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Multi response optimization in the development of anti-pilling and easy care finished rayon from bamboo and bamboo/cotton fabrics using desirability function

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K E Y W O R D S

Pilling

Smoothness Appearance

Dimensional Stability

Desirability Function

Optimization

A B S T R A C T

The present study discusses the optimization of process parameters of anti-pilling and resin finished rayon from 100% bamboo and 50:50 bamboo/ cotton fabrics used in home textile. Two weave structures, plain and five harness satin were selected. The optimization was carried out using desirability function a statistical technique for multiple response optimization. This was done by software called Design Expert 8.0.1. The five factors namely, Appretan® N 9211 as an anti-pilling agent (a non-ionic acrylate copolymer), Arkofix® NF as crease resistant agent (dimethylol dihydroxy ethylene urea, DMDHEU), fabric blend ratio, fabric weaves and curing method were analysed using 23 32 mixed level factorial design. The optimum conditions were explored for concentration of Appretan® N 9211, Arkofix® NF and curing methods. The process was evaluated with respect to pilling before and after wash, abrasion resistance, tensile, tear strength, Berger whiteness, yellowness index, dimensional stability, smoothness appearance and colour fastness to light. In order to generate the desirability values, the equal weightage was given to all response variables, but different importance was assigned based on the finish applied and industrial requirements. Four optimized recipes each for rayon from 100% bamboo and of 50:50 bamboo/cotton plain and satin weaves were suggested based on the high value of desirability.

1. Introduction

Innovation in Textile brought substitute plant fibres such as bamboo into the limelight and as an alternative to petrochemical based manmade fibres. Bamboo as a raw material is unusually versatile and sustainable resource, but the production process is still under debate and questioned its eco-friendly and green image [1]. However, this fact does not limit the use of bamboo in various textile applications.

Numerous studies have been conducted that evaluate the performance of textile fabrics. In one such study, it was mentioned that the pilling of the plain and satin fabrics made with bamboo rayon and bamboo rayon/cotton blends were poor and the use of Appretan® N9211 as anti-pilling agent helped to improve the pilling resistance properties [2-3].

In another study, the effect of different fabric weaves and weft types on the properties of Bamboo/Cotton was studied. It was mentioned that dimensional stability of the fabric was affected by the blend ratio of the yarn and weave type. The type of weave had great influence on the shrinkage in weft direction [4].

It is further explored [5] that, in a bamboo/cotton blend, the yarn imperfection and unevenness increased with an increase in the bamboo fibre content. This increase in yarn imperfection and unevenness is likely to result in increased pilling.

Besides, wrinkle resistance characteristic of bamboo textiles is poor compared to other fabrics; therefore, it is not considered the perfect choice of fabrics where wrinkle recovery is required [6-9]. It was explored in [3] that dimensional stability of bamboo and bamboo/cotton woven fabric was poor and ranges from -7.8 to -16. The sanforising process helped in improving it but it was quite above +/- 3% which is commonly required for woven plain and satin fabrics [2-3]. Various studies showed that the pilling, wrinkle and dimensional stability of the rayon from bamboo improved after anti-pilling and resin finish [2-3, 7-9]. The pilling resistance of rayon and rayon/cotton fabrics were improved up to pilling grade 4.5 after the application of anti-pilling and resin finish [7].

Similarly dimensional stability and smoothness appearance (wrinkle recovery) of plain and satin fabrics improved by resin finish. The dimensional stability improved up to -2.5% and smoothness appearance was improved within SA 3.5, here SA means Smoothness Appearance [3, 8].

It was established that pilling, dimensional stability and wrinkle recovery of bamboo is poor. In order to improve these properties fabrics need to be finished with anti-pilling and resin finish [7-10]. The use of both the finishes in one bath [3, 7-9] helps the textile industry to increase the productivity and reduce the lead time. However, to finish the fabrics without degrading its physical characteristics, strong statistical technique may require. The optimization by conventional method is costly in terms of time and material. A number of statistical techniques such as factorial design, box Behnken RSM (response surface methodology), desirability function, etc. are employed by many researchers for experiments design and optimisation of Textile processes.

Montazer, M., et al. of [11] applied the surface response methodology (RSM) for the optimisation of the amounts of different variables used in durable anti-pilling finish. Effect of different anti-pilling finishes was evaluated statistically by using M-Sat Microcomputer and completely randomized design technique [12].

Annacleta Chiweshe et al. [13] used a completely randomized 6 x 5 x 2 factorial design. The fabric type, softener treatment, and detergent type were three independent variables. The pilling and breaking strength were the variables. ANOVA and Tukey's Studentized (least significant difference, LSD) tests were carried out on the data to conclude that variables have considerable influence on breaking strength and pilling ratings.

Enzymatic hydrolysis of waste cotton was optimised by using Box-Behnken design (BBD). By this method the finest cellulose particles was determined. A 15 runs BBD with 3-factors and 3-levels were tested at the centre point. It was used for model and optimisation of process factors which influenced the particle size of hydrolysed waste cotton [14].

The optimisation of simultaneous fixation of reactive printing and crease-resistant finishing was done using the desirability function. A 21x33 mixed level factorial design for the four factors namely, chroma, concentration of crease resistant, fixation temperature and fixation method were used in the study. The optimum conditions of each factor and its level was determined. The authors claim that by using desirability function, one can have better visualization, acceptability and readability as compared to other multi characteristics optimisation techniques in Textiles [15].

From the above literature review, it is established that various statistical technique can be employed for the optimisation but the use of desirability function for multi response optimization is the suitable solution [3, 15-18]. To obtain the optimum parameters for anti-pilling and resin finish of rayon from 100% bamboo and 50/50 bamboo/cotton woven fabrics, this paper uses desirability function for the optimization of pilling before and after, abrasion resistance, tensile, tear strength, Berger whiteness, yellowness index, dimensional stability, smoothness appearance and colour fastness to light. The one of the advantages of using multi response optimization by desirability is that the goals, tolerance intervals and the related weights of the response variables can be changed as required by the textile industry.

2. Desirability Function

Derringer and Suich in 1980 has established a useful approach to optimization of multi responses using desirability function [18]. The general methodology is to first convert each response variable y_i into an individual desirability function d_i that varies over the range (Eq. 1).

$$0 \le d_i \le 1 \quad (1)$$

where, $d_i = 1$, if the y_i (response) is at its target or goal, and if the response y_i is outside an acceptable region, $d_i = 0$. Then, the design variables are chosen to maximize the overall desirability (Eq. 2).

$$D = (d_1.d_2\ldots\ldots d_m)^{1/m} \quad (2)$$

where there are m responses.

Each response needs to be given a weight (importance). Weights give added emphasis to upper or lower bounds or emphasize a target value. With a weight of 1, the d_i will vary from 0 to 1 in linear fashion. Weights greater than 1 (maximum weight is 10) give more emphasis to the goal. Weights less than 1 (minimum weight is 0.1) give less emphasis to the goal.

There are three important cases.

1. If the target or objective T for the response y is a maximum value, shown in equation (Eq. 3).

$$d = \begin{cases} 0 & y < L \\ \left(\frac{y-L}{T-L}\right)^r & L \le y \le T \\ 1 & y > T \end{cases} \quad (3)$$

2. If the target for the response is a minimum value, shown in equation (Eq. 4).

$$\begin{cases} 1 & y < T \\ \left(\frac{U-y}{U-T}\right)^r & T \le y \le U \\ 0 & y > U \end{cases} \quad (4)$$

3. The two-sided desirability function is defined as in equation (Eq. 5).

$$d = \begin{cases} 0 & y < L \\ \left(\frac{y-L}{T-L}\right)^{r1} & L \le y \le T \\ \left(\frac{U-y}{U-T}\right)^{r2} & T \le y \le U \\ 0 & y > U \end{cases} \quad (5)$$

3. Experimental

3.1 Fabric

The 100% rayon bamboo and 50/50 rayon bamboo/cotton woven fabrics were used in the present research. It was made up of regenerated cellulosic fibre produced from bamboo pulp. The 30's ring yarn of 100% rayon from bamboo and 50/50 rayon bamboo/cotton was purchased from the local industry. The yarns were woven in to plain and 5 harness satin fabrics [3] having same thread count (TC) of 76 ends per inch and 68 picks per inch. The fabrics were than pre-treated without singeing process according to industrial parameter in a local textile mill.

3.2 Chemicals

The chemicals used for experimentation were acquired from ARCHROMA Pakistan. The Appretan® N 9211 (a non-ionic acrylate copolymer dispersion, as self-crosslinking agent) was selected as anti-pilling agent.

The recipe of resin finished contains Arkofix® NF (DMDHEU based resin, a cyclic urea derivative in water), citric acid, Catalyst FM (inorganic salt- Magnesium Chloride solution in water, give better tear strength), and softener Ceralube® PIP (secondary polyethylene, non-ionic softener to improve tear strength and provide soft handle) [3].

3.3 Application Methods

The liquor for finishing was prepared in one bath. All chemicals, such as Appretan® N 9211, Arkofix® NF, Catalyst FM, citric acid and softener Ceralube® PIP weighed in particular concentration per litre and stirred thoroughly before padding. Three concentrations of Appretan® N 9211, Arkofix® NF 40, 100 and 150 g/L were selected. The concentration of Catalyst FM was taken as 25% of the concentration of Arkofix® NF in all recipes. The concentration of citric acid was kept 0.3 g/L and Ceralube® PIP was kept 20g/L in all recipes. The factors and their respective levels used in 23 32 Mixed Factorial were given in Table 1. The experiments were performed in order as mentioned in Table 3 which is provided as supplementary material.

The fabrics were finished using pad-dry- cure and pad-dry-shock cure method. In a pad-dry-cure, the fabric was padded at 80% pickup, dried at 130°C for 5 min and cured at 150°C for 3 min. In a pad-dry-shock cure, the fabric was padded at 80% pickup, dried at 130°C for 5 min and shock cured at 170°C for 30 seconds.

3.4 Evaluation of the Fabric

The rayon from 100% bamboo and 50/50 bamboo/cotton were evaluated using standard test procedures. The thirteen response variable namely; the Pilling Resistance before and after wash of the fabrics were tested by ISO 12945-2 [19], abrasion resistance at 2500 rubs by ISO 12947-2 [20], tensile strength by ISO 13934-2 [21], Tear Strength by ISO 13937-1 [22], dimensional stability by ISO 6330 5A (40°C) - tumble dry [23], Berger whiteness AATCC 110 [24], Yellowness Index by ASTM E-313-15 [25], smoothness appearance by AATCC 124 [26] and light fastness by ISO 105 BO2 [27]. Each response was tested with two replicates according to the standard test procedure. The testing was done in the laboratory maintained in standard atmospheric conditions of 65±2% relative humidity and 20±2°C temperature.

3.5 Experimental Design

A $2^3\,3^2$ mixed factorial design was selected to investigate the effect of influencing factors. The experimental model and their respective levels are given in Table 1, where Appretan® N921 is represented by (A), Arkofix® NF by (B), Fabric blend ratio by (C), Fabric weave by (D) and curing method by (E). According to the model 23 32, three factors C, D and E were tested at two levels and two factors A and B were tested at three levels. There were 72 runs, and each run was repeated two times, hence the total number of runs was 144. The trials have been carried out in random order corresponding to the design matrix shown in Table 3 (provided as supplementary material). The results were analysed and optimized using software Design Expert 8.0.1.

Table 1

The design factors and respective levels used in $2^3\,3^2$ Mixed Factorial

Factor	Name	Level		
A	Appretan® N9211	40 g/L	100 g/L	150 g/L
B	Arkofix® NF	40 g/L	100 g/L	150 g/L
C	fabric blend ratio	100% bamboo	50:50 bamboo/ cotton	-
D	Fabric weave	Plain	satin	-
E	curing method	normal cure	shock cure	-

4. Results and Discussion

The experiments were conducted as per 23 32 mixed factorial design and average results of thirteen responses are given in Table 3. The regression equations which are given to explain the relationship among the significant model terms are expressed in Eq. 6 to Eq. 17.

Y_1 (pilling resistance) = $+4.37 + 0.13\,A - 0.12C - 0.13D - 0.13E - 0.055AB + 0.13AD - 0.12CD - 0.13DE - 0.055ABE - 0.11CDE + 0.14A^2B - 0.086ABCE - 0.055ABDE + 0.14A^2BD - 0.11A^2BE - 0.086ABCDE - 0.14A^2BCE - 0.14A^2BCDE$ (6)

Y_2 (pilling resistance after 1st wash) = $+4.24 + 0.45A + 0.076B - 0.22C - 0.26\,D - 0.22E - 0.074AE + 3.776E + 0.076BD - 0.22CD - 0.21DE - 0.48A^2 + 0.13ABC - 0.077ADE + 0.081BCE - 0.18CDE - 0.48A^2D - 0.18AB^2 + 0.13ABCD + 0.079BCDE + 0.14A^2B^2 + 0.11A^2CE - 0.18AB^2D + 0.11B^2CD - 0.15A^2B^2C + 0.13A^2B^2D - 0.16A^2B^2CD$ (7)

Y_3 (warp tensile strength $= +228.65 + 1.25A - 10.31B - 27.04C - 5.98D + 4.36E + 2.29AB + 4.56AC + 5.73BC - 5.39CD - 12.49DE - 16.29A^2 - 6.76B^2 - 2.59ABC + 5.12ABD + 4.14ACE - 3.32ADE + 2.99BCD + 2.55BCE - 3.67BDE + 5.12A^2B + 6.46A^2C - 7.56A^2D - 4.21B^2D - 3.46ABCD + 2.35ABDE + 14.39A^2B^2 - 6.10A^2BC + 3.29\,A^2BD + 14.75A^2CD - 3.47AB^2C + 6.83B^2DE - 7.76A^2B^2C + 5.84A^2B^2D - 3.50A^2B^2E - 3.62A^2BCD - 6.91A^2BCE + 3.18A^2BDE - 2.40B^2CDE - 18.15A^2B^2CD + 5.23A^2B^2CE - 6.26A^2B^2DE$ (8)

Y_4 (weft tensile strength) = $+172.66 - 12.42B - 27.66C + 3.93AD + 2.77AE + 6.43BC - 12.15A^2 - 3.24ABC - 2.40CDE + 5.45A^2B + 5.18A^2C - 4.76AB^2 - 4.03ABCE + 3.41A^2CD - 3.86A^2DE +$

…(9)

Y_5 (warp tear strength) = $23.95 - 2.635A - 2.422B - 7.65C + 12.40D + 0.65AB + 0.71AC - 1.46AD + 1.02 - 1.45BD - 5.2CD - 1.59A^2 - 0.57B^2 + 0.26ABD + 0.43ACE + 0.76BCD + 1.28A^2B + 2.90A^2C - 1.45A^2D + 1.93B^2C + 0.328ABDE + 0.538ACDE + 1.27A^2B^2 - 1.18A^2BC + 0.99A^2BD - 0.42A^2BE + 2.51A^2CD + 1.85B^2CD - 2.701A^2B^2C + 0.86A^2B^2D - 1.045A^2BCD - 0.55A^2BDE + 0.75A^2CDE - 0.69AB^2CE - 2.53A^2B^2CD - 0.88AB^2CDE$ (10)

Y_6 (weft tear strength) = $+21.74 - 2.09A - 2.24B - 7.27C + 12.05D - 0.59E + 0.77AB + 1.18AC - 1.18AD - 0.52AE + 0.88BC - 1.56BD - 5.20CD + 0.76CE - 3.00A^2 - 1.12B^2 - 0.44ABC + 0.95ABD + 0.45ABE + 0.57ACD - 0.43ADE + 0.67BCD - 0.29BCE + 0.25BDE + 0.45CDE + 1.04A^2B + 2.80A^2C - 2.93A^2D + 0.86A^2E + 1.59B^2C - 1.08B^2D - 0.73ABCD + 0.36ABDE - 0.37BCDE + 2.45A^2B^2 - 0.63A^2BC + 0.93A^2BD + 2.23A^2CD - 0.36A^2CE + 1.45B^2CD - 0.51B^2CE - 2.84A^2B^2C + 2.40A^2B^2D + 0.51A^2BCE$ (11)

Y_7 (Berger whiteness) = $+64.87 - 0.99A - 2.01B + 4.12D - 0.91AC + 0.37AD - 2.73CD + 0.12CE + 0.63DE + 1.48A^2E + 1.24A^2BE + 1.37B^2CE + 2.32B^2DE - 1.20A^2BCD + 0.64A^2BCE + 0.43A^2BDE - 0.021A^2CDE - 0.97AB^2CD + 1.36AB^2CE - 1.42AB^2CDE$ (12)

Y_8 (yellowness index) = $+7.91 + 0.30A + 0.85B - 1.22D + 0.41AC + 0.98CD - 0.49A^2E - 0.53B^2C - 0.25ABCE - 0.25ABDE - 0.34ACDE - 0.30BCDE - 0.63B^2CD0.67B^2DE + 0.35AB^2CD + 0.59AB^2CDE$ …(13)

Y_9 (warp dimensional stability after 1st wash) = $-0.88 - 0.16A - 0.19B + 0.11C - 0.28D + 7.329E - 003E - 0.21AD - 0.20AE - 0.32BD + 0.35CD + 0.11DE - 0.020A^2 + 0.044ABC + 0.14ADE + 0.14BCE + 0.037CDE + 0.19A^2D + 0.35AB^2 - 0.014\,ABCD + 6.485E - 003BCDE + 0.20A^2B^2 + 0.12A^2CE + 0.23AB^2D - 0.18B^2CD - 0.30A^2B^2C - 0.25A^2B^2D + 0.14A^2B^2CD$ (14)

Y_{10} (Weft dimensional stability after 1st wash) = $-0.96 - 0.18B + 0.26A - 0.23BD - 0.39ACE + 0.26ADE - 0.23A^2BC - 0.26AB^2E + 0.32AB^2CE$ (15)

Y_{11} (smoothness appearance after 1st wash) = $+3.31 - 0.12D + -0.086AB + 0.052AC - 0.057BC + 0.13BD + 0.052CD + 0.050CE + 0.041DE - 0.089BCD + 0.041CDE$ (16)

Y_{12} (Light Fastness) = $+4.25 + -0.076AD - 0.18CD + 0.050ACE - 0.035BCD + 0.038BCDE + 0.099AB^2D - 0.078B^2CD$ (17)

To overcome the problem of conflicting responses for the development of anti-pilling and resin finished rayon from bamboo and bamboo/cotton woven fabrics, multi-response optimization has been used. In multi response optimization, desired weightage is given to all response variables. In the present study equal weightage (r) is given to get the desired results. The pilling before and after wash has been given maximum importance i.e. 5, Berger whiteness and yellowness index have given second highest importance i.e. 4 and rest of the other response variable has been kept at medium importance level. Correspondingly, combined effect of all response desirability is established for varying values of input parameters. Table 3 exhibited the range of input limits, target and weights ascribed to each parameter. The target value of Berger whiteness was set according to the industrial requirement for bleached fabric. Furthermore, same goal is set for rayon form 100% bamboo and 50:50 bamboo/cotton plain and satin due to the identical construction of the fabrics. The experiment data of light fastness shown in Table 3 exhibited that the value of light fastness ranges from 4 to 4/5 (grey scale). On contrary, for some recipes it varies from 3 to 3/5, therefore the goal for light fastness was set in range to obtain the high value of desirability. Furthermore, same goal is set for 100% bamboo and 50:50 bamboo/cotton plain and satin weave due to the identical construction of the fabrics.

Numerous options for optimization have been generated by using software, which includes level of input parameter that will give adequate overall desirability along with the values of response variables. The optimal parameters would be set as specified in Table 4 to maximize the overall desirability. The step comprises of setting the optimal input response variable level that has maximized the overall desirability. It is shown in Table 3 that for 100% bamboo satin, the option one at normal cure and option two at shock cure gives high pilling grade of 4/5 before and after wash and other associated response variables have almost same results. However, option one is selected because it requires less concentration of Appretan® N9211 and Arkofix® NF along with the high value of desirability. Similarly, for 100% bamboo among options five to eight, the normal cure (option five) is selected. Although in this option slightly higher concentration of Appretan® N9211 (7.4 g/L) is required as compared to option eight at shock cure. Nevertheless, normal cure option is selected because it gives increase value of Berger whiteness, reduces the yellowness index, and has high value of desirability.

In case of 50:50 bamboo/cotton, satin normal cure has given the best results. Among options nine and ten, the option nine is selected as it gives excellent pilling before and after wash which reduces yellowness index and concentration of binder and resin with high value of desirability.

For 50:50 bamboo/cotton among options eleven to twenty three, normal cure (option eighteen) is selected because of the same reason as mentioned for 100% bamboo plain fabric.

Since, type of weave and blend ratio are the two main qualitative factors, a single step optimization is difficult to achieve. Therefore, four best options for the satisfactory parameters to maximize the overall desirability for rayon from 100% bamboo and 50:50 bamboo/cotton plain and satin has been given in Table 5. The individual and combined desirability ratings for rayon from 100% bamboo cotton satin and plain and 50:50 bamboo/cotton satin and plain have been shown in Figure 1 to 4 respectively. The Design Expert software provides optimal designs with the desirability factor, which determines the optimal level for each factor as shown in the Figs. 5 to 8, for rayon from 100% bamboo cotton satin and plain and 50:50 bamboo/cotton satin and plain respectively. In Figs. 5 to 8, the mark with 'circle' and two ends on the line denote the current operating condition and its ranges.

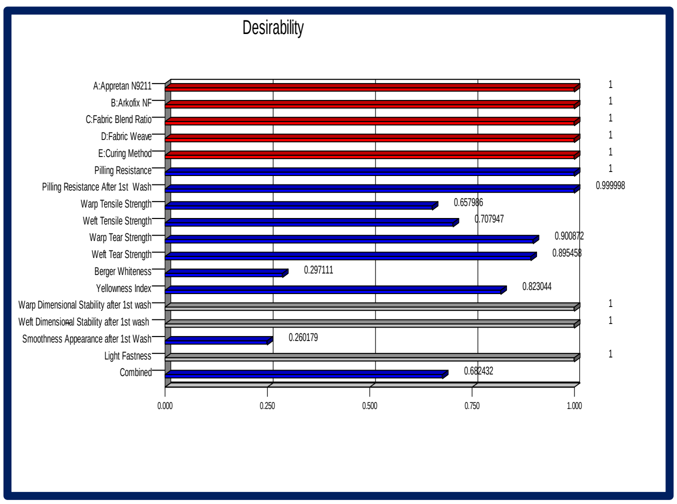

Fig. 1. Desirability ratings (individual and combined) for rayon from 100% bamboo satin

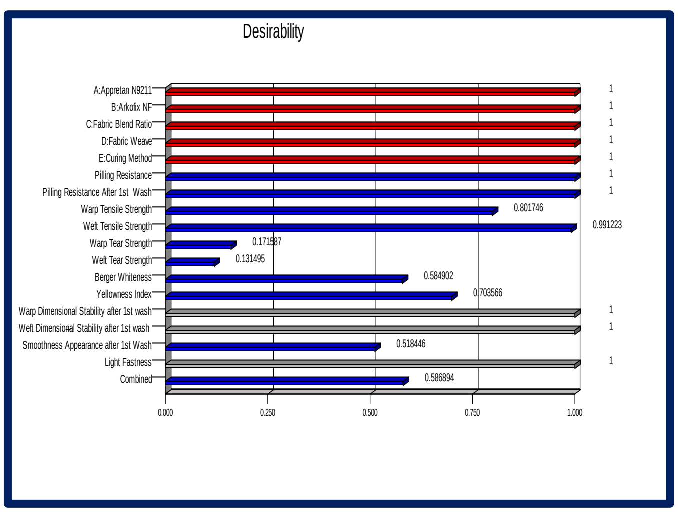

Fig. 2. Desirability ratings (individual and combined) for rayon from 100% bamboo plain

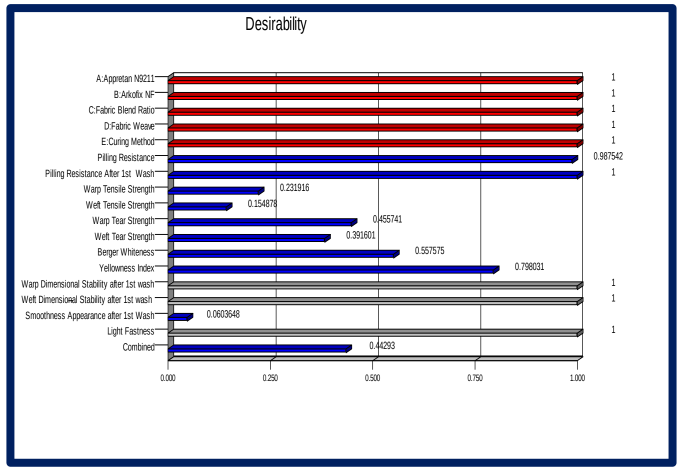

Fig. 3. Desirability ratings (individual and combined) for rayon from 50:50 bamboo/cotton satin

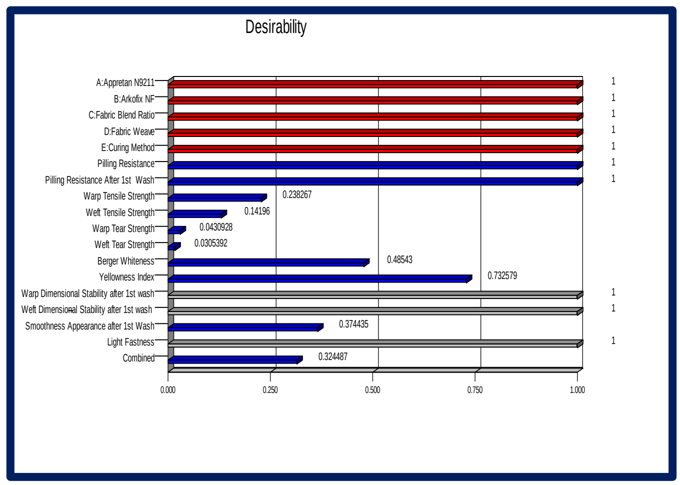

Fig. 4. Desirability ratings (individual and combined) for rayon from 50:50 bamboo/cotton plain

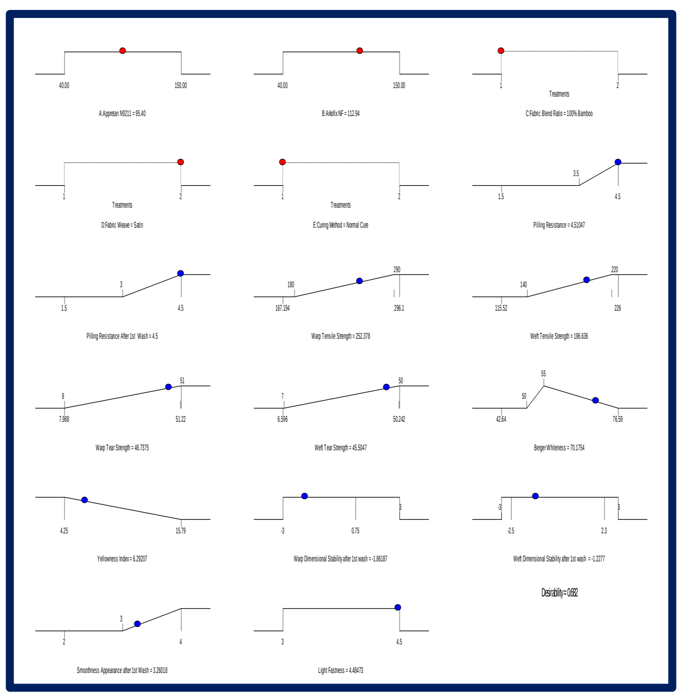

Fig. 5. Ramps for various factors of rayon from 100% Bamboo Satin

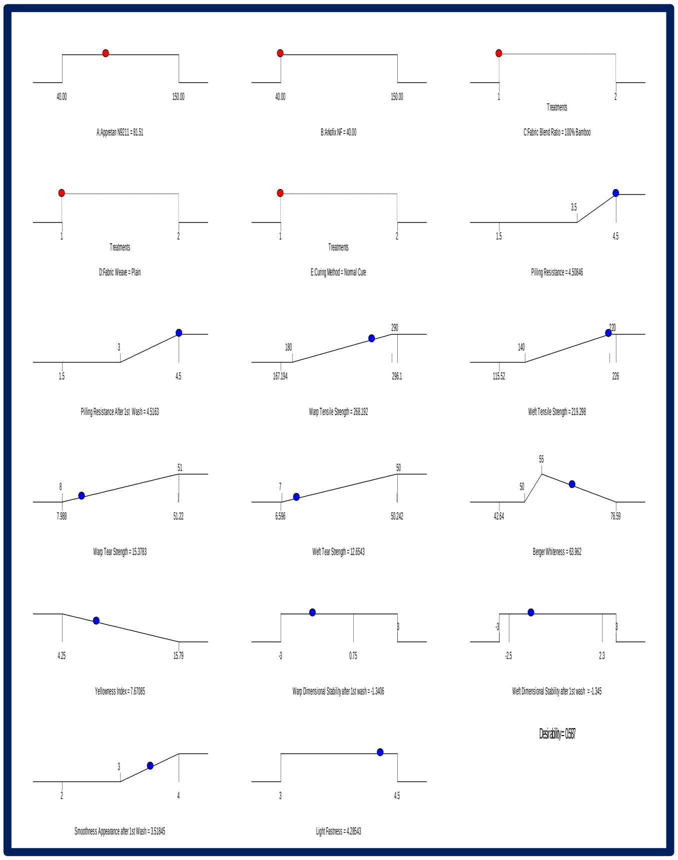

Fig. 6. Ramps for various factors of rayon from 100% bamboo plain

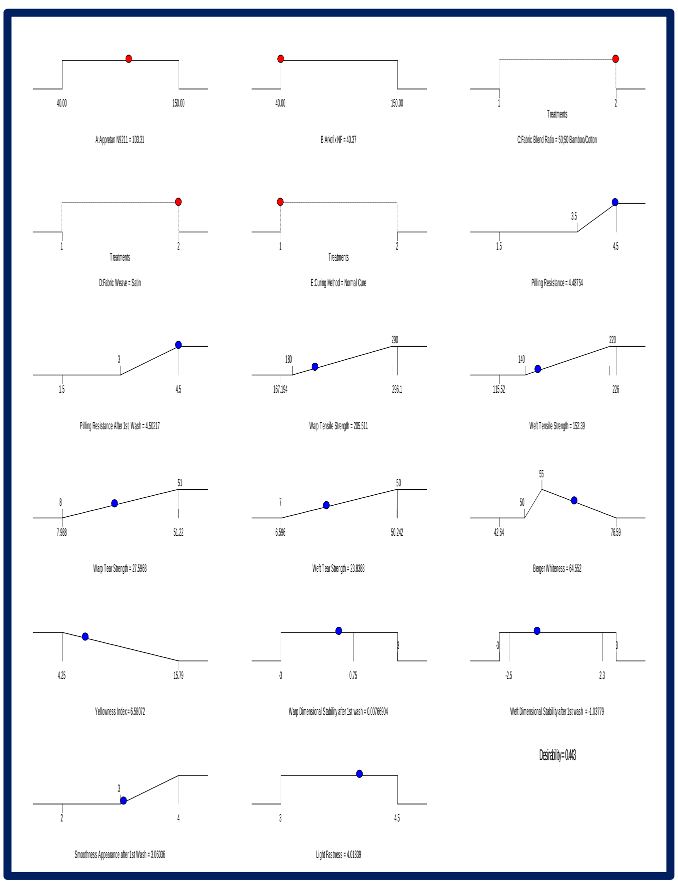

Fig. 7. Ramps for various factors of for rayon from 50:50 Bamboo/Cotton Satin

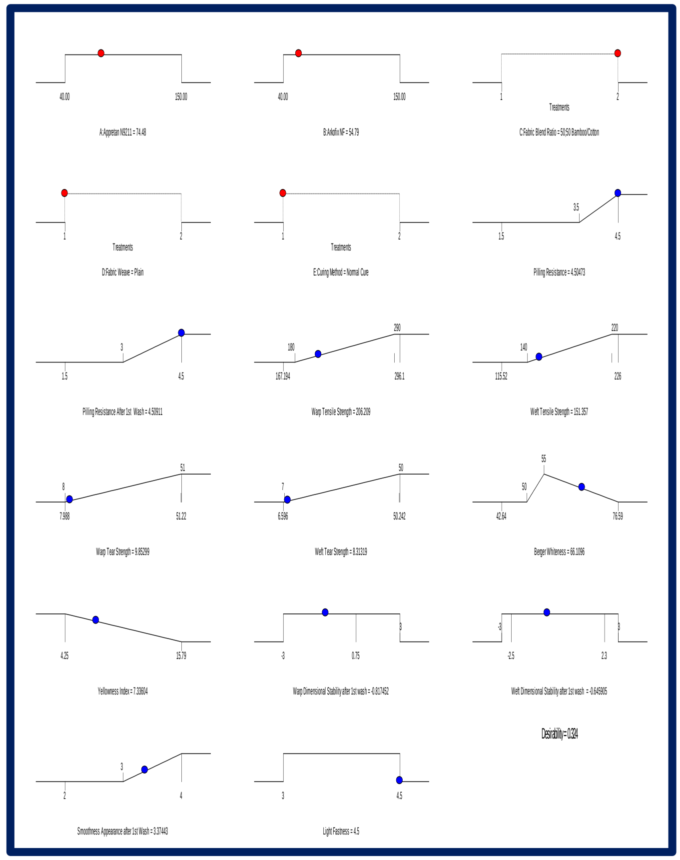

Fig. 8. Ramps for various factors of rayon from 50:50 Bamboo/Cotton Plain

5. Conclusion

This research work optimizes the process parameters for the development of rayon from 100% bamboo and 50:50 bamboo/cotton fabrics. The optimization was done by setting the goal for individual parameters and response variables. Using the Design Expert 8.0.1 twenty-three (23) different options were generated with input parameters along with the ranges of response variables that give overall acceptable value of desirability. Because of the qualitative nature of the two factors namely blend ratio and fabric weave four recipes each for rayon from 100% bamboo plain and satin and 50:50 bamboo/cotton plain and satin has been selected based on high desirability value. It is concluded that normal cure is the better option for the application of finish to get the improvement in pilling resistance, dimensional stability, smoothness appearance, Berger whiteness and other characteristics of the fabrics. Nevertheless, compared to satin fabric, plain fabric required less amount of Appretan® N9211 to attain the high pilling rating of Grade 4/5. In multi response optimization by desirability the targets, tolerance intervals and the associated weights of the response variables can be different as required by the textile industry.

Table 2

Specifications for optimized recipe

Parameters	100% bamboo		50:50 bamboo/cotton	
	Plain	Satin	Plain	Satin
Appretan® N9211	81.51	95.40	74.48	103.31
Arkofix® NF	40.00	112.94	54.79	40.37
Curing method	Normal cure	Normal cure	Normal cure	Normal cure
Desirability	0.59	0.68	0.32	0.44

Table 3

Selection of input parameters and responses

Constraints Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Appretan® N9211	is in range	40	150	1	1	3
B: Arkofix® NF	is in range	40	150	1	1	3
C: Fabric blend ratio	is in range	100% bamboo	50:50 bamboo/cotton	1	1	3
D: Fabric weave	is in range	Plain	Satin	1	1	3
E: Curing method	is in range	Normal cure	Shock cure	1	1	3
Pilling resistance	maximize	3.5	4/5	1	1	5
Pilling resistance after wash	maximize	3	4/5	1	1	5
Warp tensile strength	maximize	180	290	1	1	3
Weft tensile strength	maximize	140	220	1	1	3
Warp tear strength	maximize	8	51	1	1	3
Weft tear strength	maximize	7	50	1	1	3
Berger whiteness	is target = 55	50	76.59	1	1	4
Yellowness index	minimize	4.25	15.79	1	1	4
Warp dimensional stability	is in range	-3	3	1	1	3
Weft dimensional stability	is in range	-3	3	1	1	3
Smoothness appearance	maximize	3	4	1	1	3
Light fastness	is in range	3	4/5	1	1	3

Table 4

Input parameters for high value of desirability

S. No.	Appretan® N9211	Arkofix® NF	Fabric bend ratio	Fabric weave	Curing method	Pilling resistance	Pilling resistance after wash	Warp tensile strength	Weft tensile strength	Warp tear strength	Weft tear strength	Berger whiteness	Yellowness index	Warp DS	Weft DS	SA	Light fastness	Desirability
1	95.4	112.9	100% B	Satin	NC	4/5	4/5	252.4	196.6	46.8	45.5	70.2	6.3	-1.9	-1.2	3.3	4/5	0.68
2	102.2	122.4	100% B	Satin	SC	4/5	4/5	234.1	194.8	44.6	40.5	70.1	6.3	-1.9	-1.4	3.3	4/5	0.65
3	63.0	146.3	100% B	Satin	NC	4/5	4	212.0	182.7	43.0	38.9	66.8	7.4	-1.8	-1.2	3.4	4/5	0.62
4	53.5	150.0	100% B	Satin	NC	4/5	4	211.3	181.4	44.6	39.4	66.8	7.3	-1.6	-1.1	3.5	4/5	0.62
5	81.5	40.0	100% B	Plain	NC	4/5	4/5	268.2	219.3	15.4	12.7	64.0	7.7	-1.4	-1.3	3.5	4/5	0.59
6	80.7	40.0	100% B	Plain	NC	4/5	4/5	268.1	219.3	15.4	12.7	64.0	7.7	-1.3	-1.4	3.5	4/5	0.59
7	79.7	40.0	100% B	Plain	NC	4/5	4/5	268.0	219.4	15.4	12.7	64.0	7.7	-1.3	-1.4	3.5	4/5	0.59
8	74.1	49.1	100% B	Plain	SC	4/5	4/5	291.2	212.7	15.3	12.5	56.7	10.7	-1.0	-1.5	3.3	4	0.57
9	103.3	40.4	50:50 BC	Satin	NC	4/5	4/5	205.5	152.4	27.6	23.8	64.5	6.6	0.0	-1.0	3.1	4	0.44
10	150.0	150.0	50:50 BC	Satin	NC	4/5	4/5	194.4	149.4	21.4	17.0	57.2	10.9	-1.4	-0.9	3.1	4	0.41
11	74.5	54.8	50:50 BC	Plain	NC	4/5	4/5	206.2	151.4	10.0	8.3	66.1	7.3	-0.8	-0.6	3.4	4/5	0.32
12	75.0	54.9	50:50 BC	Plain	NC	4/5	4/5	206.2	151.4	9.8	8.3	66.1	7.3	-0.8	-0.6	3.4	4/5	0.32
13	73.8	54.7	50:50 BC	Plain	NC	4/5	4/5	206.1	151.2	9.9	8.3	66.1	7.3	-0.8	-0.6	3.4	4/5	0.32
14	75.6	54.9	50:50 BC	Plain	NC	4/5	4/5	206.3	151.6	9.8	8.3	66.1	7.3	-0.8	-0.6	3.4	4/5	0.32
15	69.6	54.3	50:50 BC	Plain	NC	4/5	4/5	205.6	150.8	10.0	8.4	66.0	7.3	-0.9	-0.6	3.4	4/5	0.32
16	80.9	55.5	50:50 BC	Plain	NC	4/5	4/5	206.6	151.8	9.7	8.2	66.1	7.3	-0.8	-0.6	3.4	4/5	0.32
17	40.0	150.0	50:50 BC	Plain	SC	4/5	4/5	200.0	162.4	10.2	7.8	57.8	10.6	-0.7	-1.0	3.3	4/5	0.32
18	57.1	53.2	50:50 BC	Plain	NC	4/5	4/5	203.2	148.4	10.3	8.5	65.6	7.5	-1.1	-0.6	3.3	4/5	0.32
19	120.1	40.0	50:50 BC	Plain	NC	4/5	4/5	200.5	149.5	9.4	7.9	65.1	7.7	-0.8	-0.6	3.5	4/5	0.30
20	85.9	62.5	50:50 BC	Plain	SC	4/5	4/5	217.2	144.4	9.6	8.0	64.7	7.9	-1.0	-0.8	3.4	4/5	0.29
21	124.8	55.9	50:50 BC	Plain	SC	4/5	4/5	220.3	143.4	9.5	7.8	64.1	8.1	-0.9	-0.8	3.5	4/5	0.29
22	150.0	134.4	50:50 BC	Plain	SC	4/5	4/5	198.4	140.9	8.4	7.5	59.1	10.	-0.3	-1.0	3.4	4/5	0.20
23	128.9	111.8	50:50 BC	Satin	SC	3/4	3	187.3	140.1	22.2	19.6	67.6	7.4	-0.6	-0.6	3.5	4	0.08

B=Bamboo, BC=Bamboo/cotton, NC=Normal cure, SC=Shock cure, DS=Dimensional stability and SA= Smoothness appearance

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