International Journal of Textile Science 2015, 4(2): 27-35
DOI: 10.5923/j.textile.20150402.01

# Statistical Analyses and Predicting the Properties of Cotton/Waste Blended Open-End Rotor Yarn Using Taguchi OA Design

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**Abstract** Quality and cost of production are two important considering parts during production of cotton/waste blended open-end rotor spun yarn. Nowadays, blending of spinning waste with virgin cotton is a common phenomenon in rotor spinning intended to lower the production cost. As a result, understanding the relationships between properties of cotton/waste blended rotor yarn and different spinning conditions are important for spinner to maintain acceptable quality. However, this paper focuses on predicting the properties of cotton/waste blended rotor yarn, using taguchi OA experimental design. In this study, the experimental quality characteristics of 16 Ne rotor yarn focused on are the, unevenness, imperfections, strength and elongation wherein before blend ratios, blending technique, two process parameters namely cylinder speed and rotor speed were used as predictors. Using ANOVA, the significant factors influencing the quality characteristics of rotor spun yarn are obtained and analyzed by interaction matrix of dependent variables. Result shows that the most influential parameter in our investigation was waste proportion as expected. Though inferior in strength, the benefits of draw frame blending in OE spinning may be more than blow room blending in terms of reducing the imperfection, irregularity and yarn elongation during processing of higher waste mixing. With increasing rotor speed, yarn evenness, imperfection and strength show a significant deterioration, in case of elongation, no consistent trend was observed.

**Keywords** Rotor speed, Cylinder speed, Blending technique, Rotor yarn, Waste, Taguchi design

## 1. Introduction

Many open-end spinning methods have been invented, but none have been successful than rotor spinning [1]. The volume of production on rotor spinning has increased in recent years which is quite understandable considering the present trend in the production and consumption of textile products [2].

Improving raw material exploitation has become the most important challenge facing scientific and industrial community [3]. Extreme competition in textile world have forced the textile mills to reduce the production cost that is directly connected with raw material cost. In spite of the technical evolution for different blow room machines, generated wastes in cotton spinning mill contain a great rate of fibers. [4] Waste utilization in textile industry of our country has gained vital importance because of high price in cotton market. Some researcher has been worked on reuse of recycled cotton waste [5-7].

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Published online at http://journal.sapub.org/textile


Various researchers have studied the effect of rotor speed and carding parameters on rotor yarn quality [8-12]. It is also observed that many researchers have studied rotor spinning process and yarn quality from different angle. No work has so far been observed on the influences of process parameters viz. cylinder speed and rotor speed for different blending technique on rotor blended yarn quality produced by using high amount of recycled wastes.

Blending is used as a means of substituting a less expensive fiber for a highly priced one and to produce yarns with qualities that cannot be obtained by using one type of material alone [13]. Blending virgin cotton fibers with recycled wastes is a widely practiced means of enhancing the performances and the desired qualities of rotor yarn in spinning mills. Different blend ratios for blended rotor spun yarn produced form virgin cotton and recycled spinning wastes are used in textile mill.

Recovered secondary raw materials can be blended with virgin cotton fibers either at blow room or at draw frame. Generally, it is said that the earlier blending of fibers give better blending. Most of the spinning mill in our country practice hand mixing of virgin cotton and recycled wastes in blow room. As a result, with huge spaces, a large number of workers are needed that add extra cost on production. On the other hand, sliver of 100% virgin cotton and sliver of 100% recycled wastes can be blended easily at finisher draw frame without extra space and labor cost to produce rotor yarn with different level of blend proportion.

However, the textile industry is one of the largest and oldest industries worldwide and yarn manufacturing is the key process of it [14]. In general, the various responses in yarn manufacturing depend on a number of independent variables. So, collecting data from improperly designed experiments and analyzing them cannot help the researcher to make appropriate inferences.

The complexity of fiber to yarn spinning process and interaction among various spinning conditions is very high. Design of Experiment (DOE) is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses, where by a systematic way of planning of experiments, collection and analysis of data is executed [15]. Statistical models were the first that used in textile disciplines to explore relationships between variables and characteristics of product and to optimize processing parameters [16]. Using experimental design as a prediction approach with higher degree of precision is a subject focused by many researchers. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [17].

Economical running behavior can only be achieved by keeping in observation the effects of process parameters on yarn properties and raw material [18]. However, it is a critical problem to optimize the spinning parameters for example cylinder speed, rotor speed etc. to produce rotor yarn using high amount of recycled wastes for both blow room blending and draw frame blending.

The work reported here is concerned about the investigation of the rotor yarn quality responses in terms of yarn regularity, imperfections, and strength and elongation by using Taguchi OA Factorial design of experiment. To conduct the tests using the taguchi approach two levels for each dependent variable (Table-1) were selected.

**Table 1.** Selected independent variables

| Variable | Value/Type | |
|---|---|---|
| Blend Ratio | 67/33 | 83/17 |
| Blending Technique | Blow Room | Draw frame |
| Cylinder Speed (rpm) | 800 | 850 |
| Rotor Speed | 80,000 | 85,000 |

# 2. Materials and Methods

## 2.1. Preparation of Yarn Samples

In this study, Flat strips (F/S) collected from carding machines during processing in spinning mill are recycled by recycling machine before pressing by bale press machine. Comber noils were collected from comber machine and pressed to form bale of comber noil. Unused packages of roving were processed at Rovematric frame to collect untwisted roving wastes and Pneumafil wastes were collected from ring frame directly without any further processing.

However, Shankar-6 fiber is used as virgin cotton to blend with spinning waste. Properties of Waste materials and Shankar-6 have been given in Table-3. Rotor yarns of 16 Ne were spun from virgin cotton and recycled wastes with two different levels of blend proportion, viz. 17:83 and 33:67 for both blow room blending and draw frame blending. In case of blow room blending, hand-mixing concept was applied in blow room to blend virgin cotton and recycled wastes. On the other hand, during draw frame blending, carded sliver produced from recycled wastes was blended with the carded sliver produced from 100% virgin cotton in finisher draw frame (RSBD-22) and blend ratio have been maintained by producing sliver of different thickness. Compositions of waste material and processing conditions of rotor spun yarn have been given in Table-2 and Table-4.

For both blending techniques, Rieter C-60 card machine and spinning frame BT-923 have been used. Carding production rate kept equal (70kgs/hr) for both blending techniques. Rotor speed was selected 80000 rpm and 85000 rpm, cylinder speed was selected 800 rpm and 850 rpm for their higher value and lower value used in our experimental design. Taguchi OA Factorial experimental design has been used in the investigation. 10 yarn samples were produced for each experimental set up according to Taguchi OA Factorial design. ANOVA table and main effect plots have been used to identify the significant processing conditions. The cut-off value 0.1 for the p value has been used to evaluate significant factors meaning when p value less than 0.1, then the null hypothesis is rejected. As a result, the factors will have influencing effect on the responses.

## 2.2. Testing of Yarn Samples

The USTER tester-5 was used to measure the evenness of yarn and imperfection/km. Yarn imperfection has been calculated by adding Thick place(+50%), Thin place(-50%) and Neps (+280%) per km. Yarn testing speed was 400m/min. Average results of 10 samples produced for each experiment according to design have been calculated. Single yarn strength and yarn elongation% have been measured by using MAG Elestretch single yarn strength tester.

**Table 2.** Composition of waste materials used in blow room mixing

| Blend ratio at percentage (Virgin cotton/Spinning waste) | Waste type | Percentage of total waste | Percentage in mixing |
|---|---|---|---|
| 17/83 | Flat strips (F/S) | 65% | 54 |
| | Comber noil | 15% | 12.5 |
| | Pneumafil | 10% | 8.3 |
| | Roving | 5% | 4.1 |
| | Filter waste | 10% | 8.3 |
| 33/67 | Flat strips (F/S) | 65% | 43.6 |
| | Comber noil | 20% | 13.4 |
| | Pneumafil | 10% | 6.7 |
| | Roving | 5% | 3.3 |

## 3. Results and Discussions

The experimental design and statistical analyses were performed using the Reliasoft. Quality parameters of 16 Ne rotor yarn produced at different level of independent variables are given in Table-5. Analysis of variance tables for selected responses viz. irregularity, imperfection, strength and yarn elongation are given in Tables 7, 8, 9 & 10 respectively. The regression co-efficient and p-values of all the terms are given in table-6. The impact of all the variables on the responses is discussed separately in the following sections:

**Yarn Irregularity**: From AONVA table of yarn irregularity, it can be said that our selected parameters have evidently two way interactions on yarn irregularity. Table-3 reveals that blend ratio (A), blending technique (B), cylinder speed (C) and the term A: B are statistically significant terms. From interaction matrix shown in figure-1, blend ratio 67/33 (virgin/recycled) produce always better result of yarn irregularity as we expected. Higher percentage of short fibers will hinder the fiber orientation in sliver during drafting process because of behaving as swimming or uncontrolled fiber.

**Table 3.** Properties of spinning waste used in mixing

| Fiber properties | Shankar-6 | Spinning waste |
|---|---|---|
| Average Fineness (Mic value) | 4.1 | 3.8 |
| Average length (mm) | 26.8 | 22.5 |
| Length CV% | 19.2 | 32.9 |
| Fiber tenacity (cN/tex) | 29.4 | 25.6 |
| Maturity ratio | 0.90 | 0.87 |
| Trash Area (%) | 0.15 | 0.28 |

**Table 4.** Processing conditions of rotor spun yarn

| Machine | Parameter | Value |
|---|---|---|
| UNIclean , B12 | Cleaning Intensity (C.I) | 0.4 |
| | Relative amount of waste (R.W) | 4 |
| UNIflex, B60 | Cleaning Intensity (C.I) | 0.3 |
| | Relative amount of waste (R.W) | 3 |
| Carding, C60 | Taker-in speed | 1200 rpm |
| | Flat speed | 0.30 m/min |
| | Cylinder speed | 800 & 850 rpm |
| | Licker in to cylinder setting | 0.22mm |
| | Cylinder to flat settings | 0.25 mm |
| | Cylinder to doffer setting | 0.2 mm |
| | Delivery rate | 70 kgs/hr |
| | Carded sliver hank | 91 gr/yd |
| Draw Frame, RSB D-22 | Total draft | 8.2 |
| | Break draft | 1.15 |
| | Delivery speed | 450 m/min |
| | Drawn sliver hank | 75 gr/yd |
| Rotor frame, BT 923 | Rotor speed | 80000 & 85000 rpm |
| | Rotor diameter | 33mm |
| | Opening roller speed | 9000 rpm |
| | Navel | Ceramic & smooth |

**Table 5.** Experimental set up for 16 experiments according to Taguchi OA Factorial design

| Expt No. | Blend Ratio | Blending Type | Cylinder Speed | Rotor Speed | Irregularity, U% | Imperfections, IPI/km | Strength, g/tex | Elongation, % |
|---|---|---|---|---|---|---|---|---|
| 1. | 83/17 | D/F | 850 | 85000 | 11.92 | 394 | 9.1 | 5.88 |
| 2. | 67/33 | D/F | 800 | 85000 | 10.85 | 319 | 9.49 | 4.9 |
| 3. | 83/17 | B/R | 800 | 85000 | 12.19 | 510 | 9.18 | 5.92 |
| 4. | 83/17 | D/F | 850 | 85000 | 11.65 | 440.5 | 8.89 | 6.24 |
| 5. | 67/33 | D/F | 850 | 80000 | 10.62 | 197.5 | 9.76 | 5.58 |
| 6. | 67/33 | B/R | 800 | 80000 | 11.47 | 239.5 | 10.01 | 5.71 |
| 7. | 83/17 | B/R | 800 | 85000 | 12.3 | 461 | 9.25 | 5.65 |
| 8. | 67/33 | D/F | 800 | 85000 | 11.08 | 268.4 | 9.64 | 5.03 |
| 9. | 83/17 | B/R | 850 | 80000 | 11.63 | 422.5 | 9.34 | 5.22 |
| 10. | 83/17 | D/F | 800 | 80000 | 11.77 | 411.1 | 9.16 | 6.13 |
| 11. | 67/33 | B/R | 800 | 80000 | 11.63 | 282.4 | 9.84 | 6.17 |
| 12. | 67/33 | B/R | 850 | 85000 | 11.5 | 301 | 9.67 | 5.07 |
| 13. | 83/17 | B/R | 850 | 80000 | 11.74 | 439.2 | 9.26 | 5.44 |
| 14. | 83/17 | D/F | 800 | 80000 | 12.09 | 450.3 | 8.76 | 6.19 |
| 15. | 67/33 | D/F | 850 | 80000 | 10.99 | 297.2 | 9.65 | 5.21 |
| 16. | 67/33 | B/R | 850 | 85000 | 11.35 | 331.8 | 9.52 | 4.83 |

**Table 6.** Regression Information for dependent variables

| Term | Coefficient | | | | P Value | | | |
|---|---|---|---|---|---|---|---|---|
| | Irregularity | Imperfections | Strength | Elongation | Irregularity | Imperfection | Strength | Elongation |
| Intercept | 11.5488 | 360.3375 | 9.4075 | 5.5731 | 0 | 1.98E-10 | 0 | 5.88E-14 |
| A: Blend Ratio | -0.3625 | -80.7375 | 0.29 | -0.2606 | 2.24E-05 | 2.23E-05 | 2.93E-05 | 0.001 |
| B: Blend Type | 0.1775 | 13.0875 | 0.1012 | -0.0719 | 0.0026 | 0.1927 | 0.0184 | 0.1999 |
| C: Cylinder Speed | -0.1238 | -7.375 | -0.0088 | -0.1394 | 0.0172 | 0.4459 | 0.8051 | 0.0267 |
| D: Rotor Speed | -0.0563 | -17.875 | 0.065 | 0.1331 | 0.2107 | 0.0879 | 0.0948 | 0.0322 |
| A:B | 0.1237 | -4.0125 | -0.0388 | 0.2044 | 0.0172 | 0.6743 | 0.2915 | 0.0041 |
| A:C | 0.0525 | 9.65 | -0.0387 | -0.0006 | 0.2397 | 0.3249 | 0.2915 | 0.9906 |
| A:D | 0.0475 | -7.575 | 0.0525 | 0.2219 | 0.2837 | 0.4342 | 0.1645 | 0.0026 |

**Table 7.** ANOVA Table for Yarn Irregularity

| Source of Variation | df | Sum of Squares (Partial) | Mean of Squares | F Ratio | P Value |
|---|---|---|---|---|---|
| Model | 7 | 3.22 | 0.461 | 16.86 | 0.0003 |
| Main Effects | 4 | 2.90 | 0.725 | 26.54 | 0.0001 |
| 2 Way Interaction | 3 | 0.32 | 0.108 | 3.965 | 0.0529 |
| Residual | 8 | 0.21 | 0.027 | | |
| Pure Error | 8 | 0.21 | 0.027 | | |
| Total | 15 | 3.44 | | | |

In comparison of blending techniques, draw frame blending gives lower irregularity than blow room blending technique. This statement is true prominently for blend ratio 67/33.It may be attributed because of separate processing of virgin cotton and recycled wastes in card during draw frame blending technique. The task of individualization and parallelization of virgin cotton performed by card cylinder hampers due to excessive recycled wastes in case of blow room blending. On the other hand, blending technique hardly improves the evenness of rotor yarn at blend ratio 83/17. Results show that higher cylinder speed and smaller rotor speed give better results in term of yarn evenness. The trend in the results can be explained as follows: higher cylinder speed creates higher carding force per unit load. Yarn irregularity (U %) decreases with the increase of carding force [19]. On the other hand, feed rate have to increase to maintain the yarn count for a given yarn twist value with the increase of rotor speed. As a result, the efficiency of combing roller in individualizing the fibers gets decreased. Ultimately yarn evenness will be less in high rotor speed in most cases. The trend is in agreement with Halimi et al. [20]. Same trend of results are found also by F.A Arain et al. and they explained that too high rotor speed results in too much increase in number of wrapper fibers and disturbs the fiber arrangement in the groove of rotor, so as a result unevenness of yarn increases [21].

**Yarn Imperfections:** Our selected experimental design model is statistically significant that have a p-value of 0.0011<0.1. From regression information given in table-3, we get blend ratio as a significant term for yarn imperfection. From interaction matrix, the influences of different factors can be stated as follows: high content of virgin cotton in blend composition leads to lesser yarn imperfections value and also at the same blend ratio, blending technique or carding speed have very little influence on yarn imperfections. It is well established that high amount of wastes used in processing deteriorates yarn quality such as yarn imperfection value. Among three independent variables viz. blending technique, cylinder speed and rotor speed, yarn imperfection results be influenced by rotor speed (p<0.1) more than other two parameters considered individually. With the increase of rotor speed, yarn imperfection value also increase. These results happened because of higher rotor speed forces the wrapper fibers to be closely wrapped around the yarn body. This type of wrapper fibers is counted as yarn neps. Fibers generally contain hooks or loops, have less time to be aligned themselves in rotor groove before yarn formation at high rotor speed. As a result, yarn imperfection value increase with the increase of rotor speed.

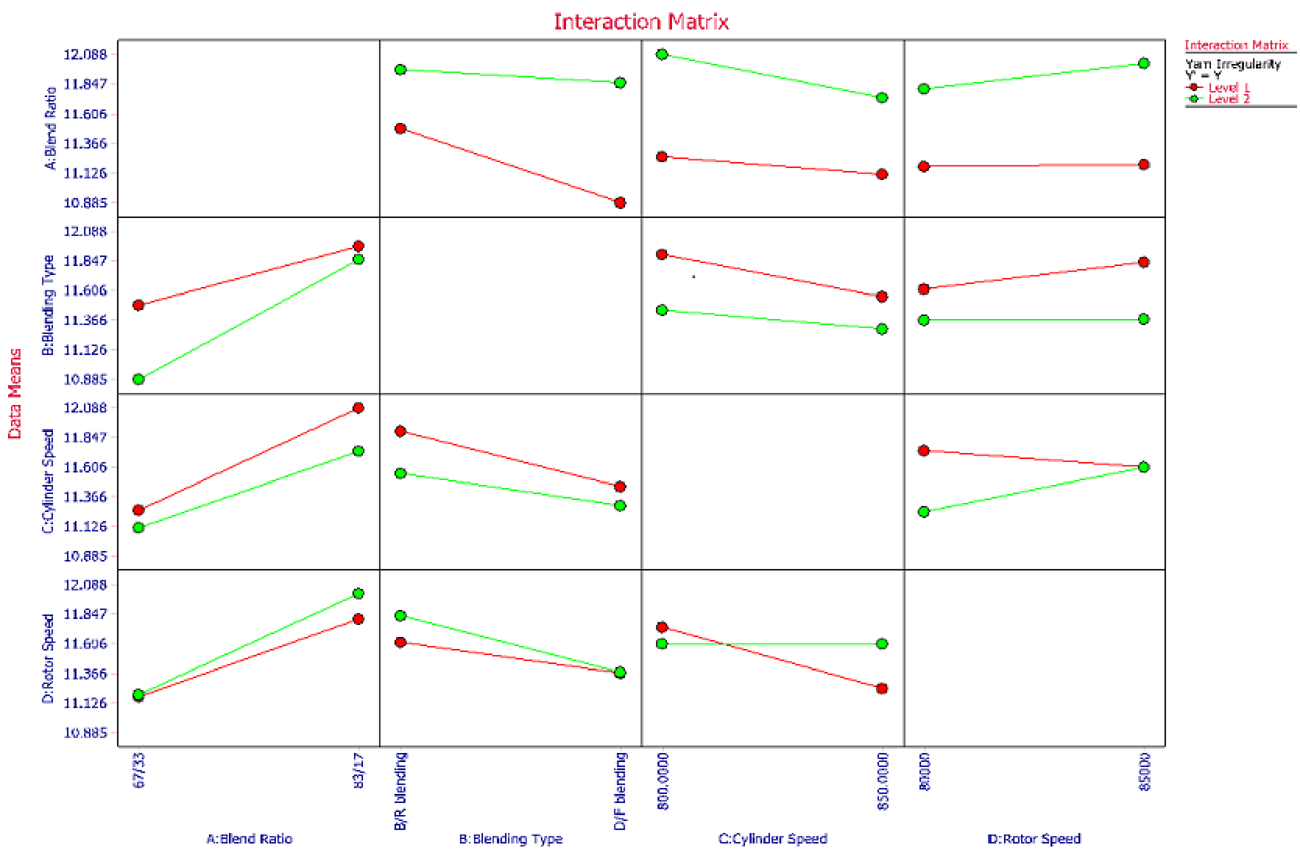


**Figure 1.** Interaction matrix for predicting yarn irregularity

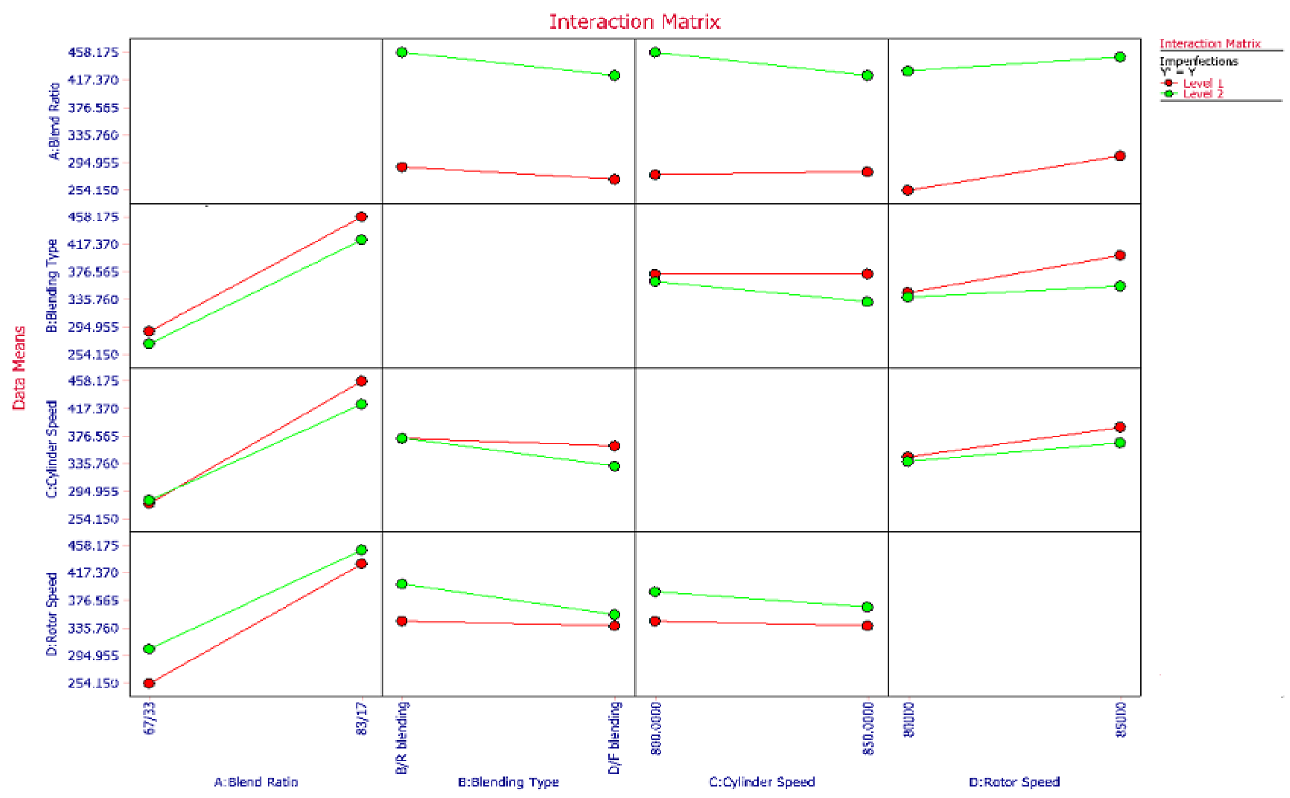


**Figure 2.** Interaction matrix for predicting yarn imperfection

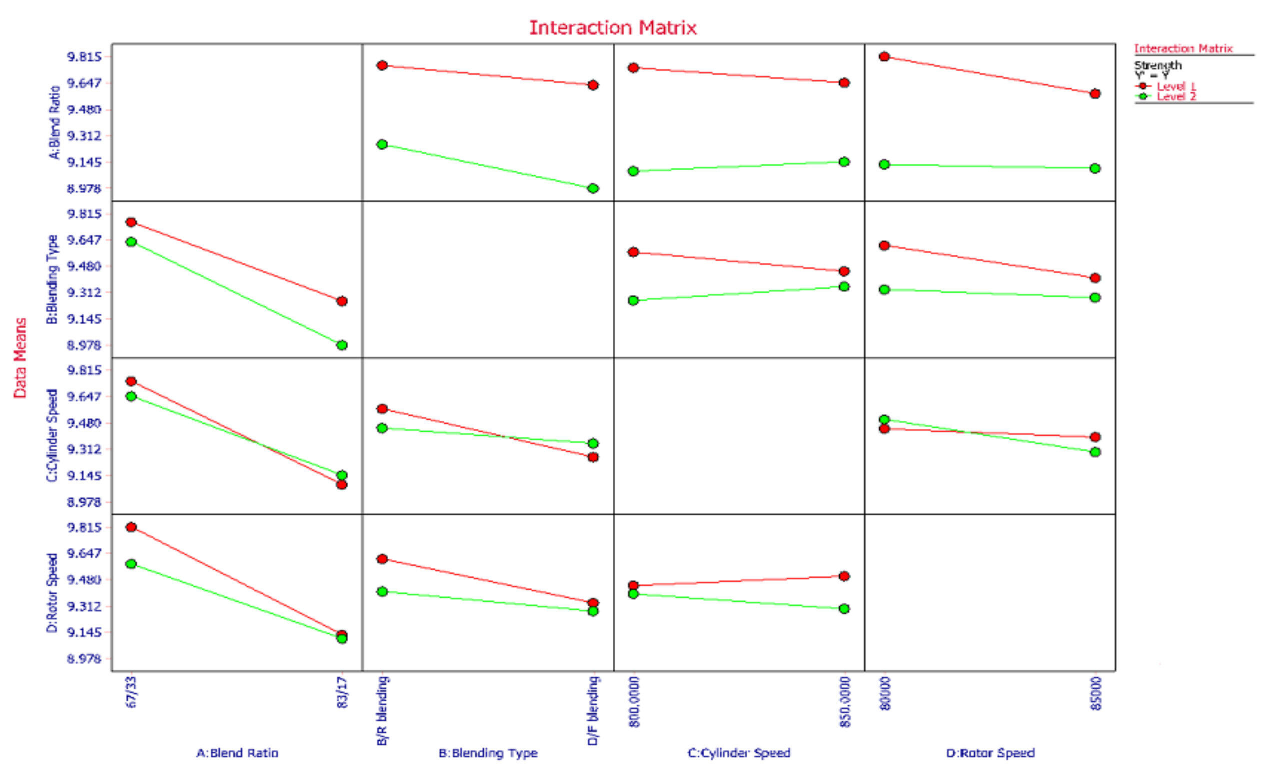


**Figure 3.** Interaction matrix for predicting yarn strength

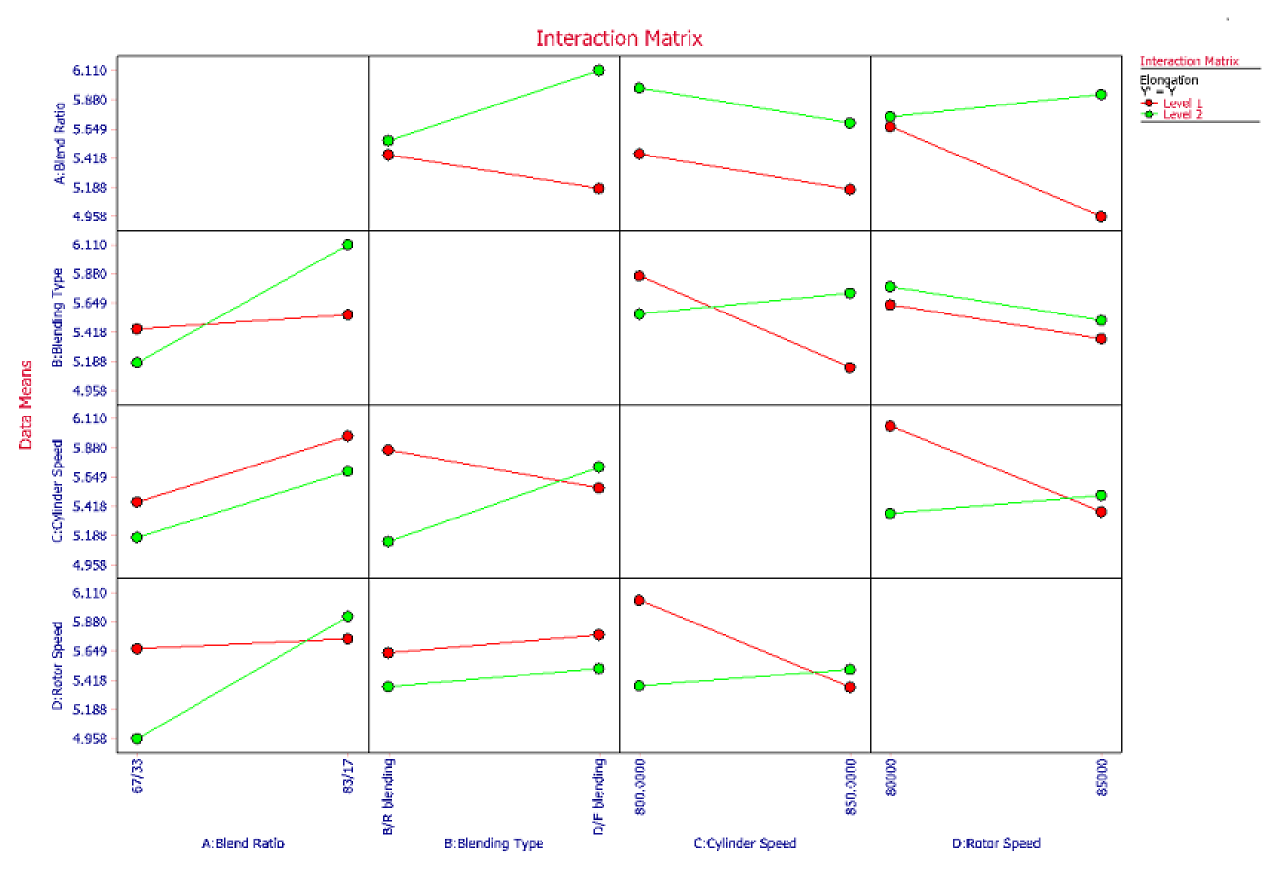


**Figure 4.** Interaction matrix for predicting yarn elongation

**Table 8.** ANOVA Table for Yarn Imperfection

| Source of Variation | df | Sum of Squares (Partial) | Mean of Squares | F Ratio | P Value |
|---|---|---|---|---|---|
| Model | 7 | 1.16E+05 | 1.65E+04 | 12.20 | 0.0011 |
| Main Effects | 4 | 1.13E+05 | 2.83E+04 | 20.86 | 0.0003 |
| 2 Way Interaction | 3 | 2665.652 | 888.5508 | 0.65 | 0.6015 |
| Residual | 8 | 1.08E+04 | 1354.2675 | | |
| Pure Error | 8 | 1.08E+04 | 1354.2675 | | |
| Total | 15 | 1.27E+05 | | | |

**Yarn Strength**: Yarn strength, is one of the most important parameter influencing the yarn's use in terms of quality. ANOVA table for yarn strength has been given in table-4. It is clear from ANOVA results of yarn strength that p value of design model and main effects indicating the significance of selected experimental design. However, according to table-3 results the independent variables blend ratio, blending technique and rotor speed have a significant effect ($p<0.1$) on the strength of yarn. Whereas cylinder speed has not the same effect ($p>0.1$). Higher percentage of virgin cotton always increase yarn strength. From interaction matrix of yarn strength (figure-3), the value of strength has been decreased slightly with the increase of rotor speed almost for any levels of other independent variables. Fibers coming out of combing roller cannot be straightened in rotor groove because of getting short time before yarn formation which results in lower yarn strength. From interaction matrix it is also seen that during blow room blending, yarn strength has been increased for any level of other variables. Homogeneity in blending is necessary to get higher yarn strength during blending of recycled waste and virgin cotton. Blending in blow room was found to be better, resulting in more homogeneous mixing of the component fibers [22]. Strength increased with high cylinder speed in case of draw frame blending whereas opposite results fount in case of blow room blending. For blow room blending, neps reduction and the effect of individualization will be less because of processing recycled waste and virgin cotton together. Virgin cotton blended with recycled wastes will face unnecessary stresses applied during processing at blow room since more cleaning actions are needed in case of recycled wastes. As a result processing virgin and recycled cotton separately in carding machine can avoid disturbances.

**Yarn Elongation**: According to p-value the independent parameters can be classified according to the level of important as: A (blend ratio)> A: D>A: B> C (cylinder speed)>D (rotor speed).Figure-4 shows the interaction effects of different factors on yarn elongation. Results indicate that yarn elongation drops at draw frame blending and higher rotor speed markedly for blend ratio 67/33 (recycled/virgin) but increases for blend ratio 83/17. It may be due to the presence of more short fibers in blend composition of 83/17 create disturbance during drafting. Parallelization of fiber in sliver will be poor that will be resulted in higher elongation of rotor yarn because of having hooked, curled fiber. On the other hand, high amount of centrifugal force will be acted on fiber during high rotor speed. As a result, yarn structure will be compact and fiber slippage will be decreased. Ultimately yarn elongation will loss at high rotor speed.

**Table 9.** ANOVA Table for Yarn Strength

| Source of Variation | df | Sum of Squares (Partial) | Mean of Squares | F Ratio | P Value |
|---|---|---|---|---|---|
| Model | 7 | 1.670 | 0.2387 | 12.6 | 0.0009 |
| Main Effects | 4 | 1.578 | 0.3946 | 20.9 | 0.0003 |
| 2 Way Interaction | 3 | 0.092 | 0.0307 | 1.63 | 0.2577 |
| Residual | 8 | 0.150 | 0.0188 | | |
| Pure Error | 8 | 0.150 | 0.0188 | | |
| Total | 15 | 1.821 | | | |

**Table 10.** ANOVA Table for Yarn Elongation

| Source of Variation | df | Sum of Squares (Partial) | Mean of Squares | F Ratio | P Value |
|---|---|---|---|---|---|
| Model | 7 | 3.2198 | 0.46 | 10.86 | 0.001 |
| Main Effects | 4 | 1.7638 | 0.441 | 10.41 | 0.002 |
| 2 Way Interaction | 3 | 1.456 | 0.485 | 11.46 | 0.002 |
| Residual | 8 | 0.3388 | 0.042 | | |
| Pure Error | 8 | 0.3388 | 0.042 | | |
| Total | 15 | 3.5585 | | | |

Cylinder speed seems to have a significant effect on yarn elongation. Working with high cylinder speed affects negatively with yarn elongation. Fibers get better orientation and straightening due to high carding force at high cylinder speed resulted in better drafting operation at finisher draw frame. So, fiber separation by opening roller in spinning frame will be easier. Better separation by opening roller will lead lower elongation in rotor yarn.

# 4. Conclusions

In this study we have tried to predict the most important quality variables of rotor spun yarn based on four independent variables by using taguchi OA factorial design. For this purpose, 16 samples of 16 Ne rotor yarn have been produced. From ANOVA results, it is clear that the significance level of regression (p value) for our selected model is less than 0.01 meaning model is significant to predict the quality of rotor spun yarn. Our model pointed out that blend ratio and rotor speed are most influencing factors for producing good quality yarn. Reducing rotor speed is beneficial to the yarn evenness, imperfections and strength. Although the shortcoming of draw frame blending is lower yarn strength but we can improve yarn quality produced from higher mixing of recycled waste in terms of evenness, imperfection and elongation by using draw frame blending in place of blow room blending. A high cylinder speed is recommended at draw frame blending and during blending of higher waste, while spinning waste content does not provide the expected results of yarn strength.

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