M. D. Teli,
R. Chakrabarti

Use of Statistical Methods to Understand the Effect of Yarn and Fabric Parameters on Desizing Efficiency

Institute of Chemical Technology, University of Mumbai,
Matunga, Mumbai: 400019, India
E-mail: textileudct@yahoo.com

Abstract
The control of fabric quality in terms of the basic structure, like yarn type, yarn count, twist multiplier, ends per inch and picks per inch, cover factor etc. is very important, as these parameters finally determine the quality aspects of the fabric during its interaction with the chemicals used in the process. In this work an attempt was made to investigate the influence of structural parameters of the yarn and fabric, like the yarn count, yarn twist multiplier and the p.p.i. on the final performance of desized, 100% cotton fabric. Desizing is the first stage of all the preparatory processes, wherein the size of the materials applied to the warp yarn during weaving is removed. This process determines the performance of the subsequent processes, such as the uniformity of scouring, bleaching, dyeing etc. which is quite crucial in maintaining the quality of the finished fabric.

Key words: *desizing efficiency, tegewa rating, box benkhen model.*

Introduction

The modern requirement of consistency of production, coupled with an increasing tendency towards automated processing machinery, have created a need for greater control over processing conditions. Rarely is the aim of the process to eliminate impurities completely or to attempt a perfect shade match, but instead the goal is to produce a product "fit for the purpose", or to determine parameters within whose limits the product is acceptable. It is axiomatic that a high quality product must normally be processed over the shortest compatible wet processing time. Hence, careful control over the process parameters, like pH, time, temperature, water quality, speed of the machine, as well as the quality and quantity of the chemicals is of prime importance. Equally important is the control of the fabric quality in terms of its basic structure, like yarn type, yarn count, ends per inch (e.p.i) and picks per inch (p.p.i), twist multiplier (TM), cover factor and also the type of weave, as these parameters finally determine the quality aspects of the fabric during its interaction with the chemicals used in the process. Understanding of the above parameters not only reduces the processing cost, but also ensures reproducibility in day-to-day production.

In our work we have tried to investigate the influence of structural parameters of the yarn and fabric, such as yarn count, yarn T.M,. and the p.p.i fot the final performance of the desized fabric [1 - 3]. 100% cotton slivers were spun into two different yarn counts at two different TM. They were then used at two different p.p.i's. for weaving the fabric. Hence, a 2^3 factorial design (i.e. three factors at two different levels each) was used for preparing different varieties of fabric. Predictions are done using regression equations. The advantage of this system lies in the fact that an empirical model can be developed, which can then be used to design fabrics with the desired properties [4]. A further comparison is made by replacing the conventional ring spun yarn with rotor yarns of equivalent count and twist multiplier.

Materials and experimental methods

The ring and rotor spun yarns were of linear density of 29.52 tex (20^s) and 24.60 tex (24^s) with a twist multiplier of 3.6 and 4.0, produced from sliver made of 100% Shankar6 cotton with a staple length of 27 mm and a micronnaire value of 3.6, obtained from Bombay Dyeing Mills Ltd., Mumbai, (India). The fabrics were woven with plain (1/1) weave using a total of eight different weft yarns with two different p.p.is i.e. 52 and 60. Warp yarns of linear density of 29.52 tex (20^s), with a 12% size pick up, were kept constant for all the fabrics, and thus a total of sixteen different fabrics were prepared.

Tensile strength

The tensile strength of the fabric was determined on a Table Model (Metric) TM-M Instron tensile strength tester. The distance between the jaws for the testing of the fabric was 20 cm, and the speed of the lower jaw was 20 cm/min. The testing was done by the raveling strip method (ISO-13934). 10 samples of both warp and weft directions were tested for each and every fabric, and the CV% were of the order of 5%.

Table 1. Experimental plan for variables used for the fabric (ring and rotor spun yarns).

Combination	Variables		
	Count (x_1)	TM(x_2)	P.P.I.(x_3)
1	-1	-1	-1
2	-1	-1	+1
3	-1	+1	-1
4	-1	+1	+1
5	+1	-1	-1
6	+1	-1	+1
7	+1	+1	-1
8	+1	+1	+1

Table 2. Actual values corresponding to coded levels related to the fabrics.

Level	Variable		
	Count(x_1)	TM(x_2)	p.p.i.(x_3)
-1	20	3.6	52
+1	24	4.0	60

Table 3. Recipe for desizing, and variables, with their levels, used in the desizing experiment.

Parameter	Level		
	-1	0	+1
pH	6.2	6.6	7.0
Enzyme concentration	0.3	0.4	0.5
Temperature, °C	80	90	100
NaCl	10 g/l		
Time	30 minutes		
MLR	1 : 30		

Weight loss

Conditioned samples were accurately weighed before and after the desizing treatment, and the weight loss (in per cent) was calculated as:

$$\text{Wt. loss} = [(W_1-W_2)/W_1] \times 100$$

where, W_1 and W_2 are the weights of the fabric before and after the desizing treatment respectively.

Shrinkage

The shrinkage (in per cent) was determined by measuring the decrease in distance between a pair of straight lines of 50 cm length marked parallel to both the warp and weft directions, as a result of desizing.

$$\text{Shrinkage} = [(L_1-L_2)/L_1] \times 100\%$$

Where, L_1 and L_2 are the distances between the parallel lines on the fabric, before and after the desizing treatment respectively.

*Table 4. Treatment conditions and the response observed and calculated after desizing; * the values indicate the ranking of the individual responses.*

Expt. No.	pH	Enz. conc.	Temp.	% Wt. loss		Tegewa rating	
				Observed	Calculated	Observed	Calculated
1	6.6 (0)*	0.5 (+1)*	80 (-1)*	13.2	12.97	7	7-8
2	6.6 (0)	0.4 (0)	90 (0)	13.55	13.58	8	8
3	6.2 (-1)	0.4 (0)	100 (+1)	11.57	11.37	6-7	6
4	6.2 (-1)	0.4 (0)	80 (-1)	11.43	11.70	6-7	6
5	7.0 (+1)	0.5 (+1)	90 (0)	12.92	12.95	7	7
6	6.6 (0)	0.4 (0)	90 (0)	13.63	13.58	8	8
7	6.2 (-1)	0.3 (-1)	90 (0)	10.74	10.71	6	6-7
8	6.6 (0)	0.5 (+1)	100 (+1)	13.09	13.32	7	7
9	7.0 (+1)	0.4 (0)	80 (-1)	12.51	12.70	7	7
10	6.6 (0)	0.3 (-1)	100 (+1)	11.40	11.63	6	6-7
11	7.0 (+1)	0.4 (0)	100 (+1)	12.87	12.60	7-8	7
12	7.0 (+1)	0.3 (-1)	90 (0)	11.67	11.67	6	6
13	6.2 (-1)	0.5 (+1)	90 (0)	11.75	11.71	6	6
14	6.6 (0)	0.3 (-1)	80 (-1)	12.64	12.40	7	7
15	6.6 (0)	0.4 (0)	90 (0)	13.49	13.58	8	8

Table 5. *Actual values and ranked position of weight loss, as well as the Tegewa rating for optimisation of the desizing process.*

Case No.	Temperature	Enzyme concentration	pH	Wt. loss (rank)	Tegewa Rating (rank)
1	80	0.3	6.2	10.84 (25)*	6 (17)*
2	80	0.3	6.6	12.64 (11)	7 (7)
3	80	0.3	7.0	11.63 (18)	6 (17)
4	80	0.4	6.2	11.43 (21)	6 (17)
5	80	0.4	6.6	12.98 (7)	8 (1)
6	80	0.4	7.0	12.51 (12)	7 (7)
7	80	0.5	6.2	11.31 (23)	6 (17)
8	80	0.5	6.6	13.20 (3)	7-8 (4)
9	80	0.5	7.0	12.45 (13)	7 (7)
10	90	0.3	6.2	10.74 (26)	6 (17)
11	90	0.3	6.6	12.27 (14)	7 (7)
12	90	0.3	7.0	11.84 (16)	6 (17)
13	90	0.4	6.2	11.91 (15)	6-7 (14)
14	90	0.4	6.6	13.63 (1)	8 (1)
15	90	0.4	7.0	13.01 (6)	7 (7)
16	90	0.5	6.2	11.75 (17)	6 (17)
17	90	0.5	6.6	13.25 (2)	8 (1)
18	90	0.5	7.0	12.92 (8)	7 (7)
19	100	0.3	6.2	9.63 (27)	6 (17)
20	100	0.3	6.6	11.40 (22)	6-7 (14)
21	100	0.3	7.0	11.10 (24)	6 (17)
22	100	0.4	6.2	11.57 (19)	6 (17)
23	100	0.4	6.6	13.19 (4)	7-8 (4)
24	100	0.4	7.0	12.87 (9)	7-8 (4)
25	100	0.5	6.2	11.47 (20)	6 (17)
26	100	0.5	6.6	13.09 (5)	7 (7)
27	100	0.5	7.0	12.81 (10)	6-7 (14)

Table 6. Tensile strength of the fabric before and after desizing.

Sr. No	Quality Count/TM/P.P.I.	Tensile strength before desizing in newtons				Tensile strength after desizing in newtons			
		Ring		Rotor		Ring		Rotor	
		Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
1	20/3.6/52	367.0	366.0	358.0	326.0	396.0	434.0	396.0	388.0
2	20/3.6/60	380.0	400.0	338.0	352.0	420.0	482.0	385.0	445.0
3	20/4.0/52	374.0	396.0	368.0	348.0	403.0	470.0	404.0	428.0
4	20/4.0/60	420.0	440.0	368.0	365.0	467.0	532.0	414.0	456.0
5	24/3.6/52	334.0	336.0	318.0	288.0	360.0	395.0	348.0	345.0
6	24/3.6/60	340.0	354.0	338.0	302.0	374.0	427.0	377.0	380.0
7	24/4.0/52	356.0	316.0	324.0	310.0	384.0	375.0	352.0	366.0
8	24/4.0/60	398.0	365.0	342.5	353.0	440.0	441.0	382.0	439.0

Tegewa rating

An iodine solution was prepared by dissolving 10 g of potassium iodide in 100 ml of water, then 0.65 g of iodine was added, and it was diluted with water to the volume of 800 cm^3. Next, ethanol was added to increase the volume to 1 litre. The desized fabric was put in the prepared solution for 1 minute and then rinsed with cold water. It was then dabbed with filter paper and immediately compared with the violet scale.

Experimental design

For the weaving of the fabric, a 2^3 factorial design was made to use, and the variables taken in to account were yarn count, yarn twist multiplier (TM), and picks per inch (p.p.i.). The experimental plan for variables used for the fabric (ring and rotor spun yarns) are presented in Table 1 whereas the actual values corresponding to coded levels related to the fabrics are shown in Table 2.

For optimisation of the conditions for desizing, the Box–Behnken [5] model was used. The variables were pH, temperature, and enzyme concentration; three levels of which were chosen (see Table 3).

Results and discussion

Optimisation of the variables for desizing process

The actual recipe for desizing as well as the variables with their different coded levels and actual values are shown in Table 3. The treatment conditions and the response observed and calculated after desizing are presented in Table 4. To optimise the process, the various responses, i.e. weight loss and Tegewa rating, were ranked (refer Table 5), where maximum values were given the rank of "1", and with decreasing values of weight loss and Tegewa ratings, the ranks were progressively increased. The individual ranks for weight loss and Tegewa rating were then added to get a cumulative overall ranking. The treatment conditions of case 14 gave the minimum cumulative ranking value of "2", and hence this was considered as the optimised desizing condition[6]. The optimised conditions for the desizing experiment thus obtained refer to a temperature of 90 °C, a pH of 6.6, and an enzyme concentration of 0.4% owf.

Statistical analysis

The response surface equations for the fabric properties are shown in Table 9. The negative coefficient of a variable in a response surface equation indicates that the particular property or response decreases with an increase in that variable, while a positive coefficient indicates that the same property increases with the increase in the variable analised [4]. But the sign and magnitude of the coefficients of the interaction between the variables again modify this trend. The relationship between the response and variable are shown with the help of 3-D graphs (Figures 1 - 8 see pages 97, 98, 99 and 100).

Shrinkage

In the case of shrinkage, the trend observed indicated slightly higher values in the weft direction than that observed in the warp direction. This is due to the

Table 7. Percent increase in tensile strength of the fabric after desizing.

Sr. No	Quality Count/TM/p.p.i	Increase in tensile strength after desizing, %			
		Ring		Rotor	
		Warp	Weft	Warp	Weft
1	20/3.6/52	7.90	18.68	10.73	19.77
2	20/3.6/60	10.46	20.57	14.09	26.59
3	20/4.0/52	7.79	19.05	9.91	23.13
4	20/4.0/60	11.24	20.94	12.35	24.88
5	24/3.6/52	7.62	17.47	9.49	19.01
6	24/3.6/60	10.15	20.63	11.71	25.71
7	24/4.0/52	7.78	18.86	8.81	18.00
8	24/4.0/60	9.94	20.81	11.57	24.45

Table 8. – Actual values of shrinkage, Tegewa rating, and weight loss after desizing.

Sr. No.	Quality Count/TM/p.p.i	Shrinkage%				Tegewa rating		Weight loss, %	
		Ring		Rotor		Ring	Rotor	Ring	Rotor
		Warp	Weft	Warp	Weft				
1	20/3.6/52	4.83	5.56	5.28	4.71	6-7	6	9.69	8.42
2	20/3.6/60	4.95	6.12	6.33	6.60	7-8	5-6	8.50	7.42
3	20/4.0/52	4.62	5.73	4.90	5.73	7	7	8.80	8.74
4	20/4.0/60	5.38	6.38	6.16	6.16	6	6-7	8.50	8.16
5	24/3.6/52	4.70	5.20	4.67	4.95	7	7	10.00	9.20
6	24/3.6/60	4.80	6.14	5.55	6.27	7	6-7	8.40	7.89
7	24/4.0/52	4.63	5.63	4.33	4.46	7-8	7-8	9.25	8.66
8	24/4.0/60	4.73	6.20	5.20	6.06	7	7	8.90	8.61

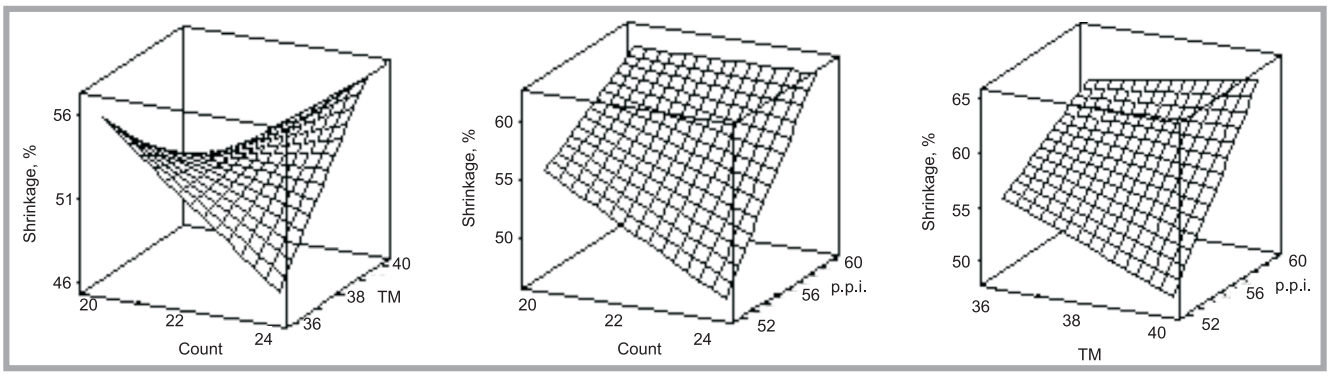

Figure 1. Response surface plot of shrinkage per cent of fabric after desizing in weft direction (weft : ring yarn).

Table 9. *Response surface equations for fabrics; ** All the response surface equations are in coded units.*

Response	Response Surface Equation**
Increase in tensile strength warp (ring)	$429.940-19.2437x_1-121.612x_2-7.825x_3+5.33437x_1x_2+0.356522x_1x_3+$ $+2.26562x_2x_3-0.0992187x_1x_2x_3$
Increase in tensile strength weft (ring)	$450.215-22.3575x_1-110.137x2-7.36375x_3+5.55312x_1x_2+0.38x_1x_3$ $+1.89062x_2x_3-0.0945312x_1x_2x_3$
Increase in tensile strength warp (rotor)	$-507.137+22.4962x_1+129.225x_2+10.3456x_3-5.82094x_1x_2.0.444812x_1x_3$ $-2.55937x_2x_3+0.113\ 672x_1x_2x_3$
Increase in tensile strength weft (rotor)	$-1957.99+80.33x_1+537.037x_2+33.7437x_3-22.3125x_1x_2-1.35937x_1x_3$ $-9.11562x_2x_3+0.376562x_1x_2x_3$
Shrinkage after desizing warp (ring),%	$223.380-9.11250x_1-61.3x_2-4.0675x_3+2.54687x_1x_2+0.17x_1x_3$ $+1.14375x_2x_3-0.04766x_1x_2x_3$
Shrinkage after desizing weft (ring),%	$687.755-31.32x_1-181.425x_2-11.5462x_3+8.24531x_1x_2+0.529375x_1x_3$ $+3.075x_2x_3-0.1395x_1x_2x_3$
Shrinkage after desizing warp (rotor),%	$77.835-3.18375x_1-22.7375x_2-1.23625x_3+0.91875x_1.x_2+0.05656x_1.x_3$ $+0.4094x_2.x_3-0.0172x_1x_2x_3$
Shrinkage after desizing weft (rotor),%	$-692.784+29.581x_1+184.965x_2+11.907x_3-7.9475x_1.x_2-0.5024x_1.x_3$ $-3.145x_2.x_3+0.1347x_1x_2x_3$
Weight loss, % (ring)	$-36.375+5.694x_1+10.8125x_2+1.13125x_3-1.375x_1x_2-0.1141x_1x_3$ $+0.284375x_2x_3+0.028125x_1x_2x_3$
Weight loss, % (rotor)	$122.985-4.31875x_1-28.275x_2-2.09125x_3+1.1125x_1x_2+0.07469x_1x_3$ $+0.50625x_2x_3-0.01875x_1x_2x_3$
Tegewa rating (ring)	$-595.25+23.625x_1+155.625x_2+11.4375x_3-6.09375x_1x_2-0.453x_1x_3$ $-2.96875x_2x_3+0.117187x_1x_2x_3$
Tegewa rating (rotor)	$-447.250+18.875x_1+113.75x_2+7.4375x_3-4.6875x_1x_2-0.3125x_1x_3$ $-1.875x_2x_3+0.0781x_1x_2x_3$

higher e.p.i (65) as compared to the p.p.i (52, 60), due to which (refer Table 9) the stress generated during weaving in the weft direction is more than that in the warp direction. Hence, when the fabric is wetted out and relaxation is allowed, the internal stress and strain in the yarn tend to relax, leading to individual yarn shrinkage, which in turn causes the shrinkage of the fabric in the respective yarn direction [6, 7]. It was also found that the shrinkage in both the warp and weft directions was more in the case of fabric having a higher p.p.i. This is due to the fact that higher p.p.i results in greater yarn stress being developed during weaving as a larger number of yarns have to be accommodated in the same space, and hence this has the propensity to revive the stress generated by relaxing in the wet stage, resulting in shrinkage of the fabric. For similar reasons it was also observed that the shrinkage was less in the fabrics of finer yarn in the weft.

Tensile strength

The tensile strength of the fabric before and after desizing are listed in Table 6. It was found that the tensile strength of the

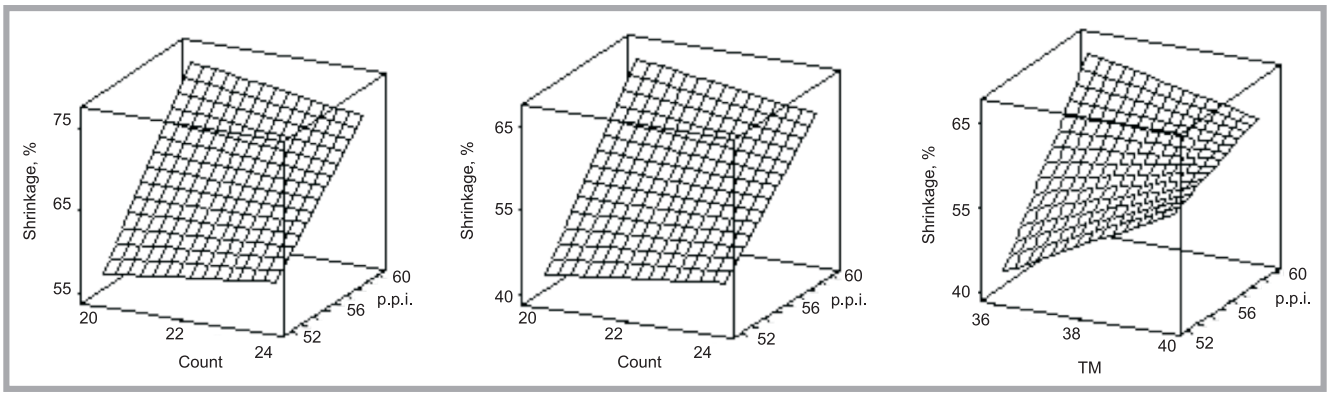

Figure 2. *Response surface plot of shrinkage per cent of fabric after desizing in weft direction (weft : rotor yarn).*

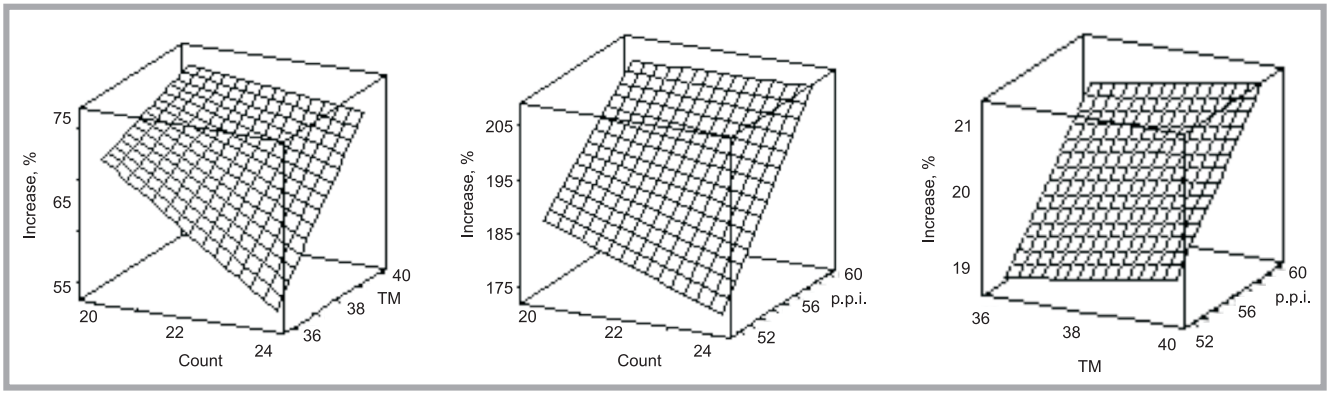

Figure 3. *Response surface plot of increase per cent in tensile strength in per cent of fabric after desizing in weft direction (weft : ring yarn).*

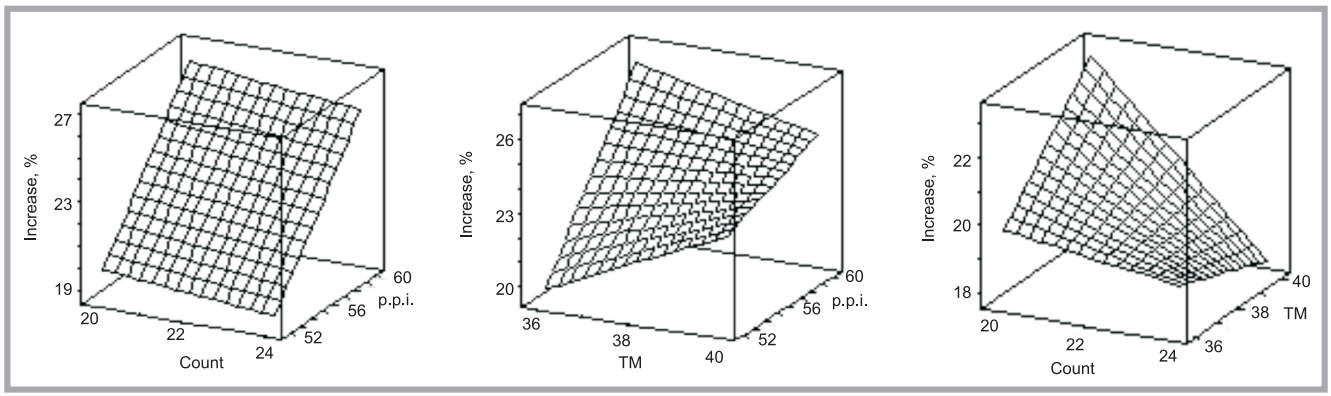

Figure 4. *Response surface plot of increase in tensile strength in per cent of fabric after desizing in weft direction (weft : ring yarn).*

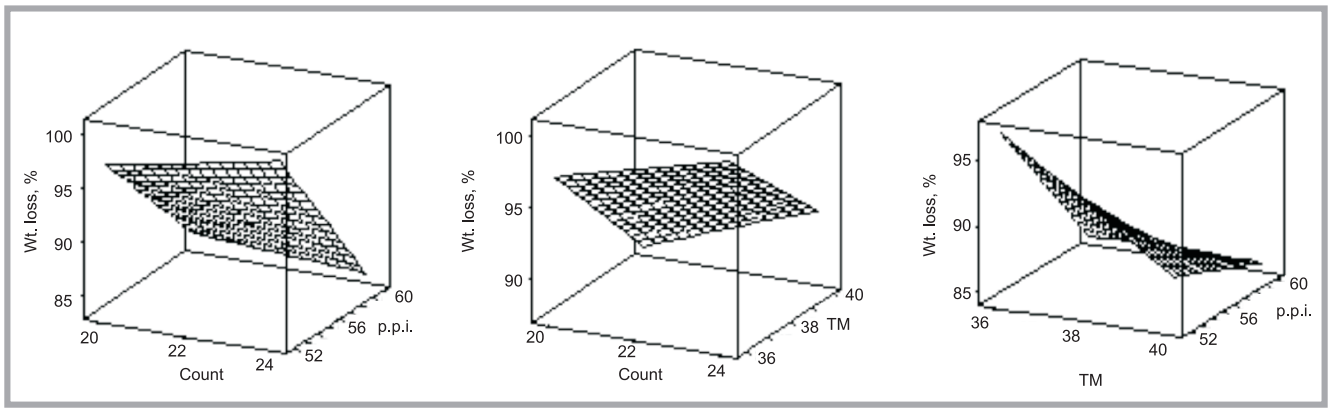

Figure 5. *Response surface plot of weight loss in per cent, after desizing in weft direction (weft : ring yarn).*

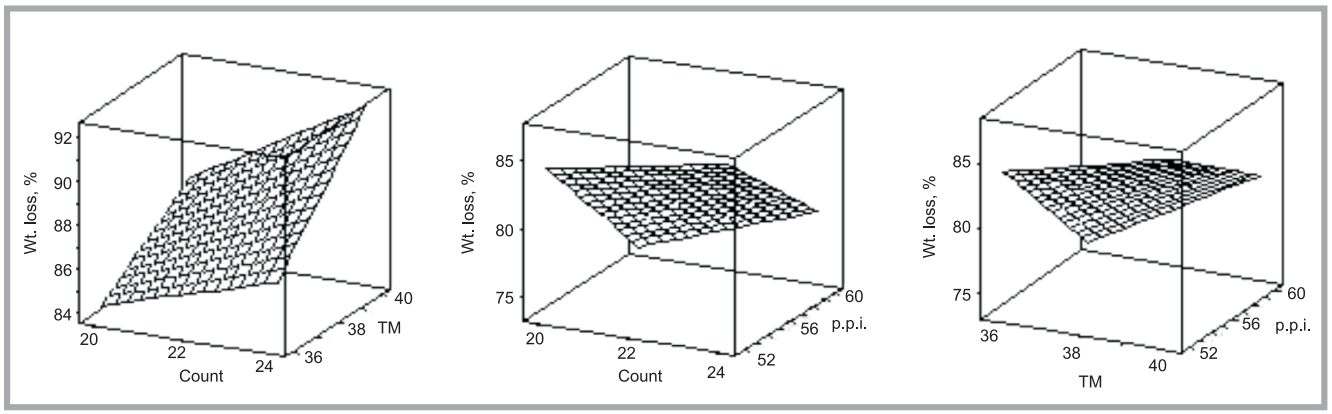

Figure 6. *Response surface plot of weight in per cent, after desizing (weft : ring yarn).*

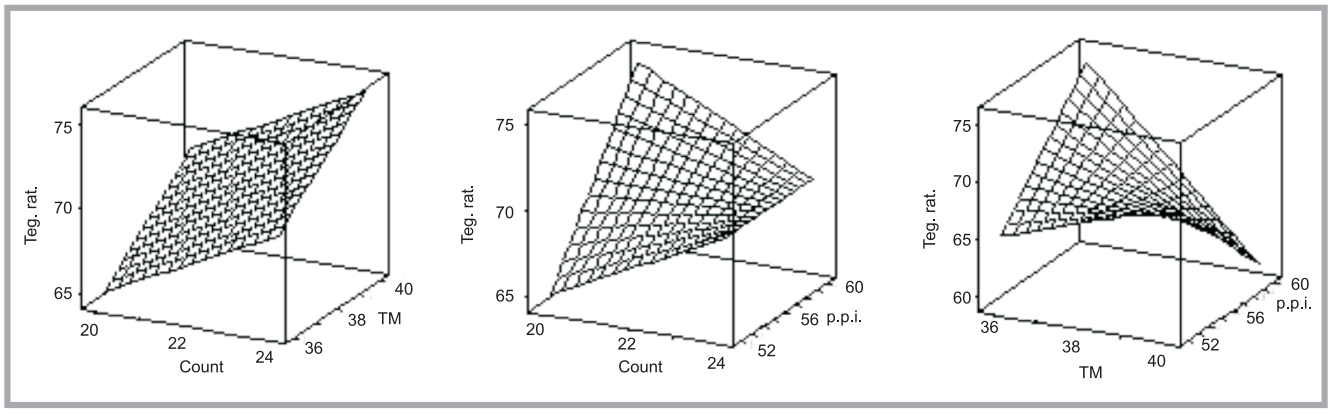

Figure 7. *Response surface plot of Tegewa rating of fabric after desizing (weft : ring yarn).*

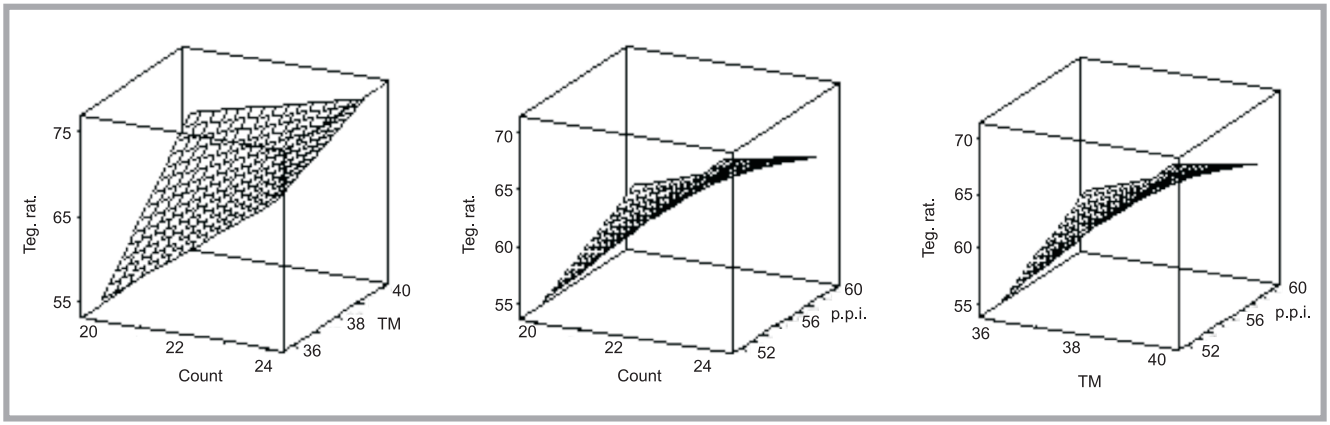

Figure 1. *Response surface plot of shrinkage per cent of fabric after desizing in weft direction (weft: ring yarn).*

fabric increased after desizing in both directions (refer Table **7**). The increase in tensile strength was found to occur with an increase in the shrinkage,% i.e. the higher the shrinkage percent, the greater the tensile strength was. Another observation was that, though the shrinkage (in per cent) was of the order of 4.5 - 6.5%, the increase in tensile strength (in per cent) was within the range of 7.8 - 26%. In other words, the increase in tensile strength was much higher than that of the shrinkage (in per cent). This is because shrinkage occurs in both directions, and therefore the fabric structure becomes denser. The load bearing number of e.p.i or p.p.i, depending on the direction in which the tensile strength of the fabric is measured, also increases, producing an increase in the resultant tensile strength (%) much higher than the original value. It was also noticed that the increase in tensile strength (%) was more in the weft direction than that of the warp direction when compared to the original grey fabric. On one hand this may be attributed to the warp yarn being sized, as desizing would result in a decrease in tensile strength. On the other hand, the fabric shows an increase in strength due to its shrinkage, as the number of warp yarns is higher in the same width of the fabric. Similarly, shrinkage also occurs in the weft direction, which causes enhanced fabric assistance. These two mutually opposing processes, acting predominantly on the warp yarn, cause a relatively lower increase in tensile strength (in per cent) than that occuring in weft direction, where there was no size. This contention is also supported in literature [7, 8, 11].

Weight loss and Tegewa rating

The weight loss was found to be higher in the fabrics of ring yarn in the weft direction than in the fabrics with rotor yarn in the weft direction, and a similar trend was also established for the Tegewa rating (refer Table 8, see page 97). This can be due to the fact that ring yarns have a more consolidated yarn structure, and hence the projection of the ring weft on the warp is confined to a smaller area as compared to the fabric of rotor yarn in the weft. In other words, for the same count and TM, the ring yarn will have a lower diameter as compared to the rotor yarn, and thus it exerts a physical hindering effect on the desizing liquor, which less effectively acts on the warp yarns. This not only leads to a lower weight loss in the fabric, but also reduced desizing efficiency [9 - 18].

Conclusion

The desizing efficiency is not only dependent on the process condition, but is also, to a large extent, determined by the yarn and fabric structure, such as yarn count, yarn TM, the type of weave and also the fabric construction parameters. Hence, during processing, proper attention should be paid to ensure not only the proper chemicals, at a specific concentration, but also the yarn and fabric construction parameters. Otherwise, the final product would fail to satisfy the desired specifications.

References

1. *Knapton J. R., Review of Progress in Coloration, 21, 7(1991).*
2. *Holme I., Review of Progress in Coloration, 22, 1(1992).*
3. *Park J.,Review of Progress in Coloration, 15, 26(1985).*
4. *Tyagi G.K., Singh A., Gupta A., and Goyal A. Indian Journal of Fibre and Textile Research, 28(6), 163-169(2003).*
5. *Box GEP, and Behnken, Technometrics. 2, 455(1960).*
6. *Gulrajani M.L., Chatterjee A., Indian. Journal of Fibre and Textile Research, 17 (3), 37-44 (1992).*
7. *Marsh J.T., An Introduction to Textile Finishing,., Chapman and Hall Ltd. Manchester, 241-243.*
8. *Collins, Journal of Textile Institute, 30, 46(1939).*
9. *Salhotra K.R., Dutta B, and Sett S K, Textile Research Journal, 51, 360(1981).*
10. *Kollegal M.G, Sridharan S, Journal of Composite Materials, 34, 240(2000).*
11. *Manohar J.S., Rakshit A.K., and Balsubramanian N, Textile Research Journal, 53, 497(1983).*
12. *Kaushik R.C.D., Tyagi G.K., Indian Journal of Fibre and Textile Research, 18, 110(1993).*
13. *Hussain G.F.S., and Krishna Iyer K.R., Indian Jounal of Fibre and Textile Research, 18, 110(1993).*
14. *Tyagi GK & Sharma D, Journal of Fiber and Textile Research, 29, 419(2004).*
15. *Gong R.H. and Chen Y, Textile Research Journal, 69, 477(1999).*
16. *Guha A., Chattopadhyay A., Jayadeva, Journal of The Textile Institute, 92, 139 (2001).*
17. *Naik N.K., Sing M.N., 2001, Journal of The Textile Institute, 83, 164 (1992).*
18. *Structural Mechanics of Fibres: Yarns and Fabrics (edited by: J.W.S. Hearle, P.Grosberg & S. Backer), Wiley International, New York, NY, USA, Vol1 PP(28).*

Received 14.06.2007 Reviewed 23.01.2008