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Optimization of sizing parameters with taguchi method[a]

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The optimum sizing parameters to obtain good strength of sized yarn and efficiency of weaving machines have been determined. Sizing process has been carried out using Ne 50/1, 60/1 and 70/1 cotton yarn and 40, 50, 60, 70, 80, 90 m/min dispatch speed of warp yarn in sizing machine. Sizing solution viscosity is kept as 14, 20, 24 Ns/m^2. Taguchi L18 mixed experimental design has been used for the analysis of input factors selected. The dispatch speed is found to be the most influential parameter for determining the strength of the sized yarn and the efficiency of the weaving machine speed. Optimum yarn strength is found using Ne 70/1 cotton yarn, 40 m / min dispatch speed and 24 Ns/m^2 sizing solution viscosity. The optimum weaving machine efficiency is obtained using Ne 60/1 cotton yarn, 70 m / min dispatch speed and 20 Ns/m^2 sizing solution viscosity.

Keywords: Cotton yarn, Sizing, Taguchi method, Yarn dispatch speed, Yarn strength, Weaving

1 Introduction

The purpose of sizing is to achieve good yarns weavability feature, such as improved yarn quality, increased weaving efficiency, smooth fabric surface, in the desizing processes easy removal of size materials from fabric without damaging and reduced raw and manufactured fabric costs[1,2]. Weaving machine efficiency is proportional to the appropriate sizing process. When the warp yarns are not sufficiently sized, number of breaks increases and weaving machine efficiency decreases. Due to increased breaks, number of knots in fabric increases, thereby increasing fabric faults results[3]. Because of these reasons, sized yarn strength is the most important parameter for maintaining weaving machine (which is the next process) efficiency. Optimum yarn strength and weaving machine efficiency can be achieved by determining accurate optimum parameters of efficient sizing process.

In early 1930s, experimental design method was used in agricultural research by Fischer. However, this classical experimental design method was not found efficient under industrial conditions. As the number of variable factors affecting the system was more, the number of experiments was also increased very quickly. Later, Genichi Taguchi reduced the variability in the experimental design. He found a solution that increased the productivity, and this solution was named as Taguchi method. In this way, a detailed analysis and evaluation were needed prior to the experiment to significantly reduce the number of experiments. Taguchi method, being experimental design techniques of extremely high quality, is found to be a useful technique[4,5].

In this study, the Taguchi method has been used for the optimization of sizing process, the input parameters are taken to get the best performance characteristics of the yarn strength and machine efficiency.

2 Materials and Methods

2.1 Materials

In this study, the sizing process optimization was carried out considering warp yarn number, sizing solution viscosity, and yarn speed through the sizing process. During the pre-trial process in the weaving, the sizing of fine yarn count was found to be more important than thicker yarns. For this purpose, Ne 50/1, Ne 60/1, and Ne 70/1 cotton yarns were selected.

2.2 Methods

2.2.1 Experiment Design

Before deciding test plan, cause-and-effect diagrams for optimization of strength output and efficiency output were obtained (Fig. 1). In the diagrams, factors affecting strength and efficiency output are given.

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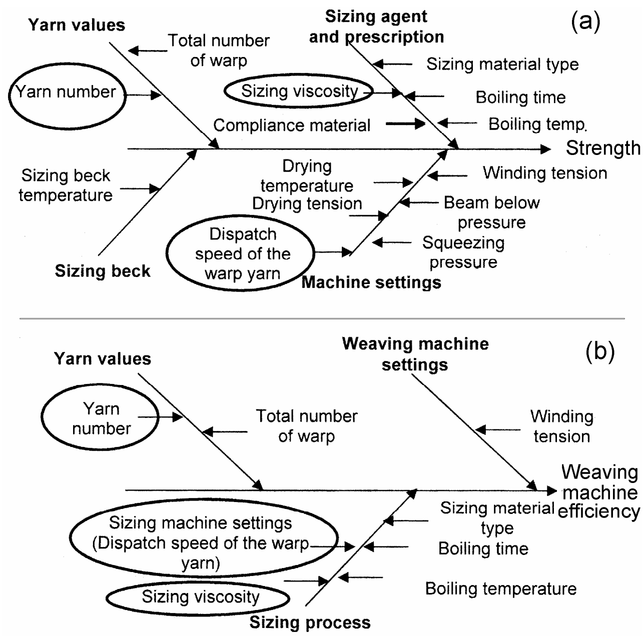

Fig. 1—Cause-and-effect diagram for (a) strength and (b) weaving machine efficiency

As per the diagram, yarn count, sizing viscosity and dispatch speed of the warp yarn are found effective on strength and efficiency output. According to Taguchi method, these factors are determined as input factors. In accordance with factors and their levels, the Taguchi experimentals design L18 (mixed 3-6 Level) orthogonal layout has been decided (Table 1).

2.2.2 Warp Yarn Strength

Sized yarns are exposed under high tension in the weaving process. In this study, for the measurement of yarn strength, TITAN strength test apparatus was used and the tests were performed according to EN ISO 2062 standard.

2.2.3 Weaving Machine Efficiency

Efficiency was determined on the basis of number of warp breaks, and the number of cuts or number of times the weaving machine stops. For weaving 1.000 m of warp yarn, efficiency was measured considering the number of warp yarns break. Vamatex (2002 model) weaving machine was used in this study.

2.2.4 Taguchi Method

In literature, there are studies about Taguchi method in various fields. Taguchi method use orthogonal arrays. The most commonly used third-level orthogonal arrays are L_9, L_{18}, and L_{27}. Both levels may be used as mixed orthogonal arrays (i.e. L_{18}, L_{36} and L_{54})[7-20]. In this study, L18 (mixed 3-6 Level) orthogonal array was used.

Table 1—Selected design of experiments L18 (Mixed 3-6 Level)[6]

Factor No. (code)	Factor	Level number	Levels
1(A)	Speed, m/min	6	40, 50, 60, 70, 80, 90
2(B)	Viscosity, Ns/m^2	3	14, 20, 24
3(C)	Yarn count, Ne	3	50/1, 60/1, 70/1

3 Results and Discussion

In Taguchi design of experiment, experimental results are converted into signal/noise (S/N) ratio and are expressed as decibels (dB). Signal/noise ratio is calculated and analyzed in different ways (i. e. smaller is the best, larger is the best or nominal is the best)[4]. By Taguchi, S/N ratio is maximized at one hand, while increasing the signal, it also reduces variation[7,21]. In this study, the larger- the better S/N ratio will be used for strength and efficiency output. With the formula given below, S/N ratio can be calculated[10]:

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

where y_i is the experimental results; and n, the number of experiment. Results of the experiments are shown in Table 2.

The optimum levels of the input parameters are determined by conducting ANOVA analysis. In many studies, contribution value (%) is also added in the ANOVA table[22,23]. Contribution of each factor value is a percentage value for the process effect. Contribution values (%) are calculated using the sum of squares values in the ANOVA table. The bigger this value on the output of that parameter is understood to be effective at that rate. Table 3, ANOVA analysis for S/N ratio of strength output is given. In the table, speed (A) has the highest value of 42.34% in contribution. The most effective input parameter on strength output is speed. Table 3 also shows ANOVA analysis for S/N ratio of efficiency output. Here also the speed (A) has the highest value of 33.56% in contribution. The most effective input parameter on efficiency output is speed.

Table 4 shows the response for S/N ratio of strength and efficiency output. In response table, last line indicates rank of inputs. According to rank, the most effective input parameter is speed (A), second effective

Table 2—Experiment results for sizing process optimization[3]

Experiment No.	Input variables			Outputs response variables		Determination of S/N ratio	
	Speed (A) m/min	Viscosity (B) Ns/m^2	Yarn count (C) Ne	Strength cN/tex	Efficiency %	Strength	Efficiency
1	40 (1)	14 (1)	50/1 (1)	33.59	61.3	31.5935	36.0069
2	40 (1)	20 (2)	60/1 (2)	37.78	84.8	31.9414	37.1999
3	40 (1)	24 (3)	70/1 (3)	53.34	52.9	33.0756	35.5795
4	50 (2)	14 (1)	50/1 (1)	32.46	72.6	30.0288	37.7049
5	50 (2)	20 (2)	60/1 (2)	35.22	86.3	30.3768	38.8980
6	50 (2)	24 (3)	70/1 (3)	34.49	78.9	31.5110	37.2776
7	60 (3)	14 (1)	60/1 (2)	30.32	71.2	29.5426	37.6832
8	60 (3)	20 (2)	70/1 (3)	34.50	83.3	31.0321	37.4939
9	60 (3)	24 (3)	50/1 (1)	33.81	69.5	30.3972	37.1251
10	70 (4)	14 (1)	70/1 (3)	32.39	81.9	30.3772	37.7861
11	70 (4)	20 (2)	50/1 (1)	35.26	87.3	30.0976	38.8484
12	70 (4)	24 (3)	60/1 (2)	29.55	80.9	30.0902	38.6104
13	80 (5)	14 (1)	60/1 (2)	33.52	79.8	29.8898	37.8528
14	80 (5)	20 (2)	70/1 (3)	34.61	63.1	31.3794	37.6635
15	80 (5)	24 (3)	50/1 (1)	34.37	86.8	30.7445	37.2947
16	90 (5)	14 (1)	70/1 (3)	35.00	78.5	30.5495	37.1867
17	90 (5)	20 (2)	50/1 (1)	32.10	77.9	30.2699	38.2490
18	90 (5)	24 (3)	60/1 (2)	31.88	76.9	30.2625	38.0110
					Mean	30.73	37.58

Table 3—ANOVA Analysis for S/N ratio of strength and efficiency output

Source	DF	Seq SS	Adj SS	Adj MS	F	Contribution, %
Strength						
A	5	8.333	8.333	1.6666	2.02	42.34463
B	2	1.527	1.527	0.7634	0.93	7.759540
C	2	3.218	3.218	1.6091	1.95	16.35245
Residual error	8	6.601	6.601	0.8251		33.54337
Total	17	19.679				
Efficiency						
A	5	7.968	7.968	1.594	1.12	33.5636
B	2	2.057	2.057	1.028	0.72	8.66470
C	2	2.330	2.330	1.165	0.82	9.81465
Residual error	8	11.385	11.385	1.423		47.9570
Total	17		23.739			

Table 4—Response table for S/N ratio of strength and efficiency outputs

Level	Strength			Efficiency		
	A	B	C	A	B	C
1	32.20	30.33	30.52	36.26	37.37	37.54
2	30.64	30.85	30.35	37.96	38.06	38.04
3	30.32	31.01	31.32	37.43	37.32	37.16
4	30.19	-	-	38.41	-	-
5	30.67	-	-	37.60	-	-
6	30.36	-	-	37.82	-	-
Delta	2.02	0.68	0.97	2.15	0.74	0.88
Rank	1	3	2	1	3	2

input parameter is yarn number (C) and third effective input parameter is viscosity (B) for both outputs.

Figure 2 shows graph obtained from Minitab 15® software for S/N ratio of strength and efficiency outputs. For strength output, the highest level of A (speed) factor is at level 1, the highest level of B (viscosity) is at level 3 and the highest level of C (yarn number) factor is at level 3. Optimum parameter combination for strength output is A1B3C3 (Experiment No. 3). That is, the speed of 40 m/ min, the viscosity of 24 Ns/m2, and the yarn count of Ne 70/1. This combination is found to be the best combination for strength output. For efficiency output, the highest level of A (speed) factor is at level 4, the highest level of B (viscosity) is at level 2 and the highest level of C (yarn number) factor is at level 2. Optimum parameter combination for efficiency output is A4B2C2 (Taguchi method recommends the combination). That is, the speed of 70 m/ min, the viscosity of 20 Ns/m2, and the yarn count of Ne 60/1. This combination is found to be the best combination for efficiency output.

3.1 Confirmation Test for Strength Output

For performing confirmation test, initial levels were selected. Following equation is used for performing confirmation test:

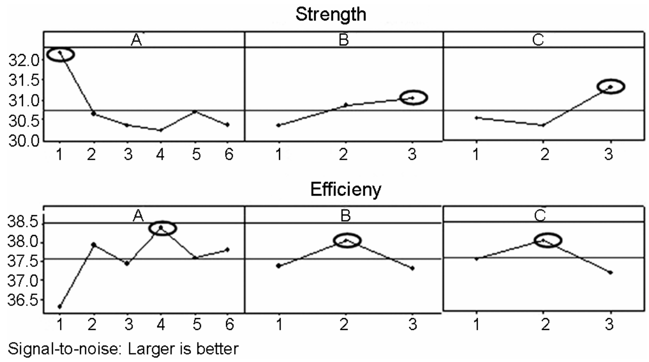

Fig. 2—S/N ratio of strength and efficiency outputs

$$\eta = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m) \qquad \ldots (2)$$

where η indicates S/N ratio of the optimum design; η_m indicates the arithmetic mean of S/N ratio calculated in the experimental design, and η_i indicates factor levels obtained from optimum experimental design.

Mean of S/N ratio is found to be 30.73 dB for strength output (Table 2). S/N ratio of optimum design is calculated by following relationship:

$$\eta = \eta_m + (\eta_{A1} - \eta_m) + (\eta_{B3} - \eta_m) + (\eta_{C3} - \eta_m)$$
$$\eta = 30.73 + (32.20 - 30.73) + (31.01 - 30.73) + (31.32 - 30.73) = 33.07 \text{ dB}$$

One of the experiments is selected as the initial design, and the difference (*d*) is obtained between the S/N ratio of the selected design and the S/N ratio of the optimal design as shown below:

d= Optimum design S/N ratio– Initial design S/N ratio … (3)

S/N= - 10 (LogL_0) – 10 (LogL_0) … (4)

Improving rate obtained from using optimum factor levels, is achieved by the following equation[24]:

$L_0/L_0=10^{d/10}$ … (5)

First trial is selected as initial design. For this test, S/N = 31.59 dB is selected. Value of *d* is found by using Eq. (3), as shown below:

d = 31.59-30.73 = 0.86 dB

Improvement is calculated by Eq.(5), as shown below:

$L_0/ L_0 = 10^{0.86/10} = 1.22$ times

According to this result, the strength of the warp yarn sized under optimum conditions is found to be improved 1.22 times.

3.2 Confirmation Test for Efficiency Output

Mean of S/N ratio is found to be 37.58 dB for efficiency output (Table 2). S/N ratio of optimum design is calculated by Eq. (2). Because A4B2C2 combination is not in the experiment plan, this combination was applied in the mill. The strength of the warp yarn sizing under this combination is measured as 44.79 cN/tex and the efficiency of the warp yarn sizing under this combination is measured as 71.8%. Predicted S/N ratio at optimum levels for efficiency output is calculated using values in Table 4. Mean of S/N ratio is found to be 37.58 dB for efficiency output (Table 2). S/N ratio of optimum design is calculated by Eq. (2), as shown below:

$$\eta = \eta_m + (\eta_{A4} - \eta_m) + (\eta_{B2} - \eta_m) + (\eta_{C2} - \eta_m)$$
$$\eta = 37.58 + (38.41 - 37.58) + (38.06 - 30.58) + (38.04 - 30.58) = 54.34 \text{ dB}$$

First trial is selected as initial design. For this test, S/N = 36.00 dB is selected. The value of *d* is found by using Eq. (3), as shown below:

d = 36.00-37.58 = -1.58 dB

Improvement is calculated by Eq. (5). According to this result, the efficiency of the warp yarn sized under optimum conditions is found to be improved 0.69 times.

$L_0/ L_0 = 10^{-1.58/10} = 0.69$ times

4 Conclusion

According to Taguchi optimization, for strength output, the sizing viscosity of 24 Ns/m2 and the yarn delivery speed of 40 m/min are found to the best for the finest yarn (Ne 70/1). The strength of the warp yarn sizing under optimum conditions is improved to ratio 1.22.

For optimum weaving machine efficiency output, the sizing viscosity should be 20 Ns/m2 and the yarn delivery speed should be 70 m/min for the Ne 60/1 cotton. The efficiency of the warp yarn sizing under optimum conditions is improved to ratio 0.69.

In this study, instead of doing full-factorial experimental design with optimum results to be obtained by 54 experiments, same results are achieved with only 18 experiments. In optimization approaches, if test time and number of trial are constraints, Taguchi method can be used.

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