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Investigation of Yarn Quality in Ring Yarn by Modifying Bottom Apron/Nose Bar with Perforations and Air-Suction

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Abstract: Currently, ring spinning has limitations of poor integration of fibers that protrude from yarn surface, which causes hairiness and irregularity. The aim of this research is to improve yarn quality by modification of bottom apron/nose bar with perforation and applying air-suction in a conventional Reiter G35 ring frame and spinning 29.52 Tex (20 Ne) and 14.76 Tex (40 Ne). To produce modified yarn 17 combinations of apron hole diameter, suction pressure, and widthwise hole distance was used. The ANOVA result shows that as suction pressure increases hairiness, tenacity, and thick place (+50%/km) were improved significantly for both counts. Based on the result suction pressure, apron hole diameter, and hole distance were optimized to 23.9 mbar, 1.58 mm and 10 mm respectively for 40 Ne and 25 mbar, 1.75 mm, and 11.6 mm respectively for 20 Ne. As compared with conventional hairiness, tenacity, thin place, and thick place of 40 Ne modified yarn were improved by 16.25%, 12.7%, 17.42%, and 14.62% respectively. Whereas hairiness, tenacity, and thick place of 20 Ne modified yarn were improved by 8.87%, 7.42%, and 18.2% respectively. Thus, the modified G35 method of yarn condensing has capability to be used as an alternative method of conventional spinning as it is capable of producing better quality yarn.

Keywords: Apron Hole Diameter, Condensed Yarn, Suction Air Pressure, Hole Distance, Yarn Quality

1. Introduction

The textile industry is more competitive today than ever in an attempt to produce high-quality clothes at minimal production costs that meet both the aesthetic and technical needs of todays' generation [1]. The current competitive market requires designers of the fabric to consider moisture absorption and wick ability properties depending on weather conditions and end-use applications [2].

The quality of the spun yarn is significantly improved by using quality raw material, suitable selection of spinning system, and type of spinning machine [3, 4]. The main objective of yarn spinning is to achieve the highest predictable yarn evenness with minimum imperfections, which imparts uniformity in yarn strength. Therefore, these improvements positively influence the quality of subsequent processes, like weaving and knitting [5, 6].

Different spinning is anticipated to take into consideration the characteristics of fiber machine intelligence, which assists to modify ideal combinations of fiber properties [7, 8]. The attempts to produce high-quality yarns have been concerned with great developments in the area of spinning [9]. These developments consist of examining, manufacturing, and optimizing various mechanisms and settings in spinning to modify conventional rings by introducing new elements or developing entirely new yarn production systems. Therefore, yarn quality refers to the physical characteristics of a yarn that influence fabric production, performance, and serviceability. These parameters include yarn hairiness, yarn strength, imperfection, and yarn evenness [10, 11].

The measures to produce better quality yarns are detection and reduction of raw material variation, reduction in coefficient of variation, and elimination of faults, which is a significant increase in yarn breaking force and elongations.

In addition, supervision, and control of all processes, finding optimum settings over all technologies, and use of automation according to existing mill settings are required [10, 11]. The further developments in ring spinning were leading to a modification of ring-spinning such as compact, double-rove, solo, nozzle-ring, and core-sheath, etc., have improved the versatility of ring spinning [8, 12]. The significant limitation of ring spinning is its low productivity, the yarn quality it produces, namely high yarn hairiness especially hairs longer than 3 mm, and irregularity. The latter is characteristic of roller drafting, which is unable to perfectly regulate the movement of short fibers and spinning geometry [13]. The introduction of compaction of fiber strand in the ring by various compact spinning reduces the problem of excessive hairiness in-ring yarns. But, the problem of hairiness variation along the length of yarn remains unsolved and will remain due to no individual control of fibers in drafting [8].

The basic modification takes place in the region of the spinning triangle. The arrangement of fiber in yarn structure is not similar to one another but all yarn is twisted by the same principle as the conventional ring. Using an air-suction device and a perforated surface mounted on the fiber flow line, fiber at the selvage of the fiber strand is completely integrated into the yarn body, thus increases yarn strength with a decrease in hairiness [14]. The drafted fiber strand in compact spinning is condensed before the twist is imparted; the fibers are arranged in a close and parallel position to one another. Improved characteristics of yarn after compacting the yarn are perfect structure thus increases yarn strength, reduces hairiness, and improved abrasion resistance [15].

The physical properties of the yarn like the tenacity and evenness of the yarn spun with the compact spinning system was higher as compared with ring yarn [16]. Generally, the ring-spun yarn has a higher imperfection index compared to compact-spun yarns [15, 17]. Fabrics woven with compact yarns have more tensile strength, and extension than fabrics woven with ring yarns [17]. There is a significant change in the physical properties of fabrics produced by compact and ring yarn concerning abrasion resistance, breaking, and tearing strength [18].

The conventional ring has been modified to produce condensed yarn with air suction pressure fitted in the front drafting zone. The reduction in yarn hairiness can be attributed to better binding of the edge fibers in the drafted ribbon due to the mingling action of air at the front drafting zone [19]. The improvements in yarn imperfection are due to the compaction of the drafted ribbon at the front drafting zone causes a higher fiber-to-fiber cohesion, which leads to better control on short fiber motion while drafting. The condensed yarns are found to be stronger and more extensive than existing ring yarns [19]. Compressed air is applied to yarn, the swirling airflow tucks ring yarn surface fibers into its body, thereby improves the consistency of yarn and reduces hairiness. Thus, applying an air nozzle significantly lowers the degree of hairiness of spun yarn [20]. Therefore, the existing literature supports the idea that yarn quality can be improved to a large extent by modifying the conventional ring spinning system. These reasons initiate the interest to further study, investigate, and manipulate the conventional ring spinning process to produce better quality yarns.

2. Materials and Method

2.1. Modifications of Conventional Ring Spinning

The bottom apron YAMADICHI 16.04 model with dimensions of 228mm*30mm*0.9mm bottom aprons were perforated as shown in Figure 1. The bottom aprons were perforated with 1mm, 1.5mm, and 2mmholediameter with widthwise hole distance 10mm, 12mm, and 14mm separately for each hole diameter [21]. Perforation has been done in two rows on the bottom apron; thus 23 pairs of holes were perforated in each apron. The perforation distance in case of perforating the next zigzag hole was 2mm. Finally, the distance of the hole for each row on the same axis of the apron was 4mm because the fiber length under 4- 5mm is lost in processing as waste and fly [22]. The nose bar was fabricated as shown in Figure 1 with dimensions 53 cm x 2.5 cm x 0.4 cm and perforated for extending and tensioning the bottom apron to the nip line of the front roller.
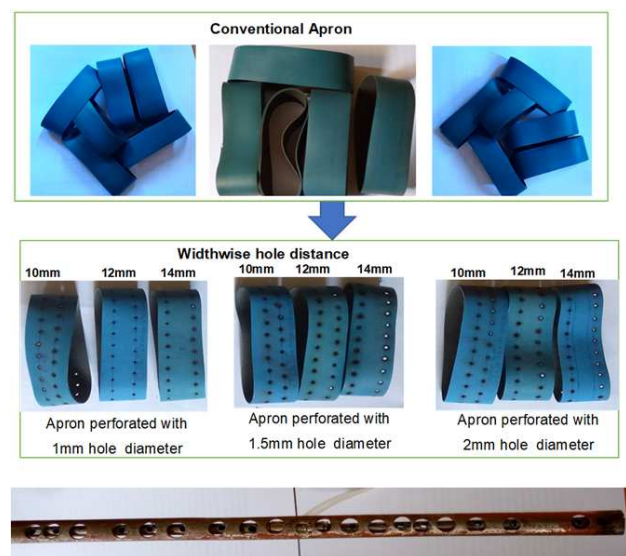

Figure 1. *Modified or perforated bottom apron and nose bar.*

The conventional G 35 ring frame the drafting arrangement was modified by perforating the bottom apron. The diameter of the needle was 1 mm, 1.5 mm, and 2 mm for perforating the aprons [6, 23-32]. Pneumatic suction pipelines for each spindle was installed under the perforated bottom apron for sucking protrude fibers by measuring with a pressure gauge.

2.2. Methods

Figure 2 described the overall method of the study in the flow diagram starting from the initial machine modification to yarn production. After the preparation of the test specimen, all the yarn is tested in the standard testing condition 65±2% relative humidity and temperature 20±2°C.
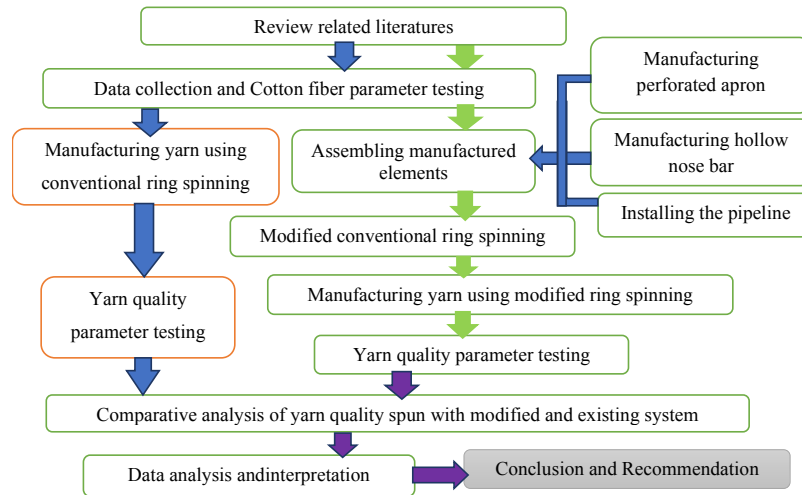
Figure 2. Methodology.

2.2.1. Fiber Parameters Test by HVI/1000

The 100% cotton fiber quality parameters were tested with Uster HVI 1000 as shown in Table 1 such as tenacity, UHML, short fiber content, maturity, elongation, and micronaire were tested.

Table 1. Fiber quality parameters.

Fiber parameter	SCI	Mst (%)	Mic	Mat	UHML (mm)	UI (%)	SF (%)	Tenacity (g/tex)	Elon (%)	Rd	+b
Average	82	4.9	3.56	0.83	24.99	79.2	11.7	17.7	7.1	78.9	9.3

2.2.2. Yarn Spinning

For manufacturing the yarn using modified and conventional rings all machine settings and process parameters were the same as shown in Table 2.

Table 2. Ring frame machine settings for the modified and conventional yarn.

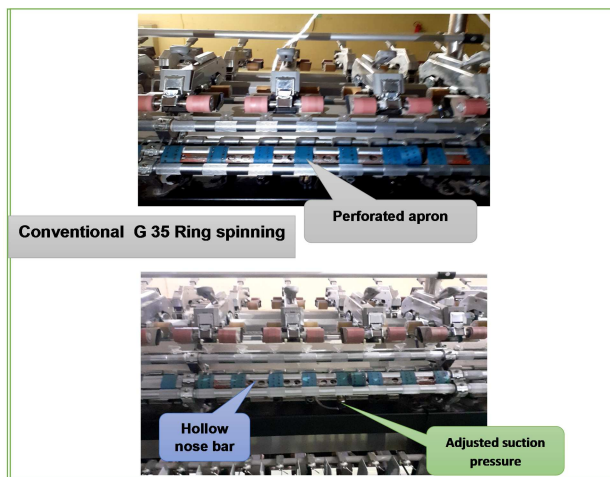| Parameters	Conventional G 35 ring		Modified G 35 ring	
	20 Ne	40 Ne	20 Ne	40 Ne
Roving count (Ne)	0.8	1.1	0.8	1.1
Twist (Tpm)	820	1080	820	1080
Spindle speed (rpm)	10000	16500	10000	16500
Spacer	3.75	3.5	3.75	3.5
Traveller number	2	4/0	2	4/0
Delivery speed (m/min)	12.2	15.3	12.2	15.3
Total draft	25	39	25	39

Figure 3. Modified G 35 ring spinning.

Figure 3 shows existing and modified yarns spun in Reiter G35 with 17 combinations of apron hole diameter, suction pressure, and widthwise hole distance on a modified G 35 ring.

Yarn property parameters spun with existing and modified G 35 ring were tested. The analysis was done by design expert with Box-Behnken design and comparison was done by independent samples t- test using Analysis of Variance (ANOVA) statistical software were used.

3. Results and Discussion

The yarn property test investigation was analyzed based on a 95% confidence interval. The degree of significance (p), which has been obtained from ANOVA, has been compared with the significance level (α) of 0.05. The effects, whose degree of significance has been lower than 0.05, have been interpreted as statistically important.

3.1. Effect of Apron Hole Diameter, Suction Air Pressure, and Width-wise Hole Distance on Properties 40 Ne Ring Yarn

Table 3 shows the average yarn test result for 40 Ne yarn spun on the modified G 35 ring.

Table 3. Average test results for 40 Ne yarn spun with modified G 35 ring with different combinations.

Run	Factor 1 A: Apron hole diameter (mm)	Factor 2 B: Suction pressure (mbar)	Factor 3 C: Widthwise hole distance (mm)	Response 1 Tenacity cN/tex	Response 2 Hairiness Index (H)	Response 3 Nep (+200%/km)	Response 4 Thin place (-50%/km)	Response 5 Thick place (+50%/km)
1	2	15	12	9.094	6.19	3287	337	1892
2	1.5	20	12	13.483	5.58	3472	335	1547
3	1.5	20	12	13.927	5.53	2395	285	1494
4	1.5	20	12	12.423	5.56	2515	305	1556
5	1	15	12	8.789	6.28	4252	347	2036
6	1	25	12	10.445	6.09	3242	301	1875
7	1.5	25	10	16.595	5.37	1896	165	1384
8	1.5	15	10	12.969	5.77	2683	236	1521
9	2	25	12	10.961	6.03	3561	314	1785
10	1	20	14	8.985	6.32	3613	370	2040
11	1.5	20	12	14.069	5.64	2281	300	1481
12	2	20	14	7.892	6.37	3357	357	2010
13	2	20	10	14.107	5.41	3146	169	1342
14	1.5	20	12	13.268	5.65	2825	330	1471
15	1.5	25	14	8.341	6.24	4227	345	1838
16	1	20	10	13.718	5.79	3863	234	1482
17	1.5	15	14	8.362	6.39	4265	356	1963

3.1.1. Hairiness Index (H)

The ANOVA in Table 4 shows that the model F-value obtained in the present study was 80.79 implies the model is significant. In this study, apron hole diameter (A), suction pressure (B), and widthwise hole distance (C), interaction effect (AC), besides quadratic terms (A^2, B^2, and C^2) have a significant effect on the hairiness of 40 Ne yarn. The hole distance had the highest F-value of 393.83 implies that it has the most significant influence on the hairiness of 40 Ne yarn. However, the interaction effect (AB), and (BC) has no significant effect on the hairiness.

A quadratic model for hairiness of 40 Ne yarn from ANOVA, in terms of coded parameters after removing non-significant model is given in Equation (1). The regression model shows that the hole diameter (A) and suction pressure (B) have a negative correlation with hairiness of 40 Ne. The holes distance (C), interaction effect (AC), and quadratic term (A^2, B^2, and C^2) have a positive correlation with hairiness of 40 Ne yarn. Thus, the model as shown in Equation (1) predicts that the linear effects of hole distance (C), interaction effect (AC), and quadratic term (A^2, B^2, and C^2) decreases the yarn hairiness for 40 Ne decreases. However, as apron hole diameter (A) and suction pressure (B) increases the hairiness index decreases.

$$\text{Hairiness index (H)}=+5.59 - 0.06A - 0.1125B + 0.3725C + 0.1075AC + 0.2928A^2 + 0.2627B2 + 0.0878C^2 \qquad (1)$$

Table 4. Analysis of ANOVA for hairiness index (H) for 40 Ne yarn.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Response 1: Hairiness of 40 Ne yarn and suggested ANOVA for the quadratic model						
Model	2.05	9	0.2277	80.79	< 0.0001	Significant
A-Apron hole diameter	0.0288	1	0.0288	10.22	0.0151	
B-Suction pressure	0.1012	1	0.1012	35.92	0.0005	
C-Widthwise hole distance	1.11	1	1.11	393.83	< 0.0001	
AB	0.0002	1	0.0002	0.0798	0.7857	
AC	0.0462	1	0.0462	16.40	0.0049	
BC	0.0156	1	0.0156	5.54	0.0508	
A²	0.3609	1	0.3609	128.03	< 0.0001	
B²	0.2907	1	0.2907	103.13	< 0.0001	
C²	0.0324	1	0.0324	11.50	0.0116	
Residual	0.0197	7	0.0028			
Lack of Fit	0.0091	3	0.0030	1.13	0.4371	Not significant
Pure Error	0.0107	4	0.0027			
Cor Total	2.07	16				

Figure 4. Relationship between actual and predicted values for hairiness of 40 Ne yarn.

As shown in Figure 5 the best-fitted model for hairiness of 40 Ne was a quadratic, with R^2 of 0.9905. This suggests that the analyzed factor explains 99.05% of the hairiness for 40 Ne yarn and that the model could not explain only 0.95% of the variation of yarn hairiness. Therefore, a strong correlation is achieved between predicted and actual for the hairiness of 40 Ne yarn.

Figure 5 shows that apron hole diameter, suction pressure, and widthwise hole distance have a significant effect on the hairiness of 40 Ne yarn. The hairiness of 40 Ne yarn was decreased as both hole diameter and suction pressure were at the center level. So far, as the hole distance increases hairiness of 40 Ne yarn was increased. Therefore, it is concluded that lower hairiness was obtained at a 10 mm widthwise hole distance due to better condensation of the edge fibers.
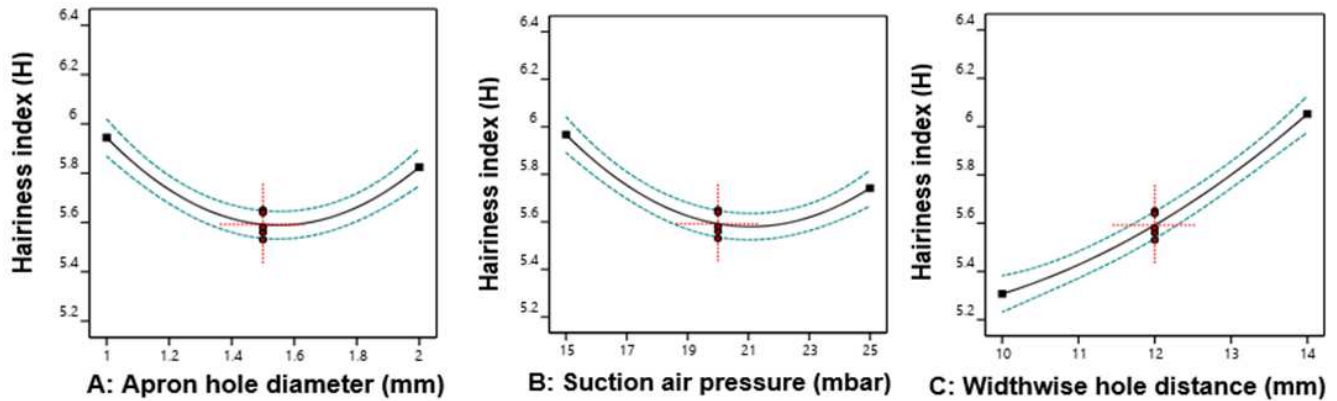

Figure 5. Effect of hole diameter, suction pressure, and hole distance on the hairiness of 40 Ne.

Figure 6 (a) shows that the minimum hairiness obtained was 5.53 when 1.5 mm hole diameter and 20 mbar suction pressure were used at a constant hole distance of 12 mm. But, the interaction effects of the apron hole diameter and suction air pressure at a constant widthwise hole distance of 12 mm have no significant effect on the hairiness of the 40 Ne yarn.
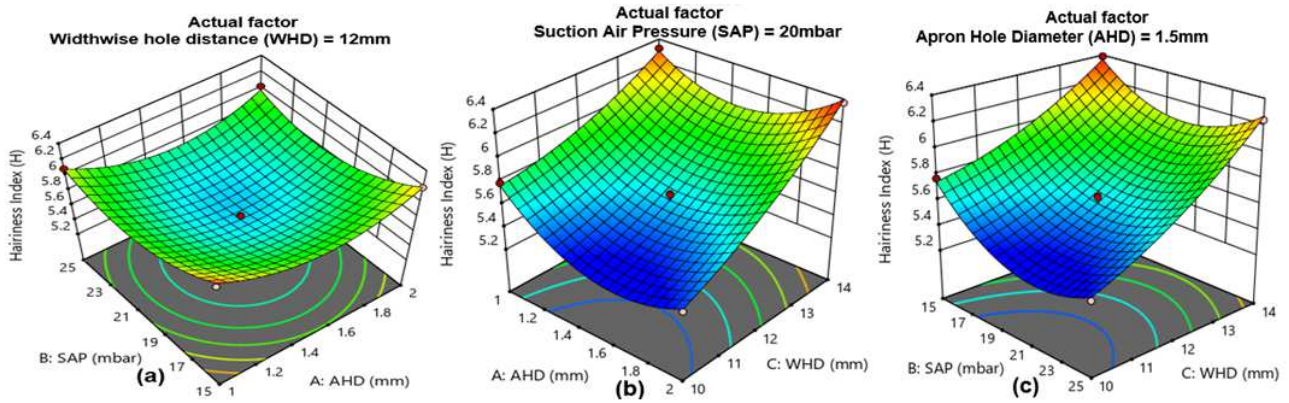
Figure 6 (b) shows the interaction effects of apron hole diameter and widthwise hole distance on the hairiness of 40 Ne yarn at the center level of suction pressure (20 mbar). It was observed that the hairiness was decreased when the widthwise hole distance was at a low level and the apron hole diameter was at the center level. Thus, the result in Table 3 shows the minimum hairiness for 40 Ne yarn was found to be 5.41 at a constant suction pressure of 20 mbar as the hole diameter was 2 mm and the widthwise hole distance was 10 mm. This result was best when compared

with all other interaction effects of apron hole diameter and widthwise hole distance at a constant suction pressure of 20 mbar as shown in Table 3. This is due to better binding and condensation of the edge fibers in the drafted ribbon because suction pressure and reduction in spinning triangles reduce yarn hairiness [19].

The interaction effect BC in Figure 6 (c) shows that the hairiness of 40 Ne yarn was decreased as the suction pressure increases with a decrease in hole distance. The result in Table 3 proves that the hairiness was found to be 5.37 as suction pressure was 25 mbar and hole distance was 10 mm at a constant apron hole diameter of 1.5 mm. Thus, it can be concluded that increasing the suction pressure to the optimum level reduces yarn hairiness significantly because the edge fibers were sucked through the air suction and the fibers are condensed to the yarn body [12, 19, 32-34].

Figure 6. *Factor interaction effect with a 3D Surface graph for hairiness of 40 Ne yarn.*

3.1.2. Tenacity (cN/tex)

Analysis of ANOVA in Table 5 shows that the model F-value attained was 35.36 implies the model is significant. In this study, the suction air pressure (B), widthwise hole distance (C), interaction effect BC, and quadratic term (A^2 and B^2) are significant effects on the tenacity of 40 Ne yarn. But, apron hole diameter (A), quadratic hole distance (C^2) and interaction AB and AC are not significant terms. Therefore, from the result, it can be concluded that as suction pressure increases to center level tenacity of 40 Ne yarn increases significantly because the fibers are condensed before twist (Mageshkumar and Ramachandran, 2012, Ma et al., 2014, Chakrabortty et al., 2020). As a result of suction pressure, the reduction in structure of the spinning triangle causes small differences in the path followed by edge fibers to integrate into yarn body enables better utilization of the fibers increases yarn tenacity [35].

The regression model of 40 Ne yarn is given in Equation (2). The model shows that the suction pressure (B) has a positive correlation with the tenacity of 40 Ne yarn. However, widthwise hole distance (C), interaction effect BC and quadratic term (A^2 and B^2) have a negative correlation with the tenacity of 40 Ne yarn. Widthwise hole distance (C) had the highest F-value of 202.71 implying that it had the most significant influence on the tenacity of 40 Ne yarn. Therefore, from the result, it can be concluded that as the suction pressure increases to an optimum level with the decrease in widthwise hole distance the tenacity of 40 Ne yarn increases significantly.

$$\text{Tenacity (cN/tex)} = +13.43 + 0.8913B - 2.98C - 0.9122BC - 2A^2 - 1.61B^2 \qquad (2)$$
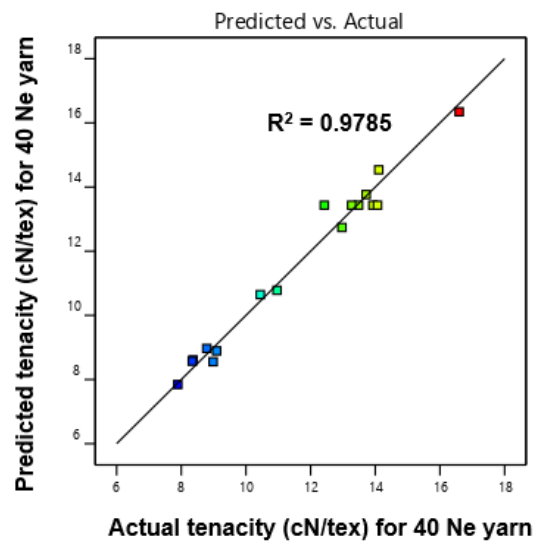

Figure 7. *Relationship between actual and predicted tenacity for 40 Ne yarn.*

The best-fitted model for the tenacity of 40 Ne yarn was a quadratic model, with R^2 value of 0.9785 as shown in Figure 7. This suggests that the analyzed factor explains 97.85% of the tenacity for 40 Ne yarn that the model could not explain only 2.15% variation. Therefore, a good agreement is achieved between the predicted and actual tenacity for 40 Ne yarn. Thus, a second-order regression model is developed to predict the tenacity of yarn.

Moreover, the predicted R^2 of 0.8714 is in reasonable agreement with the adjusted R^2 of 0.9508 and the difference is less than 0.2. In this study, the ratio of 18.751 on the fit statistics indicates an adequate signal is desirable.

Table 5. *Analysis of ANOVA for the tenacity of 40 Ne yarn.*

Response 2: Tenacity of 40 Ne yarn and suggested ANOVA for the quadratic model					
Source	111.27	9	12.36	35.38	< 0.0001	Significant
Model	0.0017	1	0.0017	0.0049	0.9462	
A-Apron hole diameter	6.35	1	6.35	18.18	0.0037	
B-Suction pressure	70.85	1	70.85	202.71	< 0.0001	
C-Widthwise hole distance	0.0111	1	0.0111	0.0318	0.8634	
AB	0.5491	1	0.5491	1.57	0.2503	

Response 2: Tenacity of 40 Ne yarn and suggested ANOVA for the quadratic model						
AC	3.33	1	3.33	9.52	0.0177	
BC	16.86	1	16.86	48.25	0.0002	
A²	10.92	1	10.92	31.25	0.0008	
B²	0.2786	1	0.2786	0.7973	0.4016	
C²	2.45	7	0.3495		0.4021	
Residual	0.7481	3	0.2494	0.5873	0.6548	Not significant
Lack of Fit	1.70	4	0.4246			
Pure Error	113.72	16				
Cor Total	111.27	9	12.36	35.38	< 0.0001	Significant

Figure 8 approves that apron hole diameter has no significant effect on the tenacity of 40 Ne yarn. But, the suction pressure and hole distance have a significant effect on the tenacity of 40 Ne yarn. The tenacity of yarn increases as suction pressure increases up to center level with the decrease in widthwise hole distance. The tenacity increases as the fiber bundles are condensed by suction so short fibers are integrated into the yarn body (Ma et al., 2014).
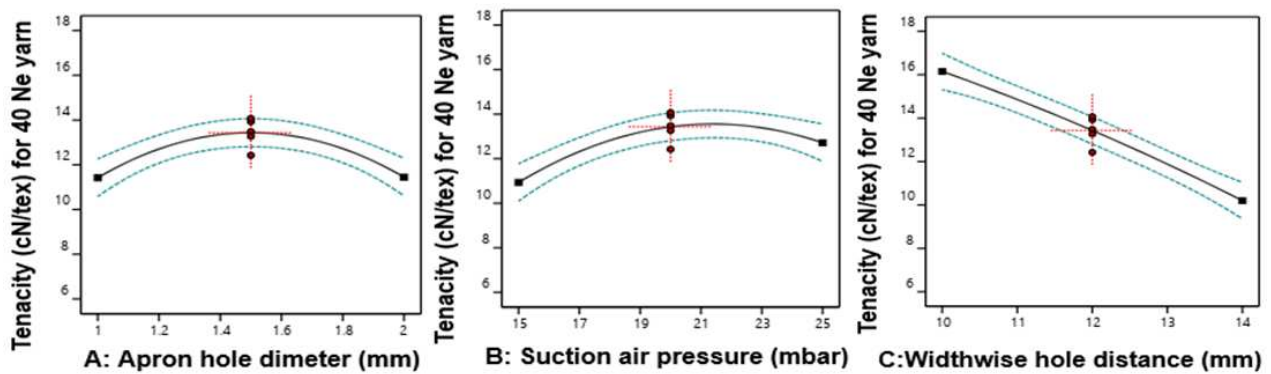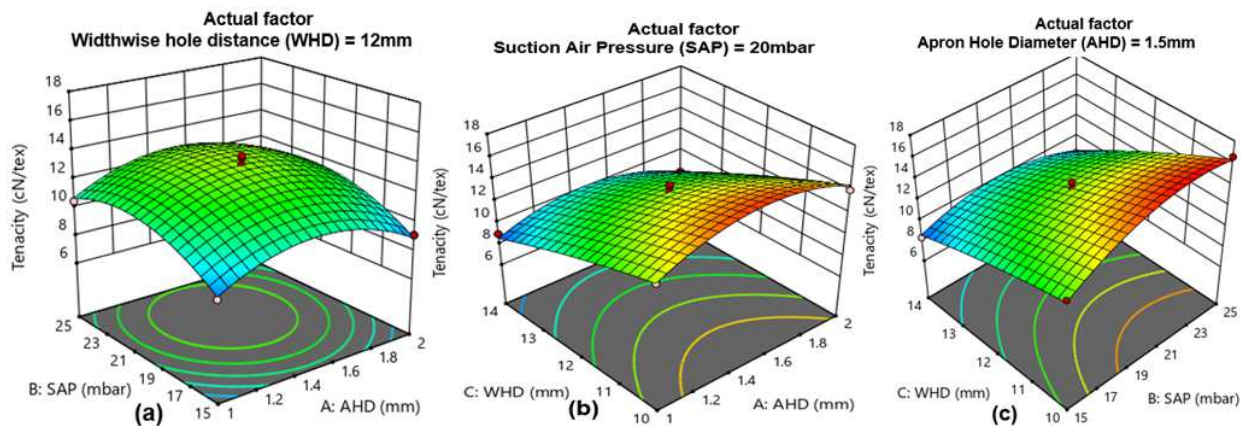

Figure 8. Effect of hole diameter, suction pressure, and hole distance on the tenacity of 40 Ne.

Figure 9. Factor interaction effect with the 3D surface graph for the tenacity of 40 Ne.

Figure 9 (a) shows that the maximum tenacity for 40 Ne yarn was 14.069 cN/tex as 1.5 mm apron hole diameter and 20 mbar suction were used at a constant hole distance of 12 mm. the 3D response in Figure 9 (b) shows that the maximum tenacity for 40 Ne was 14.107 cN/tex as 2 mm apron hole diameter and 10 mm hole distance at a constant pressure of 20 mbar as shown in Table 3. At constant suction pressure of 20 mbar tenacity of 40 Ne yarn was increased as apron hole diameter increases with decrease in hole distance [36, 37].

As shown in Figure 9 (c) the maximum tenacity for 40 Ne yarn was 16.595 cN/tex as 25 mbar suction pressure and 10 mm

widthwise hole distance was used at a constant hole diameter of 1.5 mm. Therefore, from the experimental result, it can be concluded that the tenacity of 40 Ne yarn increase with an increase in suction pressure to optimal. The suction condenses the fibers after emerging from the drafting to the nip line and sucks the protruding fibers resulting in the long fibers twisted that contributes to yarn strength (Chakrabortty et al., 2020).

3.1.3. Nep (+200%/km)

The analysis of ANOVA as shown in Table 6 shows the model F-value obtained in the present study was 1.44 implies the model is not significant. In this study, there are no

significant model terms meaning apron hole diameter, suction pressure, and hole distance have not significant effect on nep (+200%/km) for 40 Ne yarn. The lack of fit F-value of 2.87 suggests the lack of fit is not significant relative to the pure error. The correlation coefficient (R^2) between the experimental and predicted nep (+200%/km) was 0.6488.

This suggests that the analyzed factor explains 64.88% of nep (+200%/km) for 40 Ne yarn and that the model could not explain 35.12% of the variation. Therefore, a poor correlation has arisen between the predicted and actual value of the nep (+200%/km) for 40 Ne yarn. Thus, the model was not fit the response because the model is no significant effect on nep.

Table 6. Analysis of ANOVA for nep (+200%/km) for 40 Ne yarn.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Response 3: Nep for 40 Ne yarn and suggested ANOVA for the quadratic model						
Model	5.323E+06	9	5.914E+05	1.44	0.3235	Not significant
A-Apron hole diameter	3.276E+05	1	3.276E+05	0.7961	0.4019	
B-Suction air pressure	3.046E+05	1	3.046E+05	0.7401	0.4181	
C-Widthwise hole distance	1.876E+06	1	1.876E+06	4.56	0.0702	
AB	4.122E+05	1	4.122E+05	1.00	0.3503	
AC	53130.25	1	53130.25	0.1291	0.7300	
BC	1.403E+05	1	1.403E+05	0.3408	0.5777	
A²	1.308E+06	1	1.308E+06	3.18	0.1178	
B²	4.598E+05	1	4.598E+05	1.12	0.3256	
C²	2.419E+05	1	2.419E+05	0.5878	0.4683	
Residual	2.881E+06	7	4.116E+05			
Lack of Fit	1.967E+06	3	6.555E+05	2.87	0.1675	Not significant
Pure Error	9.144E+05	4	2.286E+05			
Cor Total	8.204E+06	16				

3.1.4. Thin Place (-50%/km)

The analysis of ANOVA in Table 7 shows that the model F-value obtained was 17.57 implies the model is significant. In this study, the suction pressure (B), widthwise hole distance (C), and quadratic widthwise hole distance (C^2) are significant effects on thin place (-50%/km) for 40 Ne yarn. However, the apron hole diameter (A), all interactive effects AB, AC, and BC as well as quadratic term hole diameter (A^2) and suction pressure (B^2) are not significant model terms. The lack of fit F-value of 0.69 showed the lack of fit is not significant relative to the pure error. There is a 60.50% chance that a lack of fit F-value this large could occur due to noise.

A quadratic model for the thin place (-50%/km) was given in Equation (3). The regression model shows that linear widthwise hole distance has a high positive correlation with the thin place. The hole distance (C) had the highest F-value of 126.97 implying that it had the most significant influence on thin place (-50%/km) for 40 Ne yarn. As shown in Equation (3) the linear effects of suction pressure have a negative correlation with the thin place. Thus, the model predicts that as suction pressure increases the thin place (-50%/km) decreases.

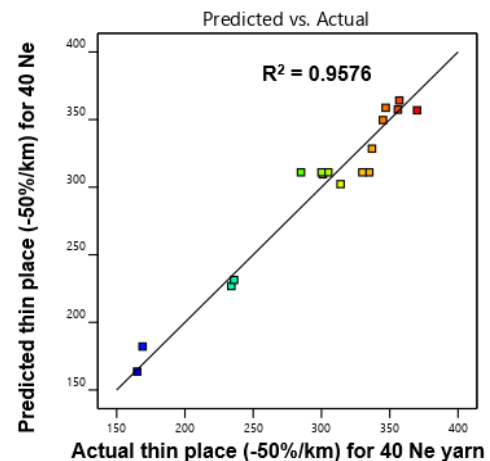Thin place (-50%/km)=+311 – 18.87B + 78C – 38.87C² (3)

Figure 10. Relationship between actual and predicted thin place for 40 Ne yarn.

The best-fitted model for the thin place (-50%/km) of 40 Ne yarn was a quadratic model, with R^2 value of 0.9576 as shown in Figure 10. This suggests that the analyzed factor explains 95.76% of the thin place (-50%/km) for 40 Ne yarn and that the model could not explain only 4.24% of the variation of thin place (-50%/km). Therefore, a strong correlation was achieved between the predicted and actual thin place (-50%/km) yarn to predict.

Table 7. Analysis of ANOVA for the thin place (-50%/km) of 40 Ne yarn.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Response 4: Thin place of 40 Ne yarn and suggested ANOVA for the quadratic model						
Model	60603.22	9	6733.69	17.57	0.0005	Significant
A-Apron hole diameter	703.13	1	703.13	1.83	0.2177	
B-Suction pressure	2850.13	1	2850.13	7.44	0.0295	
C-Widthwise hole distance	48672.00	1	48672.0	126.97	< 0.0001	
AB	132.25	1	132.25	0.3450	0.5754	
AC	676.00	1	676.00	1.76	0.2258	

Response 4: Thin place of 40 Ne yarn and suggested ANOVA for the quadratic model					
Source	Sum of Squares	df	Mean Square	F-value	p-value
BC	900.00	1	900.00	2.35	0.1693
A²	453.22	1	453.22	1.18	0.3129
B²	47.96	1	47.96	0.1251	0.7340
C²	6363.22	1	6363.22	16.60	0.0047
Residual	2683.25	7	383.32		
Lack of Fit	913.25	3	304.42	0.6879	0.6050	Not significant
Pure Error	1770.00	4	442.50		
Cor Total	63286.47	16			

Figure 11 shows apron hole diameter has no significant effect on thin place of 40 Ne yarn. However, the suction pressure and widthwise hole distance have a significant effect on the thin place (-50%/km) of 40 Ne yarn. Therefore, from the result, it can be concluded that the thin place of 40 Ne yarn was decreased as suction pressure increases. Moreover, thin place (-50%/km) for 40 Ne yarn decreases with a decrease in widthwise hole distance.
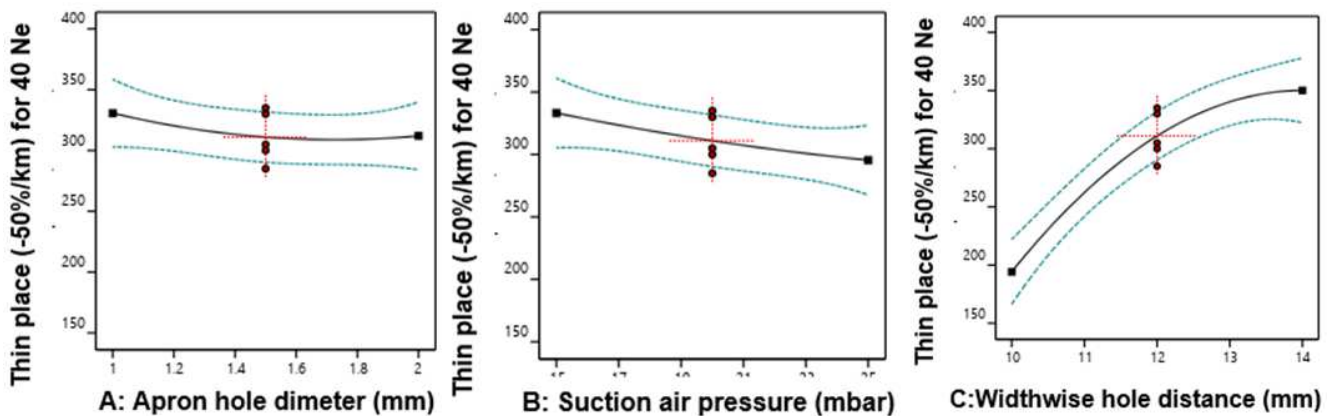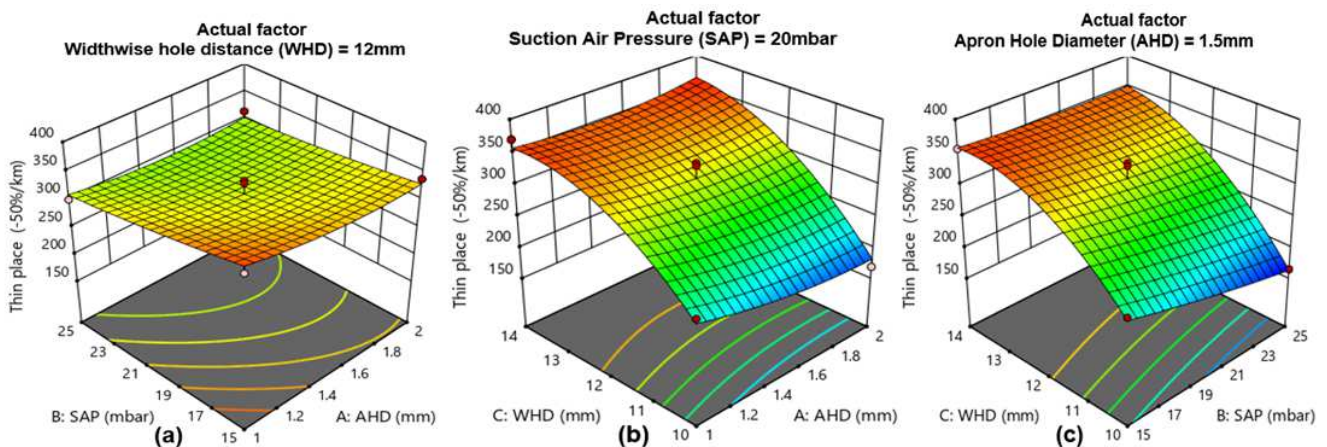

Figure 11. *Effect of apron hole diameter, suction pressure, and widthwise hole distance on thin place (-50%/km) of 40 Ne yarn.*

The 3D graph in Figure 12 reveals the interaction effects between apron hole diameter, suction pressure, and widthwise hole distance for the thin place (-50%/km) for 40 Ne yarn. The all-factor interactions of apron hole diameter, suction air pressure, and widthwise hole distance in Figure 12 show no statistically significant effect on thin place (-50%/km) of 40 Ne yarn.

Figure 12. *Factor interaction effect with the 3D graph for a thin place (-50%) of 40 Ne.*

3.1.5. Thick Place (+50%/km)

Analysis of ANOVA in Table 8 shows the model F-value obtained was 36.9 implies the model is significant. In this study, apron hole diameter (A), suction pressure (B), hole distance (C), and quadratic A^2, and B^2 are significant effects on thick place of 40 Ne yarn. However, all interaction effects and quadratic hole distance (C^2) have no significant effect on thick place (+50%/km). Lack of fit F-value of 3.09 showed that lack of fit is not significant relative to pure error.

Table 8. Analysis of ANOVA for the thick place (+50%/km) for 40 Ne yarn.

Response 5: Thick place of 20 Ne yarn and suggested ANOVA for the quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9.599E+05	9	1.067E+05	36.90	< 0.0001	Significant
A-Apron hole diameter	20402.00	1	20402.00	7.06	0.0326	
B-Suction pressure	35112.50	1	35112.50	12.15	0.0102	
C-Widthwise hole distance	5.629E+05	1	5.629E+05	194.7	< 0.0001	
AB	729.00	1	729.00	0.252	0.6309	
AC	3025.00	1	3025.00	1.05	0.3403	
BC	36.00	1	36.00	0.012	0.9143	
A²	1.939E+05	1	1.939E+05	67.09	< 0.0001	
B²	1.254E+05	1	1.254E+05	43.40	0.0003	
C²	146.57	1	146.57	0.050	0.8283	
Residual	20231.80	7	2890.26			
Lack of Fit	14129.00	3	4709.67	3.09	0.1523	not significant
Pure Error	6102.80	4	1525.70			
Cor Total	9.801E+05	16				

A quadratic model for the thick place (+50%/km) of 40 Ne was developed as shown in Equation (4) from ANOVA, in terms of coded parameters after rejecting the nonsignificant terms. The linear effects of hole diameter and suction pressure have a negative correlation with thick place. The positive coefficients for the linear, and quadratic term from the developed model in Equation (4) denotes a positive correlation, while the negative sign denotes an antagonistic relation on thick place (+50%/km) for 40 Ne yarn. However, widthwise hole distance (C) had the highest F-value of 194.74 shows that it had the most significant effect on thick place (+50%/km) for 40 Ne yarn as compared to hole diameter (A), and suction pressure (B).

$$\text{Thick place } (+50\%/km) = +1509.8 - 50.5A - 66.25B + 265.25C + 214.6A^2 + 172.6B^2 \quad (4)$$

Hence, regression coefficient R^2 of 0.9794 as shown in Figure 13 suggests that the analyzed factor explains 97.94% of thick place for 40 Ne yarn and that the model could not explain only 2.06% of the variation. Therefore, a high correlation is achieved between predicted and actual value for the thick place (+50%/km) of 40 Ne yarn thus, the second-order regression model is confirmed to predict the thick place.
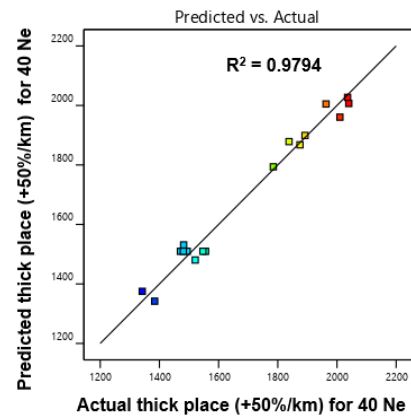

Figure 13. Relationship between actual and predicted thick place of 40 Ne yarn.

Figure 14 confirms that apron hole diameter, suction pressure, and widthwise hole distance has a significant effect on the thick place (+50%/km) of 40 Ne yarn. Therefore, from the result, it can be concluded that the thick place for 40 Ne yarn was decreased as the suction pressure increases up to center level (20 mbar). Therefore, in this study, widthwise hole distance has a more significant effect on the thick place (+50%) of 40 Ne yarn; thus, thick place decreases with a decrease in widthwise hole distance significantly.
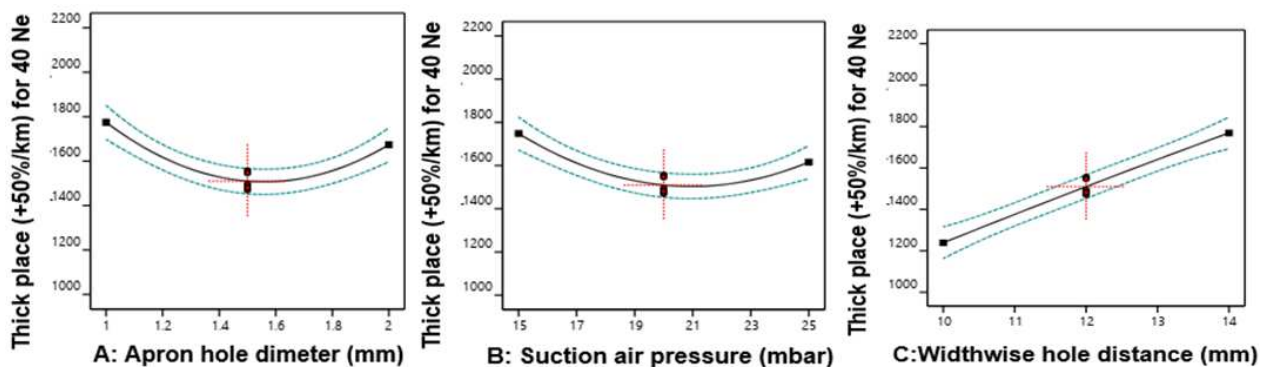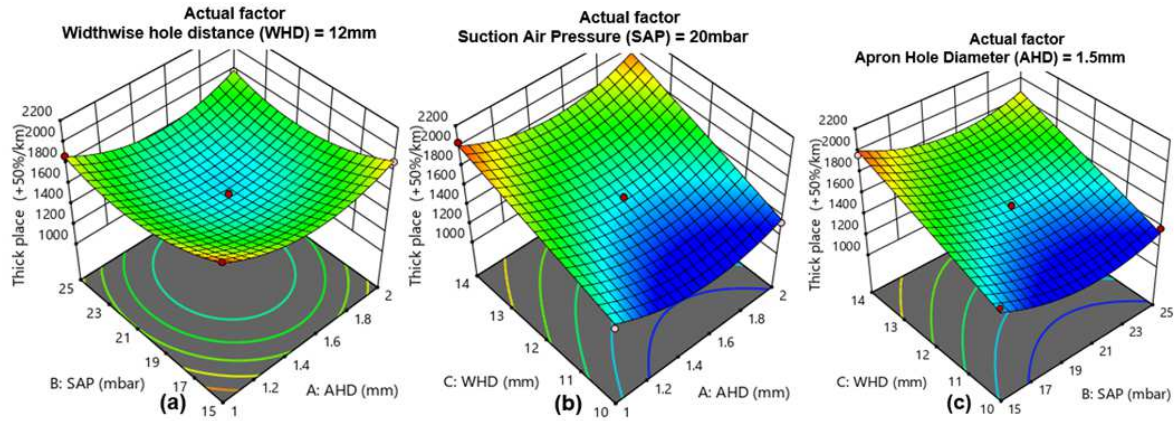

Figure 14. Effect of apron hole diameter, suction pressure, and widthwise hole distance on thick place (+50%/km) in 40 Ne yarn.

Figure 15 (a) shows that minimum thick place (+50%/km) was 1471 when 1.5 mm apron hole diameter and 20 mbar suction were used at a constant 12 mm widthwise hole distance as shown in Table 3 above. As revealed in Figure 15 (b) the minimum thick place (+50%/km) was 1342 when 2 mm apron hole diameter and 10 mm widthwise hole distance was used at constant 20 mbar suction pressure. From Figure 15 (c) it can be observed that the minimum thick place (+50%/km) was 1384 when 10 mm widthwise hole distance and 25 mbar suction pressure were used at a constant 1.5 mm apron hole diameter. Thus, the interaction effect of hole diameter, suction pressure, and widthwise hole distance (AB, AC, and BC) has no significant effect on thick place (+50%/km) of 40 Ne yarn.

Apron Hole Diameter (AHD) :   Suction Air Pressure (SAP) : Widthwise hole distance (WHD)

Figure 15. Factor interaction effect with 3D for the thick place (+50%/km) of 40 Ne yarn.

3.1.6. Optimized Solution of Apron Hole Diameter, Suction Pressure and Widthwise Hole Distance for Properties of 40 Ne Yarn

Optimization was done by design expert software with the numerical optimization method. Thus, Table 9 shows the optimized solution of apron hole diameter, suction pressure, and widthwise hole distance for properties of 40 Ne yarn. Thus, in this study 0.958 desirability shows that optimized solution for the given factor fits for the best result of the response.

Table 9. Optimized solution for 40 Ne yarn.

Apron hole diameter (mm)	Suction pressure (mbar)	Widthwise hole distance (mm)	Tenacity (cN/tex)	Hairiness Index (H)	Nep (+200%/km)	Thin place (-50%/km)	Thick place (+50%/km)	Desirability	
1.580	23.910	10.000	16.595	5.313	2359.805	167.093	1284.753	0.958	Selected

3.2. Effect of Apron Hole Diameter, Suction Air Pressure, and Widthwise Hole Distance on the Properties of 20 Ne Ring Yarn

Average yarn test results of 20 Ne yarn spun on the modified G 35 ring were shown in Table 10.

Table 10. Average test results for 20 Ne yarn spun with modified G 35 ring with different combinations.

Run	Factor 1 A: Apron hole diameter (mm)	Factor 2 B: Suction pressure (mbar)	Factor 3 C: Widthwise hole distance (mm)	Response 1 Tenacity	Response 2 Hairiness index (H)	Response 3 Nep (+200%/km)	Response 4 Thin place (-50%/km)	Response 5 Thick place (+50%/km)
1	1.5	20	12	15.307	7.84	953	44	594
2	1.5	15	10	14.791	7.85	770	31	758
3	1	20	10	15.142	7.915	821	49	715
4	1.5	20	12	15.348	7.54	870	65	629
5	1.5	25	10	18.282	7.06	1020	29	374
6	2	15	12	13.58	8.18	913	32	640
7	1	15	12	13.43	8.28	895	20	883
8	2	20	10	15.327	7.48	1045	52	485
9	1.5	20	12	14.838	7.58	998	38	643
10	1	20	14	13.63	8.59	843	42	795
11	1.5	15	14	14.086	8.48	785	81	769
12	1.5	20	12	15.279	7.61	975	35	624
13	1	25	12	16.713	7.95	783	46	595

Run	Factor 1 A: Apron hole diameter (mm)	Factor 2 B: Suction pressure (mbar)	Factor 3 C: Widthwise hole distance (mm)	Response 1 Tenacity	Response 2 Hairiness index (H)	Response 3 Nep (+200%/km)	Response 4 Thin place (-50%/km)	Response 5 Thick place (+50%/km)
14	1.5	20	12	15.326	7.54	948	55	612
15	2	25	12	16.593	7.19	813	37	385
16	2	20	14	14.642	8.09	838	69	682
17	1.5	25	14	15.984	7.93	840	28	520

3.2.1. Hairiness Index (H)

The analysis of ANOVA in Table 11 shows that the model F-value obtained in the present study was 30.92 implies the model is significant. In this study, apron hole diameter (A), suction pressure (B), widthwise hole distance (C), interaction effects (AB), and quadratic terms (A^2, and C^2) have a significant effect on the hairiness of 20 Ne yarn. The suction pressure had the highest F-value of 97.78 implies that it had the most significant effect on the hairiness of 20 Ne yarn. However, interaction effect AC, BC, and quadratic suction pressure (B^2) has no significant effect on the hairiness of 20 Ne yarn since the p-values are greater than 0.05.

Table 11. *Analysis of ANOVA for hairiness of 20 Ne yarn.*

Response 1: Hairiness index for 20 Ne and suggested ANOVA for the quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.76	9	0.3066	30.92	< 0.0001	significant
A-Apron hole diameter	0.4028	1	0.4028	40.62	0.0004	
B-Suction pressure	0.8844	1	0.8844	89.20	< 0.0001	
C-Widthwise hole distance	0.9695	1	0.9695	97.78	< 0.0001	
AB	0.1089	1	0.1089	10.98	0.0129	
AC	0.0011	1	0.0011	0.1065	0.7537	
BC	0.0144	1	0.0144	1.45	0.2673	
A²	0.2293	1	0.2293	23.13	0.0019	
B²	0.0084	1	0.0084	0.8456	0.3884	
C²	0.1124	1	0.1124	11.33	0.0120	
Residual	0.0694	7	0.0099			
Lack of Fit	0.0065	3	0.0022	0.1385	0.9319	not significant
Pure Error	0.0629	4	0.0157			
Cor Total	2.83	16				

For predicting hairiness of 20 Ne yarn the regression model from the analyzed ANOVA and given in Equation (5). The linear main effects of hole diameter, suction pressure, and its interaction effects have a negative correlation with the hairiness index of 20 Ne as shown in Equation (5). From the result and developed model, it can be concluded that the hairiness index for 20 Ne yarn decreases significantly as the suction pressure and hole diameter increase. Thus, a model has been developed for predicting the yarn quality at various apron hole diameters, suction pressure, and widthwise hole in the modified G 35 ring.

$$\text{Hairiness index (H)} = +7.62 - 0.224A - 0.332B + 0.348C - 0.165AB + 0.233A^2 + 0.163C^2 \qquad (5)$$
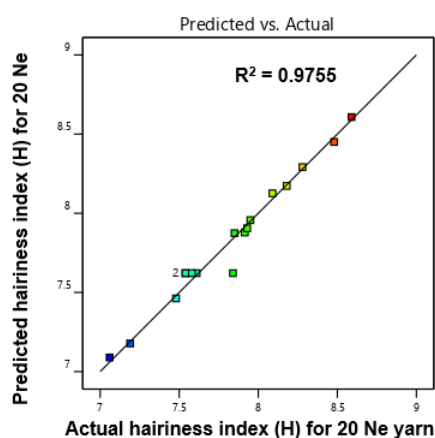

Figure 16. *Relationship between actual and predicted hairiness of 20 Ne yarn.*

The best-fitted model for predicting the hairiness index of 20 Ne yarn was a quadratic model with R^2 value of 0.9755 as shown in Figure 16. This suggests that the analyzed factors explain 97.55% of the 20 Ne yarn hairiness and that the model could not explain only 2.45% of the variation of the yarn hairiness. Therefore, a strong correlation is achieved between the predicted and actual value for 20 Ne yarn hairiness. Hence, second-order regression model is confirmed to predict the hairiness index of courser yarn.

Figure 17 shows that the apron hole diameter, suction air pressure, and the hole distance have a significant effect on the hairiness of 20 Ne yarn. The hairiness index for 20 Ne yarn was decreased as both apron hole diameter and suction pressure increases. However, as widthwise hole distance decreases hairiness index for 20 Ne yarn was decreases. Hence, to suck the edge fibers during drafting the perforation of hole distance must meet with the drafted ribbon width. Therefore, from this study, it is concluded that lower hairiness was obtained at a 10 mm hole distance.
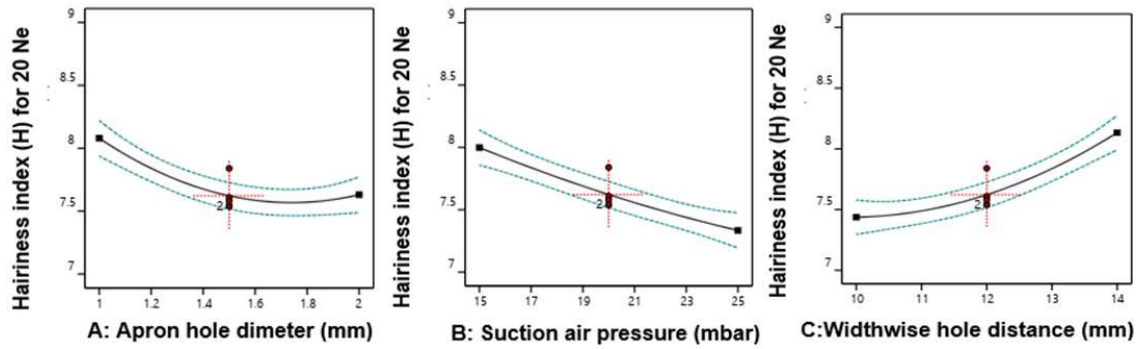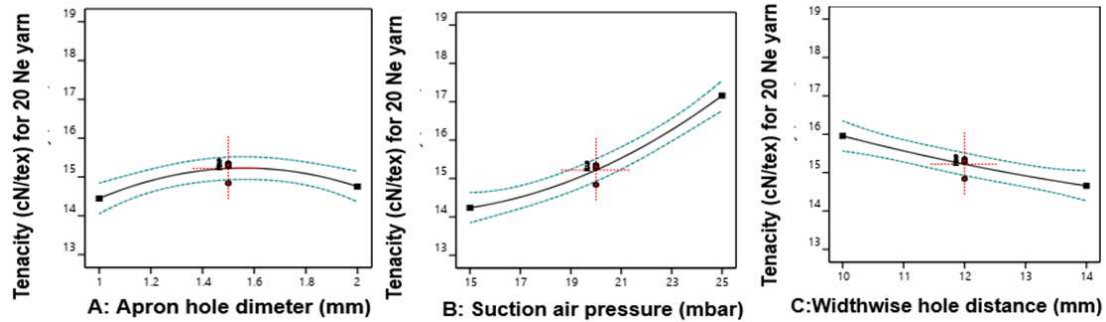
Figure 17. Effect of hole diameter, suction pressure, and hole distance on the hairiness of 20 Ne.

The 3D plot in Figure 18 (a) shows that minimum hairiness was found to be 7.19 as 2 mm hole diameter and 25 mbar suction pressure were used at a constant 12 mm hole distance as shown in Table 10 above. Furthermore, the 3D surface in Figure 18 (b) shows that the interaction effects between apron hole diameter and widthwise hole distance at a constant suction pressure of 20 mbar have no significant effect on the hairiness of the 20 Ne yarn. Figure 18 (c) reveals that interaction effects between widthwise hole distance and suction pressure at a constant hole diameter of 1.5 mm have no significant effect on the hairiness of 20 Ne yarn.

Apron Hole Diameter (AHD) :   Suction Air Pressure (SAP) : Widthwise hole distance (WHD)

Figure 18. Factor interaction effect with a 3D Surface graph for hairiness of 20 Ne.

3.2.2. Tenacity

The analysis of the ANOVA in Table 12 shows that the model F-value obtained was 34.57 implies the model is significant. In this study, suction pressure (B), widthwise hole distance (C), interaction effect BC, and quadratic effects (A^2, and B^2) are significant effects on the tenacity of 20 Ne yarn. However, hole diameter (A), interaction effect AB, AC and also quadratic effects of hole distance are not significant model terms. Therefore, from the result, it can be concluded that when the suction pressure increases tenacity of the yarn increases significantly.

For predicting yarn tenacity, the regression model from ANOVA, in terms of coded parameters after rejecting non-significant model terms is developed in Equation (6). The model shows that the linear term suction pressure (B) has a strong positive correlation with the tenacity of 20 Ne yarn. Thus, the suction pressure had the highest F-value of 221.71 implies that it had the most significant influence on the hairiness of 20 Ne yarn in comparison with hole diameter (A) and widthwise hole distance (C). However, the liner term widthwise hole distance, interaction effects BC and AC, as well as quadratic apron hole diameter (A^2) and suction pressure (B^2), has a negative correlation with tenacity. Therefore, from the result, it was observed that when suction pressure increases with a decrease in widthwise hole distance tenacity of 20 Ne yarn increases significantly. Hence using the relation in Equation (6) the tenacity of yarn can be predicted by varying the hole diameter, suction pressure, and hole distance in a modified GN35 ring frame.

$$\text{Tenacity (cN/tex)} = +15.22 + 1.46B - 0.65C - 0.3982BC - 0.6206A^2 - 0.4799B^2 \qquad (6)$$

The best-fitted model for predicting the tenacity of yarn was a quadratic model, with R^2 value of 0.9780 as shown in Figure 19. This suggests that the analyzed factor explains 97.80% of the tenacity of 20 Ne yarn and that the model could not explain only 2.2% of the variation of yarn tenacity. Therefore, a good agreement is achieved between the predicted and actual tenacity.
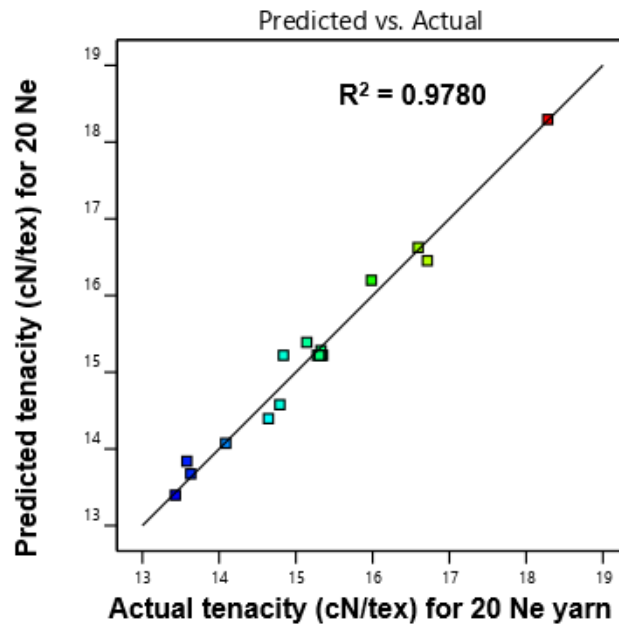
***Figure 19.** Relationship between actual and predicted tenacity for 20 Ne yarn.*

***Table 12.** Analysis of ANOVA for the tenacity of 20 Ne yarn.*

Response 2: Tenacity of 20 Ne yarn and suggested ANOVA for the quadratic model						
Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	23.95	9	2.66	34.57	< 0.0001	Significant
A-Hole diameter	0.1882	1	0.1882	2.44	0.1619	
B-Suction Pressure	17.07	1	17.07	221.71	< 0.0001	
C-Widthwise hole distance	3.38	1	3.38	43.91	0.0003	
AB	0.0182	1	0.0182	0.2367	0.6414	
AC	0.1710	1	0.1710	2.22	0.1798	
BC	0.6344	1	0.6344	8.24	0.0240	
A²	1.62	1	1.62	21.06	0.0025	
B²	0.9699	1	0.9699	12.60	0.0093	
C²	0.0313	1	0.0313	0.4064	0.5441	
Residual	0.5389	7	0.0770			
Lack of Fit	0.3543	3	0.1181	2.56	0.1930	Not significant
Pure Error	0.1846	4	0.0461			
Cor Total	24.49	16				

***Figure 20.** Effect of hole diameter, suction pressure, and hole distance on the tenacity of 20 Ne.*

Figure 20 shows that apron hole diameter has no significant effect on the tenacity of 20 Ne yarn. However, the suction pressure and hole distance have a significant effect on the tenacity of 20 Ne yarn. The tenacity of yarn increases as suction increases with a decrease in hole distance.

Figure 21 (a) shows that the maximum tenacity for 20 Ne yarn was 16.713 cN/tex when 1 mm apron hole diameter and 25 mbar suction pressure were used at a constant hole distance of 12 mm. Even though, the model interaction effects of hole diameter and suction pressure at 12 mm hole

distance are not significant. As shown in Figure 21 (b) the maximum tenacity for 20 Ne was 15.348 cN/tex as 1.5 mm hole diameter and 12 mm hole distance was used at a constant suction pressure of 20 mbar. However, the interaction effect between apron hole diameter and widthwise distance has not significant.

Moreover, in Figure 21 (c) maximum tenacity for 20 Ne yarn was 18.282 cN/tex when 25 mbar suction pressure and 10 mm hole distance was used at a constant apron hole

diameter of 1.5 mm as shown in Table 10 above. Tenacity was increased as hole distance decreases with an increase in suction pressure at a constant apron hole diameter of 1.5 mm. The result shown in Figure 21 (c) was better as compared with all other combinations of the levels of variables. Therefore, from the experimental result, it can be concluded that the tenacity of 20 Ne yarn increase with an increase in suction pressure.

Figure 21. Factor interaction effect with a 3D graph for the tenacity of 20 Ne yarn.

3.2.3. Thin Place (-50%/km)

The analysis of ANOVA as shown in Table 13 shows the model F-value obtained in the present study was 1.00 implies the model is not significant. In this study, there are no significant model terms.

Table 13. Analysis of ANOVA for the thin place (-50%/km) in 20 Ne yarn.

Response 3: Thin place for 20 Ne yarn and suggested ANOVA for the quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2360.58	9	262.29	1.00	0.5094	not significant
A-Apron hole diameter	136.13	1	136.13	0.5216	0.4936	
B-Suction pressure	72.00	1	72.00	0.2759	0.6156	
C-Widthwise hole distance	435.13	1	435.13	1.67	0.2376	
AB	110.25	1	110.25	0.4224	0.5365	
AC	144.00	1	144.00	0.5517	0.4818	
BC	650.25	1	650.25	2.49	0.1585	
A²	8.85	1	8.85	0.0339	0.8591	
B²	626.69	1	626.69	2.40	0.1652	
C²	209.27	1	209.27	0.8018	0.4003	
Residual	1826.95	7	260.99			
Lack of Fit	1205.75	3	401.92	2.59	0.1904	not significant
Pure Error	621.20	4	155.30			
Cor Total	4187.53	16				

3.2.4. Thick Place (+50%/km)

Analysis of ANOVA in Table 14 shows the model F-value obtained was 40.05 implies the model is significant. In this study, A, B, C, BC, and A² are significant model terms.

However, interaction effect AB, AC, and quadratic terms B^2 and C^2 are not significant model terms. Thus, interaction effects have no significant effect on thick place (+50%/km) of 20 Ne yarn.

Table 14. Analysis of ANOVA for the thick place (+50%/km) in 20 Ne yarn.

Response 4: Thick place of 20 Ne yarn and suggested ANOVA for the quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.930E+05	9	32556.88	40.05	< 0.0001	Significant
A-Apron hole diameter	79202.00	1	79202.00	97.43	< 0.0001	
B-Suction air pressure	1.729E+05	1	1.729E+05	212.66	< 0.0001	

Response 4: Thick place of 20 Ne yarn and suggested ANOVA for the quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
C-Widthwise hole distance	23544.50	1	23544.50	28.96	0.0010	
AB	272.25	1	272.25	0.3349	0.5809	
AC	3422.25	1	3422.25	4.21	0.0793	
BC	4556.25	1	4556.25	5.61	0.0498	
A²	5062.55	1	5062.55	6.23	0.0413	
B²	3620.87	1	3620.87	4.45	0.0727	
C²	846.02	1	846.02	1.04	0.3416	
Residual	5690.20	7	812.89			
Lack of Fit	4325.00	3	1441.67	4.22	0.0989	not significant
Pure Error	1365.20	4	341.30			
Cor Total	2.987E+05	16				

For predicting thick place (+50%/km) of yarn regression model from analyzed ANOVA in terms of coded parameters after rejecting nonsignificant model is given in Equation (7). The linear effects of apron hole diameter, and suction pressure has a negative correlation with the thick place of 20 Ne as revealed in Equation (7). The suction pressure (B) had the highest F-value of 212.66 suggesting that it had the most significant influence on the thick place (+50%/km) for 20 Ne yarn. From the analyzed result and developed model, it can be concluded that the thick place (+50%/km) for 20 Ne yarn decreases significantly as the suction pressure and hole diameter increase. Thus, a model has been developed for predicting thick place for different yarn counts at various apron hole diameters, suction pressure, and hole in the modified G35 ring.

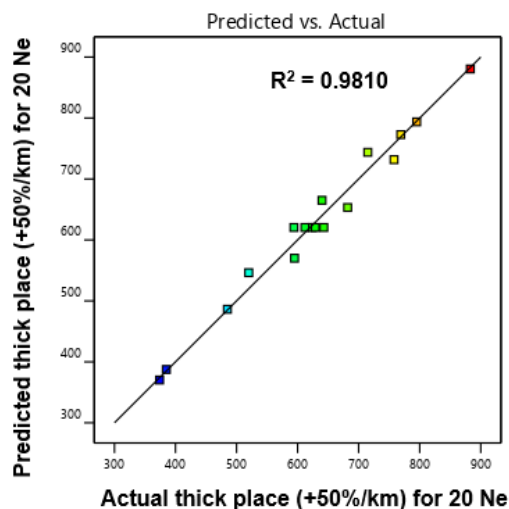$$\text{Thick place (+50\%/km)}=+620.4 - 99.5A - 147B + 54.25C + 33.75BC + 34.68A^2 \qquad (7)$$

Figure 22. Relationship between actual and predicted thick place for 20 Ne.

Therefore, regression coefficient R^2 of 0.9810 as shown in Figure 22 is closer to one indicates that correlation is best fitted for predicting thick place from ANOVA. This suggests that the analyzed factors explain 98.10% of thick place for 20 Ne yarn and that the model could not explain only 1.9% of the variation of the thick place. Hence, a high correlation is realized between predicted and actual value for the thick place (+50%/km) of 20 Ne yarn. Hence, the quadratic model is confirmed to predict the thick place for different yarn counts spun on the modified G 35 ring.

Figure 23 shows that the apron hole diameter, suction air pressure, and widthwise hole distance has a significant effect on the thick place (+50%/km) of 20 Ne yarn. Hence, from the result, it can be concluded that the thick place of 20 Ne was decreased as suction pressure increases significantly. Thus, in this study, suction pressure has a more significant effect on thick place of 20 Ne.
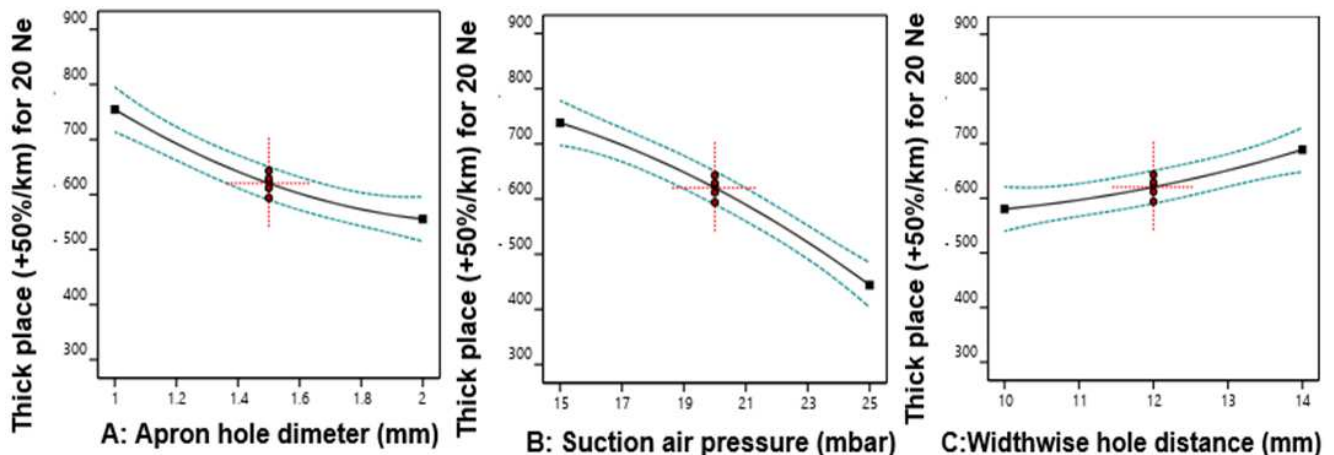

Figure 23. Effect of apron hole diameter, suction pressure, and widthwise hole distance on thick place (+50%/km) in 20 Ne yarn.

Figure 24 (a) shows that the minimum thick place (+50%/km) obtained was 385 when 2 mm apron hole diameter and 25 mbar suction air pressure were used with a constant widthwise hole distance of 12 mm as shown in Table 10 above. Even though, the model interaction effects of hole diameter and suction pressure at 12 mm hole distance are not significant. Also, in Figure 24 (b) the minimum thick place obtained was 485 when 2 mm hole diameter and 10 mm widthwise hole distance was used at a constant suction pressure of 20 mbar. Even if, the interaction effect between apron hole diameter and widthwise hole distance has no significant effect.

As shown in Figure 24 (c) the minimum thick place obtained was 374 when 25 mbar suction pressure and 10 mm widthwise hole distance was used at a constant apron hole diameter of 1.5 mm as shown in Table 10 above. Thus, from the result, it can be concluded that thick places for 20 Ne were decreased with an increase in suction pressure. The result is shown in Figure 24 (c) was best when compared with all other combinations. Therefore, from the experimental result, it can be concluded that the thick place of 20 Ne decreases with an increase in suction pressure.
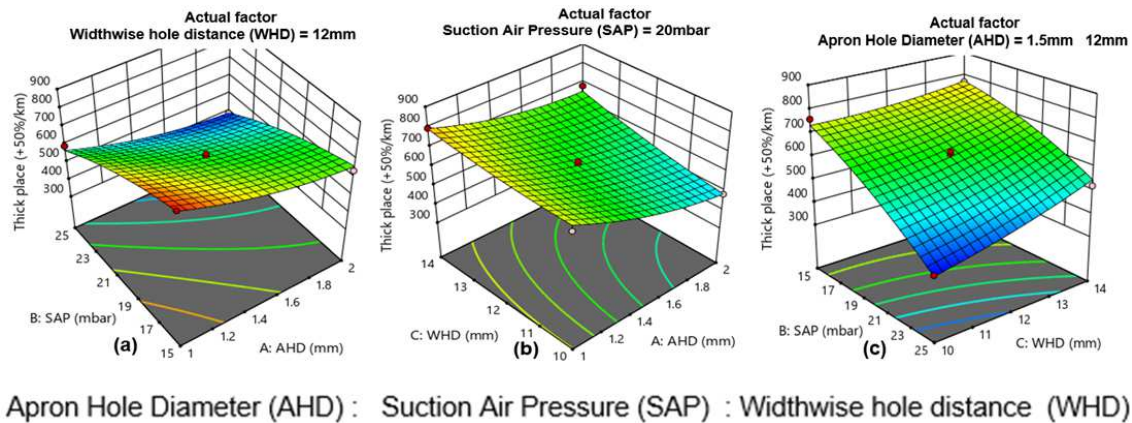

Figure 24. Factor interaction with a 3D graph for the thick place (+50%/km) of 20 Ne. 4.2.5. Nep (+200%/km).

The analysis of ANOVA in Table 15 shows the model F-value obtained in the present study was 1.28 implies the model is not significant. In this study, there are no significant model terms meaning apron hole diameter, suction pressure, and widthwise hole distance has not significant effect on nep (+200%/km) for 20 Ne yarn.

Table 15. Analysis of ANOVA for nep (+200%/km) in 20 Ne yarn.

Response 5: Nep for 40 Ne yarn and suggested ANOVA for Quadratic model						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	76603.42	9	8511.49	1.28	0.3797	not significant
A-Apron hole diameter	8911.12	1	8911.12	1.34	0.2845	
B-Suction pressure	1081.12	1	1081.12	0.1629	0.6985	
C-Widthwise hole distance	15312.50	1	15312.5	2.31	0.1725	
AB	36.00	1	36.00	0.0054	0.9433	
AC	13110.25	1	13110.2	1.98	0.2026	
BC	9506.25	1	9506.25	1.43	0.2703	
A²	4420.04	1	4420.04	0.6661	0.4413	
B²	18009.09	1	18009.0	2.71	0.1435	
C²	3701.57	1	3701.57	0.5578	0.4795	
Residual	46451.05	7	6635.86			
Lack of Fit	37116.25	3	12372.0	5.30	0.0704	not significant
Pure Error	9334.80	4	2333.70			
Cor Total	1.231E+05	16				

3.2.5. Optimization of Apron Hole Diameter, Suction Air Pressure and Width-wise Hole Distance for 20 Ne Yarn

Table 16 shows that the optimized solution of apron hole diameter, suction pressure, and widthwise hole distance for properties of 20 Ne yarn. The desirability for 20 Ne yarn was found to be 0.78 shows that the optimized solution for the given factor fits a good result.

Table 16. Optimized solution for 20 Ne yarn.

Apron hole diameter (mm)	Suction pressure (mbar)	Widthwise hole distance (mm)	Tenacity (cN/tex)	Hairiness Index (H)	Nep (+200%/km)	Thin place (-50%/km)	Thick place (+50%/km)	Desirability	
1.757	25.000	11.668	17.200	7.134	924.602	31.816	389.633	0.780	Selected

3.3. Comparison of 40 Ne Conventional Yarn with Modified Ring Yarn

The hairiness index of 40 Ne modified yarn was reduced by 16.25% as compared to conventional yarn. Besides tenacity of 40 Ne modified yarn was increased by 12.7% as compared to conventional as shown in Table 17. Thick place (+50%/km) and thin place (-50%/km) for 40 Ne modified yarns were reduced by 14.625% and 17.42% respectively. The nep (+200%/km) comparison between modified and conventional 40 Ne yarn was not done as the nep value has no significant effect on modified yarn.

Table 17. Mean comparison between conventional and modified 40 Ne yarn.

	Count 40 Ne Yarn	N	Mean	Std. Deviation	Std. Error Mean
Tenacity cN/tex	40Ne conventional yarn	5	13.1000	1.22468	.54770
	40Ne modified yarn	5	15.0546	.42993	.19227
Hairiness Index	40Ne conventional yarn	5	6.6180	.27851	.12456
	40Ne modified yarn	5	5.5420	.30037	.13433
Thick place (+50%/km)	40Ne conventional yarn	5	1995.20	20.192	9.030
	40Ne modified yarn	5	1703.40	129.947	58.114
Thin place (-50%/km)	40Ne conventional yarn	5	319.00	25.348	11.336
	40Ne modified yarn	5	263.40	41.101	18.381

A significant improvement in hairiness, tenacity, thick place (+50%/km), and thin place (-50%/km) of modified yarn was observed as compared to conventional yarn as shown in Table 18.

Table 18. Independent t-test comparison between conventional and modified 40 Ne.

Independent samples t-test for equality of means							
	t	Df	Sig.(2-tailed)	Mean d/nce	Std. Error d/nce	95% confidence interval d/nce	
						Lower	Upper
Tenacity	-3.36	4.9	.020	-1.95	.5804	-3.4493	-.459
Hairiness	5.87	7.9	.000	1.076	.1831	.65315	1.498
Thick place (+50%/km)	4.96	4.1	.007	291.8	58.81	131.43	452.1
Thin place (-50%/km)	2.57	6.6	.038	55.60	21.59	3.999	107.2

3.4. Comparison of 40 Ne Modified Yarn with Uster Statistics 2018

The hairiness of modified yarn as compared with Uster 2018 at 75% USP shows that the difference was not significant. Because the p-value for hairiness of 40 Ne between the modified with Uster was 0.109 which is greater than alpha (0.05). Thus, the hairiness of yarn spun with a modified G35 ring achieves Uster 2018 standard at 75% USP. However, yarn tenacity, thick place, and thin place comparison between modified with Uster 2018 show a significant difference. Because the p-value between the modified yarn with Uster is smaller than the alpha value (0.05) as shown in Table 19. Thus, the tenacity, thick, and thin place of modified yarn was lower as compared with Uster 2018 at 75% Uster Statistics percentile (USP).

Table 19. Comparison of 40 Ne yarn between modified and Uster 2018 at 75% USP.

	Count 40 Ne Yarn	N	Mean	Std. Deviation	Std. Error Mean
Tenacity	40Ne modified yarn	5	15.0546	.42993	.19227
	40 Ne on Uster 2018	5	15.5600	.00000	.00000
Hairiness Index	40Ne modified yarn	5	5.5420	.30037	.13433
	40 Ne on Uster 2018	5	5.3000	.00000	.00000
Thick place (+50%/km)	40Ne modified yarn	5	1703.40	129.947	58.114
	40 Ne on Uster 2018	5	400.00	.000	.000
Thin place (-50%/km)	40Ne modified yarn	5	263.40	41.101	18.381
	40 Ne on Uster 2018	5	56.00	.000	.000

Hairiness index of modified 40 Ne yarns was not significant as compared with Uster 2018 at 75%USP. As the p-values 0.109 is greater than alpha (0.05) as shown in Table 20.

Table 20. Independent sample t-test mean comparison of modified with Uster 2018.

Independent Samples t-test for Equality of Means						
	Df	Sig. (2-tailed)	Mean d/nce	Std. Error d/nce	95% confidence Interval d/nce	
					Lower	Upper
Tenacity	8	.030	-.5054	.19227	-.9487	-.0620
Hairiness	8	.109	.24200	.13433	-.0677	.55176

Independent Samples t-test for Equality of Means						
	Df	Sig. (2-tailed)	Mean d/nce	Std. Error d/nce	95% confidence Interval d/nce	
					Lower	Upper
Thick place (+50%/km)	8	.000	1303.4	58.114	1169.3	1437.4
Thin place (-50%/km)	8	.000	207.40	18.381	165.01	249.78

3.5. Comparison of 20 Ne Yarn Spun with Conventional and Modified G35 Ring

The hairiness index of 20 Ne modified yarn was reduced by 8.87% as compared to conventional as shown in Table 21.

The tenacity of 20 Ne modified yarn was increased by 7.42% as compared to conventional. The thick place (+50%/km) of modified 20 Ne yarn was reduced by 18.27% as compared to conventional.

Table 21. Mean comparison between conventional and modified 20 Ne yarn.

	Count 20 Ne Yarn	N	Mean	Std. Deviation	Std. Error Mean
Tenacity cN/tex	20 Ne conventional yarn	5	15.218	.25479	.11395
	20 Ne modified yarn	5	16.442	.37097	.16590
Hairiness index	20 Ne conventional yarn	5	7.6640	.20182	.09026
	20 Ne modified yarn	5	6.9800	.17015	.07609
Thick place (+50%/km)	20 Ne conventional yarn	5	471.60	24.765	11.075
	20 Ne modified yarn	5	385.40	21.114	9.442

The independent t-test analysis as shown in Table 22 shows that there is a significant difference in tenacity, hairiness index, and thickness (+50%/km) between modified 20 Ne yarn with conventional yarn. Thus, it is noticed that better tenacity, lower hairiness, and lower imperfection were observed for modified yarn as compared with conventional.

Table 22. Independent t-test comparison between conventional and modified 20 Ne.

Independent Samples t-test for Equality of Means						
	t	Df	Sig. (2-tailed)	Mean d/nce	Std. error d/nce	95% interval d/nce
						Lower	Upper
Tenacity	-6.08	7.08	.000	-1.22	.2012	-1.6987	-.74926
Hairiness	5.79	7.77	.000	.684	.1180	.41041	.95759
Thick place (+50%/km)	5.92	7.80	.000	86.2	14.55	52.492	119.90

3.6. Comparison of 20 Ne Modified Yarn with Uster 2018 at 75% USP

As compared with Uster 2018 with 75% Uster statistics percentile the hairiness index of the 20 Ne modified yarn was reduced by 4.01% shown in Table 23. The 5.66% tenacity of the modified yarn was lower as compared to Uster 2018 with 75% USP. Moreover, the thick place of 20 Ne modified yarn was 48.36% higher as compared to Uster 2018.

Table 23. Comparison between modified 20 Ne yarn with Uster 2018 at 75% USP.

	Count 20 Ne Yarn	N	Mean	Std. Deviation	Std. Error Mean
Tenacity cN/tex	20 Ne modified yarn	5	16.442	.37097	.16590
	20 Ne on Uster 2018	5	17.430	.00000	.00000
Hairiness Index	20 Ne modified yarn	5	6.9800	.17015	.07609
	20 Ne on Uster 2018	5	6.7000	.00000	.00000
Thick place (+50%/km)	20 Ne modified yarn	5	385.40	21.114	9.442
	20 Ne on Uster 2018	5	199.00	.000	.000

A significant difference was observed at 0.005 significance between the 20 Ne modified yarn and Uster 2018 to the hairiness index, tenacity, and thick place (+505/km). The 20 Ne modified yarn has lower tenacity and higher hairiness and thick place as compared with the Uster 2018 at 75% Uster statistics.

4. Conclusion

A technique has been developed by modifying the bottom aprons with perforation in two rows and the perforated nose bars were fabricated and fitted in conventional Reiter G35 ring frame. Suction pressure was applied and two counts of 29.52 Tex (20 Ne) and 14.76 Tex (40 Ne) were spun. To produce modified yarn 17 combinations of apron hole diameter, suction pressure, and widthwise hole distance was used Relationship between actual and predicted values for all properties were formulated using quadratic regression model for both 40 Ne and 20s Ne yarn. Optimization was done by Design expert software with the numerical optimization method. The optimized solution of apron hole diameter, suction pressure, and widthwise hole distance for properties of 40 Ne and 20S Ne yarn specifically yarn tenacity, hairiness, thin place, thick place, and nep were derived and

indicated. The yarn results were compared with conventional and Uster 2018 75% USP. A significant improvement in yarn hairiness index, tenacity, thin place and thick place of 40 Ne yarn spun on modified G 35 ring were observed in comparing with conventional yarn. Moreover, the hairiness index, tenacity and thick place of 20 Ne modified yarn were improved significantly. As compared with the Uster statistics the hairiness index of the modified 40 Ne yarn was similar as compared with Uster 2018 at 75% Uster statistics percentile. However, yarn tenacity, thick place, and thin place comparison between modified with Uster 2018 show a significant difference. The 20 Ne modified yarn has lower tenacity and higher hairiness and thick place as compared with the Uster 2018 at 75% Uster statistic. Thus, the modified G35 method of yarn condensing has a great capability to be used as an alternative method of conventional spinning as it is capable of producing better quality yarn.

5. Future Works

The suction pressure, apron hole diameter, and width-wise suction hole distance were investigated using 20 Ne and 40 Ne yarn on a modified G 35 ring and their effects on yarn quality were revealed in this study. The work and ideas proposed in this thesis can be extended in the future and possibilities of further improvements. The newly proposed methods are in an early stage of development and may be researched further to improve accuracy, performance, and application. Therefore, this research will open a good opportunity for researchers. Hence the results of this study proposed several new ideas for research in the future. The following ideas will be proposed for future work.

1) For future researchers, the fiber migration for 20 Ne and 40 Ne yarn spun on the modified G 35 ring was not done yet.
2) The effect of suction pressure, apron hole diameter, and width-wise suction hole distance on yarn fault classimates for 20 Ne and 40 Ne yarn spun on modified G 35 ring were not done.
3) The comparisons of the yarn spun on the modified G 35 with compact yarn were not done.

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