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STANDARDIZATION OF PROCESS VARIABLES FOR THE PRODUCTION OF BULKY VOID RAW SILK USING BIVOLTINE COCOONS AND INDIAN PVA YARN

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Abstract: Production of bulky silk is the need of the hour as the same is required for weft in the production of silk sarees. So far raw silk produced in charkha reeling device was used for the purpose. But due to non-availability of skilled labourers and improper working atmosphere in charkha reeling sector, alternative methods of production of bulky raw silk were thought off. In this context, introducing PVA yarn in the process of silk reeling has been developed by CSTRI by modifying the multiend reeling machine for the production of bulky void raw silk. The bivoltine cocoons along with Indian PVA yarn is used for the production of bulky silk. Using the Box and Behnken design of experiments the process variables viz., Number of cocoons, croissure length, reeling basin water temperature and reel speed have been standardized with 27 combinations of experiments. The study indicates that process variables significantly influence the reeling performance and quality of bulky void raw silk produced viz., reelability, non-broken filament length, single cocoon filament denier, raw silk percentage, average denier, cross section view of bulky void raw silk. Based on the response optimization in statistical analysis, it was observed that 20 bivoltine cocoons reeled per end along with Indian PVA yarn with 6 mm croissure length, 50°C basin temperature and reel speed of 100 m/min is ideal for the production of bulky void raw silk on modified CSTRI multiend reeling machine. The bulky void raw silk is quite useful as weft in the production of silk sarees with unique surface characteristics.

***Index Terms* - Bulky void raw silk, Indian PVA yarn, croissure length, Basin temperature and reel speed.**

I. INTRODUCTION

Indian silk reeling industry employs various reeling devices viz., Charka, Cottage basin, Domestic basin, Multiend reeling machines and Automatic silk reeling machines, for the production of raw silk. The raw silk produced from these reeling contrivances was utilized for the production of varieties of fabrics. However generally bulky raw silk is preferred as weft in silk saree production process. Till the recent past charkha reeling sector was catering to these requirements. But presently, the charkha sector is diminishing drastically due to non availability of skilled workers as well as difficult environmental conditions prevailing in the reeling units. Hence it was thought to produce bulky raw silk by introducing PVA yarn in the process of reeling cocoons, which will be subsequently removed while processing and only raw silk will prevail in the fabrics. The concept of introducing PVA yarns during the process of polyester yarn production as well as cotton spinning was tried by various researchers which has improved the characteristics and utility of the yarns to a great extent (Kothari, 2000, Ali Akbar Merrati et al., 2000 & 2001, Aneja, 2004 & 2007, Das et al, 2004, Debnath et al 2009, Jerzy Andrysiak, 2014). For this purpose, CSTRI has designed suitable modification in the Multiend reeling machine, so that PVA yarn having similar denier is introduced in the core and the silk cocoons are reeled around it. Since PVA yarn is water soluble, the yarn will directly pass through the jetteboutte from bottom of the basin through a pipe, as shown in line diagram in Fig. 1. A cabinet is designed so that PVA yarns will not come in contact with water during the process of reeling and fitted to multiend reeling machine as shown in Fig. 2. The bulky void raw silk thus produced was used as weft for the production of fabrics. The bulky voids silk yarn produced and the fabrics made are shown in Fig. 3 & 4. In the present study, standardization of reeling process parameters for the production of bulky void raw silk was studied with respect to reeling and quality parameters. For this purpose, PVA yarn was sourced from Mumbai (Indian PVA yarn) was used.

II. MATERIALS AND METHODS

2.1 PVA Yarn: The commercial PVA was sourced from Mumbai. The PVA yarn was tested for its characteristics and shown in Table 1. This yarn was used as core in reeling process for the production of void raw silk along with bivoltine cocoons.

2.2 Raw material: The commercial cocoons of bivoltine hybrid (CSR2 x CSR4 race) cocoons reared in Karnataka were used.

2.3 Drying conditions: The cocoons were dried in Batch type hot air drier following the temperature pattern of 110-100-85-70-55°C for bivoltine hybrid cocoons for a period of 5 hour. The degree of drying achieved was 39 - 42% for the cocoons.

2.4 Cooking conditions: The hot air dried cocoons were cooked using two-pan system following the temperature profiles and durations viz., Retting at 70°C for 60 seconds, High temperature for permeation at 96°C for 90 seconds, low temperature for permeation at 70°C for 60 seconds, cooking at 98°C for 90 seconds, stop steam for 20 seconds and adjustment from 98 ~ 70°C for 60 seconds by pouring cold water. The cooked cocoons were brushed at 80°C manually using paddy husk brush.

2.5 Reeling conditions: 300 good cocoons picked from the brushed cocoons were selected for reeling test and then reeled on newly modified multiend reeling machine as per the design of experiment by maintaining different basin water temperature, reel speed, croissure length and number of cocoons per end. The Indian PVA yarn is used as core. The reeling characteristics viz., Reelability%, Average filament length, Non-breakable filament length, Single cocoon filament denier, raw silk percentage and waste percentage on silk weight were recorded (Somashekar & Kawakami, 2003). The actual formulas used for the calculation of these characteristics based on the data collected are given below.

$$\text{Groping (\%)} = \frac{\text{Total no. of cocoons taken for reeling} - \text{Cocoons dropped in 1}^{st}\text{ cooking}}{\text{Total no. of cocoons taken for reeling}} \times 100 \qquad (1)$$

$$\text{Reelability (\%)} = \frac{\text{Number of reeling cocoons}}{\text{Number of feeding ends}} \times 100 \qquad (2)$$

$$\text{Average filament length (m)} = \frac{\text{Length of the raw silk reeled} \times \text{No. of cocoons maintained /end}}{\text{No. of reeling cocoons}} \qquad (3)$$

$$\text{Non broken filament length (m)} = \frac{\text{Length of the silk reeled} \times \text{No. of cocoons maintained /end}}{\text{No. of feeding end}} \qquad (4)$$

$$\text{Single cocoon filament denier} = \frac{\text{Weight of raw silk reeled} \times 9000}{\text{Length of the silk reeled} \times \text{No. of cocoons maintained/end}} \qquad (5)$$

$$\text{Raw silk (\%)} = \frac{\text{Weight of raw silk reeled}}{\text{Weight of cocoons taken for reeling}} \times 100 \qquad (6)$$

$$\text{Waste \% on silk weight} = \frac{\text{Total cooking and reeling waste weight}}{\text{Weight of raw silk reeled}} \times 100 \qquad (7)$$

2.6 Silk quality testing: The raw silk reeled was used for assessing the microscopic structure and tensile quality characteristics. The quality characteristics viz., average denier, tenacity and elongation were determined using Instron tensile testing machine following standard procedures [Bureau of Indian standards, 2002] and microscopic characteristics viz., cross section, longitudinal section were measured using Stereoscopic microscope type: 7004:D:TNC/BNC.

2.7 Data analysis: The reeling and quality characteristics data thus obtained were analyzed statistically using SPSS package.

III. RESULTS AND DISCUSSION

In order to standardize the process parameters for the production of new yarn (bulky void raw silk) on the modified multiend reeling machine this experiment was taken up. For this purpose, the process variables like croissure length, reel speed, basin water temperature and number of cocoons reeled was altered as per the Box and Behnken design of experiment. The variables selected for the study are given in Table 2.

Box and Behnken design of experiment has been adopted to formulate the experimental design in which 27 different combination are formed. This method also offers the advantage of being rotatable which mean the fitted modal estimates the precision at all points in the factor space that are estimated from the centre.

A quadratic polynomial was used to analyze the relationship of each response with the four independent variables as given below.

$$Y = bo + \sum_{i=1} bixi + \sum_{i=1} bixi^2 + \sum_{\substack{i=1 \\ i<j}} bijxixj + \sum_{j<k} \quad (8)$$

Where bo, bi, bii, bij are the coefficient of the regression equations. The i and j are the integers and y is the response of the dependent variable. The actual factor levels for the Box-Behnken designs with four factors are given in Table 3. Influence of factors of void raw silk production on reeling and yarn characteristics using Box and Behnken design of experiment is given in Tables 4 & 5 and the response surface equations derived from the analysis of reeling and yarn properties of void raw silk are given in Table 6.

3.1 Influence of process parameters of production of bulky void raw silk on reeling and quality characteristics: Tables 4 & 5 shows the various reeling and quality characteristics of bulky void raw silk at different croissure length, basin water temperature, reel speeds and number cocoons reeled. The response surface equations of various reeling parameters viz., Reelability percentage (y1), non broken filament length (y2), single cocoon filament denier (y3), raw silk percentage (y4) and quality parameters viz., average denier (y5) and yarn cross section (y6) are having significant influence on process variables viz., number of cocoons (x1), croissure length (x2), reel speed (x3) and basin water temperature (x4) are given in Table 6. The estimated regression equation was evaluated in terms of Fisher's test (p-value) and multiple correlations co-efficient (R^2). However, the other characteristics selected in the study do not show any significant influence on the process parameters.

3.1.1 Reelability: From the Table 4, it could be observed that reelability % varied from 66.4 to 90.8 for various process variables. The estimated regression co-efficient of reelability showed a significant influence on process variables. The analysis of variance of the regression co-efficient has shown dependence on croissure length and number of cocoons at 5% level. The response surface equation of reelability with process variables has shown R^2 of 87.42% (Table 6). The contour plot for the variable reelability percentage of bulky void raw silk is shown in Fig. 4a. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.637. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 1% level and having the p value of 0.000.

3.1.2 Non broken filament length: From the Table 4, it could be observed that non broken filament length varied from 597m to 870m for various process variables. The estimated regression co-efficient of non broken filament length has showed significant influence on process variables. The analysis of variance of the regression co-efficient has shown dependence on number of cocoons at 5% level. The response surface equation of the non broken filament length with process variables has shown R^2 of 75.7% (Table 6). The contour plot for the variable non broken filament length of bulky void raw silk is shown in Fig. 4b. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.408. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 1% level and having the p value of 0.019.

3.1.3 Single cocoon filament denier: From the Table 4, it could be observed that single cocoon filament denier varied from 6.14 to 15.71 for various process variables, due to the presence of PVA yarn. The estimated regression co-efficient of single cocoon filament denier has showed significant influence on process variables. The analysis of variance of the regression co-efficient has shown dependence on number of cocoons at 1% level. The response surface equation of the single cocoon filament denier with process variables has shown R^2 of 91.74% (Table 6). The contour plot for the variable single cocoon filament denier of bulky void raw silk is shown in Fig. 4c. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.001. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 1% level and having the p value of 0.000.

3.1.4 Raw silk percentage: From the Table 4, it could be observed that raw silk percentage on silk weight varied from 84% to 177% for various process variables. Higher raw silk percentage is because the yarn consists of silk and PVA. The estimated regression co-efficient on raw silk percentage has shown significant influence with number of cocoons and interaction effect of croissure length and reel speed. The analysis of variance of the regression co-efficient has shown dependence on second order polynomial equation at 5% level. The response surface equation of raw silk percentage with process variables has shown R^2 of 85.8% (Table 6). The contour plot for the variable raw silk percentage of bulky void raw silk is shown in Fig. 4d. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.191. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 1% level and having the p value of 0.000.

3.1.5 Average denier: Average denier of bulky void raw silk, which consists of both raw silk denier and PVA yarn denier values varied from 116 to 176 denier for various process variables used in the study (Table 5). The estimated regression co-efficient of average size showed significant influence on number of cocoons reeled at 5% level. The response surface equation of average size with process variables has shown R^2 of 75.57% (Table 6). The contour plot for the variable average size of bulky void raw silk is shown in Fig. 4e. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.814. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 1% level and having the p value of 0.003.

3.1.6 Microscopic cross section: The cross section of bulky void raw silk showed values varying from 146 to 236 microns for various process variables as could be seen in Table 5. The contour plot and the surface plot for the variable yarn thickness of bulky void raw silk are shown in Fig. 4f. The model summary suggests that the model is adequately fit the data with the p value for lack of fit being 0.487. From the analysis of variance results it is observed that the regression equation indicates the linear effect is significant at 5% level and having the p value of 0.001. The response surface equation of microscopic cross section with process variables has shown R^2 of 84.79% (Table 6). Thus indicating that the process variable number of cocoon reeled, significantly influence the bulkiness characteristics of void raw silk.

IV. CONCLUSION

Based on the studies conducted for standardization of bulky silk production parameters using Box and Behnken design of experiments, using SPSS statistical package, response optimizer was used and it was optimized that 20 bivoltine cocoons reeled per end along with Indian PVA yarn with 6 mm croissure length, 50°C basin temperature and reel speed of 100 m/min is ideal for the production void raw silk on modified multiend reeling machine in order to get the optimized characteristics of bulky void raw silk using Indian PVA yarn.

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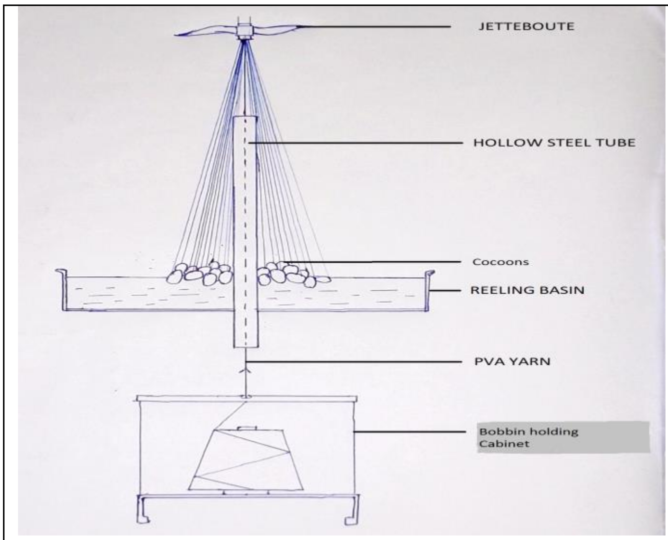

Fig. 1. Line diagram of yarn passage of PVA yarn during the process of bulky void raw silk reeling.

Fig. 2. Modified multiend reeling machine for the production of bulky void raw silk yarn along with PVA yarn.

Fig. 3 a. The bulky void raw silk yarn produced with 20 cocoons and Indian PVA yarn.

Fig. 3 b. Processed bulky void raw silk fabrics with unique appearance.

Table 1: Characteristics of Indian PVA yarn

Type	Temperature of dissolving	Size of yarn (T – d tex)	Tenacity (cN / d tex)	Elongation (%)
Indian SH	90° C	31T	2.2 ~ 3.2	11 ~ 21

Table 2: Parameters used for the study

Raw material	Bivoltine cocoons
Reel speed	80 ~ 120 RPM
Croissure length	2 ~ 10 cm
Basin water temperature	40 ~ 60° C
Number of cocoons	10 ~ 30
Data collected	Reelability%, Average filament length, Non-breakable filament length, Single cocoon filament denier, Raw silk percentage, Waste % on silk weight, Average denier, Maximum load, Tenacity, Elongation and Yarn cross section, longitudinal view characteristics.

Table 3: Actual factor level for the Box-Behnken designs with four factors

Run order	No. of cocoons	Croissure length in cm	Reel speed in RPM	Basin water temperature (°C)
1	20	2	80	50
2	30	6	100	60
3	20	6	100	50
4	20	10	120	50
5	20	2	120	50
6	20	6	120	40
7	20	10	80	50
8	30	6	120	50
9	30	2	100	50
10	20	2	100	60
11	10	6	100	60
12	10	6	120	50
13	30	6	100	40
14	20	10	100	40
15	20	6	80	40
16	20	2	100	40
17	10	6	80	50
18	10	10	100	50
19	10	2	100	50
20	30	10	100	50
21	20	6	100	50
22	30	6	80	50
23	20	6	100	50
24	20	6	120	60
25	20	6	80	60
26	10	6	100	40
27	20	10	100	60

Table 4: Influence of process parameters of production of bulky void raw silk on reeling characteristics

Run order	Groping end (%)	Reelability (%)	Average filament length (m)	Non-broken filament length (m)	Single cocoon filament denier	Raw Silk (%)	Waste (%) on silk weight
1	94	73.6	1013	730	7.7	107.5	12.6
2	94	68.1	900	600	6.63	84.0	12.4
3	92	69.1	958	634	7.83	102.2	11.4
4	86	72.9	957	675	7.85	105.8	11.3
5	88	76.2	983	725	6.92	94.7	13.3
6	88	68.9	973	649	7.5	100.6	12.3
7	88	74.8	980	710	6.69	93.2	11.3
8	90	71.3	937	661	6.76	89.1	11.0
9	88	66.4	993	638	6.21	85.1	10.7
10	90	72.3	1066	746	7.14	106.1	10.0
11	92	79.8	938	733	11.87	155.0	13.5
12	89	83.8	1038	870	10.53	160.3	14.4
13	94	67.2	955	628	6.39	85.9	10.0
14	90	72.7	981	706	7.53	107.3	17.1
15	92	75.0	1056	765	7.15	101.8	12.3
16	88	74.2	960	705	7.73	107.8	12.9
17	94	76.2	995	742	12.4	177.3	12.5
18	95	79.2	778	597	15.71	168.5	15.9
19	92	86.0	982	836	11.81	168.4	11.7
20	94	75.4	994	733	6.14	85.0	20.0
21	85	73.7	963	695	7.89	109.1	12.9
22	95	70.1	1051	712	6.37	90.3	12.1
23	96	75.0	969	704	7.89	108.7	10.0
24	88	72.5	946	657	7.63	100.5	13.8
25	90	70.4	938	653	8.16	111.2	13.3
26	97	90.8	930	836	10.37	140.7	9.8
27	95	75.4	959	701	7.41	101.1	12.8

Table 5: Influence of process parameters of production of bulky void raw silk on quality characteristics

Run order	Denier of raw silk	Max. Load (gf)	Tenacity (g/d)	Elongation (%)	Cross section view (Microns)	Longitudinal view (Microns)
1	138.1	263.4	1.9	20.2	192.1	220.8
2	176.4	431.4	2.4	19	228.0	296.2
3	155.8	339.2	2.2	17.4	167.9	205.3
4	158.3	336.3	2.2	20.2	177.7	199.3
5	144	329	2.3	19.5	186.4	233.5
6	141.2	312.6	2.2	16.1	199.5	217.2
7	147.5	370	2.5	23	171.3	217.0
8	167.1	380.8	2.3	17.8	210.8	247.5
9	171.6	402	2.3	20.3	184.6	185.8
10	143.4	319.1	2.2	18.4	224.8	211.1
11	118.8	268.2	2.3	17.9	153.1	220.4
12	116.4	251.7	2.2	17.7	168.3	232.9
13	161.6	352.4	2.2	17.4	192.8	146.9
14	139.6	309.5	2.2	17.8	235.6	286.7
15	172.1	415.5	2.4	19.7	213.5	267.4
16	137.8	285.4	2.1	18	162.4	257.4
17	123.5	238.8	1.9	18.1	154.4	232.6
18	116.8	182.4	1.6	15.7	165.2	196.0
19	125.2	218.4	1.7	17.9	146.1	256.8
20	166.8	369.9	2.2	17.9	208.3	350.7
21	143.9	243.9	1.7	16.9	173.4	263.6
22	164.9	326.3	2	16	209.0	311.9
23	120.7	374.8	3.1	17.7	191.7	237.1
24	144.6	330.7	2.3	17.8	212.5	206.6
25	174.2	432.3	2.5	21.4	211.1	261.7
26	152.4	230.4	1.5	17	162.4	215.5
27	155.3	347.9	2.2	18.4	210.0	265.5

Table 6: Response surface equations of reeling and quality characteristics of bulky void raw silk

Property	*Regression equation*	R^2 (%)
Reelability % (Y1),	Y1 = 170.7 - 3.24 XI - 2.98 X2 - 0.091 X3 - 1.80 X4 + 0.0326 X1*X1 + 0.0860 X2*X2 - 0.00079 X3*X3 - 0.0009 X4*X4 + 0.0986 X1*X2 - 0.00796 X1*X3 + 0.0299 X1*X4 - 0.0143 X2*X3 + 0.0286 X2*X4 + 0.01033 X3*X4	**87.42**
Non Broken filament length (Y2),	Y2 = 2191 - 15.2 X1 - 34.8 X2 - 13.3 X3 - 18.6 X4 + 0.258 X1*X1 + 0.95 X2*X2 + 0.0528 X3*X3 - 0.001 X4*X4 + 2.088 X1*X2 - 0.224 X1*X3 + 0.188 X1*X4 - 0.094 X2*X3 - 0.287 X2*X4 + 0.150 X3*X4	**75.71**
Single cocoon filament denier (Y3).	Y3 = 0.6 - 0.903 X1 - 0.224 X2 + 0.125 X3 + 0.528 X4 + 0.01605 X1*X1 + 0.0039 X2*X2 - 0.00084 X3*X3 - 0.00355 X4*X4 - 0.0248 X1*X2 + 0.00283 X1*X3 - 0.00315 X1*X4 + 0.00606 X2*X3 + 0.0029 X2*X4 - 0.00110 X3*X4	**91.74**
Raw silk % (Y4),	Y4 - 128 - 11.40 X1 - 6.15 X2 - 0.19 X3 + 6.51 X4 + 0.1921 X1*X1 - 0.043 X2*X2 - 0.00107 X3*X3 - 0.0424 X4*X4 - 0.0013 X1*X2 + 0.0198 X1*X3 - 0.0403 X1*X4 + 0.0792 X2*X3 - 0.0282 X2*X4 - 0.0118 X3*X4	**96.54**
Average Denier (d) (Y5),	Y5 = 666 - 5.98 X1 - 4.4 X2 - 3.45 X3 - 11.77 X4 + 0.0189 X1*X1 - 0.016 X2*X2 + 0.0142 X3*X3 + 0.0887 X4*X4 + 0.022 X1*X2 + 0.0116 X1*X3 + 0.1210 X1*X4 + 0.0153 X2*X3 + 0.063 X2*X4 + 0.0016 X3*X4	**75.57**
Microscopic cross section (Microns) (Y7)	Y7 = 853 + 0.84 X1 + 22.1 X2 - 5.23 X3 - 21.31 X4 - 0.0677 X1*X1 + 0.213 X2*X2 + 0.0217 X3*X3 + 0.2105 X4*X4 + 0.029 X1*X2 - 0.0151 X1*X3 + 0.1115 X1*X4 + 0.0379 X2*X3 - 0.550 X2*X4 + 0.0194 X3*X4	**84.79**

Note: X1 = No of cocoons, X2 = Croissure length, X3 = Reel speed, X4 = Basin temperature.

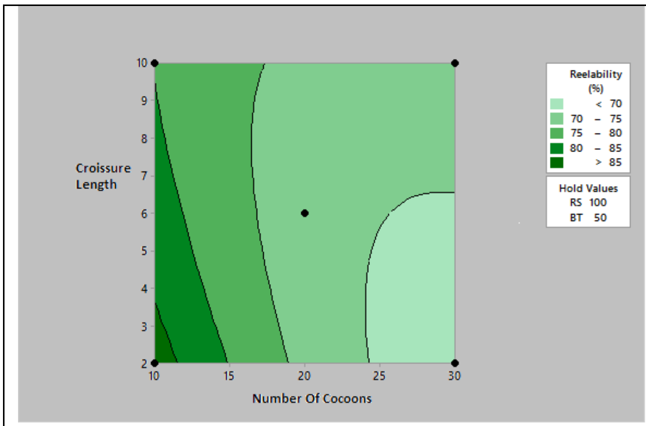

Fig. 4a. The contour plot of reelability with reference to **number of cocoons reeled for production of** void **raw silk.**

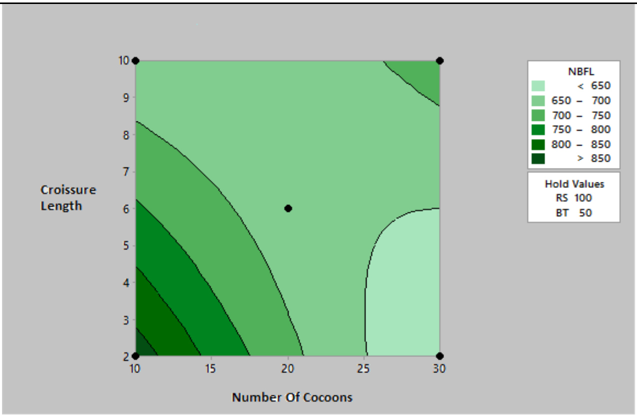

Fig. 4b. The contour plot of non broken filament length with reference to **number of cocoons reeled for production of** void **raw silk.**

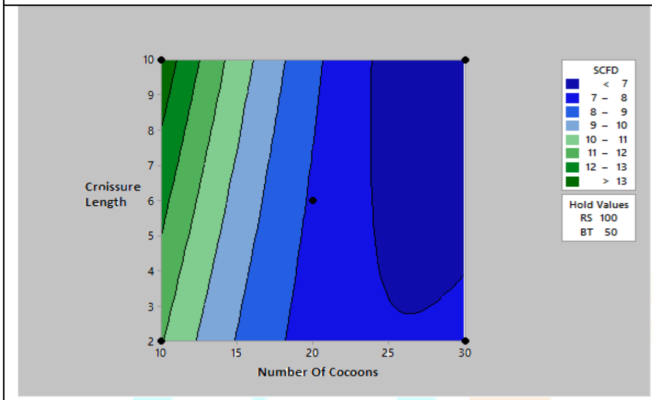

Fig. 4c. The contour plot of single cocoon filament denier reference to **number of cocoons reeled for production of** void **raw silk.**

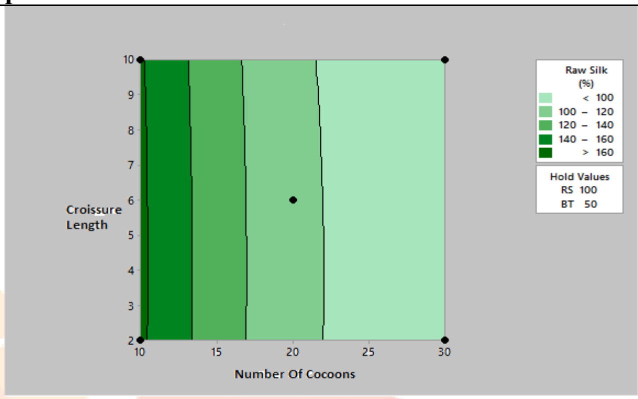

Fig. 4d. The counter plot of raw silk percentage with reference to **number of cocoons reeled for production of** void **raw silk.**

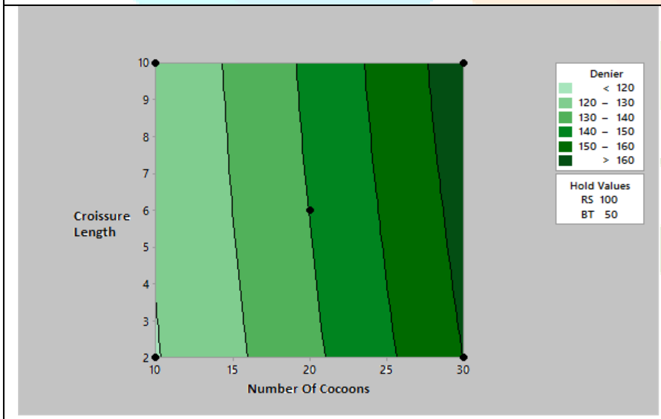

Fig. 4e. The counter plot of **denier of silk** with reference to **number of cocoons reeled for production of** void **raw silk.**

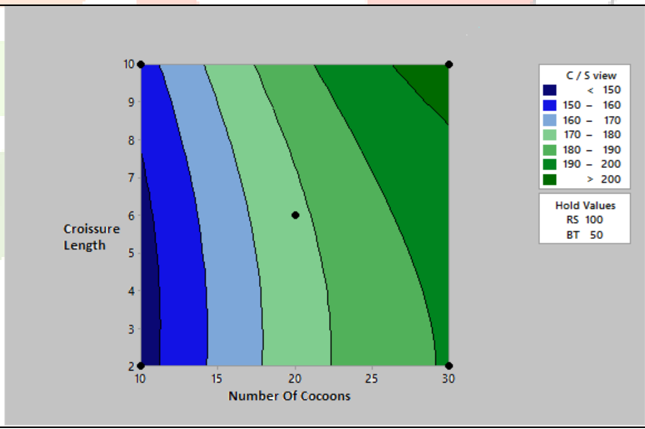

Fig. 4f. The contour plot of cross section of yarn with reference to number of cocoons reeled and croissure length for production of void raw silk.