Investigation of various factors affecting the coefficient of friction of yarn by using Taguchi method

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REZUMAT – ABSTRACT

Investigarea diferiților factori care influențează coeficientul de frecare al firelor folosind metoda Taguchi

Acest studiu are ca obiectiv analiza influenței tipului de bumbac, calității, tehnicii de filare, torsiunii, densității liniare și finisării firelor asupra coeficientului de frecare al firelor, utilizând metoda Taguchi. Pentru evaluarea nivelurilor și factorilor de răspuns, au fost realizate 72 de experimente utilizând proiectarea ortogonală L_{36} de două ori pentru abordarea Taguchi. Rezultatele au arătat că firele formate din fibre fine, pieptănate, tratate cu parafină, filate cu rotor, cu torsiune optimă și densitate liniară scăzută au cel mai mic coeficient de frecare al firelor, îmbunătățind în cele din urmă procesele textile ulterioare și calitățile produsului.

Cuvinte-cheie: coeficient de frecare, proiectare ortogonală L_{36}, densitate liniară, abordare Taguchi, fir

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This research aims to analyze certain effects of yarn characteristics such as: cotton type, yarn quality, yarn spinning technique, yarn twist and linear density and yarn finish on coefficient of friction of yarn by using Taguchi approach. For evaluation of levels and response factors, 72 experiments are performed by using L_{36} orthogonal design twice for Taguchi approach. The results show that yarns comprising of finer fibers, combed, waxed, Rotor spun, optimum twist and low linear density have lowest coefficient of friction of yarn, which ultimately improves subsequent textile processes and improve product qualities.

Keywords: Coefficient of friction, L_{36} orthogonal design, linear density, Taguchi approach, yarn

INTRODUCTION

In this modern era of 21st century, textile technologies are designed for higher rates of productivity to fulfill one of the basic needs of increasing human population, clothing. This imposes some serious restrictions on materials and equipment to produce quality product with highest efficiency and low downtimes. COF of yarns play an important role in textile fabrication, particularly in knitting where a combination of needles works together at high speeds and yarns pass through the hooks of needles. To produce faultless quality product, increase life of knitting needle and reduce yarn fluff in knitting process, COF of yarns must be lowest and within the tolerance level. In knitting, in our opinion, type of yarn material, spinning process and finishing method are the major impact factors need to be measured.

RELATED LITERATURE

Yarn formation is not as simple as its definition; it involves vast technologies, materials and influencing factors and used to produce wide range of textile products [1]. Frictional forces between yarns and knitting needles produce heat cause breakage of knitting needles and yarns [2]. An increase in yarn friction results in high end breakage rate at knitting and weaving [3]. Fiber parameters, yarn structural and bulk parameters, operational parameters and finishes are the major factors to affect the yarn frictional parameters [4]. Yarn twist is inversely while compressibility is found directly proportional to COF of yarn [5]. Rougher yarns have high COF in case of yarn-to-yarn while low COF in case of yarn to metal friction [6]. COF could be measured by Twist friction method, Capstan method, Amonton's law method, Lindberg and Gralen method [7]. Yarns with higher frictional properties gave fabrics whose frictional properties are proportionally higher [8].

Robust Design method, also called the Taguchi method, pioneered by Dr. Genichi Taguchi, focus on the effective application of engineering strategies, facilitates flexible designs and concurrent engineering [9].

Taguchi is a 4-phase process: Planning, Conducting, Analysis and Validation. Major tools used in Taguchi analysis are main effects plot for means, S/N ratio plots and results prediction for validation [10].

DESIGN OF EXPERIMENT

Rotor spun yarns are not waxed and compared to ring spun at single twist level that's why Taguchi is used twice, separate for ring and rotor spun yarns. Taguchi process is followed as:

Planning Phase – The problem is high COF causing troubles in sub-sequent knitting process and spinning complaints. The identified variables are; cotton type, yarn quality, yarn finish, linear density of yarn, twist

level and yarn spinning technique. Five factors Taguchi is used for ring spun yarns while four factors design is used to compare ring spun and rotor spun yarns. Effecting variables and response factor for both designs is elaborated below.
Taguchi design for Ring spun yarns involve:

Rotor spun vs Ring spun yarns design involve:

Table 1

DOE FOR RING SPUN YARNS				
Effecting factors	**Levels**			**Response factor**
Cotton Type	Pakistani	Indian		COF of Yarns
Yarn Quality	Carded	Combed		
Yarn Finish	Wax	Un-Wax		
T.M Level	3.7	3.9	4.1	
Count	16s	20s	24s	

Table 2

DOE FOR RING VS ROTOR SPUN YARN				
Effecting factors	**Levels**			**Response factor**
Cotton Type	Pakistani	Indian		COF of Yarns
Yarn Quality	Carded	Combed		
Spinning Technique	Ring	Rotor		
Count	16s	20s	24s	

Taguchi L_{36} orthogonal array DOE is selected for both conditions.
Conducting Phase – As per DOEs, 72 experiments are performed to analyze their impact on COF of yarn. Experiments are performed under experimental lab conditions and tested according to ASTM Standards.
Analysis Phase – Testing results are inserted in response factor column of Taguchi DOE and Taguchi is analyzed for means and S/N ratios. Taguchi analysis shows effect of each variable on response factor and indicates optimum factors to achieve best results.
Validation Phase – Results are validated by comparing nine random predicted values with Taguchi formulas and to actual experimental results.

MATERIALS & METHODS

Raw cotton is tested for fiber parameters on USTER HVI 1000. 72 yarn samples are prepared according to Taguchi DOE. Samples development process flow is shown in figure 1.

Testing

Every sample is tested for Yarn Lea Strength, Tenacity on USTER Tensorapid, and COF on MESDAN ATTRIFIL-II, Uniformity and IPI on USTER UT-5 and yarn surface characteristics through SEM. Samples are tested for COF of yarn under ASTM-D1308 standard (table 3).

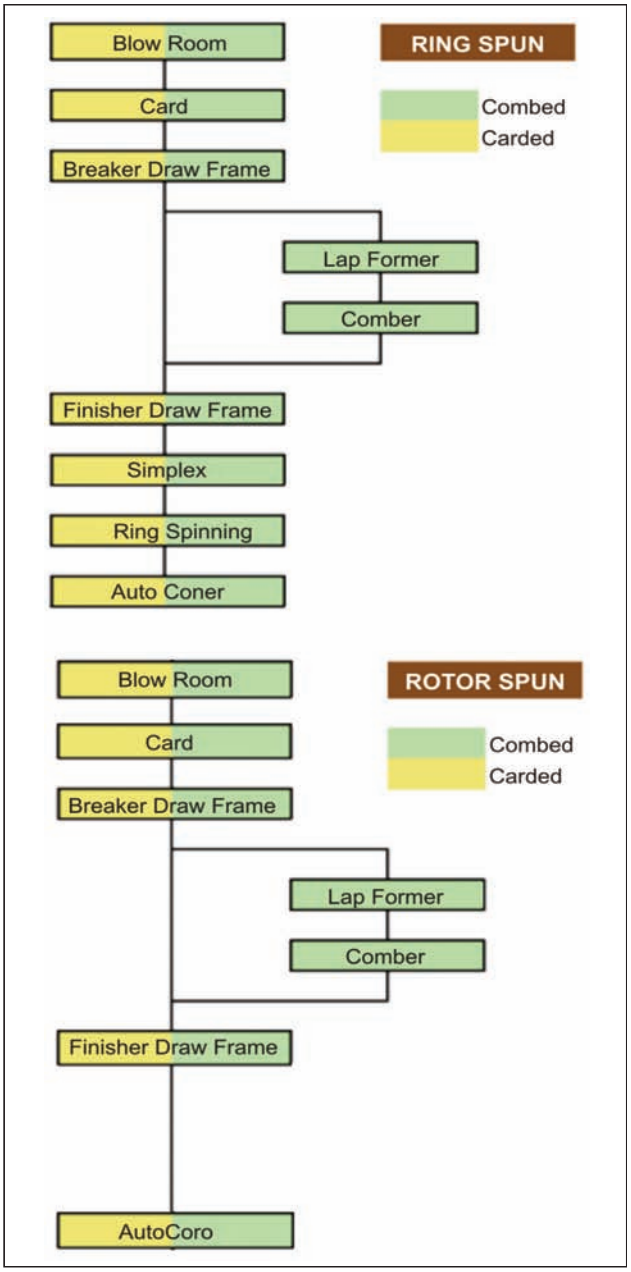


Fig. 1. Yarn Spinning Methods

Table 3

COF Testing Parameter	Value
Number of tests each bobbin	1
Sample length	50 m
Deviation among Tests	10 m
Input Tension	20.0 cN
Sliding Speed	150 m/min

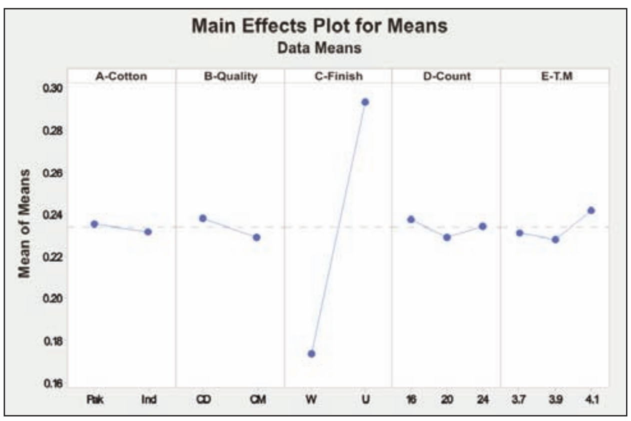
ANALYSIS & RESULTS

Testing results are analyzed by using Taguchi Method in Minitab. COF of yarns is inserted in response column and analyzed against identified variables. Analysis results are explained below.
Graph 1 shows that yarns spun from PAK Cotton have more friction than IND cotton. IND cotton has Mic. Value of 3.94 in contrast to 4.70 of PAK. High

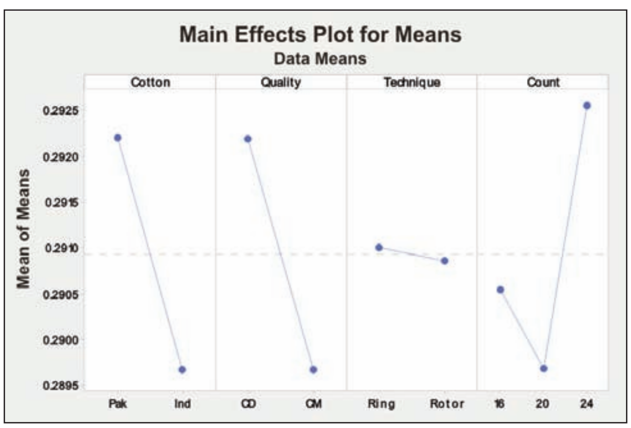
Mic. Value cause increase in contact area of the fibers and ultimately increase COF of yarns.

Carded yarns have more COF than combed yarns. Parallelization and orientation of fibers along the axis of yarn in reduce combed yarns. [12] Waxed yarns have lower COF than un-waxed yarns. Wax is a lubricant and gives smoother, slippery and unique yarn surface. SEM results have also validated this result. COF of yarns decreases with increase in indirect count. The fact is more compact structure of yarns due to fine count and high twist level. Structure that is more compact means low contact area and reduced COF. An increase is seen in COF of yarns at both low and high twist levels. This is due to the increased surface roughness and harshness of yarns at higher twist levels and more contact area due to low compactness at low twist levels. It is clear that COF is high at 3.7 and 4.1 T.M. level but low at 3.9. So, an optimum level is needed for better results.

Graph 2 represents that Rotor spun yarns have low COF than the Ring spun yarns. Rotor inserts twist inside to outside direction thus having high twist in core but low in surface due to which yarn surface is less harsh and more soft, results in lower COF of yarns. SEM results have also shown that Rotor spun yarn has smoother and even surface characteristics in contrast to Ring spun yarn. Scanning electron microscopy images for Ring spun (Waxed, Un-Waxed) and Rotor spun yarns are shown in figure 2.



Graph 1. Main effects plot for Ring Spun Yarns



Graph 2. Main effects plot for Rotor Vs Ring Spun

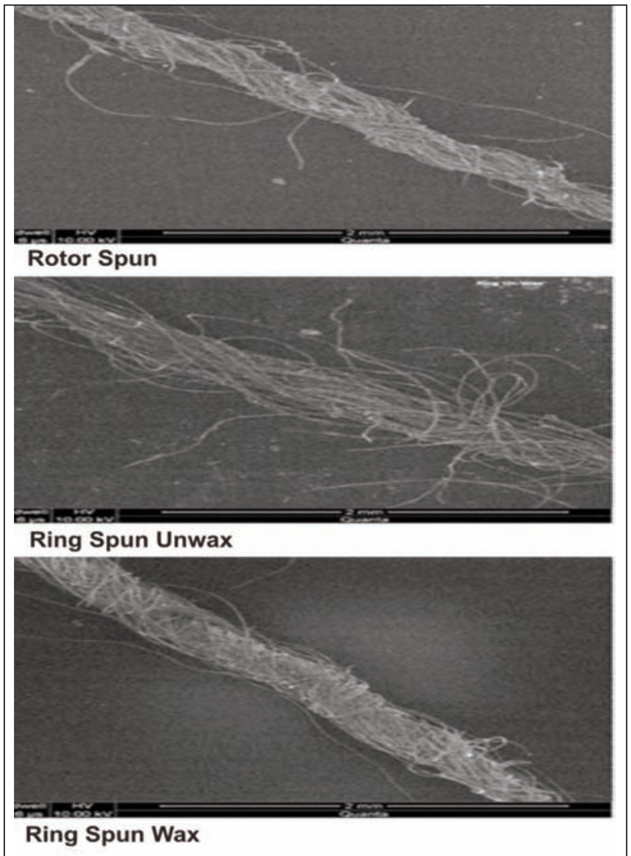


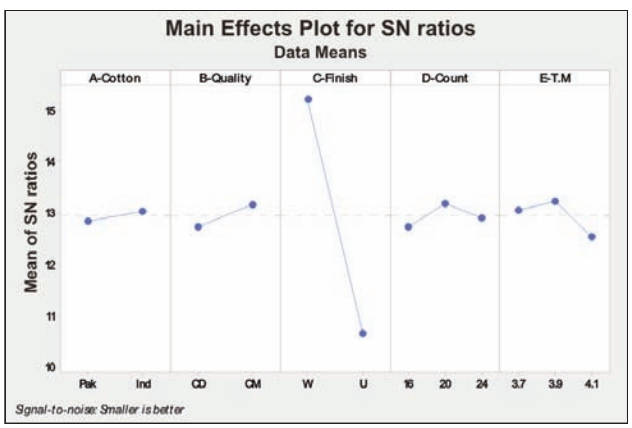
Fig. 2. SEM Images

VALIDATION EXPERIMENT

Verification experiment is performed under suggested factors, levels and conditions by *S/N* ratios graph and tables in Taguchi analysis. The results of this experiment are then compared with the predicted value calculated by formula 1.

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

S/N ratio graph produced in Taguchi analysis of Ring spun yarns is shown below:



Graph 3. SN Ratios Plot for Ring Spun

It is elaborated from the *S/N* ratios graph that IND cotton, CMB yarn, 20s and 3.9 T.M level give the best results. Therefore, these are the suggested levels of

impact factors. The mean value η_m of multiple *S/N* ratios in all experiments is 13.015 in graph.
Response table for suggested *S/N* ratios generated by Minitab in Taguchi analysis is:

Table 4

SN RATIOS RESPONSE TABLE					
Factors levels	Average SN				
	A-Cotton	B-Quality	C-Finish	D-Count	E-T.M
1	12.84	12.72	15.23	12.74	13.06
2	13.04	13.15	10.63	13.18	13.22
3	-	-	-	12.90	12.53
Delta	0.20	0.43	4.57	0.44	0.69
Rank	5	4	1	3	2

It is clear from the table that finish is ranked 1st as an effecting factor for COF while cotton is ranked last. So, the best optimum parameters combination is A2:B2: C1:D2: E2 which means IND: CMB: Wax: 20s:3.9. Now the predicted value is calculated by the formula as:

$$\begin{aligned}\eta_o &= 13.015 + (13.04 - 13.015)\\ &+ (13.15 - 13.015)\\ &+ (15.23 - 13.015)\\ &+ (13.18 - 13.015)\\ &+ (13.22 - 13.015)\\ &= 15.76\end{aligned}$$

Now the *S/N* value is known and predicted value for COF of yarn at this *S/N* ratio is calculated by following formula 2:

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

The predicted value is:

$$15.76 = -10\log\left(\frac{1}{36}\sum_{i=1}^{n} y_i^2\right) \Rightarrow y_i = 0.1632$$

Now experimental value of COF of sample (IND: CMB: Wax: 20s:3.9) is measured and the COF value of yarn is 0.1535 which is close and better to the predicted value by Taguchi design (0.1632).
S/N ratio graph produced in Taguchi analysis of Ring Vs Rotor spun yarns is shown bellow:

It is elaborated from the *S/N* ratios graph that IND cotton, CMB yarn, 20s count and rotor give the best results. The mean value η_m of multiple *S/N* ratios in all experiments is 10.7248 in graph. Response table for suggested *S/N* ratios generated by Minitab in Taguchi analysis is:

Table 5

SN RATIOS RESPONSE TABLE				
Factors levels	Average SN			
	A-Cotton	B-Quality	C-Finish	D-Count
1	10.69	10.69	10.72	10.74
2	10.76	10.76	10.73	10.76
3	-	-	-	10.68
Delta	0.08	0.08	0.01	0.09
Rank	3	2	4	1

It is clear from the table that count is ranked 1st as an effecting factor for COF while technique is ranked last. So, the best optimum parameters combination is A2:B2: C2:D2 which means Indian: Combed: Rotor:20s. Now the predicted value is calculated by the formula as:

$$\begin{aligned}\eta_o &= 10.7248 + (10.76 - 10.7248)\\ &+ (10.76 - 10.7248)\\ &+ (10.73 - 10.7248)\\ &+ (10.76 - 10.7248)\\ &= 10.8356\end{aligned}$$

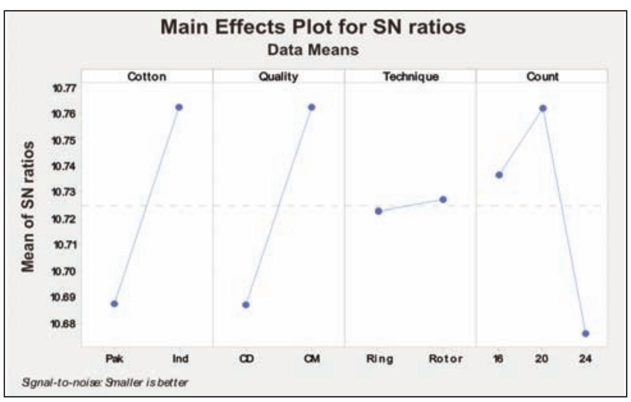
Now the value of *S/N* is known and predicted value for COF of yarn at this *S/N* ratio is calculated by formula. The predicted value is:

$$10.8356 = -10\log\left(\frac{1}{36}\sum_{i=1}^{n} y_i^2\right) \Rightarrow y_i = 0.2898$$

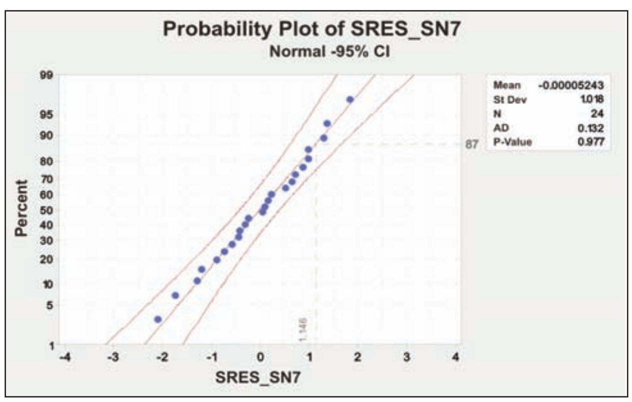
Now experimental value of COF of sample (Indian: Combed:Rotor:20s:) is measured and the COF value of yarn is 0.2895 which is very close to the predicted value by Taguchi design (0.2898).

PREDICTION OF THE COF OF OTHER CONDITION USING TAGUCHI DESIGN

Similarly, predicted and experimental values ae compared for nine conditions for each ring spun yarns



Graph 4. SN Ratios Plot for Rotor Spun



Graph 5. Normal Probability Plot for Residuals

which shows 3.35% variation and ring vs rotor spun yarns which shows 0.37% variation.

Normal probability plot has shown that residuals generally fall in a straight line and errors are distributed normally inside the outer limits. So, relative percentage errors are low and all experimental results are normal.

CONCLUSIONS

It is concluded that: the fineness, parallelization and compactness of fibers inside yarn structure are directly proportional to the COF of yarns, also demonstrated in a recent research [13]. Another research validates the yarn smoothness due to fineness and compactness [11]. SEM images and COF results have elaborated that wax reduces COF of yarns acting as an effective lubricant. Best COF values of yarns achieved at optimum twist level not too low or high depicts that COF of yarns increase at both low and high twist levels. Yarn structure and twisting technique show robust impact on COF of yarns as rotor spun yarns were found superior than the ring spun yarns in case of COF. Experimental verification and graphs have shown that there are very little errors between experimental and predicted values. Moreover, Taguchi design is proved as a powerful tool to analyze, predict, compare and find errors. At the end the normal probability plot for residuals elaborate that all the results lie on the straight line within the normal limits. These results are also supported by previous researches [4–6].

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