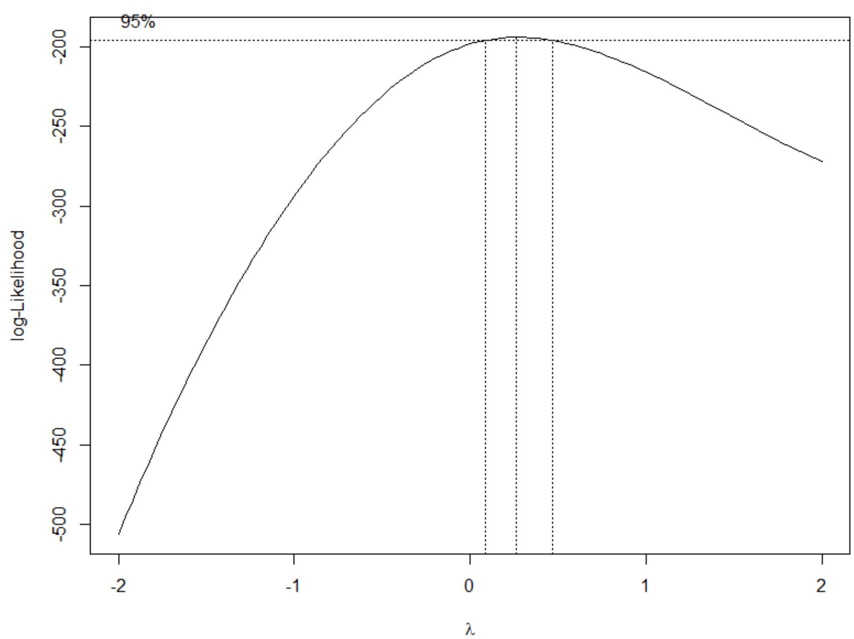
- **Regression Analysis between Growth (Y4) and Elastane (X)**

The linear regression output is shown in Figure 5.44.

```
Call:
lm(formula = Y4 ~ X, data = Training)

Residuals:
    Min      1Q  Median      3Q     Max 
-15.026  -4.026  -3.446  -0.499  29.501 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)   18.061      1.654  10.921  < 2e-16 ***
X            -50.887     16.290  -3.124  0.00225 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.525 on 118 degrees of freedom
Multiple R-squared:  0.07638,	Adjusted R-squared:  0.06855 
F-statistic: 9.758 on 1 and 118 DF,  p-value: 0.002246
```

Figure 5.44: Regression output of Modulus5 – Weft variable

According to the above result, the multiple R- squared value is low. In order to improve the accuracy of the regression model, a boxcox transformation is applied.



λ = 0.5

Figure 5.45: Boxcox Transformation for Growth

Then the best lambda value given by boxcox transformation is applied with Y4 variable and again applied the regression analysis as Y4^0.5 ~ X. the X and Y4^λ gives the best model with highest accuracy.

```
lm(formula = (Y4)^0.5 ~ X, data = Training)

Residuals:
     Min       1Q   Median       3Q      Max
-2.96044 -0.49634 -0.42650  0.01639  2.90798

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   4.2740     0.2119  20.169  < 2e-16 ***
X             7.8390     2.0873  -3.756  0.00027 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1068  on 118 degrees of freedom
Multiple R-squared: 0.8361  ,    Adjusted R-squared:  0.7941
F-statistic:  14.1 on 1 and 118 DF,  p-value: 0.00027
```

Figure 5.46: Regression output of Growth – Weft variable after the Transformation

Accordingly, the model could be represented as,

$$\widehat{Y4} = \widehat{\beta 0} + \widehat{\beta 1} X$$

$$\widehat{Y4} = 4.2740 + 7.8390X \tag{8}$$

- **ANOVA Test**

Then the Anova test is performed to validate the equation to see whether β1 will be 0. In case if it equals to 0, the equation will not useful since β1 value is a constant. The Anova analysis output is shown in figure 5.47.

```
Analysis of Variance Table

Response: (Y4)^0.5
           Df Sum Sq Mean Sq F value  Pr(>F)
X           1  9.860  9.8605  14.105 0.00027 ***
Residuals 118 82.493  0.6991
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 5.47: Anova Test of Extension – Weft variable

According to the results of Anova analysis, it proves that the value of β1 will not equal to 0 and the model could be used.

- **Normality Test**

Finally, the distribution of the residuals is analyzed using Shapiro- Wilk normality test.

```
        Shapiro-Wilk normality test

data:  fullmodel.inv$residuals
W = 0.76036, p-value = 1.028
```

Figure 5.48: Normality Test of Residuals in Extension – Weft variable

The two hypothesis are;

$$H_0: Residuals\ follow\ normal\ distribution$$

$$H_1: Residuals\ do\ not\ follow\ normal\ distribution$$

The p value was 1.028 which is greater than 0.05. Therefore, it can be concluded that H_1 will be rejected at 5% of a significance level and the H_0 will be accepting. This implies that there is no pattern in residual distribution and it's normal.

5.4 Research Findings

Stretch and recovery test is one of the main textile tests uses to measure the maximum stretchability at required force and recovery of the fabric after a specific time. The buyers required an acceptable extension range and a recovery value. The stretch and recovery test would uses to check whether the fabric owns the buyers' requirements.

However, the stretch and recovery test would require more time to test the fabric specimens which wastes the time and cost of textile laboratory staff. Therefore, this study was undertaken to predict the results of the stretch and recovery test. A mathematical model has built by including several formulae. The test will not be performed using the CRE machine but, the results given by the stretch and recovery test will be calculated by the formulae included in the model. When a single jersey fabric is to be tested with its known elastane percentage, the relevant output parameters will be calculating by using the formulae derived as the results of the research study. The formulae are listed from 1 to 8 in section 5.3 above.

5.4.1 Model Validation

There are four hypothesis developed in this research .They are,

H_a: There exists a relationship between the modulus at 2nd load curve and the elastane percentage of the fabric.

H_b: There exists a relationship between the modulus at 5th load curve and the elastane percentage of the fabric.

H_c: There exists a relationship between the extension at 15N and the elastane percentage of the fabric.

H_d: There exists a relationship between the growth and the elastane percentage of the fabric.

All these hypothesis were tested by performing Anova test for each regression model derive in the analysis stage which discussed in above section 5.3. The model trend lines for each model were drawn to identify the behavior of the data points around the regression line. Accordingly, all regression models were evaluated to validate the hypothesis.

The samples were tested for five different elastane levels. They are 4%, 7%, 10%, 13% and 13.7%. The modulus measures of the stretch and recovery test for both warp and weft directions given by the CRE machine are illustrated in the above figure 5.48. Since the data points are scattered in nearby locations to each, it seems the elastane data is categorical. However, the percentages used as elastane values are the frequently used measures of CRE machine and hence they cannot be categorical values.

<u>H_a: There exists a relationship between the modulus at 2nd load curve and the elastane percentage of the fabric.</u>

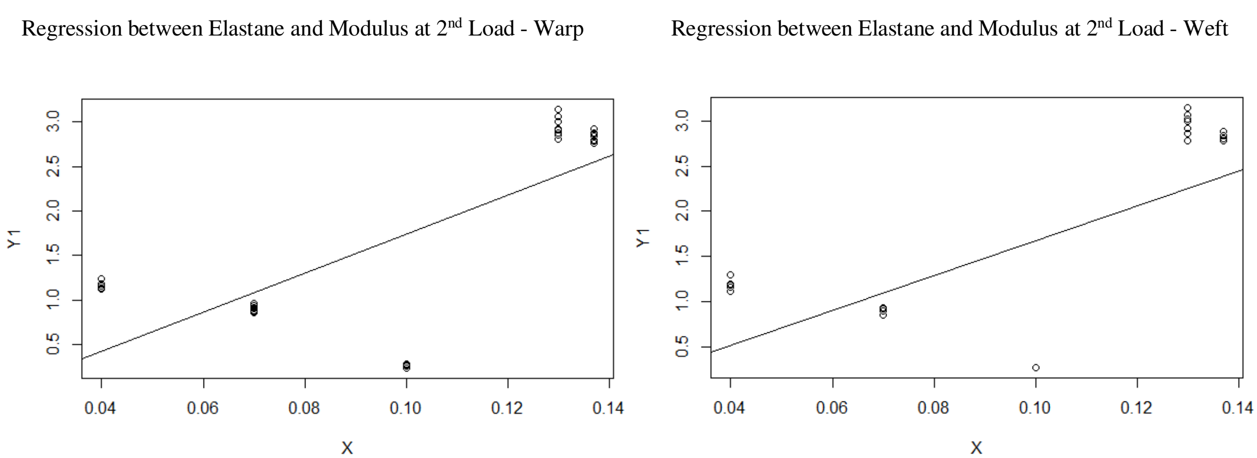


Figure 5.49: Trend on Elastane and Modulus at 2nd Load Curve

'X' means the extension and 'Y' means the modulus at 2nd load curve. According to that, the both regression lines denoted a positive relationship between the two variables. The relationship given by regression output of the test in warp direction is represented by,

$Modulus\ @\ 2nd = 0.30334 + 2.0101 Elastane$. In 95% of confidence level the trend line says that when elastane value increases by 1 unit, the modulus at 2nd load curve increases by 2.0101. The overall accuracy of the model is 82.4%. The output given by weft test has the regression line with 81% of an accuracy in 95% of confidence as, $Modulus\ @\ 2nd = 0.63513 + 5.07696 Elastane$. The trend line would say that when elastane value increases by 1 unit, the modlus at 2nd load curve increases by 5.07696.

Accordingly, these results would clearly depicted that there is a strong positive relationship among elastane and modulus at 2nd load curve and the hypotheses H_a is accepted.

H_b: There exists a relationship between the modulus at 5th load curve and the elastane percentage of the fabric.

Regression between Elastane and Modulus at 5th Load - Warp

Regression between Elastane and Modulus at 5th Load - Weft

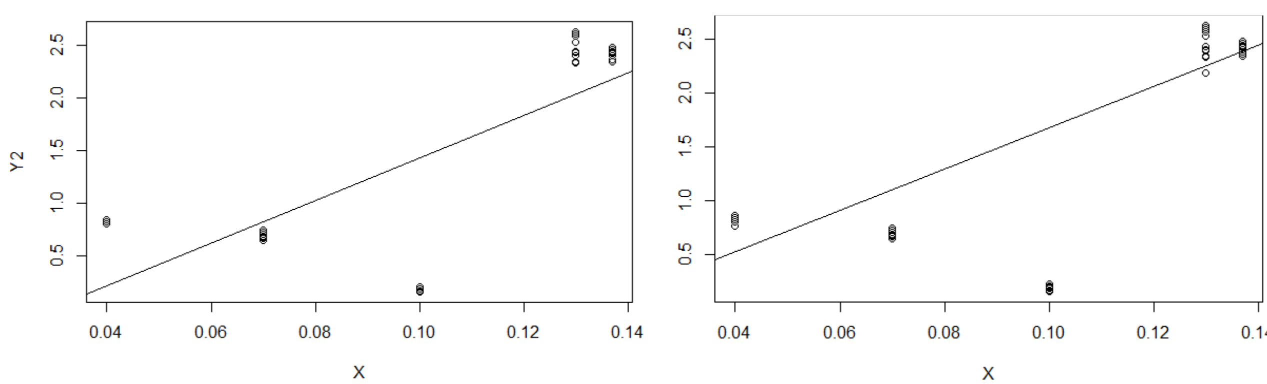


Figure 5.50: Trend on Elastane and Modulus at 5th Load Curve

In here, 'X' means the extension and 'Y' means the modulus at 5th load curve. According to that, the both regression lines denoted a positive relationship between the two variables. The relationship given by regression output of the test in warp direction is represented by, $Modulus\ @\ 5th = 1.934 + 1.4563 Elastane$. In 95% of confidence level the trend line says that when elastane value increases by 1 unit, the modulus at 5th load curve increases by 1.4563. The overall accuracy of this model is 56.8%. The output given by weft test has the regression line with 48.9% of an accuracy in 95% of confidence as

$Modulus\ @\ 5th = 0.35433 + 7.20796 Elastane$. The trend line would say that when elastane value increases by 1 unit, the modlus at 2nd load curve increases by 7.20796.

Accordingly, these results would clearly depicted that there is a strong positive relationship among elastane and modulus at 5th load curve and the hypotheses H_b is accepted.

H_c: There exists a relationship between the extension at 15N and the elastane percentage of the fabric.

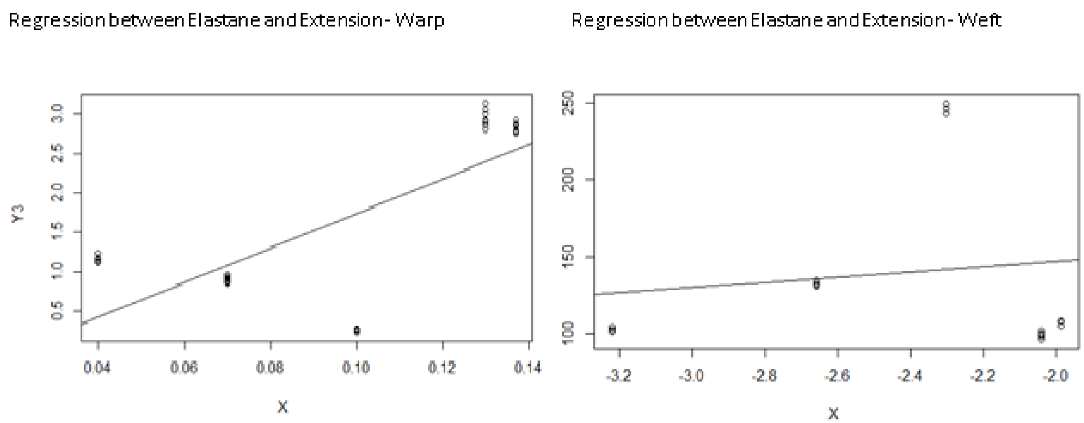


Figure 5.51: Trend on Elastane and Extension

'X' means the extension and 'Y' means the modulus at 2nd load curve. According to that, the the warp regression lines denoted a negative relationship and the weft regression line denoted a positive relationship between the two variables. The relationship given by regression output of the test in warp direction is represented by, $Extension = 98.041 + 19.693 Elastane$. In 95% of confidence level the trend line says that when elastane value increases by 1 unit, the modulus at 2nd load curve increases by 19.693. The output given by weft test has the regression line says that $Extension = 180.5666 + 0.4799 Elastane$. The trend line denoted that when elastane value increases by 1 unit, the modlus at 2nd load curve increases by 0.4799.

Accordingly, these results would clearly depict that there is a relationship among elastane and extension and the hypotheses Hc is accepted.

H_d: There exists a relationship between the growth and the elastane percentage of the fabric.

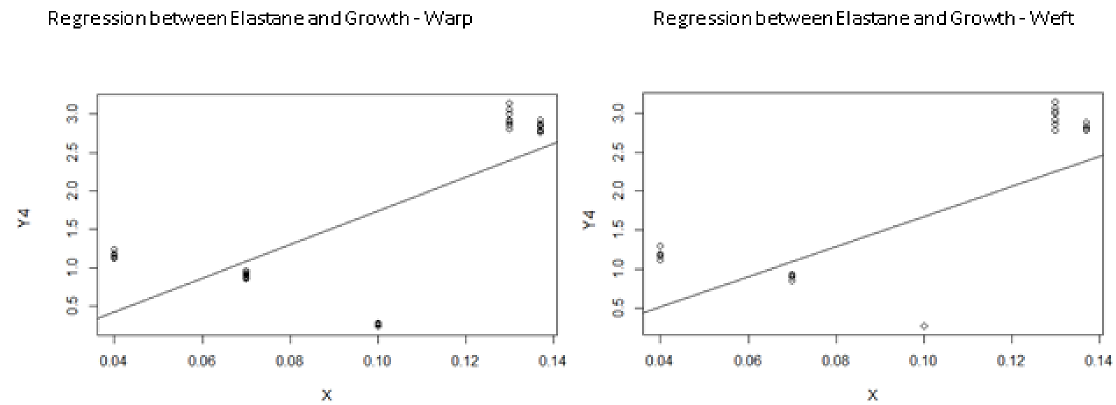


Figure 5.52: Trend on Elastane and Growth

'X' means the extension and 'Y' means the growth. According to that, both regression lines denoted a negative relationship between the two variables. The relationship given by regression output of the test in warp direction is represented by $Growth = 5.70232 + 0.56645 Elastane$,. In 95% of confidence level the trend line says that when elastane value increases by 1 unit, the growth increases by 0.56645. The output given by weft test has the regression line as, $Growth = 4.2740 + 7.8390 Elastane$. The trend line would say that when elastane value increases by 1 unit, the modlus at 2^{nd} load curve increases by 7.8390.

Accordingly, since there exists a relationship between the two variables, the hypotheses H_d is accepted.

Finally, as shown in figure 5.53, an automated tool has been developed by incorporating the model derived in the study to perform the test efficiently and conveniently.

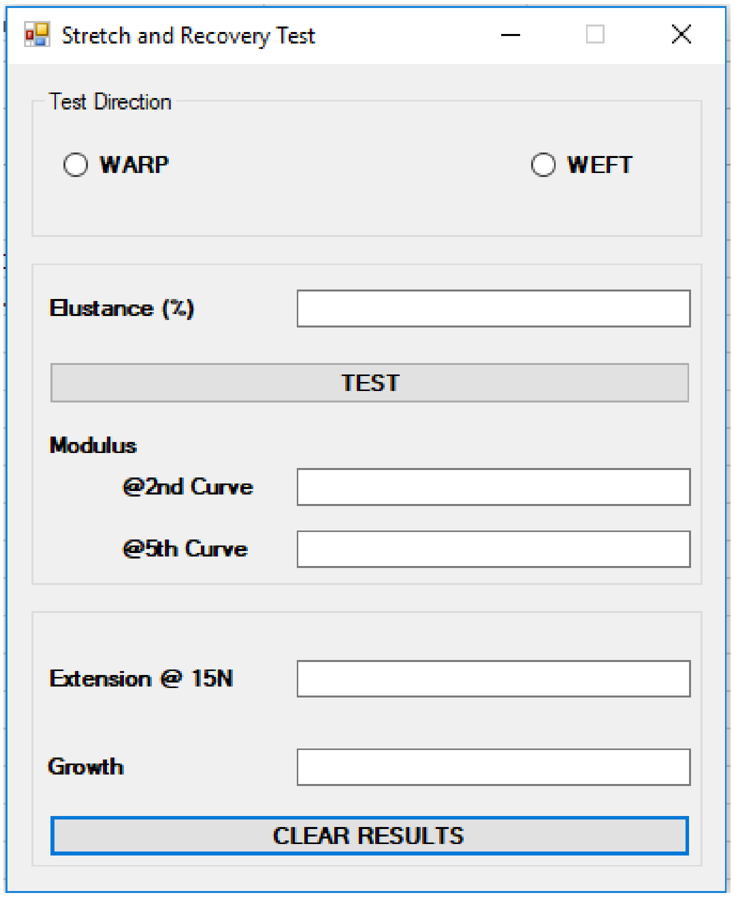


Figure 5.53: Stretch and Recovery Tool

User would selects the direction of the test; (1) warp or (2) weft and enter the elastane percentage of the fabric. Then Click on the "Test" button as shown in the figure 5.31 to calculate the Modulus values, extension and growth values based on the equations derived in the statistical model.

This chapter discussed the flow of the execution of research approach to meet the objective of the study and the results obtained in the data analysis step. After performing a comprehensive analysis, a prediction model is built using linear regression model. The model is presented and assessed the validity of the proposed hypotheses.

Chapter 6: Conclusion

6.1 Introduction

Staff of Textile Testing labs carry out fabric tests based on the standards recorded in test methods. They work with heavy workload with immediate targets for test report delivery. The report results are very critical and urgent in some cases.

Stretch and recovery tests are performed using a device called a CRE machine. The CRE machine requires a considerable number of hours to conduct the test which makes them unable to achieve target delivery dates of the test reports. Therefore, this research was carried out to find a method to perform stretch and recovery test without using the CRE machine.

This chapter aims to review the findings of the research, the implications, research contributions and the restrictions of the research. The chapter is organized in four stages. First, the research questions and the research findings. Secondly, it discusses the drawbacks. Next, it discusses the limitations of this research. Finally, suggestions are presented for further research in future.

6.2 Reexamine the research questions

The primary research question was "How to model and predict the results of the stretch and recovery test for single jersey fabric". Specially, the research aims to answer the main research question, through several supportive sub research questions defined. The first sub question is "What are the extension and recovery properties to consider for the analysis?" Second is "What is the best analysis method to determine the relationship between stretch and recovery with the elastane percentage of the fabric?"

To answer these research questions, a theoretical framework was developed to design mathematical model to predict the results of the stretch and recovery test for single jersey fabric.

To answer the first subsidiary research question, "What are the extension and recovery properties to consider for the analysis?", It was identified during the literature review, that the important properties are measured by the CRE machine itself and are used in modeling the test.

To answer the second subsidiary research question, “What is the best analysis method to determine the relationship between stretch and recovery with the elastane percentage of the fabric?” After finding the behavior of the variables in the dataset, it has been identified that the prediction model has to be developed using the linear regression analysis.

Once the regression analysis is performed to the warp and weft directions of the fabric, the regression model was used to derive the mathematical formula to derive the mathematical foundation of the test variables. Accordingly, the four equations were derived for the results calculation in warp direction. They are;

- $Modulus\ @\ 2nd = 0.30334 + 2.0101 Elastane$
- $Modulus\ @\ 5th = 1.934 + 1.4563 Elastane$
- $Extension = 98.041 + 19.693 Elastane$
- $Growth = 5.70232 + 0.56645 Elastane$

As discussed in chapter 5, the modulus at 2^{nd} load was built with 80% and 5^{th} load was built with 76% of accuracy. The model for extension has shown 69.7% of accuracy while the growth measured under 79.7% of accuracy.

Similarly, another four equations were generated for the results calculation in weft direction. They are;

- $Modulus\ @\ 2nd = 0.63513 + 5.07696 Elastane$
- $Modulus\ @\ 5th = 0.35433 + 7.20796 Elastane$.
- $Extension = 180.5666 + 0.4799 Elastane$.
- $Growth = 4.2740 + 7.8390 Elastane$

The modulus at 2^{nd} load was built with more than 80% and 5^{th} load was built with 74.2% of accuracy. The model for extension has shown 72.3% of accuracy while the growth measured under 79.4% of accuracy.

6.3 Shortcomings

This research is to model and predict the results of the stretch and recovery test for single jersey fabric. After performing the regression analysis on the data, a set of regression equations were derived and have been included into the model. The tool calculates the values for modulus at 2^{nd} load and at 5^{th} load, extension and growth attributes. Even though the calculated results are quite closer to the actual values, the exact similar values to the actual results cannot be taken. However, this research attempted to predict the results of the Stretch and recovery test, the predicted results are accepted.

6.4 Limitations

This study was conducted only for single jersey fabric and only a few properties such as stitch density, yarn count, loop length, machine gadget and machine diameter were selected as constants. The model suitability for the other types of fabrics might vary.

6.5 Suggestions for future work

This research contributes/facilitates to the work performed by textile laboratory staff substantially. Since the CRE machine requires more duration for the test specimen preparation and more time for the test, testing staff will be able to use simple applications developed based on the findings of the study.

The modeling techniques can be further enhanced to consider the stitch density, yarn count, loop length, machine gadget and machine diameter for modeling, without keeping them constant.

References

Abdessalem S.B, Youssef Ben Abdelkader, Sofiene Mokhtar, P, Saber Elmarzougui (2009). Influence of Elastane Consumption on Plated Plain Knitted Fabric Characteristics, Journal of Engineered Fibers and Fabrics, 4(4), 30-35

Abend, Gabriel. "The Meaning of Theory." Sociological Theory 26 (June 2008): 173–199; Swanson, Richard A. Theory Building in Applied Disciplines. San Francisco, CA: Berrett-Koehler Publishers 2013.

Almetwally, Alsaid Ahmed, Idrees, Hatim M.F., Hebeish, Ali Ali (2014, Predicting the tensile properties of cotton/spandex core-spun yarns using artificial neural network and linear regression models, The Journal of The Textile Institute,Col 105 issue 13, 1221-1229.

Asahi Kasei (2008), Dorlastan in circular knitting, Dorlastan product information technical report, Spandex Europe GmbH, Germany.

Asit Ghosh, Asif Ahmed Tonmoy, Saurov Saha (2020), Effect of Lycra percentage on the physical properties of single jersey weft knitted fabric, Journal of Textile Engineering & Fashion Technology, 6 (1), 29- 35

Bahadir M.C, Senem Kursun Bahadir, and Fatma Kalaoglu (2012), An Artificial Neural Network Model for Prediction of Bursting Strength of Knitted Fabrics, International Conference on Machine Learning and Computer Science (IMLCS'2012), 167-170.

Boudreau, M-C., Gefen D., & Straub, D. W. (2001). Validation in Information Systems Research: A State-of-the-Art Assessment. MIS Quarterly, 25(1), 1-16.

Cuden, A. P., Srdjak, M., Pelko, H., (2000), Optimization of the cotton/Lycra plain knitted Fabric parameters, International Journal of Polymeric Materials, 47, 633 – 648.

Elshakankery, M.H., & Almetwally, A.A. (2012). Physical and Stretch Properties of Woven Cotton Fabrics Containing Different Rates of Spandex.

Eltahan, Eman, (2016) Effect of Lycra Percentages and Loop Length on the Physical and Mechanical Properties of Single Jersey Knitted Fabrics, Journal of Composites

Eman Eltahan (2016), Effect of Lycra Percentages and Loop Length on the Physical and Mechanical Properties of Single Jersey Knitted Fabrics, Journal of Composites, Volume 2016,1-7

Hall, B., & Howard K. (2008). A synergistic approach: Conducting mixed methods research with typological and systemic design considerations. Journal of Mixed Methods Research, 2(3), 248-269.

Hamza ALIBI, Faten FAYALA, Abdelmajid JEMNI, Xianyi ZENG, A Neural Network System for Designing New Stretch Fabrics

Jaeger, R. G, & Halliday, T. R. (1998). On Confirmatory versus Exploratory Research. Herpetologica, 54, S64–S66.

Kothari, C. R., & Grag G. (2014). Methodology of the Research : methods and techniques (3rd ed.). New Delhi: New age International.

Kumar, R. (2005). Methodology of the Research: A Step By Step Guide for Beginners (2nd ed.). Australia: Pearson Education.

Kumar, V.; Sampath, V. R. Investigation on the Physical and Dimensional properties of Single Jersey Fabrics made from Cotton Sheath - Elastomeric Core Spun. FIBRES TEXT EAST EUR, 2013; 21(3): 73-75,

Ogulata N. S, Cenk Sahin,R. Tugrul Ogulata, Onur Balci (2006), The Prediction of Elongation and Recovery of Woven Bi-Stretch Fabric Using Artificial Neural Network and Linear Regression Models, FIBRES & TEXTILES in Eastern Europe April / June, Vol. 14, No. 2 (56)

Olena Kyzymchuk and Liudmyla Melnyk (2018), Stretch properties of elastic knitted fabric with pillar stitch, Journal of Engineered Fibers and Fabrics, 1- 10.

Qing CHEN, Pibo Ma, Haiwen Mao, Xuhong Miao, Gaoming Jiang (2017),The effect of knitting parameter and finishing on elastic property of PET/PBT warp knitted fabric, AUTEX Research Journal, Vol. 17, No 4, 350-360.

Saber Ben Abdessalem, Youssef Ben Abdelkader, Sofiene Mokhtar (2009), Saber Elmarzougui, Influence of Elastane Consumption on Plated Plain Knitted Fabric Characteristics, Journal of Engineered Fibers and Fabrics, Volume 4, Issue 4

Sadek R, A. M. El-Hossini, A. S. Eldeeb, A.A. Yassen (2012), Effect of Lycra Extension Percent on Single Jersey Knitted Fabric Properties, Journal of Engineered Fibers and Fabrics 7(2), 11- 16.

Mohsen Shanbeh, Hossein Hasani and Somayeh Akhavan Tabatabaei (2011), Modelling and Predicting the Breaking Strength and Mass Irregularity of Cotton Rotor-Spun Yarns Containing Cotton Fiber Recovered from Ginning Process by Using Artificial Neural Network Algorithm, Modelling and Simulation in Engineering, vol. 3, 1-8.

Srivastava, A., & Thomson S. B. (2009). Framework analysis: A qualitative methodology for applied policy research. Journal of Administration & Governance, 4(2), 72-79.

Van de Vijver, F. J. R. (2011). Cross-cultural Research Methods in Psychology. New York: Cambridge University.

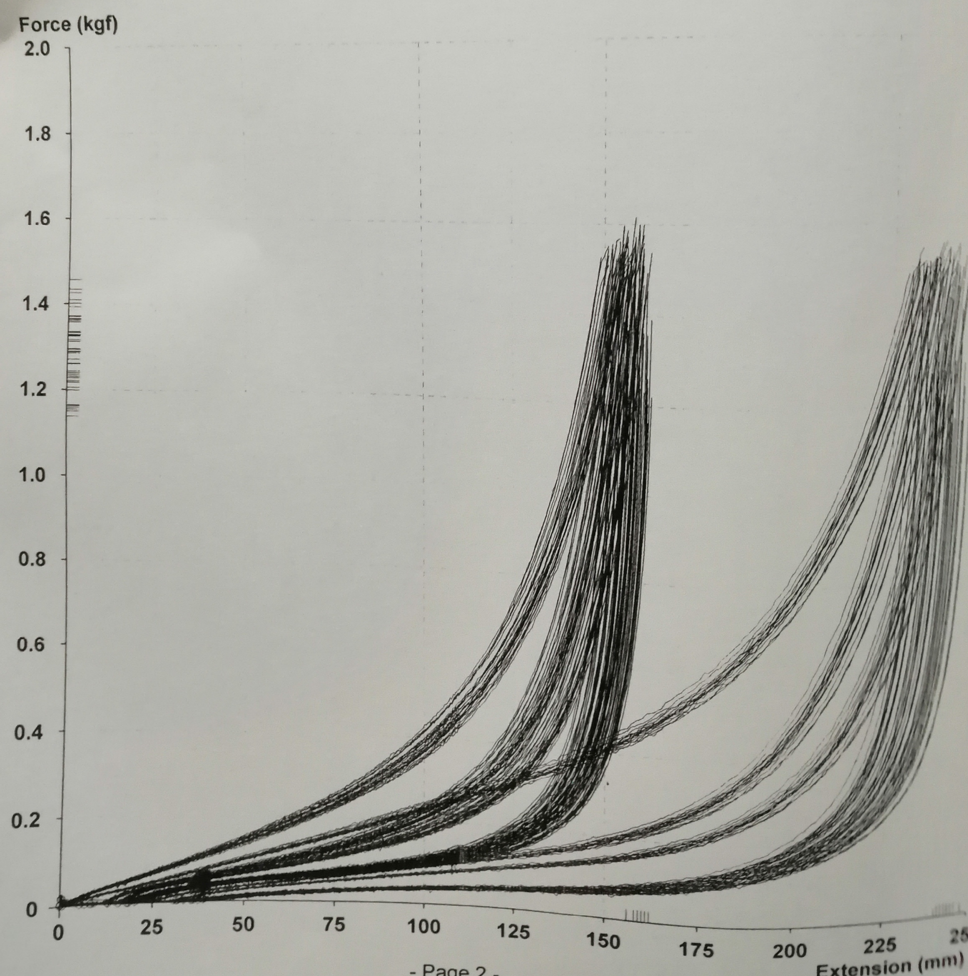
Eltahan, Eman, (2016) Effect of Lycra Percentages and Loop Length on the Physical and Mechanical Properties of Single Jersey Knitted Fabrics, Journal of Composites,

Appendix

C:\QMat\EN 14704-1;2005 Elasticity of Fabrics - Strip Test (Fixed Load)(Lord&unload Cav)

10%.

Specimen	2nd L(40%) kgf	2nd U(40%) kgf	5th L(40%) kgf	5th U(40%)	at 1.5 kgf %	0 sec Decay %	Growth %
- Weft 9	0.0286	0.0061	0.0204	0.0041	246.0	N/A	23.00
- Weft 10	0.0265	0.0041	0.0184	0.0020	242.0	N/A	23.00
- Weft 11	0.0275	0.0031	0.0168	0.0031	240.0	N/A	23.00
- Weft 12	0.0245	0.0102	0.0184	0.0020	244.0	N/A	23.00
- Weft 13	0.0245	0.0061	0.0163	0.0020	245.0	N/A	24.00
- Weft 14	0.0265	0.0041	0.0184	0.0041	248.0	N/A	24.00
- Weft 15	0.0286	0.0041	0.0184	0.0020	243.0	N/A	24.00
- Weft 16	0.0265	0.0061	0.0163	0.0020	243.0	N/A	24.00
Mean	0.0268	0.0045	0.0179	0.0026	244.5	-	23.50
Std. Dev.	0.0015	0.0019	0.0011	0.0009	2.422	-	0.516
Coe. Var.	5.50	42.73	6.37	34.81	0.991	-	2.197



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