Indian Journal of Fibre & Textile Research
Vol. 43, September 2018, pp. 295-300

Effect of spinning process parameters on mélange yarn quality by Taguchi experimental design

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Received 30 January 2017; accepted 24 March 2017

The important yarn quality parameters, like evenness, imperfection, hairiness, strength and breaking elongation percentage, of blow-room blended cotton mélange yarn have been studied using Taguchi experimental design. The impacts of process parameters, such as shade depth (%), twist multiplier and ring frame spindle speed, have been studied in presence of two unavoidable and uncontrolled noise parameters. The experimental results show that the mélange yarn quality parameters are significantly affected by shade depth and ring frame spindle speed. A ranking of the three controlled parameters and the percentage contribution of each of these parameters have also been evaluated. The shade depth is found most dominating factor affecting cotton mélange yarn quality. The set of optimum parameters that correspond to the highest S/N ratio of evenness, imperfections, hairiness, strength and breaking elongation percentage have also been determined.

Keywords*:* Cotton fibre, Mélange yarn, Shade depth, S/N ratio, Twist multiplier, Yarn imperfection

1 Introduction

Mélange yarns are known for their attractive appearance due to the unique colour effect which is produced by mixing two or more different coloured fibres at different ratios. Coloured spun yarns are mainly manufactured by conventional ring spinning system which is known to have lower production efficiency[1]. Thilak and Saravanan[2] proposed that textile materials are being consumed at higher rates due to special appearance and obsolescence of fashion. Haofei *et al.*[3] has described the optimal dyeing systems for resistance to the physical strength loss during dyeing. Some studies have been reported on the impact of dyeing parameters, and stages of dyed fibre mixing on mélange yarn quality characteristics[4-9]. Cotton fibres entangle at greater extend during fibre dyeing process and hence subsequent intense mechanical process involved during yarn manufacturing leads to more fibre damage, making the mélange yarn manufacturing process more difficult[4,7]. Ishtiaque and Das[5] have observed that each stage of mechanical processing consistently deteriorates the dyed fibre length and related parameters at rotor spinning process. Hafeezullah *et al.*[6] have studied the impact of cotton fibre dyeing parameters on mélange yarn quality parameters like yarn evenness, nep count, hairiness & tenacity, and concluded that the optimization of cotton fibre dyeing parameters is important for better mélange yarn quality. Behera *et al.*[8] have explained that melange yarns can be produced either by adding different coloured fibres in blow room or by adding different coloured carded sliver with grey sliver in draw frame. Ishtiaque *et al.*[9] have reported on the optimization of different ring frame process parameters for better yarn quality and production. They have concluded that the yarn unevenness, imperfections and hairiness increase with the increase of spindle speed. Most of the researchers who had worked on mélange yarn qualities are primarily concerned with dyeing parameters and stages of dyed fibre mixing. However, no study has been reported on the individual and interactive effect of raw material, spinning process parameter and productivity on mélange yarn qualities. Therefore, in this study an attempt has been made to study the effect of raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) on mélange yarn qualities using Taguchi experimental design. Two noise parameters, namely spinning position in the ring frame and yarn position at ring frame bobbins have been considered.

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2 Materials and Methods

2.1 Materials

Grey and black dyed combed Sankar 6 cotton fibres have been used to produce 20^s Ne mélange yarns. Dyed fibres were opened using Mixing Bale Opener (MBO) and then blended by weight with grey fibres in a Tuft Blender. In case of mélange yarn production, the dyed fibre percentage in the mixing is commonly known as shade percentage or shade depth (%). The mixing of dyed and grey fibres was done at blow room stage to produce 'blow room blended mélange yarn'. Three controlled factors, namely shade depth (%), yarn twist multiplier (TM) and ring frame spindle speed (rpm) were chosen and for each factor three levels were selected. Two different noise parameters were considered in this study, i.e. samples were made at two different positions of the ring frame (gear side and fan side) and at two positions of the bobbin (top and bottom). Yarn samples were prepared in a conventional ring spinning system according to the L9 orthogonal array as shown in Table 1. The controlled factors X_1, X_2 and X_3 correspond to shade depth (%), TM and spindle speed (rpm) respectively. For each of the experimental run, two noise factors each at two levels produce four repetitions. Therefore, total number of samples was 9 × 4 = 36. The actual values of the controlled and noise factors corresponding to their coded levels are shown in Table 2.

2.2 Testing

All the thirty six yarn samples were conditioned at standard temperature of 27±2°C and relative humidity of 65±4% for 24 h. Subsequently, the samples were evaluated for yarn evenness (U %), imperfections (IPI), hairiness index (HI), strength (cN/tex) and breaking elongation (%). Yarn U%, IPI and HI were examined by a capacitance based evenness tester USTER-4 with yarn withdrawal speed of 400 m/min and testing time of 1 min. For each of 36 yarn types, 10 readings were taken for measuring the average U%, IPI and HI. The tensile properties of yarns were tested by Uster Tensojet using the specimen test length of 500 mm, extension rate of 400 m/min and pre-tension of 0.5 cN/tex. Average yarn strength and breaking elongation were estimated for each type of yarn based on 100 tests.

Table 1 — L9 (3^3) orthogonal array

Experimental run	Controlled factor			Noise factor	
	X_1	X_2	X_3	Machine end	Bobbin position
1	-1	-1	-1	±1	±1
2	-1	0	0	±1	±1
3	-1	+1	+1	±1	±1
4	0	-1	0	±1	±1
5	0	0	+1	±1	±1
6	0	+1	-1	±1	±1
7	+1	-1	+1	±1	±1
8	+1	0	-1	±1	±1
9	+1	+1	0	±1	±1

2.3 Analysis of Response

The Taguchi method is a statistical approach developed by Genichi Taguchi[10]. This method has become an important tool in engineering for improving the quality of manufactured products by minimizing the effect of causes of variation. In this method, a special set of arrays known as orthogonal arrays and signal to noise ratio (S/N) are used. In orthogonal array, combination of a set of arrays of parameters and levels are used to conduct minimum number of experiments to provide complete information of all the parameters that influence the response. A typical L9 orthogonal array is shown in Table 1 with three parameters, each having three levels. The outputs of the experiments are then transformed into a signal to noise ratio (S/N ratio) that represents the ratio of sensitivity to variability. Higher S/N ratio indicates better quality. The S/N needs to be maximized in order to minimize the effect of noise. The S/N ratio is calculated using the following equations based on whether the response parameters are 'nominal-the-best', 'larger-the-better', or 'smaller-the-better'[10-12], as shown below:

Nominal the best

$$\frac{S}{N} = 10\log\left[\frac{\bar{y}}{S_y^2}\right] \quad \text{... (1)}$$

Table 2 — Controlled and noise factors and their levels

Factors	Coded level		
	-1	0	+1
Controlled factor			
Shade depth, % (X_1)	10	40	70
Twist multiplier (TM) (X_2)	3.5	3.7	3.9
Spindle speed, rpm (X_3)	12500	13500	14500
Noise factor			
Machine end	Motor	—	Gear
Bobbin position	Top	—	Bottom

Larger the better

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad \text{... (2)}$$

Smaller the better

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \quad \text{... (3)}$$

where $\bar{y}$ is the mean of observed data; S_y^2, the variance of *y; n,* the number of experiments in the orthogonal array; and y_i , the i^{th} value measured.

In the present work, S/N ratios of the yarn U%, IPI and HI have been calculated using Eq. (3) for 'smaller-the-better', whereas that of yarn strength and breaking elongation (%) have been calculated using Eq. (2) for 'higher-the-better'. The optimum level for each response is the level at which the S/N ratio is maximum. An ANOVA analysis of the S/N ratio is also done to understand the percentage contribution of each controlled parameter.

3 Results and Discussion

3.1 Yarn Strength and Breaking Elongation

The experimental results of average yarn strength and breaking elongation with their calculated S/N ratios (larger-the-better) are shown in Table 3. It is observed that the maximum S/N ratio for yarn strength is 26.24 and that for breaking elongation is 13.24. The combination of parameters for maximum S/N ratio for yarn strength is 10% (shade depth), 3.9 (TM) and 14500 rpm (spindle speed), and that for the breaking elongation is 40% , 3.9, 12500 rpm for shade depth, TM and spindle speed respectively.

The response of S/N ratios of yarn strength and breaking elongation are shown in Table 4. The summary of ANOVA conducted on S/N ratios of yarn strength and breaking elongation along with the percentage contributions of different parameters are shown in Table 5. It is obvious that the shade depth (%) is the most dominating factor affecting yarn strength with 63.96% contribution. The next dominating factor affecting yarn strength is TM which has 26.52% contribution. The spindle speed has only a little contribution i.e. 5.6% on yarn strength. In case of yarn breaking elongation, the most dominating parameter is spindle speed followed by TM and shade depth with percentage contribution of 67.43%, 24.32% and 4.06% respectively.

The effect of various parameters on S/N ratios of yarn strength is depicted in Fig. 1 (a). It is evident from Fig. 1 (a) that yarn strength reduces with the increase of shade depth (%) which may be ascribed to the higher proportion of weak dyed fibre content in the yarn cross section. During dyeing the fibre strength reduces, which, in turn, reduces the yarn

Table 3 — Average values of yarn strength, breaking elongation (%) and S/N ratios

Experiment number	Factors			Strength, cN/tex		Breaking elongation, %	
	X_1	X_2	X_3	Value	S/N ratio	Value	S/N ratio
1	-1	-1	-1	18.93	25.54	4.42	12.90
2	-1	0	0	19.98	26.01	4.46	12.93
3	-1	+1	+1	20.52	26.24	4.37	12.80
4	0	-1	0	18.34	25.27	4.45	12.87
5	0	0	+1	17.65	24.93	4.04	12.10
6	0	+1	-1	19.13	25.63	4.60	13.24
7	+1	-1	+1	16.98	24.6	4.17	12.36
8	+1	0	-1	17.86	25.03	4.57	13.11
9	+1	+1	0	18.52	25.35	4.59	13.23

Table 4 — Response for S/N ratios of yarn strength and breaking elongation

Factor	Yarn strength, cN/tex					Yarn breaking elongation, %				
	Average S/N			Range	Rank	Average S/N			Range	Rank
	Level -1	Level 0	Level +1			Level -1	Level 0	Level +1		
X_1	25.93	25.28	24.99	0.94	1	12.88	12.74	12.90	0.16	3
X_2	25.14	25.33	25.74	0.60	2	12.71	12.71	13.09	0.38	2
X_3	25.40	25.54	25.26	0.28	3	13.08	13.01	12.42	0.66	1

Table 5 — ANOVA summary conducted on S/N ratios of yarn strength and breaking elongation

Factors	Yarn strength, cN/tex				Yarn breaking elongation, %			
	SS	DF	MS	PC	SS	DF	MS	PC
X_1	1.3899	2	0.69497	63.96	0.048319	2	0.024159	4.03
X_2	0.57628	2	0.28814	26.52	0.28978	2	0.14489	24.33
X_3	0.12178	2	0.060891	5.60	0.80344	2	0.40172	67.43
Residual	0.085046	2	0.042523	3.92	0.050038	2	0.025019	4.21
Total	2.173	8			1.1916	8		

SS–Sum of squares; DF–Degree of freedom; MS–Mean square; PC–Percentage contribution.

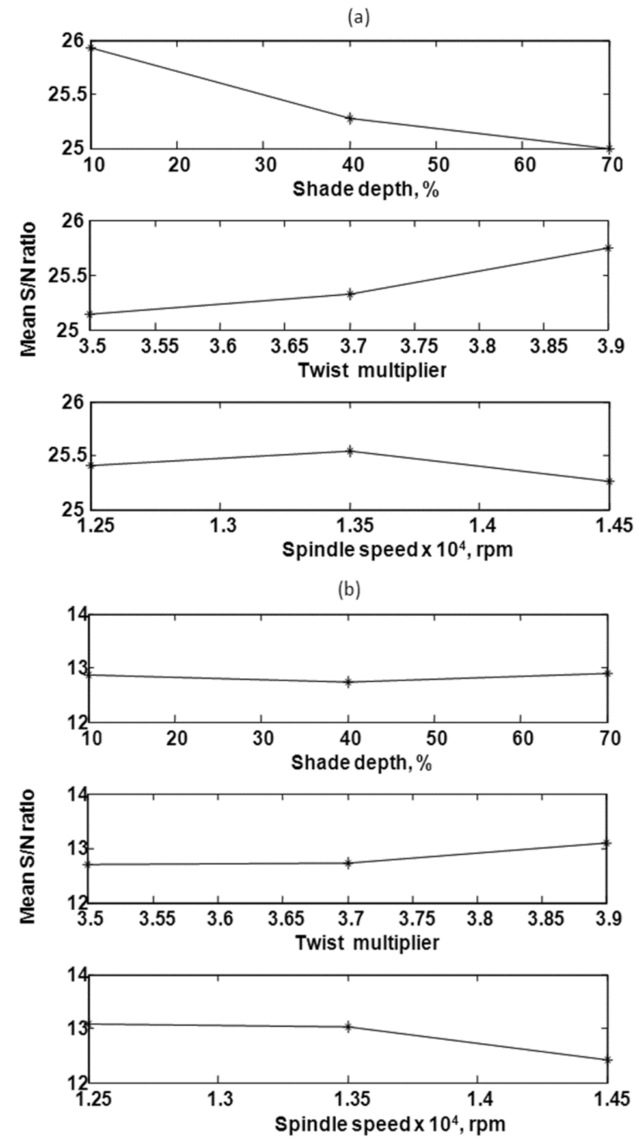

Fig. 1 — S/N ratio plot of yarn strength (cN/tex), and (b) breaking elongation (%)

strength. It is also evident from Figure 1(a) that yarn strength increases with the TM in the present experimental set up. An increase in twist increases the fibre-to-fibre cohesion, resulting in higher yarn strength. The spindle speed doesn't show any significant effect on the yarn strength within the given experimental range.

Figure 1(b) depicts the effect of various parameters on S/N ratios of yarn breaking elongation. It is apparent that there is hardly any impact of shade depth (%) on yarn breaking elongation (%) within the experimental range. Figure 1(b) also shows that yarn breaking elongation is marginally increased with the increase of TM but it is significantly reduced at higher spindle speed. Increase of TM increases the fibre helix angle in the yarn. While a yarn is subjeced to tensile testing, initially the helical fibres become straight to some extent before their straining. This phenomenon could be the reason for marginal increase of yarn breaking elongation with higher TM. However, at higher spindle speed, twisting occurs at higher spinning tension which causes more straightening of fibres while they are emerging out from the front roller nip, thereby reducing yarn breaking elongation.

3.2 Yarn U%, IPI and HI

The experimental results of average U%, IPI, HI and their corresponding S/N ratios are shown in Table 6. It is observed from Table 7 that the highest S/N ratios of yarn for U%, IPI, HI are -18.8, -28.52 and -13.19 respectively. The combination of parameters for highest S/N ratio for U% and IPI is 10% (shade depth), 3.5 (TM) and 12500 rpm (spindle speed) and that for HI is 10% (shade depth), 3.7 (TM) and 13500 rpm (spindle speed).

The ANOVA of S/N ratios of U%, IPI and HI is depicted in Table 8 along with the percentage contribution of different parameters on these responses. It is evident from Table 8 that the shade depth (%) is the most dominating paramter influencing the U%, IPI and HI with percentage contributions of 95.88%, 88.16% and 95.05% respectively. The second dominating factor is the

Table 6 — Average values of yarn U%, IPI, HI and their S/N ratios

Experiment number	Factors and their levels			Yarn properties					
	X_1	X_2	X_3	U%	S/N ratio	IPI	S/N ratio	HI	S/N ratio
1	-1	-1	-1	8.71	-18.8	26.63	-28.52	4.70	-13.44
2	-1	0	0	8.73	-18.82	28.25	-29.04	4.57	-13.19
3	-1	+1	+1	8.88	-18.97	34.58	-30.79	4.74	-13.51
4	0	-1	0	9.39	-19.45	51.07	-34.18	5.70	-15.12
5	0	0	+1	9.46	-19.52	54.3	-34.72	5.72	-15.15
6	0	1	-1	9.31	-19.38	50.67	-34.13	5.49	-14.79
7	+1	-1	+1	9.64	-19.68	52.35	-34.44	5.80	-15.27
8	+1	0	-1	9.5	-19.56	41.22	-32.31	5.48	-14.77
9	+1	+1	0	9.5	-19.56	45.27	-33.14	5.54	-14.88

Table 7 — Response for S/N ratios of yarn U%, IPI and HI

Factors	U%					IPI					HI				
	Average S/N			Range	Rank	Average S/N			Range	Rank	Average S/N			Range	Rank
	Level -1	Level 0	Level +1			Level -1	Level 0	Level +1			Level -1	Level 0	Level +1		
X_1	-18.86	-19.45	-19.59	0.73	1	-29.44	-34.34	-33.29	4.90	1	-13.38	-15.02	-14.97	1.65	1
X_2	-19.31	-19.29	-19.30	0.02	3	-32.37	-32.02	-32.68	0.66	3	-14.61	-14.37	-14.39	0.24	3
X_3	-19.25	-19.27	-19.39	0.14	2	-31.65	-32.12	-33.31	1.66	2	-14.33	-14.40	-14.64	0.31	2

Table 8 — ANOVA summary conducted on S/N ratios of yarn U%, IPI and HI

Factors	U%				IPI				HI			
	SS	DF	MS	PC	SS	DF	MS	PC	SS	DF	MS	PC
X_1	0.90731	2	0.45366	95.88	39.887	2	19.944	88.16	5.231	2	2.6155	95.05
X_2	0.0002511	2	0.00012554	0.03	0.66472	2	0.33236	1.47	0.1046	2	0.0523	1.901
X_3	0.036268	2	0.018134	3.83	4.4192	2	2.2096	9.77	0.1601	2	0.08008	2.9105
Residual	0.002426	2	0.001213	0.26	0.27131	2	0.13565	0.60	0.0075	2	0.00375	0.13633
Total	0.94626	8			45.243	8			5.503	8		

SS–Sum of squares; DF–Degree of freedom; MS–Mean square; PC–Percentage contribution.

spindle speed with a percentage contribution of 3.83%, 9.77% and 2.91% respectively for U%, IPI and HI, nevertheless TM has a little influence on these responses in the present experimental setup.

Figure 2 shows the effect of various parameters on U% and IPI, whereas Figure 3 depicts the same for HI. It is observed from the Figure 2 that both U% and IPI increase at higher shade depth (%). As the shade becomes more darker, there is an increase in the fibre entanglement as well as fibre-to-fibre friction. Hence, the opening and drafting of fibres turn out to be more difficult which eventually leads to higher yarn unevenness and imperfections at darker shade. Also it is noted that the TM has a marginal influence on both U% and IPI. The spindle speed has no significance influence on U% but yarn imperfection increases at higher spindle speed. At higher spindle speed the balloon size increases, which increases the frictional contact area at balloon control ring and traveller. Thus, the rubbing action among yarn surface and thread guide, balloon control ring, ring traveller is more. As a result of the enhanced rubbing action, the longer protruding fibres of the yarn body get rolled up and generates neps and thick places. This leads to an increase in the yarn imperfections at higher spindle speed.

From Fig 3, it is evident that HI increases with the increase of shade depth (%). The difficulty in opening of fibres during the mechanical processing at darker shade causes more chance of fibre breakage and thereby it increases the short fibre generation. The presence of more number of short fibres increases the number of protruding fibres in the yarn surface, which in turn, increase the hairiness of the yarn. Moreover, the fibre becomes coarser after dyeing and the coarser

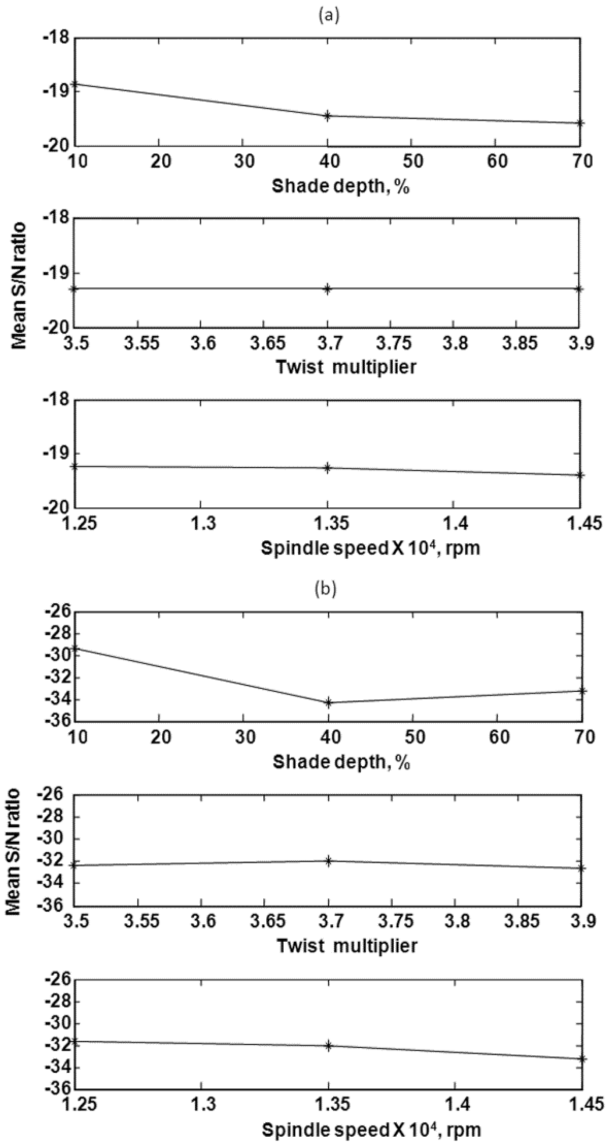

Fig. 2 — S/N ratio plot of (a) U%; and (b) IPI

fibres have a tendency to migrate in the the outer surface of the yarn body during spinning. This phenomenon may also cause higher hairiness at darker shade. It is also observed from Fig 3 that spindle speed and TM have only a little influence on HI.

4 Conclusion

The influence of shade depth (%), TM and spindle speed on the cotton mélange yarn qualities has been studied using Taguchi experimental design. Based on the S/N ratio and ANOVA results, it has been observed that the shade depth (%) and spindle speed (rpm) are the most significant parameters affecting mélange yarn quality. The change in surface

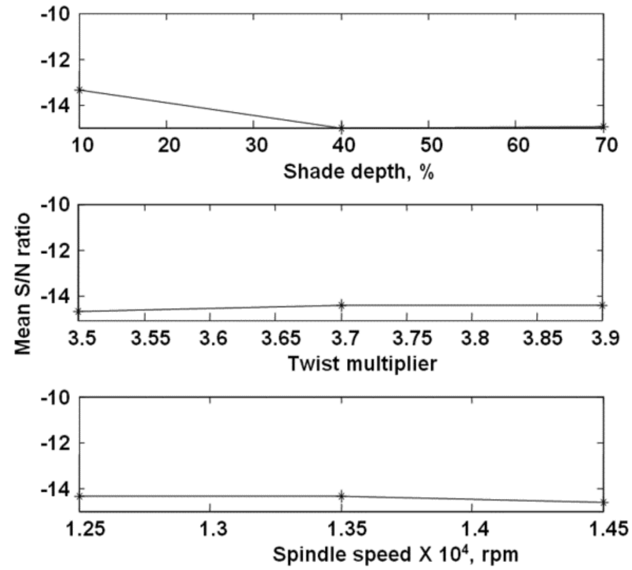

Fig. 3 — S/N ratio plot of HI

characteristics of cotton fibres during dyeing makes the mélange manufacturing process more difficult. Problems arising in drafting of dyed cotton at higher production speed also make the productivity level a limiting factor in achieving better mélange yarn quality. TM has significant impact on only yarn strength and breaking elongation (%).

References

1 Zhuanyong Z, *Indian J Fibre Text Res*, 39 (2014) 296.
2 Thilak V & Saravanan D, in *Roadmap to Sustainable Textiles and Clothing*, edited by S S Muthu (Springer, Singapore), 2014, 139.
3 Haofei H, Wei M, Shufen Z & Rongwen L, *J Appl Polym Sci*, 120(2) (2010) 886.
4 Naik H & Bhat N P, *Manmade Text India*, May (2008) 161.
5 Ishtiaque S M & Das A, *Indian J Fibre Text Res*, 28(3) (2003) 65.
6 Hafeezullah M, Nazakat K L & Samiullah M, *Int J Appl Sci Eng Res*, 4 (2015) 401.
7 Moghassem A R, *Int J Eng, Transactions B: Applications*, 20 (2) (2007) 203.
8 Behera B K, Hari P K, Bansal S & Singh R, *Indian J Fibre Text Res*, 22(1997) 84.
9 Ishtiaque S M, Rengasamy R S, Ghosh A, *Indian J Fibre Text Res*, 29 (2004) 190.
10 Taguchi G, Chowdhury S & Wu Y, *Taguchi's Quality Engineering Handbook* (John Wiley & Sons) , 2005, 1654.
11 Ross P J, *Taguchi Techniques for Quality Engineering* (McGraw-Hill International Editions) , 1996, 329.
12 Roy R K, *Design of Experiments Using the Taguchi Approach* (Wiley-Interscience Publication), 2001, 538.