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Experimental Investigation and Mathematical Modelling of Tensile Strength for Single Step Fixation process of Reactive Printing and Crease Resistance Finishing of Cotton Fabric using DOE

Fareha Asim, Muzzaffar Mahmood

Abstract— **Statistical design of experiment (DOE) is an important tool for improvement and development of existing products or processes. This paper investigates the effect on tensile strength of cotton fabric for single step fixation of reactive printing and crease resistance finishing using DOE. The effects of dye concentration, concentration of crease resistant, fixation method and fixation temperature on the tensile strength of cotton fabric were investigated using software Design Expert 8.0. The results showed that tensile strength significantly improved using Econtrol method of fixation at 135°C. The statistical and graphical analysis of the significant factors showed the curvature effect of influential factor on the tensile strength of single step fixation process of reactive printing and crease resistance finishing of cotton fabric. The fitted regression equation of tensile strength modelled the relationship of significant factors on the single step fixation process. It has been observed that predicted values are in good agreement with the experimental data, the correlation coefficient was found to be 0.9497.**

***Index Terms*— ANOVA, crease resistance finishing, DOE, tensile strength, reactive printing.**

I. Introduction

Design of experiment [1-6] is an important tool used to analyze and improve the existing process as well as for the development of new process. A number of theoretical and experimental studies exist providing detailed information about the effect of process parameters and operating conditions of reactive printing and crease resistance finishing [7-14]. Furthermore, Reports in literature reveal that single step fixation for reactive printing and crease resistance finishing of cotton fabric has been explored earlier [15]. This paper investigates effects on tensile strength for single step fixation of reactive printing and crease resistance finishing of cotton fabric. The mathematical model for tensile strength has been developed to depict the relationship of different factors being studied. The detailed analysis of tensile strength of cotton fabric including ANOVA, residual analysis, model adequacy checking and regression analysis has been performed. The experiments have been conducted in random order. The results were analyzed using software Design Expert 8.0. The uncertainty analyses for tensile strength shows that the predicted values are in good agreement with experimental data and are sufficiently accurate.

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Fareha Asim, Textile Engineering Department, NED University of Engineering & Technology, Karachi, Pakistan, 92-21-99261261.

Muzzaffar Mahmood, Mechatronics Engineering, PAF-KIET, Karachi Institute of Economics & Technology, Pakistan.

II. EXPERIMENTAL

A. Fabric

Commercially singed, desized, scoured, bleached and mercerized cotton fabric with gsm of 136 g/m^2 and construction of 40x40 s, 130 ends/inch x 73 picks/inch is being used for this work.

B. Chemical and Colorants

The Crease resistance finishing liquor was prepared by adding Magnesium chloride ($MgCl_2$) 30 g/l , Silicon softener 20 g/l, An ionic Softener 20 g/l and Wetting Agent 1 g/l. The Crease resistant finishing agent used was modified dimethylol dihydroxy ethylene urea. The final finish bath was prepared with different concentrations of crease resistant as outlined in Table I.

A commercially available thickener sodium alginate 30g/kg, sodium bicarbonate 30 g/kg, urea 200 g/kg, reduction inhibitor 10 g/kg and sodium hexametaphosphate 5 gm/kg was added to prepare the stock paste for printing. However, stock paste manufactured for the experiments conducted using the Econtrol method of fixation is free from urea. The print paste was prepared by adding various chroma values of MCT reactive dye as mentioned in Table I.

Table I: Factors and respective levels used in $2^1.3^3$ mixed factorial design

Factor Name		Levels		
		-1	0	+1
A	Chroma	1(%)	2 (%)	3 (%)
B	Conc. Of Crease Resistant	100(g/l)	150 (g/l)	200(g/l)
C	Fixation Method	Curing		E-Control
D	Fixation Temperature	130 (°C)	140 (°C)	150 (°C)

C. *Method*

The single step fixation of reactive printing and crease resistance finishing is carried out as follows: In the first stage pre-treated fabric was padded with the crease resistance finishing liquor and squeezed to have a 70% wet pickup. The fabric was then dried at 100°C for 1 min. In the second stage dried fabric was printed by the lab scale Rotary Printing machine with the print paste. The finish-print fabric was fixed using different fixation methods as mentioned in Table I. The samples were finally washed.

D. *Evaluation of Tensile Strength*

The fabric strength properties were assessed by measuring the breaking load of fabric using the standard test procedure ASTM D 5035. Each value reported for breaking load is the mean of two samples tested, each having a coefficient of variance not more than +/- 5%.The samples processed with single step fixation were compared with those produced from a conventional two-step process of reactive printing and crease resistance finishing.

III. STATISTICAL ANALYSIS

After processing the experimental trials, tensile strength values were measured using Titan universal strength tester. The tensile strength values were statistically analyzed using software Design Expert 8.0. The Summary of ANOVA results of $2^1.3^3$ mixed factorial design is presented in Table II. The results obtained from the different runs are mentioned in Table III. The Model adequacy was evaluated using normal plot of residual, residuals v/s run, residuals v/s predicted and predicted v/s actual plots mentioned in Fig. 1, 2, 3 and 4 respectively. There is no severe indication of non-normality and the residuals are normally distributed and the equality of variance does not seem to be violated.

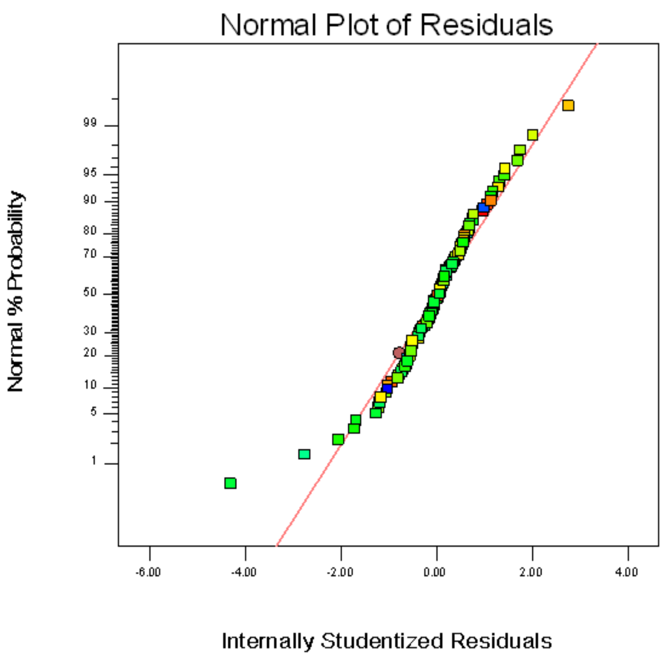

Fig. 1: Normal plot of residuals for tensile strength

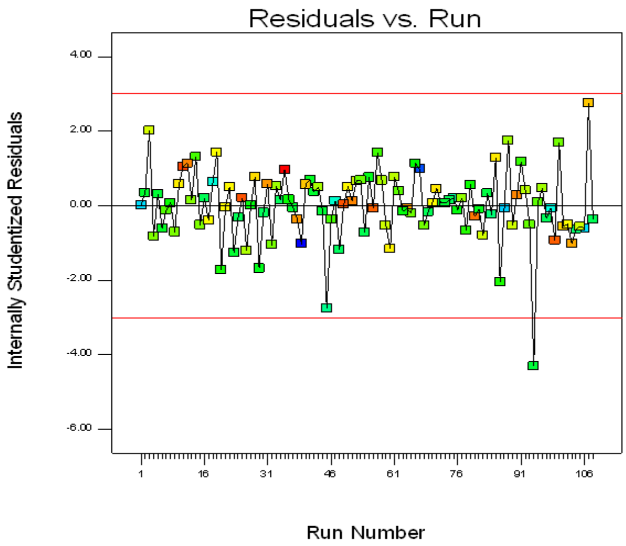

Fig. 2: Residual vs. run number for tensile strength

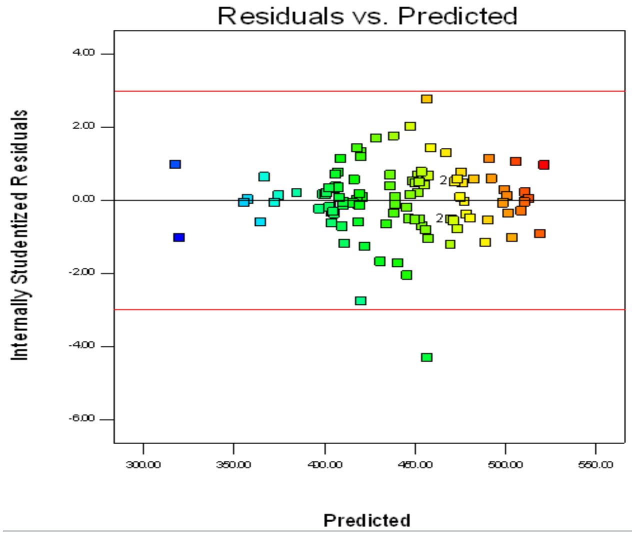

Fig. 3: Residual vs. predicted plot for tensile strength

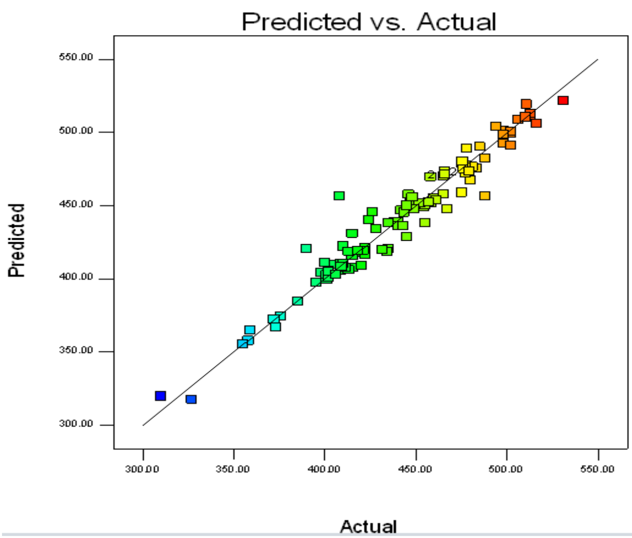

Fig. 4: Predicted vs. actual plot for tensile strength

IV. RESULTS AND DISCUSSION

A. *Analysis of variances (ANOVA)*

The Sixth model has been selected for the response variable tensile strength warp. The details of ANOVA of tensile strength warp are shown in Table III. The Model p-value less than 0.05 implies the model is significant. In this case interactions AC, AD, BC, BD, CD, are significant model terms.

The Lack of Fit p-value of 1.000 implies the Lack of Fit is not significant relative to the pure error. The Predicted R-Squared of 0.8354 is in reasonable agreement with the Adjusted R-Squared of 0.9012. Adequate Precision of 21.237 indicates an adequate signal. The graphs of significant model terms for tensile strength have been shown from Figure 5 to 10. The graphs of significant model terms illustrate that the tensile strength of the single step fixation process is dependent on the interaction and curvature effect of all the four potential design factors. The interaction plots shown in Fig. 5, 7 and 9 revealed that the Econtrol mode of fixation will give higher tensile strength values in the case of combined fixation of reactive printing and crease resistance finishing. The interaction plot of fixation mode and fixation temperature shown in Figure 9 illustrates that the Econtrol fixation method at 135-140 °C can be effectively used for the single step fixation process for getting higher values of tensile strength. The mathematical model of tensile strength has been shown in Equation 1.

B. *Model with significant variables t α = 0.05*

$$
\begin{aligned}
TensileStrength &= 433.6 - 1.86A + 3.92B - 13.40C \\
&+ 3.14D + 10.46AB - 0.25AC - 6.79AD - 12.65BC \\
&- 1.94BD + 2.57CD - 18.22A^2 + 4.72B^2 + 32.02D^2
\end{aligned}
\tag{1}
$$

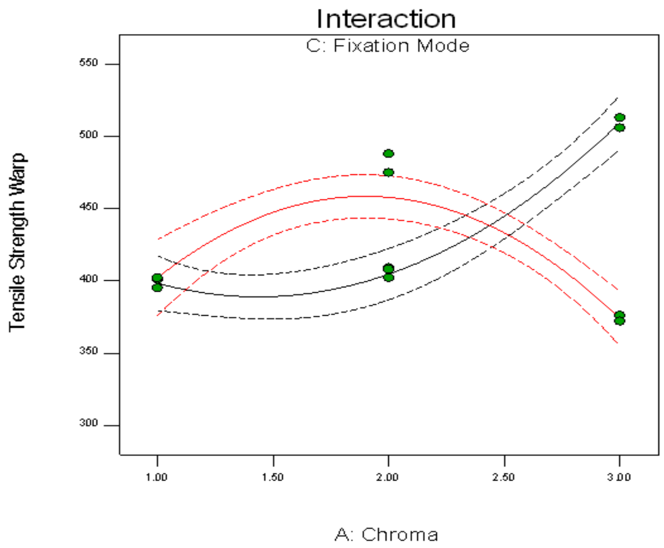

Fig. 5: Interaction plot of AC with respect to tensile strength warp

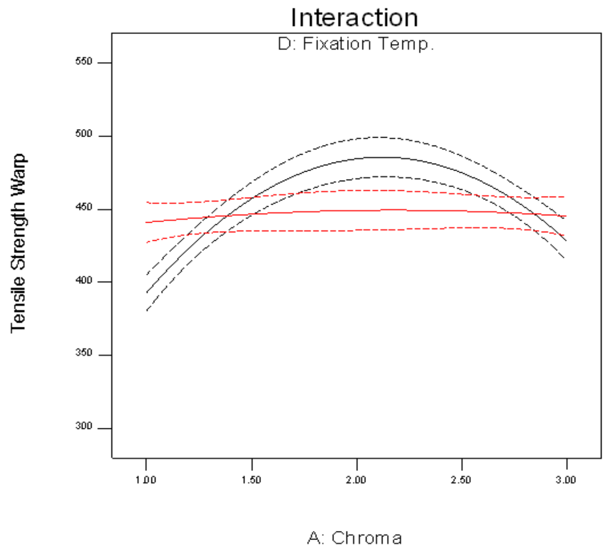

Fig. 6: Interaction plot of AD with respect to tensile strength warp

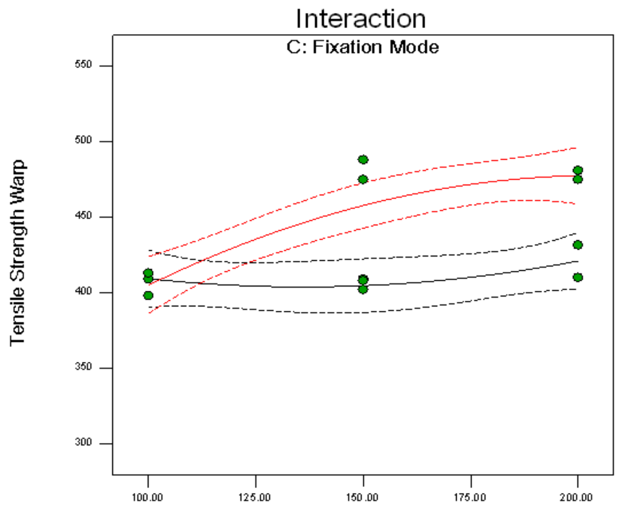

Fig. 7: Interaction plot of BC with respect to tensile strength warp

B: Conc. of CR

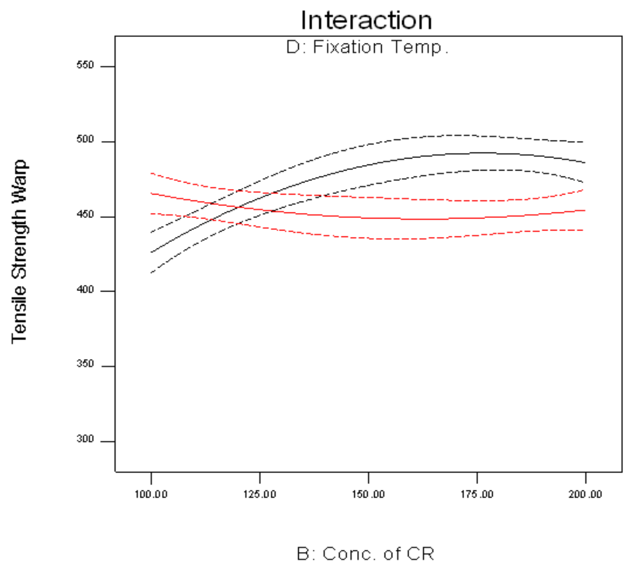

Fig. 8: Interaction plot of BD with respect to tensile strength warp

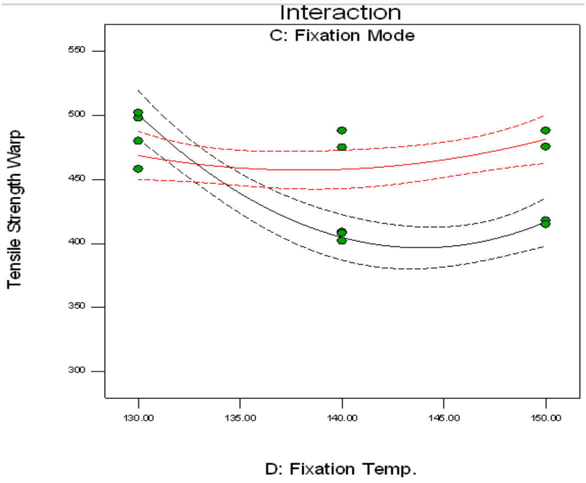

Fig. 9: Interaction plot of CD with respect to tensile strength warp

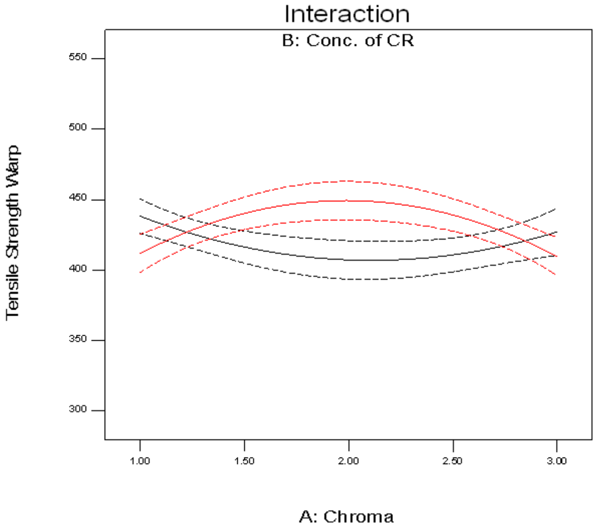

Fig. 10: Interaction plot of AB with respect to tensile strength warp

Table III: ANOVA for tensile strength warp of $2^1.3^3$ mixed factorial design

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value
Block	400.84	1	400.84		
Model	$1.878x10^5$	52	3610.94	19.59	< 0.0001
A-Chroma	2753.15	1	2753.15	14.94	0.0003
B-Concentration of CR	3549.03	1	3549.03	19.25	< 0.0001
C-Fixation Method	4485.48	1	4485.48	24.33	< 0.0001
D-Fixation Temperature	2502.78	1	2502.78	13.58	0.0005
AC	7893.38	1	7893.38	42.82	< 0.0001
AD	1019.01	1	1019.01	5.53	0.0224
BC	1845.28	1	1845.28	10.01	0.0026
BD	5041.00	1	5041.00	27.35	< 0.0001
CD	4632.03	1	4632.03	25.13	< 0.0001
Residual	9953.65	54	184.33		
Lack of Fit	5554.15	49	113.35	0.13	1.0000
Pure Error	4399.50	5	879.90		
Cor Total	$1.981x10^5$	107			
Std. Dev.	13.58	C.V%	3.09	PRESS	32541.04
R^2	0.9497	Adj R^2	0.9012	Pred R^2	0.8354

Table II: Summary of ANOVA results of $2^1.3^3$ mixed factorial design

Source	Sum of Squares	d.o.f	Mean Square	F value	p value	Remarks
Model	$1.878x10^5$	52	3610.94	19.59	< 0.0001	Significant
Residual	9953.65	54	184.33			
Lack of fit	5554.15	49	113.35	0.13	1.000	Not significant
Pure error	4399.50	5	879.90			
$R^2 = 0.9497$, $R^2_{adj} = 0.9012$; adequate precision = 21.237						

V. CONCLUSION

The statistical analysis of the influential factors revealed the quadratic effect of significant factor on the tensile strength of single step fixation process. Furthermore, the model had been tested for adequacy and found that the assumption of normality and independency are not violated. R^2 values were very high, suggesting that models accounted for most of the variability.

The fitted regression equations of tensile strength modeled the relationship of each factor on the tensile strength. The high values of coefficient of determination as indicated in Table II & III implied that the fitted model effectively predict the tensile strength of single step fixation process. It had been found that single step fixation process using an Econtrol method at 135-140°C for fixation provide more than twenty five percent (25%) enhancement in tensile strength properties as compared to traditional two-steps.

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AUTHOR PROFILE

Engr. Dr. Fareha Asim is an Associate Professor in Textile Engineering Department, NED University of Engineering & Technology, Pakistan. She obtained her doctorate degree in Textiles. Her areas of research include printing and finishing. She is a senior member of AATCC, NEDAN, PEC and corporate member of SDC. She has ten international journal publications. She also participated in various international conferences and presented research papers. She is the gold medalist of the batch during her B.E (Textile). She also won young researcher award

Engr. Dr. Muzzaffar Mahmood is HoD Mechatronics Engineering, PAF-KIET. He did PhD (AE), CIT, UK. His research interest is in Applied Energy, Power Generation and Applied Statistics, Mechanical Engineering