Redesign of the sizing process optimization to produce warp yarn with strong weaving ability

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ABSTRACT

The research focuses on optimization of the sizing process parameters for cotton warp yarn material. The sizing process is a crucial step where warp yarn is coated with a starch solution before weaving. The aim is to produce warp yarn with strong weaving ability, thereby facilitating the entire process. To achieve this, several factors are considered, namely the steam bar, and squeeze roll pressure, including machine speed. The techniques used to address this issue include Taguchi in collaboration with Grey Relational Analysis (GRA) to effectively address multi-responses. In this analysis, the larger the better characteristic was applied to S/N Ratio, indicating that the higher the GRG value, the closer it is to the desired optimum condition. Based on the calculations from S/N Ratio response table for the GRG, it can be determined that factor steam bar pressure was selected at 4 Bar, with an average S/N Ratio value of -2.935. factor squeeze roll should be set to level 10 Km/m^3, as it yields an average S/N Ratio value of -2.912. Factors squeeze roll) and C (Machine Speed) were selected at levels 2 (10 Km/m^3) and 1 (45 M/Min) with average values of -2.912, and -4.771, respectively.

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1. INTRODUCTION

PT. PCP is a state-owned enterprise that deals in all types of textiles and related products. The company specializes in manufacturing grey shuttle and air jet loom (AJL) fabrics. In order to remain competitive in the national industrial landscape, PT. PCP needs to focus on improve the quality of its products and enhancing production efficiency. Currently, there is a significant issue with product quality. The grey fabric produced by the AJL machine with a PS 210 construction in March exhibits a relatively high defect rate of 52%. This problem is attributed to several factors, including deviations from standard operating procedures (SOPs), the use of non-original machine components, and subpar material quality. Product quality is a competitive advantage that reflects ability of the manufactured item to meet predefined quality requirements or specifications. Good product quality enhances brand image, customer trust, and loyalty.

In March, the Grey Finishing department of PT. PCP, recorded a significant increase in defects across various fabric constructions, drawing significant attention within the company. One specific defect that has become a focal point is warp breakage. This issue arises from shortcomings in the sizing process, due to insufficient

improvement in yarn strength (less than 30%) and reduction in its elongation (less than 17%). During the sizing process, warp defects occur more than 10 times, whereas the company standard is less than 5 times. Warp yarn runs vertically parallel to the length of the fabric. Weft yarn is horizontally woven or interlaced with warp yarn. To tackle this challenge effectively, a series of experiments must be conducted to identify the appropriate sizing process settings.

Several research [1-5] have used Taguchi and Grey Relational Analysis (GRA) methods to optimize sizing parameters for good strength of sized yarn. Other studies [6-10], conducted research that focused on optimizing the process condition. The optimization process emphasized on significant factors, such as weft yarn type, fabric design, weft density, air pressure, and shed closing timing. Meanwhile, [11], successfully addressed multi-response optimization on some mechanical and comfort properties of bi-stretch woven fabrics. The [12] depicts the application of Taguchi-GRA to optimize the durability of sheeting fabrics. Recently, a hybrid Taguchi-metaheuristic techniques is proposed to solve global numerical optimization problem with continues variables, such as Genetic Algorithm, Ant Colony Optimization, and Neural Network. They are applied the strength of elastic denim yarns before and after steaming [13-15].

The present research focuses on optimization of the sizing process parameters for cotton warp yarn material. The objective is to optimize the sizing process, ensuring the production of warp yarn with strong weaving ability. The noise factor eliminated in this research is the reduction in machine sizing power because it reduces the temperature within the sizebox as well as affects the sizing process. The methods used to address this issue include Taguchi in collaboration with GRA to effectively address multi-responses.

2. METHODS

This research adopted a combination of Taguchi method and GRA. Application procedure of the Taguchi method based on GRA in this study is shown in Figure 1.
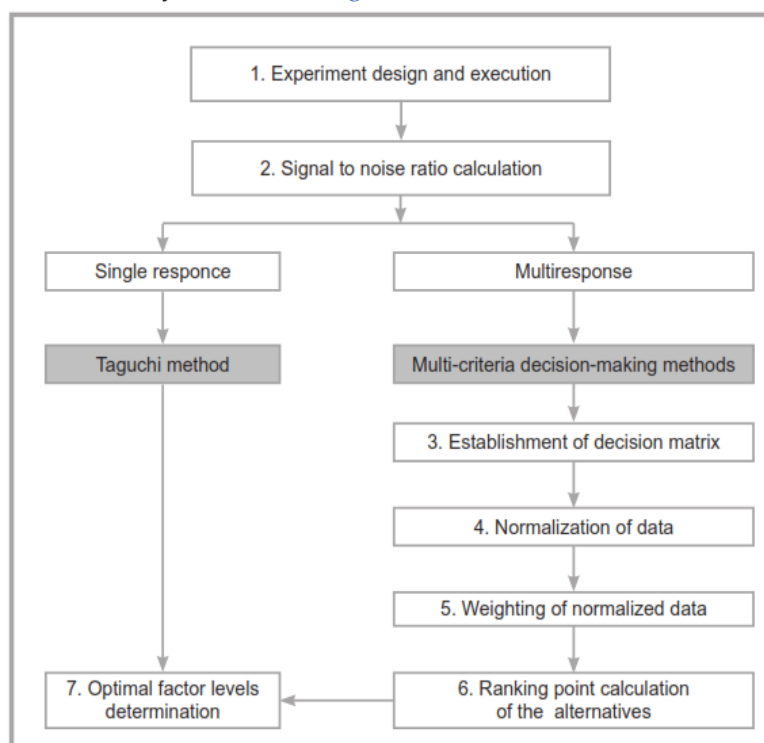
Figure 1. The Taguchi method's procedure based on GRA in accordance with Kuo et al. (2008) in [3]

Data collection was conducted from April to July 2023, and it comprised experimental test results and a historical dataset obtained from the company. However, two main variables were observed in the collected data, namely the improvement in warp yarn strength and the reduction in its elongation, specifically for Primissima Weaving III. The evaluation of the sizing process was carried out in the Quality Control department.

Taguchi or Robust Design is an engineering method aimed at reducing product defects, improving process quality, minimizing total costs, and optimizing resource usage [16-22]. In the context of product manufacturing, this method is inherently robust, reflecting its strength and resilience. This is why it is also known as Robust Design. Taguchi concept of quality engineering comprised two fundamental methods, on-line and off-line quality control. On-line quality control includes the direct monitoring and control of quality at every stage of production. Off-line quality control is focused on optimizing process and product design to support and enhance the effectiveness of on-line efforts .

The Signal-to-Noise Ratio (S/N Ratio) is a significant metric used to evaluate the influence of design parameter changes on product performance. It is calculated as the logarithm of the square of the loss function and serves as an important indicator of product quality. Several S/N Ratio calculations are stated as follows:

1. *Smaller the better*

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \sum_{i=1}^{r} Y_i^2 \right) \tag{1}$$

2. *Nominal is the best*

$$SN_{LTB} = -10 \, log_{10} \left(\frac{\mu^2}{\sigma^2} \right) \tag{2}$$

$$\mu^2 = \frac{1}{n} \sum_{i=1}^{r} y_i \tag{3}$$

$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^{r} (y_i - \mu)^2 \tag{4}$$

3. *Larger the better*

$$SN_{LTB} = -10 \, log \left[\frac{1}{n} \sum_{i}^{n} \frac{1}{y_i^2} \right] \tag{5}$$

4. *Signed to target*

$$SN_{ST} = -10 \, log_{10} \sigma^2 \tag{6}$$

GRA is a highly valuable tool for conducting multi-response data analysis. It allows for the simultaneous optimization of Taguchi experimental designs with multiple responses [3, 7-12, 23-27]. The core concept is centered on using GRA to optimize these multiple responses by leveraging S/N Ratio values obtained with Taguchi method, ensuring they are in line with desired characteristics. The optimal combinations are further evaluated to yield the highest Grey Relational value.

ANOVA is a statistical method that divides variance into identifiable sources and allocates degrees of freedom within an experimental context [28-30]. While ANOVA is an abbreviation for Analysis of Variance, it serves as a statistical testing procedure similar to the t-test. A significant advantage of this method lies in ability to test for differences among more than two groups, making it particularly valuable for comparing multiple sets simultaneously.

3. RESULTS

After calculating S/N Ratio for all experiments, the next step is to compute its response for each factor and corresponding level in respect to both warp yarn strength (Table 1) and elongation responses (Table 2). In the context of warp yarn strength response, it was observed that Factor A (Bar Pressure) attained the highest average value at level 2. Factors B (Squeeze Roll) and C (Machine Speed), obtained the largest average warp yarn strength values, at levels 1, and 2, respectively. For warp yarn elongation response, it was observed that Factor A (Bar Pressure) achieved its maximum average value at level 2. Likewise, Factors B (Squeeze Roll) and C (Machine Speed) exhibited their highest average at level 2

Table 1. Average yield of warp thread strength response

Experiment	Steam Pressure (Bar)	Squeeze Roll (Kg/m³)	Machine Speed (M/min)	R1	R2	R3	Average	SNR Avg.
1	3	0	45	31.45	31.36	31.45	31.353	29.926
2	3	10	50	31.76	31.75	31.77	31.727	30.028
3	4	0	50	31.86	31.84	31.87	31.823	30.055
4	4	10	45	32.05	32.09	32.05	32.097	30.129

Table 2. Average results of warp yarn elongation response

Experiment	Steam Pressure (Bar)	Squeeze Roll (Kg/m³)	Machine Speed (M/min)	R1	R2	R3	Average	SNR Avg.
1	3	0	45	17.63	17.67	17.63	17.643	24.932
2	3	10	50	18.13	18.20	18.16	18.163	25.184
3	4	0	50	17.92	17.86	17.97	17.917	25.065
4	4	10	45	18.66	18.62	18.73	18.670	25.423

4. DISCUSSION

4.1. Control Factor Analysis

The sizing process is a crucial step where warp yarn is coated with a starch solution before weaving. The objective is to create warp yarn that possesses strong weaving ability. To achieve this, several factors are considered, namely the starch solution composition, steam bar, and squeeze roll pressure, including machine speed. In this research, the starch solution composition was not selected as an experimental factor due to cost considerations.

1. Steam Bar Pressure Factor
   The steam bar pressure factor has a significant impact on the entire sizing process. It directly affects the starch cooking process, where higher pressure leads to faster and more optimal cooking outcomes. The steam bar pressure also affects the temperature in the sizebox, thereby preventing the starch solution from hardening. In the present research, the primary focus when observing the steam bar factor centers on its impact during the drying process. Based on calculations, higher steam bar pressure leads to better production process. In this context, the steam bar pressure set at level 2 (4 Bar) is superior to that at level 1 (3 Bar).
2. Squeeze Roll Pressure Factor
   The squeeze roll pressure in the sizing process is determined by the following factors, yarn type being processed, the starch solution used, and the desired quality of warp yarn. The goal is to apply the appropriate pressure to efficiently remove excess starch solution, ensuring warp yarn has the right and consistent application. Conversely, assuming the squeeze roll pressure is not set correctly, it can cause warp yarn to become too stiff or possess excessive starch content. In this research, the squeeze roll hardness level is already quite high, ranging from 80 to 81 shore, while the standard is 60 to 61. Squeeze roll pressure at level 2 (10 Km/m³) produce a significant increase in warp yarn strength compared to when set at 1 (0 Km/m³). Regarding warp yarn elongation response, squeeze roll pressure at level 1 (0 Km/m³) is lower than that set at 2 (0 Km/m³).
3. Machine Speed Factor
   The machine speed in the sizing process holds significant importance, influencing the efficiency, quality, and stability of textile production. Higher machine speeds tend to increase production throughput, reduce cycle times, and accelerate warp yarn production. It also has certain disadvantages, such as the high risk of warp yarn breakage. The company standard maximum machine speed is 55 M/min. However, in some cases, higher speeds are used to achieve production targets. This deviation from the standard speed typically leads to warp yarn breakage issues.

4.2. *Optimal Level Settings with GRA*

Process of determining optimal level settings entails using the Grey Relational Grade (GRG) to simultaneously enhance both responses. In this research, the obtained optimal level settings are A2-B2-C1. These specific combinations were derived by selecting levels with the highest averages. Meanwhile, the response table was constructed using S/N Ratio values obtained from the GRG. In this analysis, the larger the better characteristic was applied to S/N Ratio, indicating that the higher the GRG value, the closer it is to the desired optimum condition (Figure 2).
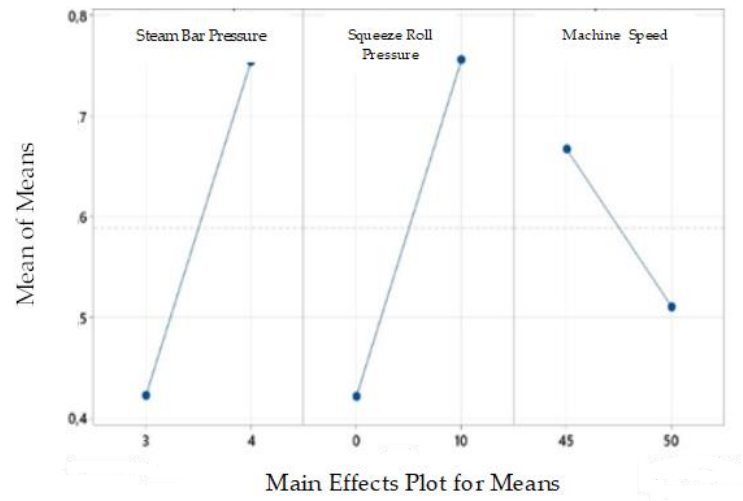

Figure 2. Optimal level settings

Based on the calculations from S/N Ratio response table for the GRG, it can be determined that Factor A (Steam Bar Pressure) was selected at level 2 (4 Bar), with an average S/N Ratio value of -2.935. Factor B (Squeeze Roll) should be set to level 2 (10 Km/m3), as it yields an average S/N Ratio value of -2.912. Factors B (Squeeze Roll) and C (Machine Speed) were selected at levels 2 (10 Km/m^3) and 1 (45 M/Min) with average values of -2.912, and -4.771, respectively.

4.3. *ANOVA Analysis*

ANOVA test conducted on S/N Ratio response of warp yarn strength revealed that factors A, B, and C contributed 61.08%, 33.18%, and 5.74%, respectively (Figure 2). In contrast, for S/N Ratio response analysis of warp yarn elongation, factors A, B, and C contributed 24.44%, 69.17%, and 6.39%. According to the analysis, the most influential factor in the wearp yarn strength response was factor A, which represented steam bar pressure. While for the elongation response, the most significant factor was B, depicting squeeze roll pressure. There is a significant correlation between the observed variables and the resulting responses.
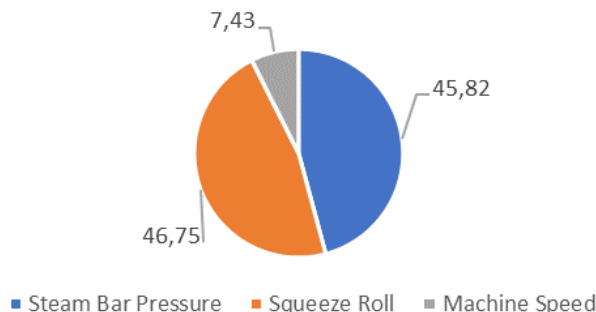

Figure 3. ANOVA test GRG

S/N Ratio values were used to subject the GRG to ANOVA test (Figure 3). This analysis of the GRG values yielded new F-statistic and percent contributions (p) for each factor. The most significant factor is the

squeeze roll pressure (B), followed closely by the steam bar pressure (A) with p-values of 46.75%, and 45.82%, respectively. In comparison, the machine speed factor has a lower p-value of 7.43%.

5. CONCLUSION

In conclusion, the results of the multi-response optimization achieved through GRA method, simultaneously optimized warp yarn strength and elongation, as follows. Factors steam bar pressure, squeeze roll, and machine speed were at levels 4 Bar, 10 Km/m3, and 45 M/min, respectively.

The results of ANOVA calculation on the SNR GRG values revealed that three factors did not exert significant influence on the reduction of variance in the larger-the-better quality characteristic. The contributions of each factors A, B, and C to the entire analysis were 45.82%, 46.75%, and 7.43%, respectively. Future studies could be considered on the effect of warp yarn count and viscosity. In addition, it is necessary to increase the number of experimental levels .

ACKNOWLEDGMENT

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