

Mathematical Modelling of Dry Crease Recover Angle for Single Step Fixation of Reactive Printing and Crease Resistance Finishing of Cotton Fabric Using DOE

Fareha Asim^{1,*}, Muzzaffar Mahmood²

¹Department of Textile Engineering, NED University of Engineering & Technology Karachi, Pakistan
²Department of Mechanical Engineering, NED University of Engineering & Technology Karachi, Pakistan

Abstract The study was carried out to develop the mathematical model of crease recovery angle for single step fixation process of cotton fabric for reactive printing and crease resistance finishing using design of experiment. Single step fixation process using Monochlorotriazine (MCT) based reactive dye and modified dimethyloldihydroxy ethylene urea (DMDHEU) based crease resistant was investigated to model the relationship of significant factors on the dry crease recovery angle. The effects of several factors governing the single step process, such as dye concentration, concentration of crease resistant, fixation method and temperature, on dry crease recovery angle were examined. Initially sets of screening experiments have been conducted to identify the significant factors and their interaction. Furthermore, the detailed analysis of significant factors including ANOVA, residual analysis, model adequacy checking and regression analysis has been performed. However, mathematical model have been developed as a function of significant factors namely concentration of crease resistant, fixation method and fixation temperature. The statistical analysis of the significant factors revealed the quadratic effect of each factor on the crease recovery angle in single step fixation process. The uncertainty analyses for measurements shows that the predicted values are in good agreement with experimental data and are sufficiently accurate.

Keywords Crease Resistance Finishing, Design of Experiment, Dry Crease Recovery Angle, Mathematical Modelling, Reactive Printing

1. Introduction

In Textile processes, it is often of primary interest to develop the relationships between the key process variables and the performance characteristics. Mathematical Modelling play an important role in developing, analysing and predicting the relationship from experiments with certain level of confidence [1-6]. When several variables influence a certain characteristic of a product, the best strategy is then to design an experiment (DOE) so that objective conclusions can be drawn rather than judgemental. In the context of DOE in Textile two types of process variables: qualitative and quantitative factors [7-12]. The aim of this work was to develop the mathematical model of crease recovery angle for single step fixation process of reactive printing and crease resistance finishing process. The significant factors for the single step fixation of reactive printing and crease resistance finishing process had been reviewed previously [13-16].

In the current study of single step fixation process of

reactive printing and crease resistance finishing chroma, concentration of crease resistant and fixation temperature are quantitative factors. However fixation method is the qualitative factor.

2. Experimental

2.1. Process Route

The single step fixation of reactive printing and crease resistance finishing is carried out as follows: Crease Resistant Finish-Dry-Reactive Print-Fix-Wash-Dry-Conditioned.

In the first step ready to print fabric was padded with the crease resistant finish liquor, and then squeezed to obtain a 70% wet pickup. The fabric was then dried at 100°C for 1 min. The dried fabric was printed by lab scale Rotary Printing machine. The finish-print fabric was concurrently fixed using Econtrol method at 135°C for 5 minutes. The fixed samples were finally washed, dried and conditioned.

2.2. Evaluation of Dry Crease Recovery Angle (DCRA)

The crease resistant properties were evaluated by measuring the dry crease recovery angles (DCRA). The print-finish fabrics were conditioned (at temperature 25±1°C

* Corresponding author:

fareha@neduet.edu.pk (Fareha Asim)

Published online at <http://journal.sapub.org/textile>

Copyright © 2013 Scientific & Academic Publishing. All Rights Reserved

and relative humidity $65 \pm 1\%$) before the measurement of DCRA values. The dry crease recovery angle (DCRA) of the fabric was measured using AATCC test method 66-1990. The wider the DCRA is, the higher the crease recovery. 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. The experiment data is shown in Table 1 and 2.

2.3. Statistical Analysis of the Data

After processing the experimental trials, DCR A values were measured using crease recovery tester. The results obtained from the different experimental sets are presented in Table 2. The DCR A values were statistically analysed.

Residual analysis and model adequacy checking were performed. The experiments have been conducted in random order. The results were analysed using software Design Expert 8.0.

2.4. Model Adequacy Checking

2.4.1. The Normality Assumption

The normal probability plot of the residual for dry crease recovery angles has been shown in Figure 1. There is no severe indication of non-normality, nor is there any evidence pointing to possible outliers and the equality of variance assumption does not seem to be violated.

Design-Expert® Software
DCRA Warp

Color points by value of
DCRA Warp:

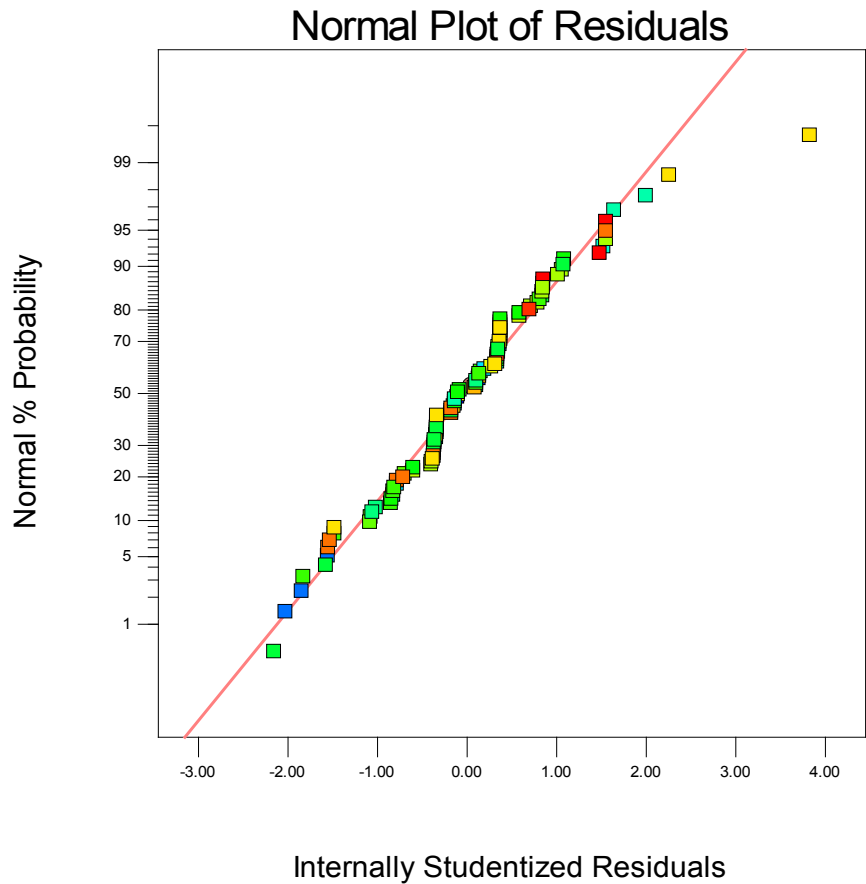


Figure 1. Normal plot of residuals for DCRA

2.4.2. Residual Analysis

Residual versus run number and residual versus predicted plots of dry crease recovery angle have been shown from Figure 2 and 3. The pattern of the residuals showed that they are normally distributed and the equality of variance does not seem to be violated.

Design-Expert® Software
DCRA Warp

Color points by value of
DCRA Warp:

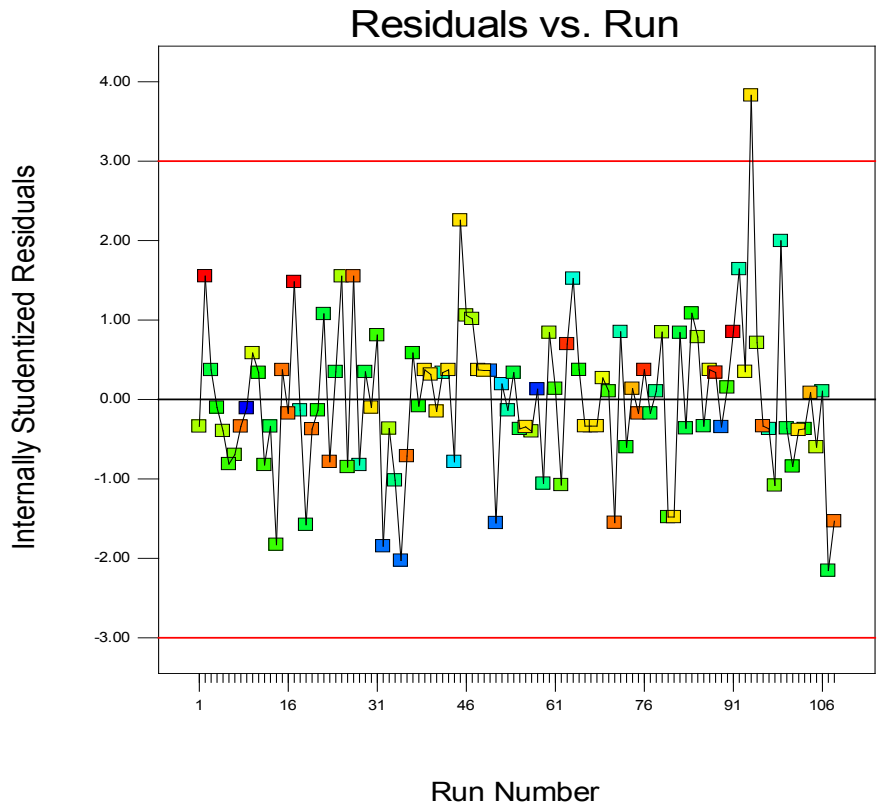


Figure 2. Residual vs. run number for DCRA

Design-Expert® Software
DCRA Warp

Color points by value of
DCRA Warp:

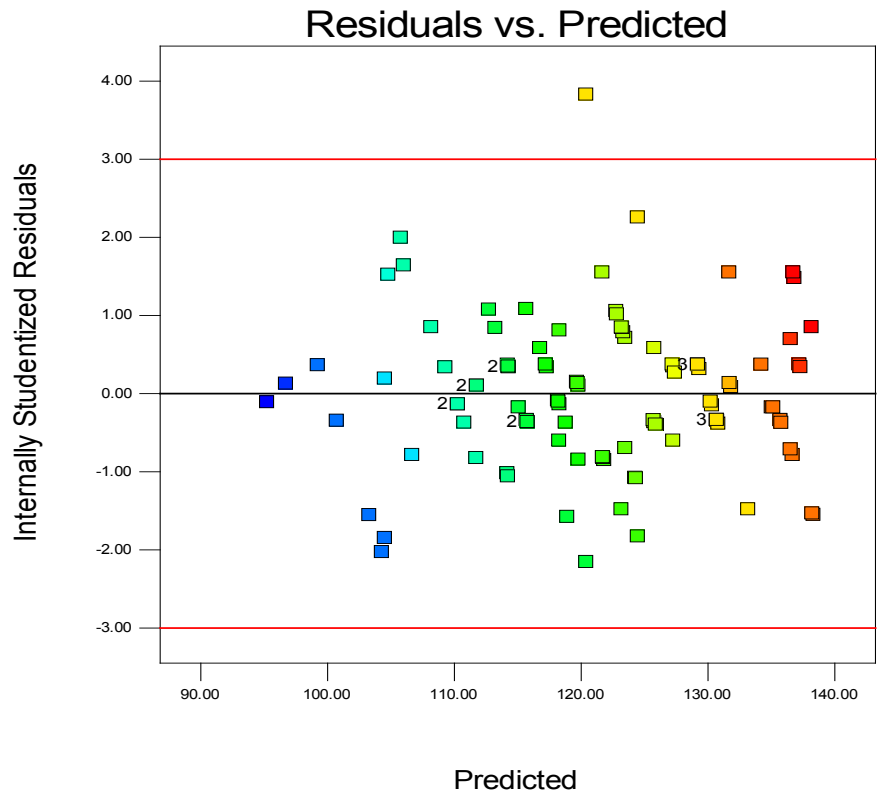


Figure 3. Residual vs. predicted plot for DCRA

Design-Expert® Software
DCRA Warp

Color points by value of
DCRA Warp:
140
95

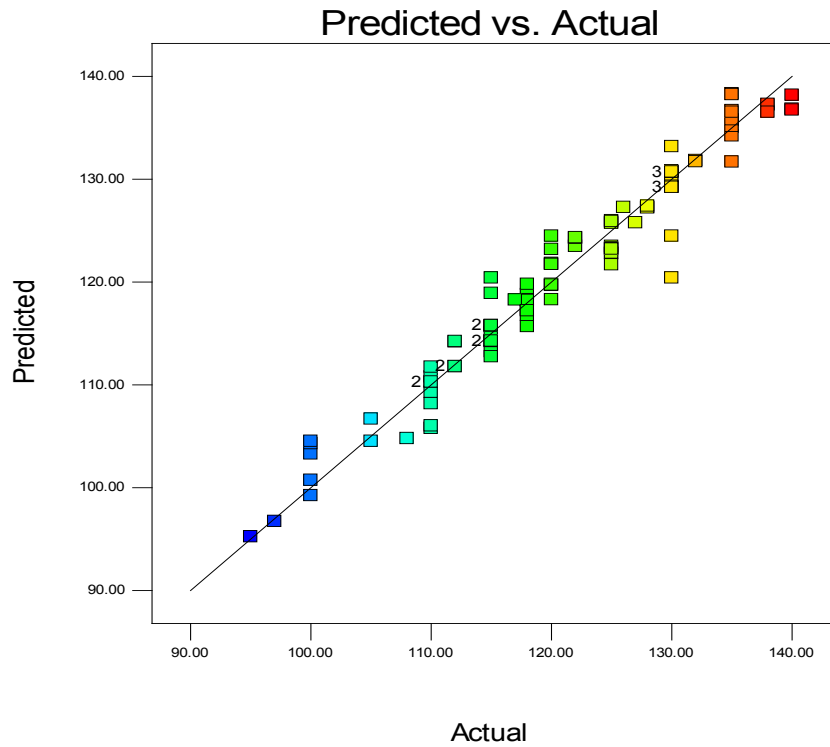


Figure 4. The predicted vs. actual plot for DCRA

2.5. Analysis of Variances (ANOVA)

Table 1 shows the summary of ANOVA results of dry crease recovery angle for single step fixation process of reactive printing and crease resistance finishing. The model p-value implied that the respective model is significant for dry crease recovery angle. As can be seen in Table 1,

The "Lack of Fit p-value" of 0.9998 implies the Lack of Fit is not significant relative to the pure error representing that the suggested models are well-fitted to the observed response. The "Pred R-Squared" of 0.8630 is in reasonable agreement with the "Adj R-Squared" of 0.9189 specifying the respective model is adequate.

The actual and predicted plot of dry crease recovery angle has been shown in Figure 4. The actual values are the measured response data for particular run and the predicted values are the results generated using the approximate functions. It is found that the adequate precision of

Dry crease recovery angle is found to be 20.27, which measured the signal to noise ratio is much greater than 4, (Table 1). This indicates the model is adequate to be used to navigate the design space. Focusing on the model maximizing the "Adjusted R-squared" and the "Predicted R-squared" different process order selection has been made for dry crease recovery angle. The alias structures of the dry crease recovery angle are shown in Table 3.

Table 1. Summary of ANOVA results of dry crease recovery angle (DCRA)

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value	Remarks
DCRA Warp (°): Sixth Model						
Model	11315.30	52	217.60	24.10	< 0.0001	Significant
Residual	487.53	54	9.03			
Lack of fit	303.53	49	6.19	0.17	0.9998	Not significant
Pure error	184.00	5	36.80			
$R^2 = 0.9587, \text{Pred } R^2 = 0.8630, R^2_{\text{adj}} = 0.9189; \text{Adequate Precision} = 20.279$						

Table 2. ANOVA for DCRA warp

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value
Block	164.03	1	164.03		
Model	11315.30	52	217.60	24.10	< 0.0001
B-Concentration of CR	666.13	1	666.13	73.78	< 0.0001
C-Fixation Method	77.68	1	77.68	8.60	0.0049
D-Fixation Temperature	220.50	1	220.50	24.42	< 0.0001
AC	134.84	1	134.84	14.94	0.0003
AD	522.58	1	522.58	57.88	< 0.0001
BC	276.13	1	276.13	30.58	< 0.0001
B ²	82.38	1	82.38	9.12	0.0038
ABC	70.95	1	70.95	7.86	0.0070
ABD	172.14	1	172.14	19.07	< 0.0001
ACD	106.84	1	106.84	11.83	0.0011
BCD	115.56	1	115.56	12.80	0.0007
A ² B	364.19	1	364.19	40.34	< 0.0001
A ² C	363.01	1	363.01	40.21	< 0.0001
A D ²	115.12	1	115.12	12.75	0.0008
B ² C	441.83	1	441.83	48.94	< 0.0001
B ² D	63.02	1	63.02	6.98	0.0108
BD ²	247.52	1	247.52	27.42	< 0.0001
CD ²	72.21	1	72.21	8.00	0.0066
ABCD	45.54	1	45.54	5.04	0.0288
A ² B ²	77.11	1	77.11	8.54	0.0051
A ² BC	54.91	1	54.91	6.08	0.0169
A ² BD	38.53	1	38.53	4.27	0.0437
A ² CD	56.08	1	56.08	6.21	0.0158
A ² D ²	78.96	1	78.96	8.75	0.0046
AB ² C	44.04	1	44.04	4.88	0.0315
AB ² D	91.18	1	91.18	10.10	0.0025
ACD ²	78.26	1	78.26	8.67	0.0048
B ² D ²	333.86	1	333.86	36.98	< 0.0001
BCD ²	475.02	1	475.02	52.61	< 0.0001
A ² B ² C	148.14	1	148.14	16.41	0.0002
A ² B ² D	62.04	1	62.04	6.87	0.0114
A ² BD ²	151.34	1	151.34	16.76	0.0001
A ² CD ²	108.69	1	108.69	12.04	0.0010
AB ² CD	181.16	1	181.16	20.07	< 0.0001
AB ² D ²	55.46	1	55.46	6.14	0.0163
ABCD ²	176.49	1	176.49	19.55	< 0.0001
B ² CD ²	125.14	1	125.14	13.86	0.0005
A ² B ² D ²	269.95	1	269.95	29.90	< 0.0001
A ² BCD ²	69.79	1	69.79	7.73	0.0075
AB ² CD ²	73.99	1	73.99	8.20	0.0060
Residual	487.53	54	9.03		
Lack of Fit	303.53	49	6.19	0.17	0.9998
Pure Error	184.00	5	36.80		
Cor Total	11966.85	107			
Std. Dev.	3.00	C.V%	2.47	PRESS	1616.45
R ²	0.9587	Adj R ²	0.9189	Pred R ²	0.8630

Table 3. Alias structures for DCRA

S.No.	Aliases
1.	$[A] = A^3 = A^5$
2.	$[B] = B^3 = B^5$
3.	$[D] = D^3 = D^5$
4.	$[AB] = A^3B = AB^3 = A^3B^3 = A^5B = AB^5$
5.	$[AC] = A^3C = A^5C$
6.	$[AD] = A^3D = AD^3 = A^3D^3 = A^5D = AD^5$
7.	$[BC] = B^3C = B^5C$
8.	$[BD] = B^3D = BD^3 = B^3D^3 = B^5D = BD^5$
9.	$[CD] = CD^3 = CD^5$
10.	$[A^2] = A^4 = A^6$
11.	$[B^2] = B^4 = B^6$
12.	$[D^2] = D^4 = D^6$
13.	$[AB^2] = A^3B^2 = AB^4$
14.	$[ABC] = A^3BC = AB^3C$
15.	$[ABD] = A^3BD = AB^3D = ABD^3$
16.	$[ACD] = A^3CD = ACD^3$
17.	$[AD^2] = A^3D^2 = AD^4$
18.	$[A^2B] = A^4B^3 = A^4B$
19.	$[A^2D] = A^4D^3 = A^4D$
20.	$[BCD] = B^3CD = BCD^3$
21.	$[BD^2] = B^3D^2 = BD^4$
22.	$[B^2D] = B^2D^3 = B^4D$
23.	$[A^2C] = A^4C$
24.	$[B^2C] = B^4C$
25.	$[CD^2] = CD^4$
26.	$[AB^2C] = A^3B^2C = AB^4C$
27.	$[AB^2D] = A^3B^2D = AB^2D^3 = AB^4D$
28.	$[ABCD] = A^3BCD = AB^3CD = ABCD^3$
29.	$[ABD^2] = A^3BD^2 = AB^3D^2 = ABD^4$
30.	$[ACD^2] = A^3CD^2 = ACD^4$
31.	$[A^2BC] = A^2B^3C = A^4BC$
32.	$[A^2BD] = A^2B^3D = A^2BD^3 = A^4BD$
33.	$[A^2CD] = A^2CD^3 = A^4CD$
34.	$[BCD^2] = B^3CD^2 = BCD^4$
35.	$[B^2CD] = B^2CD^3 = B^4CD$
36.	$[A^2B^2] = A^4B^2 = A^2B^4$
37.	$[A^2D^2] = A^4D^2 = A^2D^4$
38.	$[B^2D^2] = B^4D^2 = B^2D^4$

3. Results and Discussion

3.1. Analysis of Dry Crease Recovery Angle (DCRA)

The sixth order model has been selected for the response variable DCRA Warp. The detail of ANOVA of DCRA Warp is shown in Table 2. The Model p-value less than 0.05 implies the model is significant. In this case $B, C, D, AC, AD, BC, B^2, ABC, ABD, ACD, BCD, A^2B, A^2C, AD^2, B^2C, B^2D, BD^2, CD^2, ABCD, A^2B^2, A^2BC, A^2BD, A^2CD, A^2D^2, AB^2C, AB^2D, ACD^2, B^2D^2, BCD^2, A^2B^2C, A^2B^2D, A^2BD^2, A^2CD^2, AB^2CD, AB^2D^2, ABCD^2, B^2CD^2, A^2B^2D^2, A^2BCD^2, AB^2CD^2$ are significant model terms.

The graphs of significant model terms for DCRA have been shown from Figure 5 to 15. The graphs of significant model terms revealed that the dry crease recovery angle of the single step fixation process of reactive printing and crease resistance finishing is dependent on the interaction and curvature effect of concentration of crease resistant, fixation mode and fixation temperature. Figure 8 and 9 indicated that the Econtrol process supersedes the conventional curing process for fixation and gives a higher dry crease recovery angle in the single step fixation process. Figure 16 illustrates the interaction plot of fixation mode and fixation temperature. The graph clearly shown that the Econtrol process at 130°C gives a higher dry crease recovery angle in the CPF process. The reduced regression equation of dry crease recovery angle has been shown in Equation (1). Whereas, the fitted regression equation has been presented in Equation (2). The alias structures are shown in Table 3.

3.2. Mathematical Model with Significant Variables at $\alpha = 0.05$

$$DCRAWarp = 125.09 + 1.59A + 1.90B + 4.33C + 3.66D - 2.32AB - 1.97AC + 3.56AD + 0.62BC - 0.14BD - 4.12CD - 1.23A^2 - 0.67B^2 - 3.35D^2 \quad (1)$$

3.3. Fitted Regression Equation of DCRA

$$DCRAWarp = 123.15 - 0.83A + 9.12B - 3.49C + 5.25D - 0.82AB - 4.58AC + 5.60AD - 5.87BC - 1.44BD - 1.50CD + 0.68A^2 + 5.23B^2 + 2.85D^2 + 2.19ABC + 2.39ABD - 2.53ACD - 2.69BCD - 8.38A^2B + 8.65A^2C - 1.85A^2D + 0.90AB^2 + 4.99AD^2 + 9.44B^2C - 3.44B^2D + 3.82CD^2 + 1.24ABCD - 6.55A^2B^2 + 3.25A^2BC + 1.92A^2BD - 3.22A^2CD - 6.59A^2D^2 + 3.14AB^2C - 2.92AB^2D - 1.79ABD^2 + 4.11ACD^2 - 2.44B^2CD - 13.16B^2D^2 + 9.44BCD^2 - 5.26A^2B^2C + 4.17A^2B^2D + 1.01A^2BCD + 6.61A^2BD^2 - 4.54A^2CD^2 + 4.11AB^2CD - 4.20AB^2D^2 + 4.23ABCD^2 - 4.99B^2CD^2 + 2.45A^2B^2CD + 15.04A^2B^2D^2 - 4.49A^2BCD^2 - 4.84AB^2CD^2 \quad (2)$$

Design-Expert® Software
DCRA Warp

— CI Bands

X1 = B: Conc. of CR

Actual Factors

A: Chroma = 2.00

C: Fixation Mode = Average

D: Fixation Temp. = 140.00

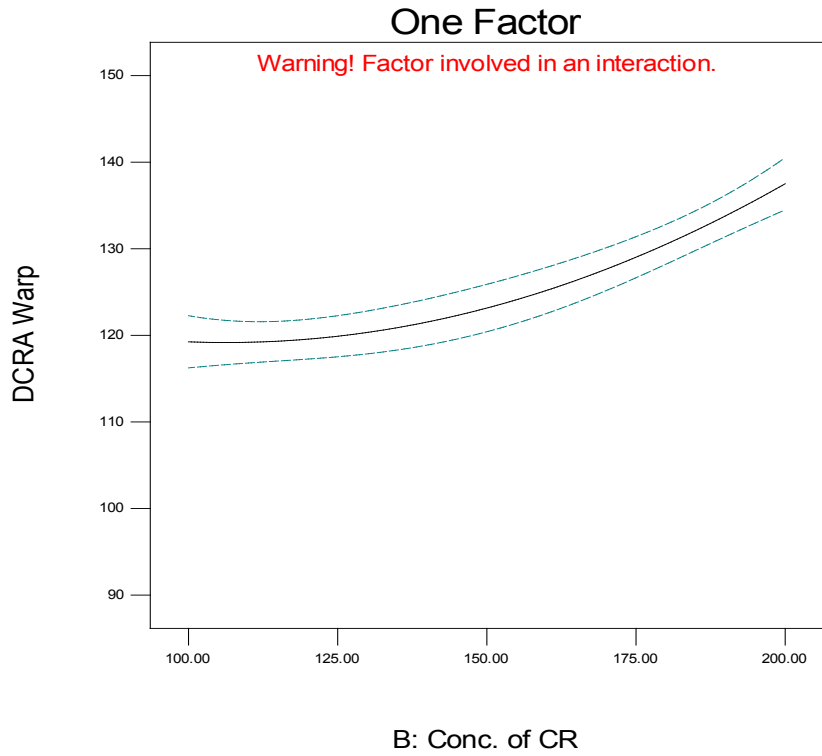


Figure 5. Effect of B on DCRA warp

Design-Expert® Software
DCRA Warp

● Design Points

X1 = C: Fixation Mode

Actual Factors

A: Chroma = 2.00

B: Conc. of CR = 150.00

D: Fixation Temp. = 140.00

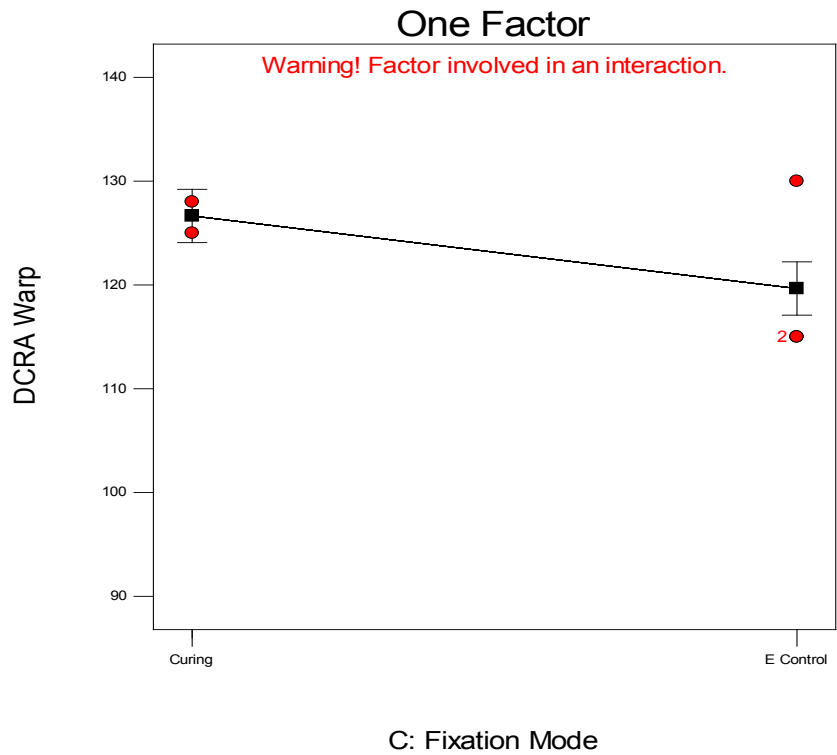


Figure 6. Effect of C on DCRA warp

Design-Expert® Software
 DCRA Warp

— CI Bands

X1 = D: Fixation Temp.

Actual Factors
 A: Chroma = 2.00
 B: Conc. of CR = 150.00
 C: Fixation Mode = Average

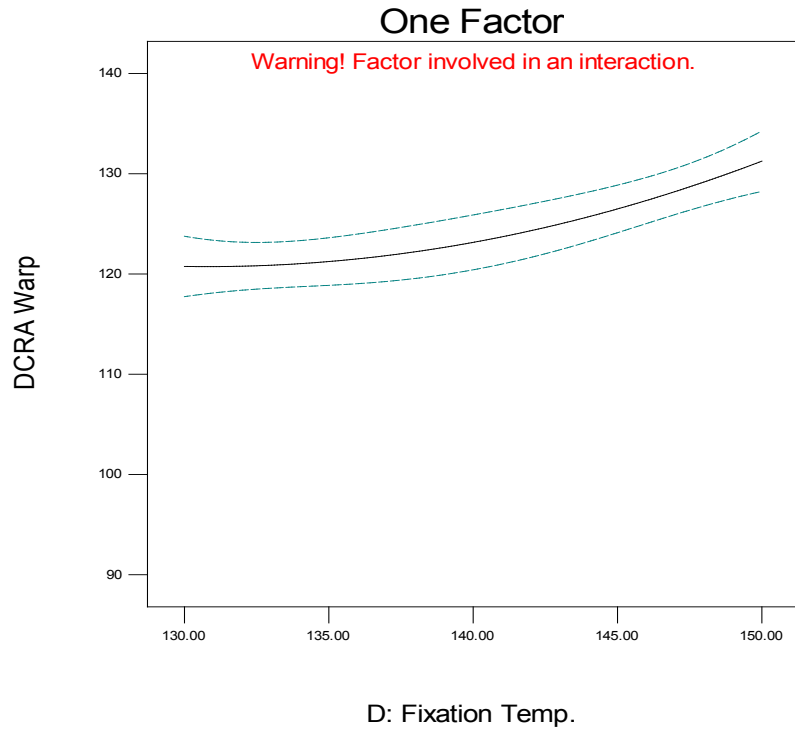


Figure 7. Effect of D on DCRA warp

Design-Expert® Software
 DCRA Warp

— CI Bands
 ● Design Points

X1 = A: Chroma
 X2 = C: Fixation Mode

Actual Factors
 B: Conc. of CR = 150.00
 D: Fixation Temp. = 140.00

■ C1 Curing
 ▲ C2 E Control

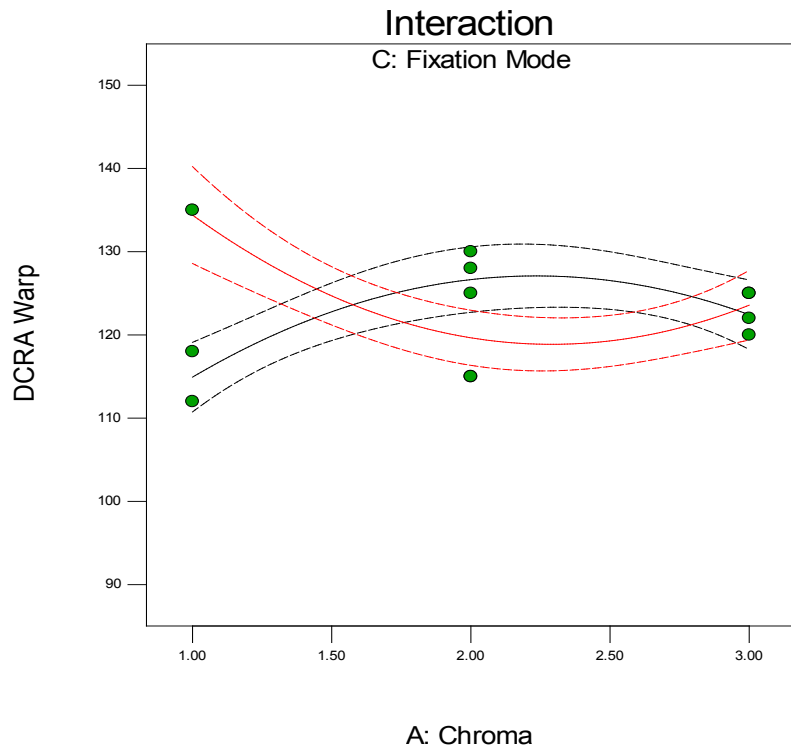


Figure 8. Interaction plot of AC with respect to DCRA warp

Design-Expert® Software
 DCRA Warp

— CI Bands
 ● Design Points

X1 = A: Chroma
 X2 = D: Fixation Temp.

Actual Factors
 B: Conc. of CR = 150.00
 C: Fixation Mode = E Control

■ D- 130.000
 ▲ D+ 150.000

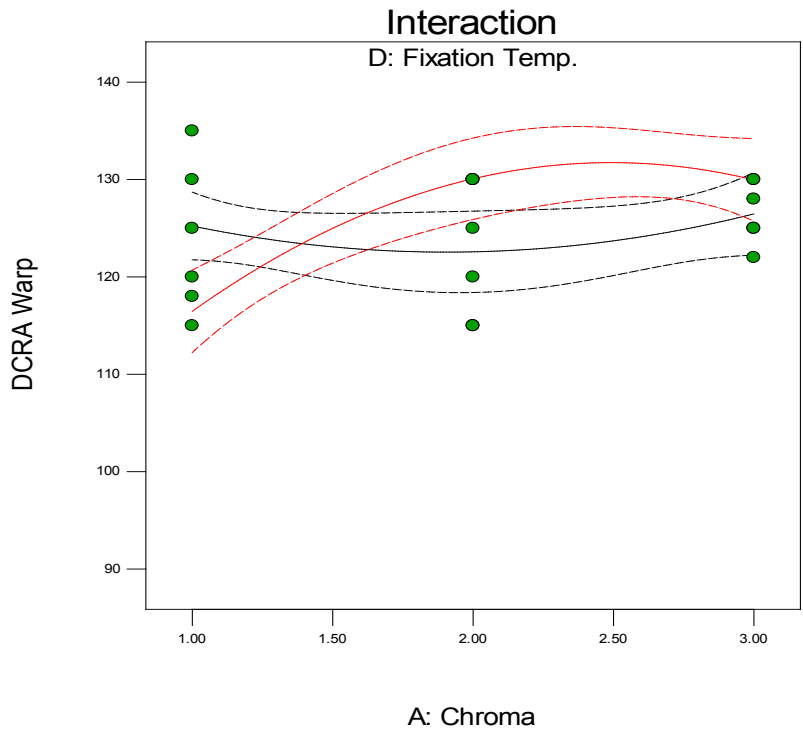


Figure 9. Interaction plot of AD with respect to DCRA warp

Design-Expert® Software
 DCRA Warp

● Design Points

140
 95

X1 = A: Chroma
 X2 = D: Fixation Temp.

Actual Factors
 B: Conc. of CR = 150.00
 C: Fixation Mode = E Control

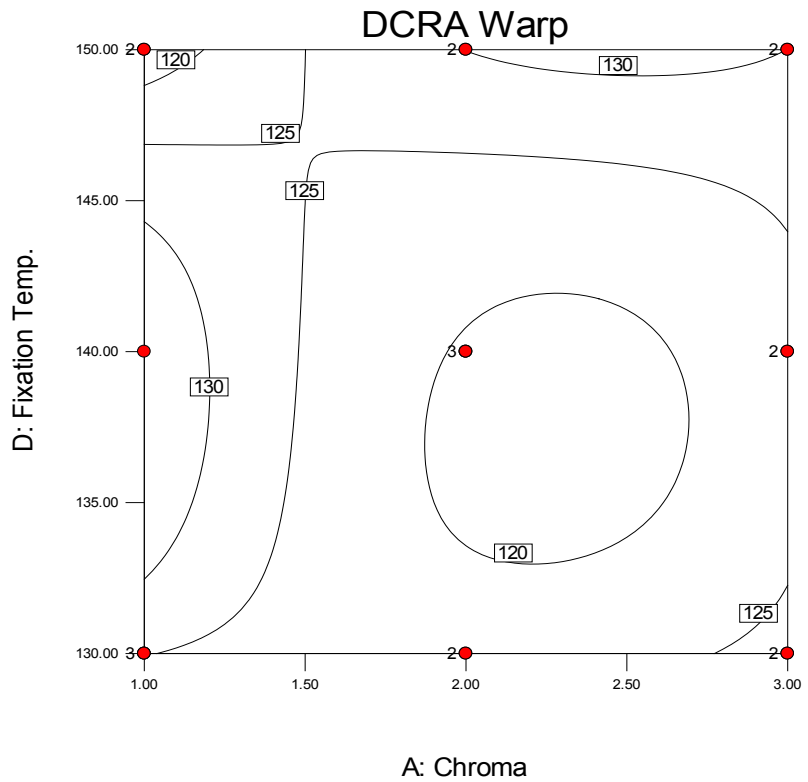


Figure 10. Contour plot representing DCRA warp versus chroma and fixation temperature

Design-Expert® Software
 DCRA Warp

— CI Bands
 ● Design Points

X1 = B: Conc. of CR
 X2 = C: Fixation Mode

Actual Factors
 A: Chroma = 2.00
 D: Fixation Temp. = 140.00

■ C1 Curing
 ▲ C2 E Control

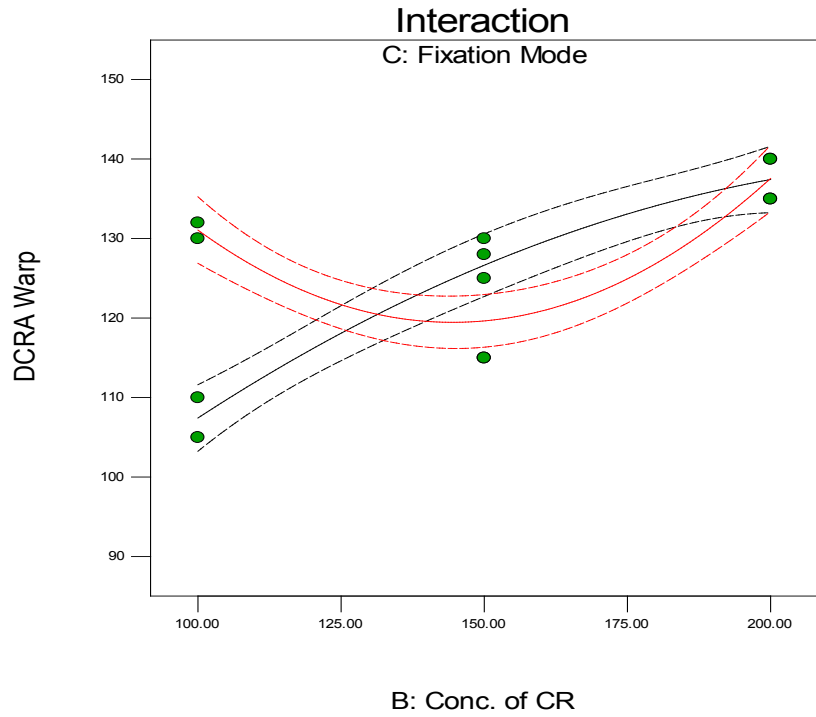


Figure 11. Interaction plot of BC with respect to DCRA warp

Design-Expert® Software
 DCRA Warp

— CI Bands
 ● Design Points

X1 = A: Chroma
 X2 = B: Conc. of CR

Actual Factors
 C: Fixation Mode = E Control
 D: Fixation Temp. = 140.00

■ B- 100.000
 ▲ B+ 200.000

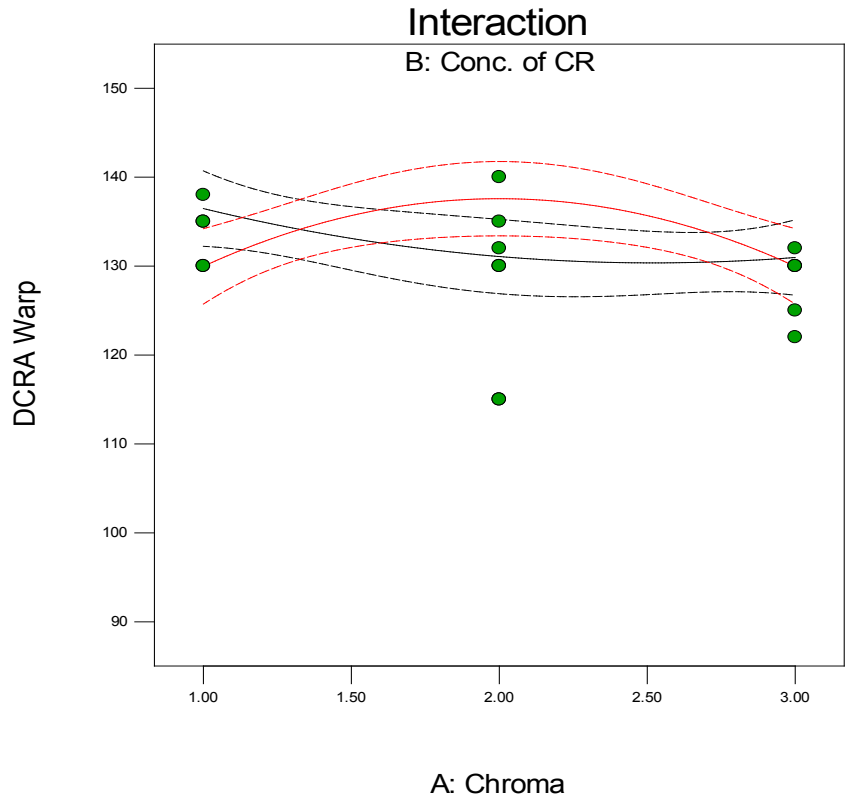


Figure 12. Interaction plot of AB with respect to DCRA warp

Design-Expert® Software
DCRA Warp

— CI Bands
● Design Points

X1 = B: Conc. of CR
X2 = D: Fixation Temp.

Actual Factors
A: Chroma = 2.00
C: Fixation Mode = E Control

■ D- 130.000
▲ D+ 150.000

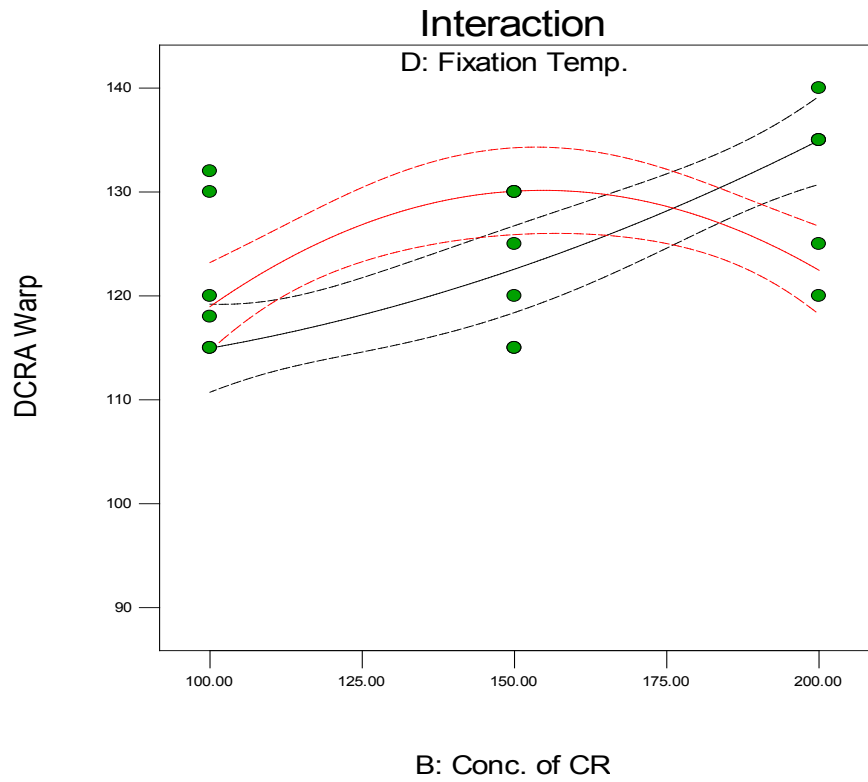


Figure 13. Interaction plot of BD with respect to DCRA warp

Design-Expert® Software
DCRA Warp

● Design Points
140
95

X1 = B: Conc. of CR
X2 = D: Fixation Temp.

Actual Factors
A: Chroma = 2.00
C: Fixation Mode = E Control

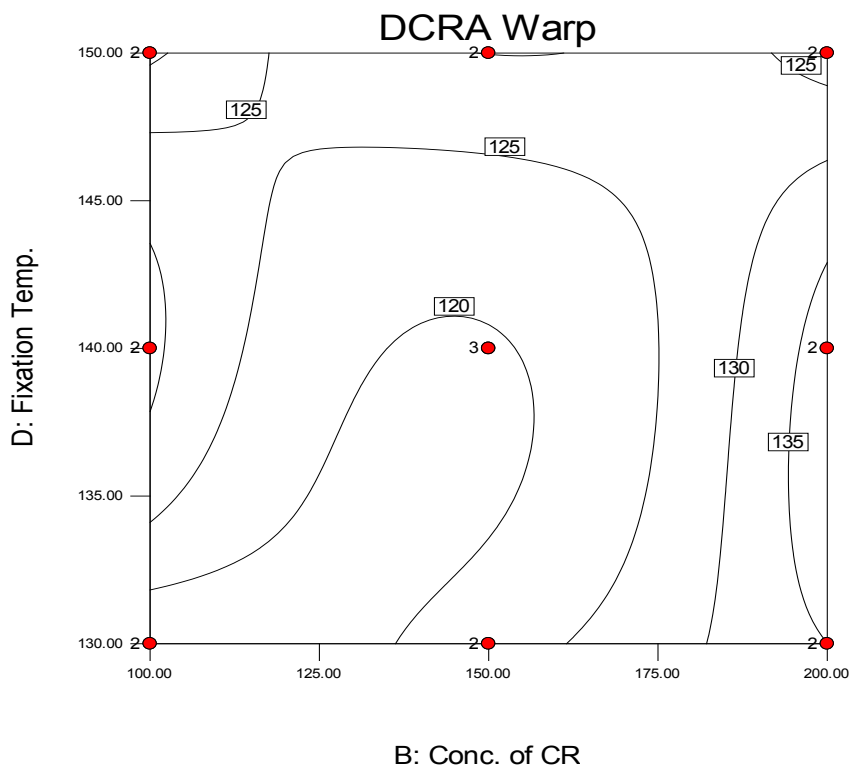


Figure 14. Contour plot representing DCRA warp versus concentration of CR and fixation temperature

Design-Expert® Software
DCRA Warp

— CI Bands
● Design Points

X1 = D: Fixation Temp.
X2 = C: Fixation Mode

Actual Factors
A: Chroma = 2.00
B: Conc. of CR = 150.00

■ C1 Curing
▲ C2 E Control

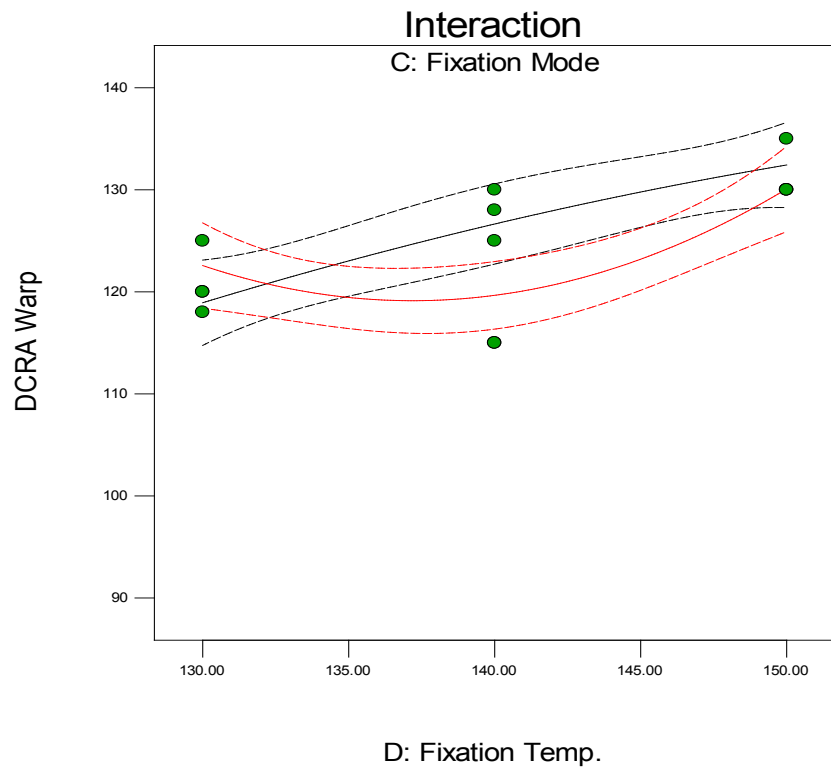


Figure 15. Interaction plot of CD with respect to DCRA warp

4. Conclusions

The factorial design of experiments for single step fixation process of reactive printing and crease resistance finishing was studied. The quadratic effect of three factors namely, concentration of crease resistant, fixation method and fixation temperature on dry crease recovery angle were identified. The statistical analysis gave a reasonably good fit with an F-value of 24.10 and an R²-value of 0.9587. According to the significance effect obtained in variance analysis, the concentration of crease resistant was the most significant factor for the dry crease recovery angle under the conditions investigated. The information obtained from the mathematical model has been used to create optimal parameters of single step fixation process of reactive printing and crease resistance finishing process.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Gul Ahmed Textile Mills Ltd and Clariant Pakistan Ltd, for carrying out the necessary experimental work.

REFERENCES

[1] H. Tavanai, S. M. Taheri, M. Nasiri, "Modelling of Colour

Yield in Polyethylene Terephthalate Dyeing with Statistical and Fuzzy Regression", *Iranian Polymer Journal*, 14 (11), 954-967 (2005)

- [2] H. Tavanai, A. Z. Hamadani, M. Askari, "Modelling of Colour Yield for Selected Reactive Dyes in Dyeing Cotton Cloth by Two Phase Pad-steam Method", *Iranian Polymer Journal*, 15 (3), 207-217(2006)
- [3] V. Vassileva, E. Valcheva, Z. Zheleva, "The Kinetic Model of Reactive Dye Fixation on Cotton Fibres", *Journal of the University of Chemical Technology and Metallurgy*, 43(3), 323-326 (2008)
- [4] F. Asim, M. Mahmood, M. A. Siddiqui, "Optimization of process parameters for simultaneous fixation of reactive printing and crease resistant finishing using desirability function", *International Conference on Systems Engineering and Engineering Management*, 1098-1105 (2011)
- [5] F. Asim, M. Mahmood, "Multi response optimization of simultaneous fixation of reactive printing and crease resistant finishing using desirability function", *International Journal of Statistics and Applications*, 2(6), 126-131 (2012)
- [6] F. Asim, M. Mahmood, "Optimization of process parameters for simultaneous fixation of reactive printing and crease resistant finishing", *Journal of Textile and Apparel Technology Management*, 7(3), Spring (2012)
- [7] Y. H. ElHamaky, S. Tawfeek, D. F. Ibrahim, D. Maamoun, S. Gaber, "Printing Cotton Fabrics with Reactive Dyes of High Reactivity from an Acidic Printing Paste", *Coloration Technology*, 123(6), 365-373 (2007)

- [8] N. S. E. Ahmed, Y. A. Yourself, R. M. El-Shishtawy, A. A. Mousa, "Urea/Alkali Free Printing of Cotton with Reactive Dyes", *Coloration Technology*, 122(6), 324-328 (2006)
- [9] Y. Yang, V. Naarani, "Effect of Steaming Conditions on Colour and Consistency of Ink-Jet Printed Cotton Using Reactive Dyes", *Coloration Technology*, 120(3), 127-131 (2004)
- [10] C. W. M. Yuen, S. K. A. Ku, P. S. R. Choi, C. W. Kan, "Study of the Factors Influencing Colour Yield of an Inkjet-Printed Cotton Fabric", *Coloration Technology*, 120(6), 320-325 (2004)
- [11] Y. Can, M. Akaydin, Y. Turhan, E. Ay, "Effect of Wrinkle Resistance Finish on Cotton Fabric Properties", *Indian Journal of Fibre & Textile Research*, 34, 183-186 (2009)
- [12] M. S. Hassan, Crease Recovery Properties of Cotton Fabrics Modified by Urea Resins under the Effect of Gamma Irradiation", *Radiation Physics and Chemistry*, 78(5), 333-337 (2009)
- [13] F. Asim, M. Mahmood, "Reactive Printing & Crease Resistance Finishing of Cotton Fabrics. Part-I Study of Influential Factors by an Experimental Design Approach", *Journal of Textile & Apparel, Technology and Management*, 7(1), (2011)
- [14] F. Asim, M. Mahmood, "Reactive Printing and Crease Resistance Finishing of Cotton Fabrics-Effects of Fixation Modes by $2^2.4^1$ Mixed Factorial Design", *International Journal of Textile Science*, 1(6), 94-100 (2012)
- [15] F. Asim, M. Mahmood, "Effects of Process Parameters on Single Step Fixation of Reactive Printing and Crease Resistance Finishing of Cotton Fabrics using 2^3 Factorial Design", *International Journal of Textile Science*, 2(1), February (2013)
- [16] S.M. Mortazavi, M.A. Alsharif, M. Jannesari, "A study on Simultaneous Fixation of Reactive Dye Printing and Crease Resist Finishing on Cotton Fabric (Effect of DMDHEU Concentration, Types of Catalyst and Drying Conditions)", <http://140.134.132.124:8080/dspace/bitstream/2377/3912/1/c05atc902007000039.pdf>