# TEAR AND TENSILE STRENGTH OF 100% COTTON WOVEN FABRICS' BASIC STRUCTURES: REGRESSION MODELLING

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## ABSTRACT

This research paper aims to estimate the tear and tensile strength of woven fabrics while considering a number of construction factors. Construction variables include ends per cm (EPCm), picks per cm (PPCm), an overall configuration of yarn, and fabric's areal density or grams per square meter (GSM). While the statistical relationship in deciding the fabric strength is very complicated considering all variables, the correlation-regression model is used to explain the influence of structural parameters on the tear and tensile strength of various fundamental fabrics' designs. With different thread densities varying reed counts, and heald count using 100 percent cotton yarn having 36.9 tex, eight different designs of plain, twill, and sateen are prepared for the study. Four regression models, built to predict the tear and tensile strength of the sample woven fabrics, are vital components of this research. It is noticed that the setting of yarn affects the tensile strength of the fabrics, and the fabric pattern determines the tear strength of the fabrics. For higher tear strength, matt weave, and tensile strength, a twill structure is desired within this scope of the fabric structures.

## KEYWORDS

Tear; Tensile; Strength; Woven; Regression; Modelling, Prediction.

## INTRODUCTION

Strength is the first property that has the most significant effect when choosing the necessary fabrics to produce clothing or apparel. These are based mainly on the expected end-use [1]. The tensile and tear behavior of the fabric depends not only on the strength of the yarn alone but also on other variables, including the use of fiber or blend form, twist amount, twist angle, yarn count, spinning systems, yarn bending behavior, frictional properties, interlacement pattern, fabric construction parameters, series of warp and weft, finishing treatment etc. [2]. The geometry of the fabric, thread density, and weaving design also have a significant effect on the strength of the fabrics. The strength also be influenced based on the production state during wet processing and finishing treatment [3-5]. Also, test conditions such as temperature, humidity, loading time, loading quantity, jaw distance, and measuring methods often influence the difference in the intensity of the fabric value. For all these controllable and uncontrollable variables relevant to fiber, yarn, and fabric during production cycles, creating a simple direct quantitative connection between the yarn's intensity and the fabric's corresponding strength is quite complicated. In this respect, it is crucial to identify the right ways to decide the parameters before manufacturing fabrics to ensure the tremendous loss of supplies, time, electricity, labor, and money [2-6].

Different fabric manufacturing processes, such as spinning, knitting, non-woven, and braiding, are available [7]. Strong dimensional stability and good cover are seen between them by woven fabric. Strength is one of the most significant features of woven fabric [8]. In stretching a test piece to a breaking point, the highest tensile force measured is called tensile strength or breaking strength. Tearing intensity is the average force needed to continue a tear already begun in a fabric [9]. During the tearing test, threads break singly or in small clusters. Threads that have been twisted skew and slide. The strain is first carried by a few strands. The adjacent yarn also fails. Yarns may cluster around the tear due to increased extensibility or fewer frictional restrictions, however yarn strength may not improve tear strength. Again, breaking force is determined by area. Tensile force at the point of rupture is referred to as tenacity. Tensile strength of fabrics is affected by yarn density and cross-section of fabrics itself and yarn from which it is composed of. Thread density and oblique yarn orientation need more efforts to balance the weight. Crimping causes yarn to stretch. More crimp extends the cloth. Floats increase thread density while

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decreasing extension. Weaving decreases fabric extensibility by tightening the warp and weft and tensile strength fell [10].

These two strengths (tear and tensile) had different application in the textile field to produce fabrics considering wear and tear resistance and produce higher tensile strength in technical textiles manufacturing. However different research approached are done in predicting these strength properties in different way. Multiple linear regression (MLR), artificial neural network (ANN), Automated Machine Learning (AutoML), and Fuzzy techniques are some preferred tools that have been used to predict the strength of the fabric of composite fabric considering different variations in count, thread density (warp and weft), inter- yarn friction, float length, interlacing points, design (plain, twill, matt), loading direction (uniaxial or biaxial), fiber composition (single or blends), fiber composition (single/blends), spinning (ring/rotor), yarn strength transfer efficiency etc. [11-14]. When utilizing hidden layers in prediction models, machine learning approach outperformed regression method in prediction using learnt data [15]. However, the input parameters consideration and design variation cannot be included as a whole in modeling for incapability in numerical or weighted value expression. Because various weave designs might have the same float length or yarn densities [10].

To know the effect of design variation (basic plain, twill and sateen) on tensile and tear strength of woven fabrics having similar loom setting and yarn properties within the smallest repeat sizes, this experiement is performed. Although machine learning approach is better this experiment only used multiple linear regression tool primarity to investigate the found result from testing the sample fabrics produced in this study with the relation of considered parameters. Here, the primary objective of this research is to forecast woven fabrics considering various construction variables. Ends per cm (EPCm), picks per cm (PPCm), maximum yarn setting, and cloth areal density in gram per square meter (GSM) are considered to be primary factors. At the same time, numerous researchers have established different fabric weaving factors [10, 16]. But there are too many considerations linked to the strength of the fabric, such as yarn count, twist, fiber fineness, rigidity, fiber density, the shape of the fabrics, cover, yarn density, layer number, tightness factor, and so on [17].

The objectives of the study are to develop four regression models to predict both warp and weft way tear strength as well as warp and weft tensile strength of woven fabrics having eight different weave structures of plain, twill, and sateen. The objectives of the study are mentioned below:

- To explore the effect of loom settings on output variables warp way (Y1) and weft way (Y2) tear strength and warp way (Y3) and weft way (Y4) tensile strength.
- To explore the effect of design types on output variables warp way (Y1) and weft way (Y2) tear strength and warp way (Y3) and weft way (Y4) tensile strength.
- To investigate the effect of "EPCm, PPCm, Law's maximum thread density and GSM with output variables warp way (Y1) and weft way (Y2) tear strength and warp way (Y3) and weft way (Y4) tensile strength.

Due to the difficulty of integrating all those variables to represent the configuration of the weave, the correlation-regression tool and ANOVA are used to explain the influence of structural parameters of fabrics on the tear and tensile strength of fabrics with various fundamental designs. Regression tools are used to evaluate study theories that have been established from literature reviews [18]. And after checking approaches [19], the impact of yarn environment and design styles on the intensity of fabrics is observed. Finally, predictors such as PPCm, EPCm, GSM, and Law's maximum yarn setting of the sample woven fabrics are provided by four regression models. Here following effects in alternate hypothesis statements are analyzed statistically:

H1-H8: There is a significant difference in yield of warp way tear strength (Y1), weft way tear strength (Y2), warp way tensile strength (Y3), and weft way tensile strength (Y4) for different loom settings (H1,H2, H3, H4 respectively) and similarly across design types (H5, H6, H7, H8 respectively).

H9-H12: EPCm (H9), PPCm (H10), Law's max yarn set (H11), and GSM (H12) have significant effect on warp way tear strength (Y1).

H13-H16: EPCm (H13), PPCm (H14), Law's max yarn set (H15), and GSM (H16) have considerable impact on weft way tear strength (Y2).

H17-H20: EPCm (H17), PPCm (H18), Law's max yarn set (H19), and GSM (H20) have significant effect on warp way tensile strength (Y3).

H21-H24: EPCm (H21), PPCm (H22), Law's max yarn set (H23), and GSM (H24) have considerable impact on weft way tensile strength (Y4).

## EXPERIMENTAL METHODOLOGY

### Materials

36.9 Tex, 100% cotton rotor yarn is used to manufacture woven fabrics. It has a lea strength of 81.93 kg at 25 0C with 78% relative humidity in the testing lab. Single yarn strength is 5.6 N, with 6.9%

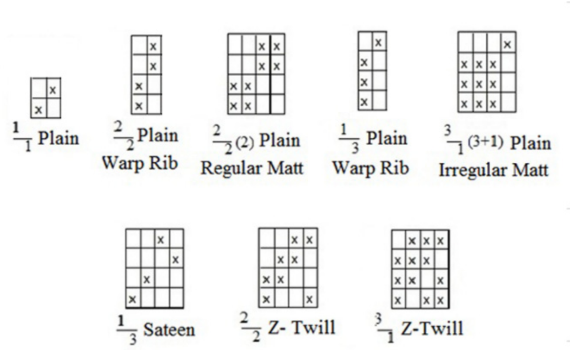


**Figure 1.** Fabrics' design repeats used in this experiment.

breaking extension and tenacity is 15 cN/Tex. As the interlacement ratio of plain, twill, and satin fabric differs in various way, and their stiffness are affected by the angle of weaving, in this experiment, fabrics structures for eight woven designs, namely $\frac{1}{3}$ sateen, $\frac{2}{2}$ z-twill, $\frac{3}{1}$ z-twill, $\frac{1}{1}$ plain, $\frac{2}{2}$ plain warp rib, $\frac{2}{2}(\mathbf{2})$ plain regular matt, $\frac{3}{1}$ plain warp rib and $\frac{3}{1}(\mathbf{3}+\mathbf{1})$ plain irregular matt are prepared. For data processing in the statistical tools following descriptions are used to represent types of fabrics (Fig. 1).

Finally, 8 (Designs)×3 (Loom Setting) = 24 samples are being tested according to the testing methods. To produce these fabrics, 40 Stockport reed drawing 2 in a dent (40 heald count) and 60 Stockport reed drawing 1 in a dent (30 heald count), and 2 in a dent (60 heald count) in Automated Sampling Rapier Loom (CCI Tech Inc.). For collecting tear (5×2×24=240) and tensile strength (5×2×24 =240) in both warp and weft direction "240 + 240 =480" specimens are produced, tested and average values are recorded in Table 2.

## Instruments

Lea strength tester, single yarn tester (Pytan), Automated Sampling Rapier Loom (CCI Tech Inc.), universal tensile tester (Titan 500 Newton) and Elma tear tester (133 N), wrap reel and weight balance (yarn count test method), and twist tester are used in this experiment. All data is recorded in a single working sheet then the relation among the factors of fabrics is analyzed using a graphical method, SPSS 23, and R-Studio software.

## Standards and methods for testing

Single yarn strength, fabrics' tear, and tensile strength are tested as ASTM D2256/D 2256M:2010 [20], Elma Tear with max load 133 N as ISO 13937-1:2000 [21], and Universal Tensile Tester as ISO 13934-2:2014 [22] respectively. 5 breaks are performed both for warp and weft direction with similar setting and speed. The machine speed of tensile testing is 50 mm/min. After enzymatic desizing, washing for 25 min at 50 0C temperature with 1 ml detergent, the samples were dried and relaxed for 72 hours before testing.

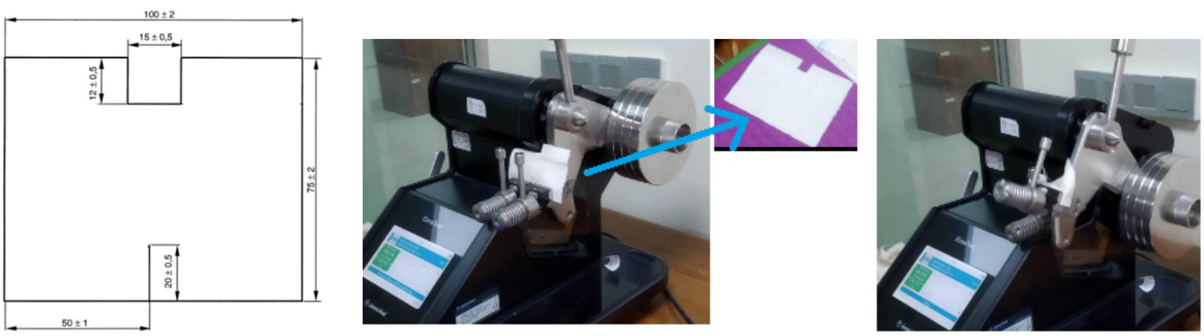


**Figure 2.** Fabric tear strength testing specimen size and testing [21].

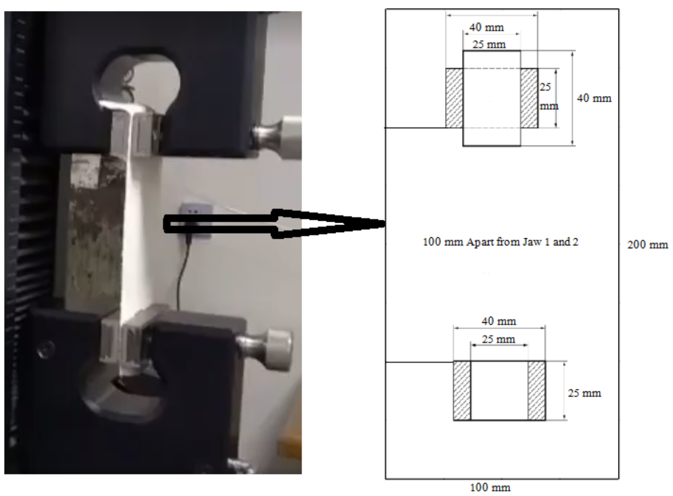


**Figure 3.** Fabric tensile strength testing specimen size and testing [22].

**Table 1.** Some symbols and their meanings in this experiment.

| | | | | | |
|---|---|---|---|---|---|
| $Y_i$ | Warp way tear strength (Y1), Weft way tear strength (Y2), Warp way tensile strength (Y3), Weft way tensile strength (Y4) | $laws_{\frac{max}{yarn_{set}}}$ | $S(yN)^{1/2}$ Where, S= setting ratio varying with weave upto 4 float, y =cloth setting constant depends on yarn numbering system, N indirect count of yarn | F | t-test value |
| $\beta_{0-4}$ | Constant for regression models | gsm | Gram per squar meter (GSM) | p | Probability value |
| $\epsilon$ | Error term | R and Adjusted $R^2$ | Reliability of the beta values | H1-H24 | Research Hypothesis |
| EPCm | Ends per centimeter | W | Shapiro-Wilk values | | |
| PPCm | Picks per centimeter | df | Degree of freedom | | |

## Variables

Dependent variables are warp way (Y1) and weft way (Y2) tear strength and warp way (Y3) and weft way (Y4) tensile strength of the fabrics. Again, independent variables are EPCm, PPCm, GSM, and Law's max yarn set. $\frac{1}{1}$ plain, $\frac{2}{2}$ plain warp rib, $\frac{2}{2}(\mathbf{2})$ plain regular matt, $\frac{3}{1}$ plain warp rib, $\frac{3}{1}(\mathbf{3}+\mathbf{1})$ plain irregular matt, $\frac{2}{2}$ z-twill, $\frac{3}{1}$ z-twill, and $\frac{1}{3}$ sateen structure of fabric 1/1P, 2/2P, 2/2(2)P, 3/1 P, 3/1(3+1)P, 2/2T, 3/1T, and 1/3S are used respectively for software processing in R-studio 3.6 and SPSS 23. Some symbols and their meaning are enlisted in Table 1.

## Statistical methods

Following statistical analyses were conducted throughout this study:

1. The level of significance for all hypotheses was taken as $\alpha = 5\%$. A p-value less than $\alpha$ indicates the test's significance (i.e., reject the null hypothesis).
2. Shapiro -Wilk test was performed to check whether response/output variables and residuals of the regression model are normally distributed or not.

The hypothesis statement of the Shapiro -Wilk test is given below:

$H_0$: Variable or data is normally distributed

$H_a$: Variable or data is NOT normally distributed

3. Two-way ANOVA was conducted to understand the effect of fabric setting and design type on output variables. A p-value less than $\alpha$ indicates a significant impact.
4. Multiple linear regression techniques were applied to assess the effect of five predictor variables like EPCm, PPCm, Laws maximum yarn setting, and GSM on output variables. A p-value less than $\alpha$ indicates the model's significance and significant individual effect of each predictor variable. For four response variables, four separate regression models was developed:

$$\mathbf{Y_i = \beta_0 + \beta_1\,(EPCm) + \beta_2(PPCm) + \beta_3(Law's\ maximum\ yarn\ setting) + \beta_4\,(GSM) + \epsilon\,;\, i = 1, 2, 3, 4} \quad (1)$$

where in each model, the error term $\epsilon$ is assumed to be normally distributed with mean 0 and constant variance $\sigma_e^2$.

## RESULTS AND DISCUSSION

In this section effect of the design or changing of fabrics' structures and loom settings on tear and tensile strength are tested by two-way ANOVA. Then, by regression analysis four specific models are prepared using EPCm, PPCm, Law's maximum yarn setting, and GSM as influencing factors of the fabrics where other factors assumed constant during production of the fabrics samples. Considering constant yarn properties like yarn count, fiber consumptions, twist per inch the loom setting changed within Stockport reed count 30 with 1 and 2 yarn per dent, and Stockport reed count 40 with single yarn drawn per dent. The data set is summarized in Table 2.

## Two-way ANOVA of strength (Y1-Y4) for loom setting and design name

A two-way ANOVA was conducted to determine if there is a difference in average "OUTPUT" with loom setting and design type (derivatives of plain, twill and sateen) which is mentioned as 'design_name' variable here from 'table 3' to 'table 6'. Since there are four output variables warp way tear strength (Y1), weft way tear strength (Y2), warp way tensile strength (Y3), and weft way tensile strength (Y4) in this study, so four two-way ANOVA have been performed separately.

Table 3 indicates that the loom setting's main effect is insignificant, F(2,14)= 0.92, p=0.42, which means that the average warp way tear strength (Y1) is almost the same for the three loom setting. The main effect of the fabric design is significant, F(7,14)=2.89, p=0.04; that is average warp way tear strength (Y1) differs significantly from design to design, and the highest average of warp way tear strength (Y1) was yielded for design $\frac{2}{2}\,(2)$ plain matt.

**Table 2.** Data summary for tear and tensile strength in warp and weft way due to different design and loom setting.

| Loom Setting | Design Name | EPCm | PPCm | Law's Max Thread Density | GSM | Tear Strength (N)* | | Tensile Strength (N)* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Warp way | Weft Way | Warp way | Weft Way |
| Reed Count (Stock Port) 60 and Heald Count 30 | $\frac{1}{1}$ Plain | 15 | 14 | 22 | 132.47 | 56.390 | 64.011 | 158.678 | 159.551 |
| | $\frac{2}{2}$ Plain Warp Rib | 14 | 14 | 30 | 128.95 | 92.132 | 78.373 | 144.548 | 130.681 |
| | $\frac{2}{2}$ (2) Plain Regular Matt | 16 | 13 | 30 | 135.49 | 100.950 | 103.010 | 141.525 | 111.855 |
| | $\frac{3}{1}$ Plain Warp Rib | 15 | 14 | 33 | 143.98 | 62.296 | 76.838 | 155.143 | 115.397 |
| | $\frac{3}{1}$ (3+1) Plain Irregular Matt | 17 | 14 | 33 | 147.29 | 75.424 | 70.724 | 159.277 | 104.566 |
| | $\frac{2}{2}$ Z-twill | 16 | 14 | 30 | 143.28 | 80.386 | 88.242 | 142.465 | 132.514 |
| | $\frac{3}{1}$ Z-twill | 15 | 14 | 33 | 134.27 | 84.252 | 88.754 | 138.579 | 123.679 |
| | $\frac{1}{3}$ Sateen | 17 | 14 | 33 | 146.97 | 81.405 | 92.152 | 142.964 | 136.200 |
| Reed Count (Stock Port) 40 and Heald Count 40 | $\frac{1}{1}$ Plain | 19 | 17 | 22 | 158.68 | 39.681 | 48.406 | 252.439 | 239.639 |
| | $\frac{2}{2}$ Plain Warp Rib | 21 | 18 | 30 | 179.08 | 105.640 | 85.288 | 238.676 | 187.382 |
| | $\frac{2}{2}$ (2) Plain Regular Matt | 20 | 17 | 30 | 169.26 | 106.390 | 102.505 | 209.917 | 194.409 |
| | $\frac{3}{1}$ Plain Warp Rib | 20 | 18 | 33 | 181.52 | 108.470 | 84.684 | 242.757 | 184.091 |
| | $\frac{3}{1}$ (3+1) Plain Irregular Matt | 21 | 18 | 33 | 178.73 | 93.060 | 95.304 | 209.777 | 184.762 |
| | $\frac{2}{2}$ Z-twill | 20 | 18 | 30 | 171.35 | 96.719 | 100.558 | 233.029 | 208.370 |
| | $\frac{3}{1}$ Z-twill | 20 | 18 | 33 | 179.17 | 83.534 | 90.806 | 230.675 | 216.376 |
| | $\frac{1}{3}$ Sateen | 21 | 18 | 33 | 183.73 | 72.418 | 85.810 | 207.945 | 238.204 |
| Reed Count (Stock Port) 60 and Heald Count 60 | $\frac{1}{1}$ Plain | 25 | 24 | 22 | 218.11 | 18.858 | 32.798 | 405.833 | 338.846 |
| | $\frac{2}{2}$ Plain Warp Rib | 26 | 25 | 30 | 219.36 | 63.872 | 56.667 | 428.512 | 341.938 |
| | $\frac{2}{2}$ (2) Plain Regular Matt | 25 | 25 | 30 | 210.38 | 100.408 | 104.193 | 371.480 | 333.181 |
| | $\frac{3}{1}$ Plain Warp Rib | 26 | 25 | 33 | 215.67 | 122.200 | 64.117 | 388.311 | 330.500 |
| | $\frac{3}{1}$ (3+1) Plain Irregular Matt | 27 | 26 | 33 | 220.32 | 132.810 | 129.400 | 357.948 | 357.381 |
| | $\frac{2}{2}$ Z-twill | 26 | 26 | 30 | 224.45 | 59.613 | 72.977 | 392.879 | 366.607 |
| | $\frac{3}{1}$ Z-twill | 26 | 25 | 33 | 223.05 | 47.421 | 48.136 | 319.733 | 440.507 |
| | $\frac{1}{3}$ Sateen | 27 | 26 | 33 | 229.65 | 41.407 | 71.366 | 374.405 | 360.847 |

Note:* mean values are taken from 5 tests.

From 'Table 4' it is seen that as weft way tear strength (Y2) the main effect of loom setting is not significant, $F(2,14)=1.59$, $p=0.24$, implying that average weft way tear strength (Y2) does not differ significantly across loom setting. Whereas the main effect of the fabric design is significant, $F(7,14)=3.20$, $p=0.03$. So, it can be said that design has an impact on weft way tear strength (Y2) and design $\frac{\mathbf{2}}{\mathbf{2}}$ $(\mathbf{2})$ plain matt had the highest average yield.

In the same procedure, two-way ANOVA was carried out, and the result is displayed in 'table 5'. The main effect of the loom setting is very significant on the yield of Y3, $F(2,14)=316.9$, $p=0.00$. The highest average of warp way tensile strength (Y3) is obtained for loom setting 2. On the other hand, the fabric design effect is insignificant; the average yield of warp way tensile strength (Y3) is almost the same for eight designs with same loom setting, $F(7,14)=2.07$, $p=0.12$.

**Table 3.** Response variable warp way tear strength (Y1).

| Source of variation | Df | Sum Square | Mean Square | F | p |
|---|---|---|---|---|---|
| Loom Setting | 2 | 903.99 | 451.99 | 0.92 | 0.42 |
| design_name | 7 | 9963.02 | 1423.29 | 2.89 | 0.04 |
| Residuals | 14 | 6890.9 | 492.21 | | |
| Total | 23 | 17757.9 | | | |

**Table 4.** Response variable weft way tear strength (Y2).

| Source of variation | Df | Sum Square | Mean Square | F | p |
|---|---|---|---|---|---|
| Loom Setting | 2 | 862.7 | 431.34 | 1.59 | 0.24 |
| design_name | 7 | 6064.3 | 866.33 | 3.20 | 0.03 |
| Residuals | 14 | 3791.0 | 270.79 | | |
| Total | 23 | 10718.0 | | | |

**Table 5.** Response variable warp way tensile strength (Y3).

| Source of variation | Df | Sum Square | Mean Square | F | p |
|---|---|---|---|---|---|
| Loom Setting | 2 | 222090.7 | 111045.3 | 316.9 | 0.00 |
| design_name | 7 | 5084.9 | 726.4 | 2.07 | 0.12 |
| Residuals | 14 | 4906.3 | 350.5 | | |
| Total | 23 | 232081 | | | |

**Table 6.** Response variable weft way tensile strength (Y4).

| Source of variation | Df | Sum Square | Mean Square | F | p |
|---|---|---|---|---|---|
| Loom Setting | 2 | 222103 | 111052 | 210.45 | 0.00 |
| design_name | 7 | 7252 | 1036 | 1.96 | 0.13 |
| Residuals | 14 | 7388 | 528 | | |
| Total | 23 | 236743 | | | |

Thus, from Table 3 to Table 6 hypotheses H3, H4, H5 and H6 are accepted. On the other hand, hypotheses H1, H2, H7, and H8 are rejected. Thus it is proved that loom setting variation in yarn setting influences the tensile strength of fabrics and design variation influences the tear strength of the fabrics. Thus, an increase in the yarn setting greatly affects the fabric's tensile strength change. The more yarn present in the fabric tensile strength will be high. Again, whether the number of yarns more or less design variation influences its tear strength. The more floats of yarn are present in the fabrics, the more the tear strength. It also supports the result found by Eryuruk S.H. and Kalaoğlu F. [23] that weft tearing strength values found greater than the warp tearing strength and change in tear strength as the number of threads per metre in either direction. Again the thread densities improves the tensile strength [24-25].

As a result of the inability to present fabric design in numerical numbers such as EPCm, PPCm, and GSM, Law's maximum thread density in 'table 1' is the term used in regression models due to its consideration of fabric design in its formula to limit the maximum yarn density for specific yarn count and fabric design. A drawback of the research is that the fundamental design and its derivatives cannot be separated with distinct justified numerical values to consider in the regression models which is a scope of further research. Thus, design parameters and their numerical expression needs to be further analyzed. Law's max yarn set is the term that consider both the yarn representing unit and basic fabric design variation that improves the model prediction strength in this regard [10].

## Regression models with ANOVA

**Regression Model 1:** Dependent variable warp way tear strength (Y1)

$$\widehat{\mathbf{Y_1}} = \mathbf{16.367 + 20.629 * EPCm + 2.46 * PPCm + 4.695 * laws_{\substack{max \\ yarn_{set}}} - 3.095 * gsm} \quad \text{(A)}$$

**Regression Model 2:** Dependent variable weft way tear strength (Y2)

$$\widehat{\mathbf{Y_2}} = \mathbf{33.258 + 13.816 * EPCm + 0.754 * PPCm + 3.509 * laws_{\substack{max \\ yarn_{set}}} - 2.015 * gsm} \quad \text{(B)}$$

**Regression Model 3:** Dependent variable warp way tensile strength (Y3)

$$\widehat{\mathbf{Y_3}} = \mathbf{-20.290 - 2.102 * EPCm + 16.877 * PPCm - 4.549 * laws_{\substack{max \\ yarn_{set}}} + 0.755 * gsm} \quad \text{(C)}$$

**Regression Model 4:** Dependent variable weft way tensile strength (Y4)

$$\widehat{\mathbf{Y_4}} = \mathbf{-84.04 - 1.665 * EPCm + 18.872 * PPCm - 2.729 * laws_{\substack{max \\ yarn_{set}}} + 0.419 * gsm} \quad \text{(D)}$$

**Regression Model 5:** Dependent variable log weft way tensile strength (log(Y4))

$$\widehat{\mathbf{log(Y_4)}} = \mathbf{1.753 + 0.006 * EPCm + 0.022 * PPCm - 0.009 * laws_{\substack{max \\ yarn_{set}}} + 0.002 * gsm} \quad \text{(E)}$$

From Table 7, the overall impact of independent variables significantly impacts warp way tear strength (Y1). However, the estimated model can explain a 79.7% variation in warp way tear strength (Y1). The model residuals are also normally distributed, W=1.880, p=0.009, which indicates the excellent fit of the model.

Again, The overall model 2 (model B) is significant, F(4,19)=4.579, p=0.009. The estimated model can explain a 70.1% variation of weft way tear strength (Y2) . The model residuals are also normally distributed, indicating a well-fitted model, W=2.238, p=0.018.

**Table 7.** ANOVA for regression models.

| *ANOVA for regression* | Source of variation | Df | Sum Square | Mean Square | F value | Model Summary |
|---|---|---|---|---|---|---|
| ***Model 1 of Y1 (A)*** | Regression | 4 | 8729.966 | 2182.491 | 4.593 | R=0.701, Adjusted $R^2$=0.385, W = 1.880, p-value = 0.009 |
| | Residuals | 19 | 9027.946 | 475.155 | | |
| | Total | 23 | 17757.912 | | | |
| ***Model 2 of Y2 (B)*** | Regression | 4 | 4813.391 | 1203.348 | 3.872 | R=0.670, Adjusted $R^2$= 0.333 , W = 2.238, p-value = 0.018 |
| | Residuals | 19 | 5904.616 | 310.769 | | |
| | Total | 23 | 10718.007 | | | |
| ***Model 3 of Y3 (C)*** | Regression | 4 | 223540.839 | 55885.210 | 124.32 | R= 0.981, Adjusted $R^2$=0.955, W = 2.036, p-value = 0.000 |
| | Residuals | 19 | 854.991 | 449.526 | | |
| | Total | 23 | 232081.830 | | | |
| ***Model 4 of Y4 (D)*** | Regression | 4 | 222607.584 | 55651.896 | 74.804 | R=0.970, Adjusted $R^2$ =0.928, W = 1.066, p-value = 0.000 |
| | Residuals | 19 | 14135.373 | 743.967 | | |
| | Total | 23 | 236742.957 | | | |
| ***Model 5 of Y5 (E)*** | Regression | 4 | 0.821 | 0.205 | 75.45 | R= 0.97, Adjusted $R^2$= 0.928, W = 1.427, p-value = 0.000 |
| | Residuals | 19 | 0.052 | 0.003 | | |
| | Total | 23 | 0.873 | | | |

On the other hand, to investigate the overall impact of EPCm, PPCm, Law's maximum yarn setting, GSM on warp way tensile strength (Y3); model 3(C) has been fitted. The fitted model is highly significant, F(4,19)=124.32, p=0.000. The R=0.981 implies that the fitted model can predict a 98.1% variation in warp way tensile strength (Y3) . The model's residual (C) is normally distributed, W=2.036, p=0.000.

Though, model 4 (D) is overall significant, F(4,19)=74.804, p=0.000, but the residuals are not normally distributed, W=1.066, p=0.000. This may be due to functional misspecification of the model. So, another model is developed taking the logarithm of weft way tensile strength (Y4). Now, semi-log model 5 (Model E) is highly significant, F(4,19)=75.45, p=0.000 and the model's residuals are also normally distributed, W=1.427, p=0.000. The estimated model can explain 97.0% variation in weft way tensile strength (Y4).

Table 8 indicates that EPCm has a positive and very significant effect on warp way tear strength (Y1), t(19)=2.547, p=0.020. The impact of the law's maximum yarn setting on warp way tear strength (Y1) is positive and highly significant, t(19)=3.490, p=0.002. The effect of GSM on warp way tear strength (Y1) is negative and highly significant, t(19)=-2.892 p=0.009. Moreover, PPCm has positive impact but is not statistically significant. Thus, hypotheses H9, H11, and H12 are accepted, whereas H10 is rejected. But their overall effect made the model satisfactory with the goodness of fit.

Again, EPCm, Law's maximum yarn setting, and GSM significantly affect weft way tear strength (Y2) (p=0.048, 0.004, 0.031, respectively). Thus, hypotheses H13, H15, and H16 are accepted, whereas H14 is rejected. But their overall effect made the model satisfactory with the goodness of fit.

On the other hand, it also indicates that PPCm has a significant positive effect, and Law's maximum yarn setting significantly negatively impacts warp way tensile strength (Y3) where p=0.003, p=0.003, respectively. Other variables' impacts are not significant. Thus, hypotheses H18 and H19 are accepted, whereas H17 and H20 are rejected. But their overall effect made the model satisfactory with the goodness of fit.

The interpretation of the estimated coefficient of the semi-log model differs from the linear model. "Table-8" implies that the yield of weft way tensile strength (Y4) increases at a rate of 0.022 for a unit of PPCm, or 2.2%. Interpretation of other coefficients is in the same manner. Again, the yield of weft way tensile strength (Y4) decreases at a rate of 0.009 for a unit of Law's max yarn setting or 0.9%. But they have a very significant effect on the yield of weft way tensile strength (Y4). Thus, hypotheses H22 and H23 are accepted, whereas hypotheses H21 and H24 are rejected. But their overall effect made the model satisfactory with the goodness of fit.

## Fractional changes of strength based on design

According to float length, it can be said that the float length of the fabric significantly affects tear strength. With the increased float length, more yarns are close to each other, thus increasing tear strength. But, it is not clearly said from the data the effect of change in float length how the tensile strength changes as it

**Table 8.** Regression coefficients for models.

| *Regression coefficients* | Variables/predictor | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|---|
| **Model Y1 (A)** | (Intercept) | 16.367 | 46.293 | 0.354 | 0.728 |
| | EPCm | 20.629 | 8.101 | 2.547 | 0.020** |
| | PPCm | 2.460 | 5.037 | 0.488 | 0.631 |
| | laws_max_yarn_set | 4.695 | 1.345 | 3.490 | 0.002*** |
| | gsm | -3.096 | 1.071 | -2.892 | 0.009*** |
| **Model Y2 (B)** | (Intercept) | 33.258 | 37.438 | 0.888 | 0.385 |
| | EPCm | 13.816 | 6.551 | 2.109 | 0.048** |
| | PPCm | 0.754 | 4.073 | 0.185 | 0.855 |
| | laws_max_yarn_set | 3.509 | 1.088 | 3.225 | 0.004*** |
| | gsm | -2.015 | 0.866 | -2.327 | 0.031** |
| **Model Y3 (C)** | (Intercept) | -20.290 | 45.027 | -0.451 | 0.657 |
| | EPCm | -2.102 | 7.879 | -0.267 | 0.793 |
| | PPCm | 16.877 | 4.899 | 3.445 | 0.003*** |
| | laws_max_yarn_set | -4.549 | 1.308 | -3.477 | 0.003*** |
| | gsm | 0.755 | 1.041 | 0.725 | 0.478 |
| **Model Y4 (D)** | (Intercept) | -84.040 | 57.926 | -1.451 | 0.163 |
| | EPCm | -1.665 | 10.137 | -0.164 | 0.871 |
| | PPCm | 18.872 | 6.302 | 2.994 | .007*** |
| | laws_max_yarn_set | -2.729 | 1.683 | -1.621 | 0.121 |
| | gsm | 0.419 | 1.340 | 0.312 | 0.758 |
| **Model Y5 (E)** | (Intercept) | 1.753 | .111 | 15.823 | .000 |
| | EPCm | .006 | .019 | .319 | .753 |
| | PPCm | .022 | .012 | 1.805 | .087* |
| | laws_max_yarn_set | -.009 | .003 | -2.713 | .014** |
| | gsm | .002 | .003 | .647 | .525 |

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

didn't show any clear indication due to the fluctuation of the tensile strength much with the change of the design of the fabrics and yarn set [23-25].

For distinct heald counts, rib, matt, twill, and sateen show greater warp way tear strength than plain fabric in Fig. 4. Similar result found for twill weave by Asaduzzaman M. et al. [26], and the strength increases with the increase of heald counts that supports the result found by Malik Z.A. et al. [25]. Matt fabric with a similar float length shows greater strength than rib, twill, and sateen (Fig. 2) which further shows different from Asaduzzaman M. et al. [26] due to the change is weave design of plain structure.

For different heald counts, it is seen that rib, matt, twill, and sateen showed greater weft way tear strength than plain fabric. And the strength increases with the increase of heald counts. The tear strength of matt fabric is higher than that of rib, twill, and sateen, with a similar float length (Fig. 5). These also supported by result found in work of Asaduzzaman M. et al. and Malik Z.A. et al. [25-26]. Thus contact between warp and weft yarn or interlacement pattern or variation in weave design plays a vital role in warp and weft tear strength which is also supported by Radwan S.S. [27].

It is found in Fig. 6 that matt, twill, and sateen show lower warp way tensile strength than that of plain fabric except $\frac{2}{2}$ plain warp rib and $\frac{2}{2}$ z-twill. But, the change is not very continuous except $\frac{3}{1}$ z-twill structures in this experiment which are similar found by Asaduzzaman M. et al. [26].

Fig. 7 demonstrates that the tensile strength of the rib, matt, twill, and sateen fabric is lower than that of the plain structure. However, the strength of these fabrics becomes greater with the increase of the heald count and demonstrates more than that of plain construction. Concerning plain fabric construction, twill and sateen fabric change is more regular than rib and matt. Here with the increase of yarn densities below the optimum level the weft way tensile strength of twill and sateen was found lower than plain weave that supports the result found by Asaduzzaman M. et al. [26] but at the optimum level the strength become higher than the $\frac{1}{1}$ plain weave which is again support the theoretical context of Gokarneshan N. [28].

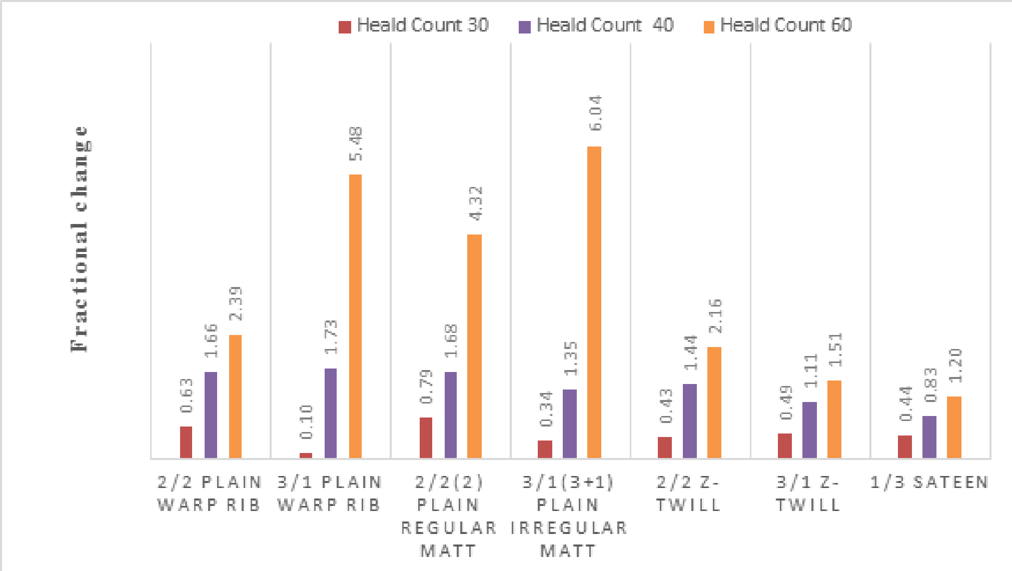


**Figure 4.** Fractional change in warp way tear strength from the plain weave

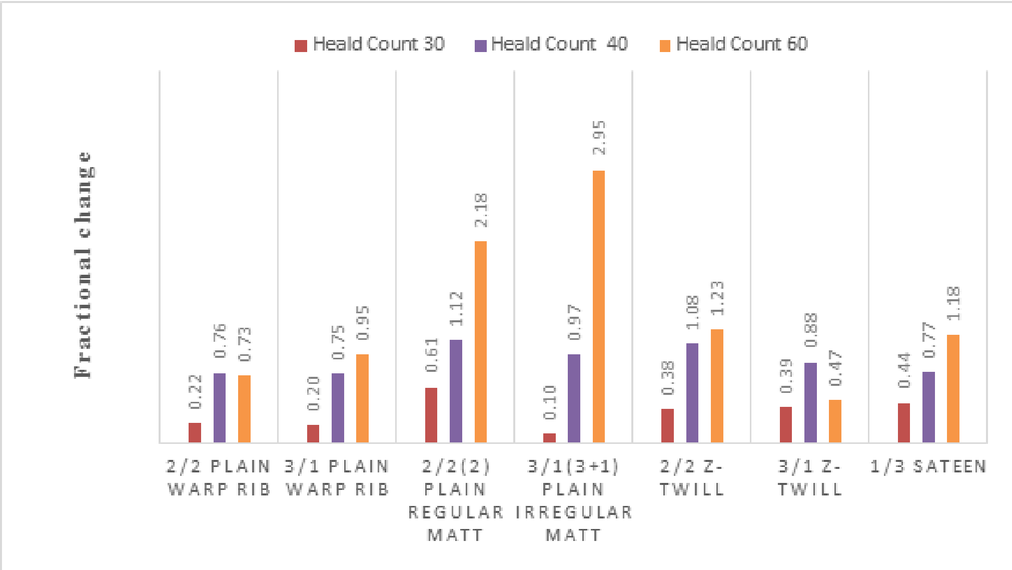


**Figure 5.** Fractional change in weft way tear strength with respect to plain weave.

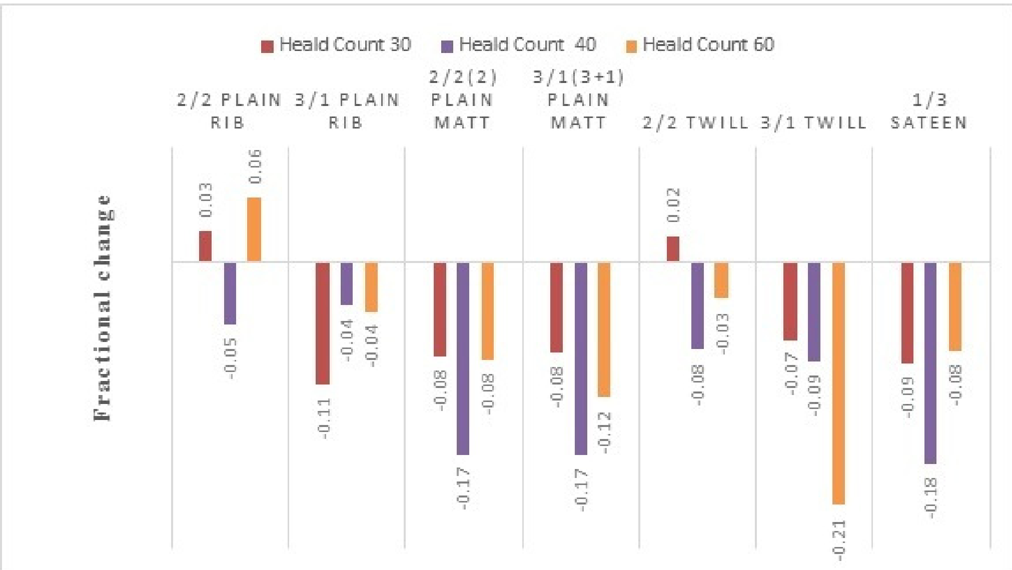


**Figure 6**. Fractional change in warp way tensile strength with respect to plain weave structure.

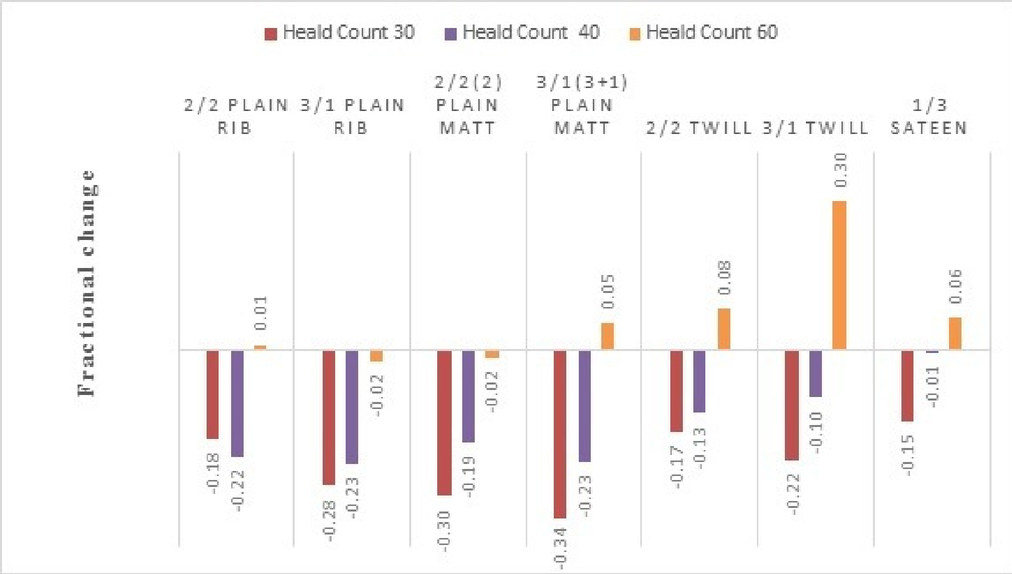


**Figure 7**. Fractional change in weft way tensile strength from the plain weave structure.

The four regression models can precisely predict the values using EPCm, PPCm, and Law's maximum yarn setting as influencing factors. As the yarn used in this research is one thus, fiber composition and yarn properties remained constant in this study. It was most challenging to find out the relation of these factors with the tear and tensile strength and consider design variation in the prediction model. Law's maximum yarn setting parameters use the float length and yarn count during measurement and are statistically significantly related to tear and tensile strength. As float length is still the same for different weave designs thus, there are still spaces to improve this model. This study also uses graphical representations to understand the variation of tear and tensile strength with design variation.

This study found that all models can predict the tear and tensile strength with accuracy from 70.1% to 97.3% at a 5% significance level considering EPCm, PPCm, Law's maximum yarn setting, and GSM as independent variables. Among these parameters, the most significant factor for tear strength is EPCm and PPCm for tensile strength. It is also observed that design variation significantly influences tear strength, and fabric setting or yarn density greatly varies the tensile strength of the fabric. Thus, hypothesis testing shows changing yarn density in fabric structure does not influence tear strength, but yarn floating or weave design significantly influences the tear strength of the fabrics. On the other hand, design change or weave interlacement does not considerably change the tensile strength of the fabrics. Other hypothesis testing shows that EPCm, Law's maximum yarn setting, and GSM significantly influence warp and weft tear strength. On the contrary, PPCm and Law's maximum yarn setting significantly affect warp and weft way tensile strength.

This research's hardest part was considering weave factors in prediction models. As most of the weave factors have high inter-correlation. They cannot be viewed in a single model; only Law's maximum yarn setting is considered in prediction models. To understand effect of float length and comparison with basic plain structure for tear and tensile strength, a graphical representation was the only option that authors found during this study. The float length of the fabric significantly affects tear strength. With the increased float length, more yarns are close to each other, thus increasing tear strength. But, it is not clearly said from the data the effect of change in float length how the tensile strength changes as it didn't show any clear indication due to the fluctuation of the tensile strength much with the change of design of the fabrics and yarn set.

It is also found that the tear strength increases with the increase of heald counts. The tear strength of matt fabric is higher than that of rib, twill, and sateen, with a similar float length. At the same time, twill and sateen show lower warp way tensile strength than that of plain fabric, except $\frac{2}{2}$ warp rib, $\frac{2}{2}$ z-twill and $\frac{3}{1}$ z-twill structures in this experiment.

The tensile strength of the rib, matt, twill, and sateen fabric is lower than that of the plain structure. However, the strength of these fabrics becomes greater with the increase of the heald count and demonstrates more than that of plain construction. With regard to plain fabric construction, the change in twill and sateen fabric is more regular than rib and matt.

## CONCLUSION

Mathematical models concentrating on the fundamentals of woven textiles may struggle to provide adequate findings since all of the model's uncertainties cannot be accounted for. Due to the accuracy required, mathematical modeling of fabric constitutive equations necessitates the use of a specialist approach. Certain variables are used as assumptions for prediction in predictive, descriptive, and computational models. Mathematical approaches are also case-specific. Four variables, EPCm, PPCm, GSM, and Law's maximum yarn setting, are utilized to generate four regression models to predict fabric strength in the sample to understand the effect of these parameters on the tear and tensile strength of the 100% cotton woven fabrics. Combining yarn composition, textile structure, twisting, and test techniques in a single formula is difficult. This research determines the optimum parameters and statistical representation to predict fabric strength. Floating parameters impact test performance and parameters like elongation. Such variables are omitted from regression models to avoid ambiguity. Research shows that thread setting and fabric design influence tear and tensile strength. As yarn properties such as single yarn power, fiber, twist, count, lea strength, etc., are the same, they dramatically alter the design result's tear strength. Thread density affects tensile strength more than design, however. Four regression models might be used within the scope of the design and yarn properties, and more research could be done with more yarn variation. Despite certain disadvantages, four regression models fit well (67%-98.1%) in this case. Here, the matt and twill weave structure showed more tear strength and tensile strength respectively. So, these structures can be the best choice for specific strength in technical textile production for higher tear and tensile strength. The prediction models can be adjusted with consideration of other parameters and more design structures. Therefore in models, GSM had a negative impact on weft way tear strength, EPCm and PPCm on warp way tensile strength, and PPCm on weft way tensile strength, which might be due to woven fabric relaxation and design variation or floating of warp and weft threads. The impact of other parameters positively on tear and tensile strength also might be balancing the negative influence of those parameters in respected cases. As, design of the fabric cannot be expessed in the numerical value as like other parameters (EPCm, PPCm, Law's Max Yarn setting and GSM) the models did not consider the design variables. Design variables as categorical or ordinal variables are needed to adjust the models with various designs. Again, Choosing fibers other than 100% cotton and yarn count other than 36.9 Tex will enhance the possibility of versatile technical applications from lower strength to higher strength. Thus, stiffness and other properties will be another option in proper selection of the fabric design to meet the technical requirements.

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