Regression model development for showing relation between mechanical yarn stretch (%) in sizing and Warp yarn breakage (cmpx) in looms using ANOVA model

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Abstract: Mechanical yarn stretch (%) in sizing process is amongst one of the process control parameters affecting warp yarn breakages in looms. This study tries to develop a model showing the relation between mechanical yarn stretch percentages with warp yarn breakages in loom shed. For that experimentation is done in Bahir Dar textile sh. Company weaving mill using cotton yarn of 20's used for making of 20's*20's/24*24 (threads/cm) of fabric particulars or bed sheet article. For sizing, maize starch is used & the main sizing parameter measurements have been kept equal other than mechanical yarn stretch percentage, having four different levels of treatments taken randomly. These differently treated4 weavers' beams are loaded on 4 picanol air-jet looms having same loom settings and monitored by same weaver group. The loom-shed is kept to have an R.H of 60% and temperature of 24^{o}c. The experimentation follows a single factor ANOVA with 4 levels of mechanical yarn stretch percentages and 10 replicates. Using significance level of $\alpha = 0.05$, the experimentation shows mechanical yarn stretch percentage significantly affects the warp yarn breakages in looms. For comparing pairs of treatment means that significantly differs, a multiple comparison method is used. Other than treatment means between the first and second level of treatments, the rest pairs of treatment means are significantly different. From the experiment, a correlation coefficient (R2) of 84.4% is computed. In this study, plot for predicted versus residual value is also made, which shows the model is adequate and fitting.

Keywords: Stretch%, warp yarn cmpx, cotton yarn, ANOVA, linear regression model

1. INTRODUCTION

The process of sizing imposes stresses along the yarn path. The stresses occurring in sizing machine varies among the different machine parts, i.e. between creel and squeezing roller, at the drying cylinders, at the head stock, during winding of the weavers' beam, etc. Because of the stated acting forces, the warp yarn in sizing operation stretches. It is described as mechanical yarn stretch and its unit is in percentage. The most critical issue in sizing is to control the yarn stretch. As yarns pass through the long path from creel to head stock, the tension applied in the process will tend to elongate it. If this elongation is not controlled, the deformation so introduced will be permanently set in the yarn (Bhuvenesh et al., 2004).

The control of yarn elongation (stretch) between the squeezing rolls of the size box and the first drying cylinder is critical, since the wet yarns under high heat undergo stretching even at low tensions. This must be controlled by proper selection of the drive system, such as digital or variable speed differential transmission between the size box and the drying unit (Gandhi, 2012). The tension develops when the yarn is passed through the drying cylinders for ensuring proper drying. The surface speeds of all the drying cylinders should be controlled and if they are uniform, no stretch will develop in the drying zone (Bhuvenesh et al., 2004).

A uniform stretch from section beam to section beam throughout the warp must be maintained. For sizing machines, which the stretch control % is clearly shown on the machine's control panel, we can directly take the figure as mechanical yarn stretch %. But suppose the machine is old model and no control panel is there, we have to calculate the mechanical yarn stretch % in sizing as per the SOP (standard operating procedure) stated below:

SOP to check the stretch % [the below stated operating procedures are followed & taken by many textile factories as standard procedures]. Purpose of checking stretch %: to reduce elongation loss % and reduction of warp yarn breakage in loom shed:

- Back meter counter must be fixed at back of the sow box,
- At starting of the beam set the front machine counter at '0'
- At the same time set the back meter counter also at '0'
- At the time of completion of the beam note & record the reading of the front machine counter,
- At the same time note & record the reading of the back meter counters,

The stretch % to be calculated as follows:
Stretch %=Front counter reading-back counter reading/back counter reading*100[the stated formula is followed & taken by many of the textile factories as standard working formula]

2. MATERIALS AND METHODS

2.1. Materials

The experiment is conducted in Bahir Dar textile factory with the use of cotton yarn having the following details: for the experiment cotton yarn of 20's which is produced in open end-spinning has been used. Tables 1 & 2 most important sample fibre properties and yarn parameters, that has been used for the experimentation has been stated in detail (Company dataset).

Table 1: Sample cotton fibre parameters

S.no	Length (mm)	Short fibre content (%)	Moisture content (%)	Micronaire (%)	Strength (CN/tex)	Maturity (%)	Elongation (%)	Trash content (%)
1	26	8	8	4.0	27	86	6.7	4

Table 2: Sample raw cotton yarn parameters

S.no	Yarn type	Type of Spinning machine	Count	Elongation (%)	Yarn twist level (TPM)	Strength (CN/tex)	Evenness (U %)	Imperfection level
1	Cotton	OE	20’s	5.7	900	9.5	11	Thin place= -50% 7/kmThick place = + 50%, 40/kmNeps = +280% 9/km
2	Cotton	OE	20’s	5.7	900	9.5	11	
3	Cotton	OE	20’s	5.7	900	9.5	11	
4	Cotton	OE	20’s	5.7	900	9.5	11	

Table 3: Sample sized cotton yarn and fabric particular parameters

S.no	Type of size material used	Size-pickup %	Size viscosity (seconds)	R.F (concentration) %	Moisture content (%)	Stretch (%)	Fabric particulars
1	Maize starch	6%	13	5	7	1.34	20’s*20’s/24 (EPC)*24 (PPC), bed sheet product
2	Maize starch	6%	13	5	7	1.62	
3	Maize starch	6%	13	5	7	5	
4	Maize starch	6%	13	5	7	1	

Table 4: Picanol air-jet loom settings for conducting the experiment

S.no	Loom speed (rpm)	Back rest height (cm)	Adjusted warp tension (KN)	Front shed angle (degrees)	Shed closing time (degrees)
1	500	4	2.5	26	280

As it is stated in the Table 3, throughout the experiment cotton yarn of 20’s has been used with the same size concentration (%age), moisture content (%age), size viscosity (seconds) and size pick-up (%age) with the use of maize starch as a sizing ingredient. Keeping the stated parameters, the same, mechanical yarn stretch (%) has been varied for experimentation. So in this research, the effect of stretch on warp yarn breakage (warp cmpx) in picanol air-jet looms of same weaver group has been assed. Here, all the 4 weavers’ beams have been loaded on 4 Picanol air-jet looms operated by same weaver-group and all the looms were running at 500 RPM having same loom settings as it is stated in the above table (Table 4) &with a loom shed condition of (R.H of 60% and temperature of 240c).

3. RESULTS AND DISCUSSIONS

A single factor experiment with a= 4 levels of the factor and n = 10 replicates, i.e. 40 runs of experimentation are conducted. The selection of treatment levels is made randomly, and in Table 5 results are shown.

Table 5: Data showing observations vs. sources of variations

Stretch (%)	Observations (Warp cmpx)										Total, $y_{i..}$	Average, $\overline{y_{i..}}$
1	2.3	4.0	3.1	2.5	2.9	2.1	2.1	2.3	2.5	1.9	25.7	2.57
1.34	3.2	3.5	2.4	4.1	3.6	3.9	4.5	3.8	3.5	4.2	36.7	3.67
1.62	5.6	7.2	4.5	5.2	5.4	6.0	5.6	7.4	7.8	8.0	62.7	6.27
5	25.1	25.2	8.5	12.9	15.6	16.2	16.7	17.8	15.5	19.0	172.5	17.25
											297.6	7.44

Total, $y_{i..}$ = 25.7+36.7+62.7+172.5
= **297.6**
Average, $\overline{y_{i..}}$ = (2.57+3.67+6.27+17.25)/4
= **7.44**

Analysis of sum of squares

$SS_T = 2.3^2+4.0^2+\ldots\ldots+19^2 - 297.6^2/40$

= 1606.296………………………... (1)

$SS_{Treatments} = 1/10\,[25.7^2+,..+172.5^2]-297.6^2/40$

= 1355.348…………………(2)

$SS_{Error} = SS_T - SS_{Treatments}$………………. (3)

= 1606.296-1355.348 = 250.948

Analysis of degree of freedom (DF)

Table 6 Analysis of degree of freedom (DF)

	DF
Between treatments	a-1, 4-1=3
Error (within treatments)	N-a, 40-4=36
Total	N-1, 40-1=39

Analysis of mean squares

$MS_{Treatments} = SS_{Treatments}/a-1$……………… (4)

= 1355.348/3= 451.7827

$MS_{Error} = SS_{Error}/N-a$………………………(5)

= 250.948/36= 6.9708

$F_o = MS_{Treatments}/MS_{Error}$…………………. (6)

= 451.7827/6.9708= **64.81**

Suppose we select $\alpha = 0.05$, the probability of reaching the correct decision on any single comparison is 0.95 (Klaus and Oscar, 2008). Now we compare F_o with the distribution table at $\alpha = 0.05$ significance level. We get $F_{0.05,\,3,\,36}$= 2.87

F_o= 64.81>2.87, so we reject H_o (null hypothesis), which tells: $\mu_1=\mu_2=\ldots\mu_a$ and accept H_1, which tells $\mu_i \neq \mu_j$ for at least one pair and conclude that the treatment means differ; that is mechanical yarn stretch % in sizing process significantly affects the warp yarn breakages (warp cmpx) in looms. Since it is known that the process parameter significantly affects the warp cmpx, process optimization and regression model development is needed.

Table 7: ANOVA for warp yarn breakage (warp cmpx) experiment

Source of variation	Sum of squares	Degrees of freedom	Mean square	F_o
Mechanical yarn stretch %	1355.348	3	451.782	
Error	250.948	36	6.971	64.81
Total	1606.296	39		

Comparisons among treatment means

In this study for comparing the pairs of treatment means that differ, a multiple comparison method is used (Robert et al., 2003).

Contrasts

So in this paper by using the idea of contrast method, multiple comparisons between treatment means are made and discussed in detail. In this article it is seen that the four different levels of mechanical yarn stretch %age produces different results of warp yarn breakages (warp cmpx). But still which treatment level is actually causing the difference has to be known. In this study it is suspected that the average treatment mean found with the first treatment level (warp yarn stretch %age of 1) and second treatment level (warp yarn stretch %age of 1.34) seems to produce the same warp yarn breakage (warp cmpx). To be sure about that hypothesis testing is conducted and discussed in detail (George, 2008).

H_o: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$ or equivalently,
H_o: $\mu_1 - \mu_2 = 0$
H_1: $\mu_1 - \mu_2 \neq 0$

From the experimental results it is clearly shown that the average results for warp yarn breakages (cmpx) found by lowest levels of mechanical yarn stretch %age, i.e. 2.57 differs from the average results for warp yarn breakages (cmpx) found by highest levels of mechanical yarn stretch %age, i.e. 17.25. So no need of testing the below stated hypothesis:
H_o: $\mu_1 + \mu_2 = \mu_3 + \mu_4$
H_1: $\mu_1 + \mu_2 \neq \mu_3 + \mu_4$ or equivalently,

H_o: $\mu_1 + \mu_2 - \mu_3 - \mu_4 = 0$
H_1: $\mu_1 + \mu_2 - \mu_3 - \mu_4 \neq 0$

So now we can have the contrast as a linear combination of parameters with the form:
$C = \sum_{i=1}^{a} c\, i\mu i$

Where the constants for contrast sum to zero, so now the first hypothesis can be expressed in terms of contrasts as:
H_o: $\sum_{i=1}^{a} c\, i\mu i = 0$
H_1: $\sum_{i=1}^{a} c\, i\mu i \neq 0$

Since the first hypothesis is followed, the contrast constants are: $c_3 = c_4 = 0$, $c_1 = +1$ and $c_2 = -1$

By using the below described two basic ways, now testing of the hypothesis can be made. First approach: by following t-test.

We write the contrast in terms of the treatment averages as: $C = \sum_{i=1}^{a} c\, i$yi.

$$t_o = \frac{\sum_{i=1}^{a} c\, i\text{yi.}}{\sqrt{MS_E/n \sum_{i=1}^{a} c\, i^2}} \quad \ldots\ldots(7)$$
where n=10

1*2.57+(-1*3.67) +0*6.27+0*17.25
$= -1.1/\sqrt{(0.697 * 2)} = -0.93$

The null hypothesis would be rejected if $|t_o|$ exceeds $t_{\alpha/2, N-a}$.

$t_{0.025,36} = 2.028$

So here $|t_0| = 0.93$, which is lower than 2.028, the second approach uses an F test. For this, the F_0 value is computed as below:

$$t_o = \frac{\sum_{i=1}^{a} c\, i\text{yi.}}{\sqrt{MS_E/n \sum_{i=1}^{a} c\, i^2}} \quad \ldots\ldots(7)$$
where n=10

Here the null hypothesis would be rejected if $F_0 > F_{\alpha, 1, N-a}$, so $F_0 = (-0.93)^2 = 0.865$ and

$F_{0.05,1,36} = 4.11$

So in both methods, the tests show null hypothesis is accepted. So the treatment means between the first treatment level (warp yarn stretch %age of 1) & the second treatment level (warp yarn stretch %age of 1.34) is not significantly different. It is also suspected that the average treatment mean found with the second treatment level (warp yarn stretch %age of 1.34) and third treatment level (warp yarn stretch %age of 1.62) seems to produce the same warp yarn breakage (warp cmpx). To be sure about that hypothesis testing is conducted and discussed in detail:

H_o: $\mu_2 = \mu_3$

H_1: $\mu_2 \neq \mu_3$ or equivalently,

H_o: $\mu_2 - \mu_3 = 0$

H_1: $\mu_2 - \mu_3 \neq 0$

So now we can have the contrast as a linear combination of parameters with the form:

$C = \sum_{i=1}^{a} c_i \mu_i$

Where the constants for contrast sum to zero, so now the hypothesis can be expressed in terms of contrasts as:

$H_o: \sum_{i=1}^{a} c_i \mu_i = 0$

$H_1: \sum_{i=1}^{a} c_i \mu_i \neq 0$

The contrast constants are: $c_1 = c_4 = 0$, $c_2 = +1$ and $c_3 = -1$

By using the below described two basic ways, now testing of the hypothesis can be made. First approach: by following t-test. We write the contrast in terms of the treatment averages as:

$C = \sum_{i=1}^{a} c_i y_{i.}$

$$t_o = \frac{\sum_{i=1}^{a} c_i y_i}{\sqrt{MS_E/n \sum_{i=1}^{a} c_i^2}}$$

0*2.57+1*3.67 + (-1*6.27) + 0*17.25

$= -2.6/\sqrt{(0.697 * 2)} = -2.2$

The null hypothesis would be rejected if $|t_o|$ exceeds $t_{\alpha/2, N-a}$.

$t_{0.025,36} = 2.028$

So here $|t_0| = 2.2$, which exceeds 2.028,

The second approach uses an F test. For this, the F_0 value is computed as below:

$$F_0 = t_0^2 = \frac{(\sum_{i=1}^{a} c_i y_{i.})^2}{MS_E/n \sum_{i=1}^{a} c_i^2} \quad \text{…………(8)}$$

Here the null hypothesis would be rejected if $F_0 > F_{\alpha, 1, N-a}$

So $F_0 = (-2.2)^2 = 4.84$ and $F_{0.05,1,36} = 4.11$

So in both methods, the tests show null hypothesis is rejected. So the treatment means between the second treatment level (warp yarn stretch %age of 1.34) & the third treatment level (warp yarn stretch %age of 1.62) is significantly different. It is also suspected that the average treatment mean found with the third treatment level (warp yarn stretch %age of 1.62) and fourth treatment level (warp yarn stretch %age of 5) seems to produce the same warp yarn breakage (warp cmpx). To be sure about that, hypothesis testing is conducted and discussed in detail:

H_o: $\mu_3 = \mu_4$

H_1: $\mu_3 \neq \mu_4$ or equivalently,

H_o: $\mu_3 - \mu_4 = 0$

H_1: $\mu_3 - \mu_4 \neq 0$

So now we can have the contrast as a linear combination of parameters with the form:

$C = \sum_{i=1}^{a} c_i \mu_i$

Where the constants for contrast sum to zero, so now the hypothesis can be expressed in terms of contrasts as:

$H_o: \sum_{i=1}^{a} c_i \mu_i = 0$

$H_1: \sum_{i=1}^{a} c_i \mu_i \neq 0$

The contrast constants are: $c_1 = c_2 = 0$, $c_3 = +1$ and $c_4 = -1$

By using the below described two basic ways, now testing of the hypothesis can be made.

First approach: by following t-test.

We write the contrast in terms of the treatment averages as: $C = \sum_{i=1}^{a} c_i y_{i.}$

$$t_o = \frac{\sum_{i=1}^{a} c_i y_i}{\sqrt{MS_E/n \sum_{i=1}^{a} c_i^2}}$$

0*2.57+0*3.67 + 1*6.27 + (-1*17.25)

$= -10.98/\sqrt{(0.697 * 2)} = -9.299$

The null hypothesis would be rejected if $|t_o|$ exceeds $t_{\alpha/2, N-a}$.

$t_{0.025,36} = 2.028$

So here $|t_0| = 9.299$, which exceeds 2.028,

The second approach uses an F test. For this, the F_0 value is computed as below:

$$F_0 = t_0^2 = \frac{(\sum_{i=1}^{a} c_i y_{i.})^2}{MS_E/n \sum_{i=1}^{a} c_i^2}$$

Here the null hypothesis would be rejected if $F_0 > F_{\alpha, 1, N-a}$

So $F_0 = (-9.299)^2 = 86.47$ and $F_{0.05,1,36} = 4.11$

So in both methods, the tests show null hypothesis has to be rejected. So the treatment means between the third treatment level (warp yarn stretch %age of 1.62) & the fourth treatment level (warp yarn stretch %age of 5) is significantly different.

Process optimization and linear regression model development (Gandhi, 2012)**.**

The empirical model/development of linear regression model helps for process optimization, hence for finding the levels of the warp yarn stretch (%age) that result in the best values of the warp yarn breakage (warp cmpx). Percentage (%) in sizing and warp. yarn breakage (warp cmpx) in looms is computed as (Max, 2011).

$$y = \beta_o + \beta_1 X_1 + € \ldots\ldots\ldots\ldots (9)$$

$$\beta = (X'X)^{-1} X'y \ldots\ldots\ldots\ldots\ldots (10)$$

So from the data achieved based on the experimentation done, we have:

X=	**1**	**1**	**y=**	**2.57**	**X'= 1 1 1 1**
	1	**1.34**		3.67	1 1.34 1.62 5
	1	**1.62**		6.27	
	1	**5**		17.25	

X'X = 1*1+1*1+1*1+1*1

$(X'X)^{-1}$= 1/ [(4*30.42) -(8.96)^2] * 30.42 -8.96 / -8.96 4 = 0.73 -0.215 / -0.215 0.096

=4, 1*1+1*1.34+1*1.62+1*5
=8.96
= 1*1+1.34^2+1.62^2+5^2= 30.42

X'y = X'X = 4 8.96 / 8.96 30.42 X'y = 29.76 / 103.89

1*2.57+1*3.67+1*6.27+1*17.25
= 29.76
=1*2.57+1.34*3.67+1.62*6.27+5*17.25
= 103.89

$\beta = (X'X)^{-1}X'y \ldots\ldots\ldots\ldots\ldots (10)$

Now we can compute $\beta = (X'X)^{-1}X'y$ as:

β_o= (0.73*29.76) + (-0.215*103.89)
= **-0.6126**

β_1= (-0.215*29.76) + (0.096*103.89) = **3.5755**

So the linear regression model showing the relationship between mechanical yarn stretch percentage (%) in sizing and warp yarn breakage (warp cmpx) in looms is computed as (Max, 2011).:

$$y = \beta_o + \beta_1 X_1 + € \ldots\ldots\ldots\ldots\ldots (9)$$

$$\mathbf{y = -0.6126 + 3.5755X_1}$$

Where y, is warp yarn breakage (warp cmpx), X_1, is mechanical yarn stretch (%) in sizing,

So based on the regression model that has been developed earlier, calculation of predicted value has been made (Table 8) showing the results.

Table 8: Results for calculated predicted value

Stretch (%)	Observations (Warp cmpx)										Predicted value
1	2.3	4	3.1	2.5	2.9	2.1	2.1	2.3	2.5	1.9	2.9628
1.34	3.2	3.5	2.4	4.1	3.6	3.9	4.5	3.8	3.5	4.2	4.17847
1.62	5.6	7.2	4.5	5.2	5.4	6	5.6	7.4	7.8	8	5.17961
5	25.1	25.2	8.5	12.9	15.6	16.2	16.7	17.8	15.5	19	17.2648

Table 9: Results for Residual value

Stretch (%)	Residual value = observed value-predicted value									
1	-0.6628	1.0372	0.1372	-0.4628	-0.0628	-0.8628	-0.8628	-0.6628	-0.4628	-1.0628
1.34	-0.97847	-0.67847	-1.77847	-0.07847	-0.57847	-0.27847	0.32153	-0.37847	-0.67847	0.02153
1.62	0.42039	2.02039	-0.67961	0.02039	0.22039	0.82039	0.42039	2.22039	2.62039	2.82039
5	7.8352	7.9352	-8.7648	-4.3648	-1.6648	-1.0648	-0.5648	0.5352	-1.7648	1.7352

Analysis of predicted versus Actual value

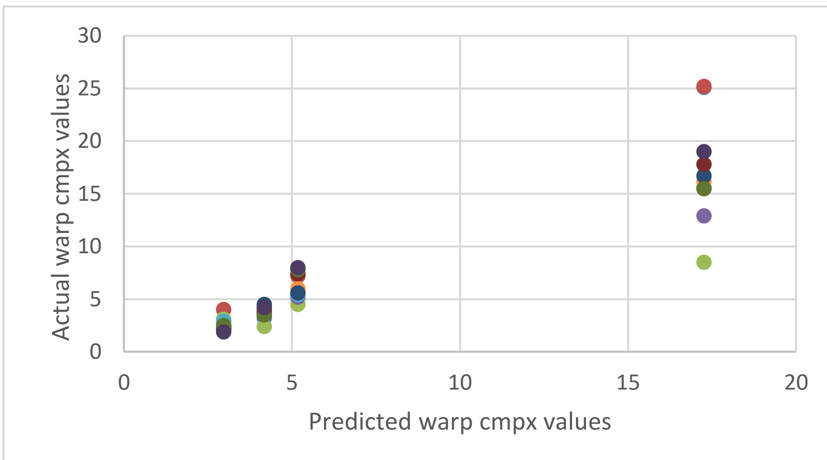

Figure 1: Plot for Predicted versus Actual warp cmpx value

Computation of R^2

$R^2 = SS_{Treatments}/SS_T$………. …………. (11)

$=1355.348/1606.296$

$=0.844$, 84.4%

Thus, in this experiment, the factor 'mechanical yarn stretch' explains about 84.4 percent of the variability in warp yarn breakage (warp cmpx). From the result of correlation, the variance of the predicted value explains the variance of observed/actual value to an extent of about 84.4%.

Analysis of predicted versus residual value

So from the two plots, it is seen that the differences between the observed warp yarn stretch and the predicted warp yarn stretch values are small and unbiased, i.e. anywhere in the observation axis, the predicted values are not shown to be systematically too high/too low. This shows us the developed linear regression model fits the data well. Additionally, from the figure below (Figure 2), the residual does not follow any obvious pattern, i.e. it is structure less& the residuals are randomly scattered around zero. Because of this, we can tell that the developed linear regression model is adequate and fitting.

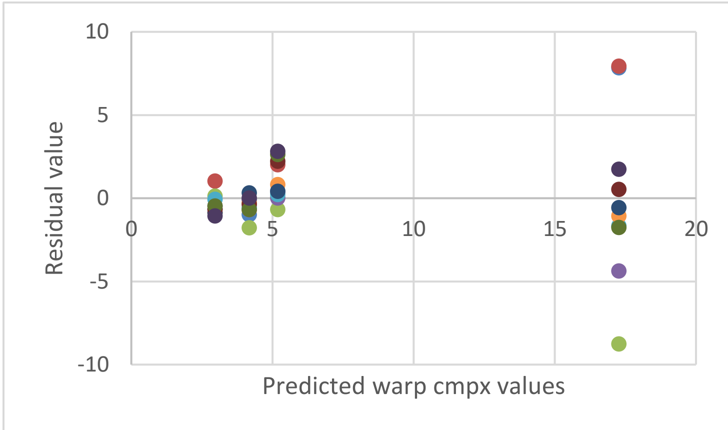

Figure 2: Plot for Predicted versus Residual value

4. CONCLUSIONS

The experiment is done in Bahir Dar textile sh. Company weaving mill with the use of cotton yarn having 20's with same size pick-up, concentration, viscosity and moisture content percentages is used for assessing the effects of different level of treatments of mechanical yarn stretch percentages on warp yarn breakages (warp cmpx) in Picanol air-jet looms of same weaver group having same loom settings and running at the speed of 500 RPM. Using a single factor experiment of 4 levels of the mechanical yarn stretch percentage and 10 replicates, i.e. 40 runs has been made for computing ANOVA analysis.With the use of 0.05 significance level (α=0.05), it is proved that mechanical yarn stretch (%) significantly affects the warp yarn breakage (cmpx) and for comparing pairs of treatment means that significantly differs, a multiple comparison method with contrasts has been made. besides treatment means between the first and second level of treatments, the other pairs of treatment means are significantly different. Since this is the case, process optimization and linear regression model development has been conducted. Based on the model, calculations of predicted values and correlation coefficient (R^2) is computed to be 84.4%. a plot for predicted versus residual value has also been made showing that the developed linear regression model is adequate and fitting.

5. REFERENCES

Bhuvenesh C. Goswami, R.D. and Anandjiwala, D.M.H. (2004). Textile Sizing. Marcel Dekker, New York, USA.

Gandhi, K.L. (2012). Woven Textiles Principles, Developments and Applications. Woodhead publishing series in Textiles.

George, C. (2008). Statistical Design. Springer Science+Business Media, LLC.

Klaus, H. and Oscar, K. (2008). Design and Analysis of Experiments: Introduction to Experimental Design. John Wiley & Sons, New Jersey, USA.

Max, D.M. (2011). Design of Experiments: An Introduction based on Linear Models. Taylor and Francis Group, LLC.

Montgomery, D.C. (2012). Design and Analysis of Experiments. John Wiley & Sons, New Jersey, USA.

Robert, L.M., Richard, F.G.and James, L.H. (2003). Statistical Design and Analysis of Experiments: With Applications to Engineering and Science. John Wiley & Sons,New Jersey, USA.