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Prediction of the Impact of Ring Spinning Machine Front Roller Rubber Cot Shore Hardness on Spun Yarn Quality Parameters

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Article

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ABSTRACT

The yarn quality is mostly determined by the spinning settings, process control methods, and raw material. The most crucial and fundamental process in ring spinning is drafting, which has a significant impact on the quality of the yarn. Yarn quality is greatly impacted by drafting elements such as shore hardness. This study aimed to predict the effect of different degrees of shore hardness in the ring machine front roller rubber cot on 100% cotton and 32s Ne ring spun yarn quality parameters. The backline shore hardness was constant. Cotton yarn properties, including mass uniformity, imperfection level, unevenness, hairiness, tensile strength, and elongation, were measured and analyzed in accordance with ASTM D1425-96 and ASTM D2256, 2015 test standards, respectively. Linear regression equations were developed for prediction. A linear regression analysis showed that there is a positive correlation between shore hardness and yarn quality parameters with higher R^2 values. Therefore, almost in all cases, the value of R^2 was above 0.834, which signifies one can make a definite prediction about the yarn properties with different shore hardness. From the result of this study, it can be concluded that the quality of the produced yarn is superior to about 63-65° shore hardness values.

KEYWORDS

ring spinning, shore 'A' hardness, yarn quality parameters, linear regression, durometer

INTRODUCTION

The textile industry is one of the essential industries, especially for developing countries, due to its labour-intensive nature. The industry is huge and mainly concerned with the making of yarn and fabrics [1]. Among the different technologies of textile product manufacturing, yarn manufacturing is one of the most complicated processes because of the desired fineness and uniformity of yarn manufactured from millions of non-uniform fibres [2]. Ring spinning is one of the most effective spinning techniques for yarn manufacturing [3-7]. Ring spinning accounts for about 75% of global long and short staple yarn production. The main reason attributed to the success of ring spinning over other spinning systems is the superior quality, notable strength, and evenness of ring-spun yarns over those produced by other systems [8]. The operation of the ring-spinning system can be divided into drafting, twisting and winding steps. The drafting step plays an important role in the quality of yarn [9,10].

Nowadays, lifting is accomplished through quality. Quality has become extremely important in all spheres of life. At present, the enhancement of yarn quality is the main challenge facing textile technologists. Yarn quality is crucial to the cost-effective achievement of a spinning mill. Global competition and market requirements dictate the necessity to produce quality yarns at a reasonable price is important. Yarn quality is a combination of four basic elements: consistency (yarn evenness and appearance integrity using thick places, thin places and neps), bulk integrity (count, density and twist), surface integrity (hairiness, diameter and shape) and purity. Yarn quality is a multifaceted characteristic and it is influenced by different factors, but overall yarn quality is influenced by raw materials quality, men, machine setting, air conditioning, maintenance, material handling, process control technique and machine components [11-13].

Ring spinning technique also has significantly influenced the quality of yarn. There are some parameters which are greatly affect the quality of ring-spun carded yarn such as drafting system, roller gauge, ring traveller, ring cop diameter, spindle speed, material throughput rate etc. Drafting is the most vital and essential process in spinning, and it has a very significant effect on the yarn quality. Drafting components have also a significant impact on yarn quality and production costs in ring spinning, particularly, spinning top roller covers i.e., cots and drafting aprons [14-16]. These are the main apparatuses of the drafting operations and positively, it has more influence on the quality of the yarn produced. Mostly cots are used in draw frame, comber, roving frame and ring spinning, aprons are used only in roving frame and ring spinning. The purpose of cots is to avoid the fibres getting crushed or damaged, and also to give a proper grip on the fibres when they are being drafted and use of aprons is to control the short fibres which are also known as floating fibres to the possible extent and help to produce regular and stronger yarns with greater drafts [3,17].

A front top roller cot in ring spinning should also offer adequate pulling force to overcome drafting resistance. Mathematically, the force of pulling required at front top rollers cot frictional resistance between fibres and force exerted by the aprons on fibres [18]. The degree of shore hardness is one of the key properties of the top roller cot and varies for different types of fibre, applications etc. The raw material mixtures are based on exceptional rubber in the hardness range of approx. 63º to 83º shore A hardness is used as coating raw materials. Generally, the shore hardness of a rubber cot is measured by using an instrument called 'Durometer' and the value is expressed in A scale. Cots are available in wide shore hardness ranging from 63° to 90° shore. In general Shore Hardness means a measure of the resistance a material has to indentation and Shore hardness of rubber is a measure of the resistance of

a material to penetration of a spring-loaded needle-like indenter. Shore hardness of the cot roller to deliver constant pressur e on the fibre strand. This helps with effective drafting with
the assistance of aprons, which results in a better grip and control of the fibres during the drafting arrangement which are more advantageous for producing good quality yarn [17,19].
Various studies were conducted regarding drafting parameters of spinning systems to improve the yarn quality. Although very few researchers have done studies concerning the effect of shore hardness on yarn quality and properties, according to the author's knowledge, no one has studied the relationship between shore hardness and different yarn quality parameters for a particular count in a textile factory in Ethiopia, i.e., 32s Ne ring spun yarn. This paper discusses the relationship between shore hardness and yarn quality using a linear regression model and the impact of ring machine front roller rubber cot shore hardness on yarn evenness, imperfection (thin, thick and neps), strength, elongation and hairiness quality were also investigated. This study also will help the spinners of Ethiopia to select the appropriate cot roller with optimum shore hardness of the front and back line at the drafting system in a ring spinning frame to get the required quality of the cotton carded yarn.

EXPERIMENTAL

Materials and Methods

Cotton fibre

100% cotton fibre (Metema, Ethiopia) with different fibre properties was kindly obtained from Bahir Dar Textile Share Company, Bahir Dar, Ethiopia. Table 1 shows the average cotton fibre properties used in this study.

Table 1. Fibre properties

Properties	Average value	Properties	Average value
The upper half mean length (mm)	29.03	Elongation (%)	6
Uniformity index (%)	82.5	fibre micronaire	4.3
Short fibre content (%)	8.4	Trash content (w)(kg)	27
Spinning consistency index (%)	125	Maturity Index (Mat)	0.86
Colour (Degree of reflectance) (%)	77.6	Neps/grams	108
+b (yellowness) (%)	9.6	Moisture content (%)	5
Strength (gram/tex)	27.3	Raw material trash (%)	4.5

Rollers

Roller (Alufitt cot) having a different shore A hardness was supplied by Super Tex Cots and Aprons, Mumbai, India.

Shore Hardness Testing: For this study, the shore hardness of a rubber cot is measured by using a Durometer, analogue type shore hardness tester (HPSA-R20, Germany) and the value is expressed in the ‘A’ scale. The measurement was done with a constant measuring pressure corresponding to shore A according to the ASTM D 2240-2015 [20] standard testing method.

Shore Hardness Cot Selection and Mounting

As shown in Figure 1, nine different front top rollers have different shore ‘A’ hardness values such as (63°, 65°, 68°, 72°, 75°, 80°, 83°, 85° & 90°) and for backline position standard 83° Shore hardness cot selected. The selection of the cot was done based on availability, nature of the raw material processed, the linear density of the material, type of application/process/ mechanical conditions maintenance aspects and ambient conditions.

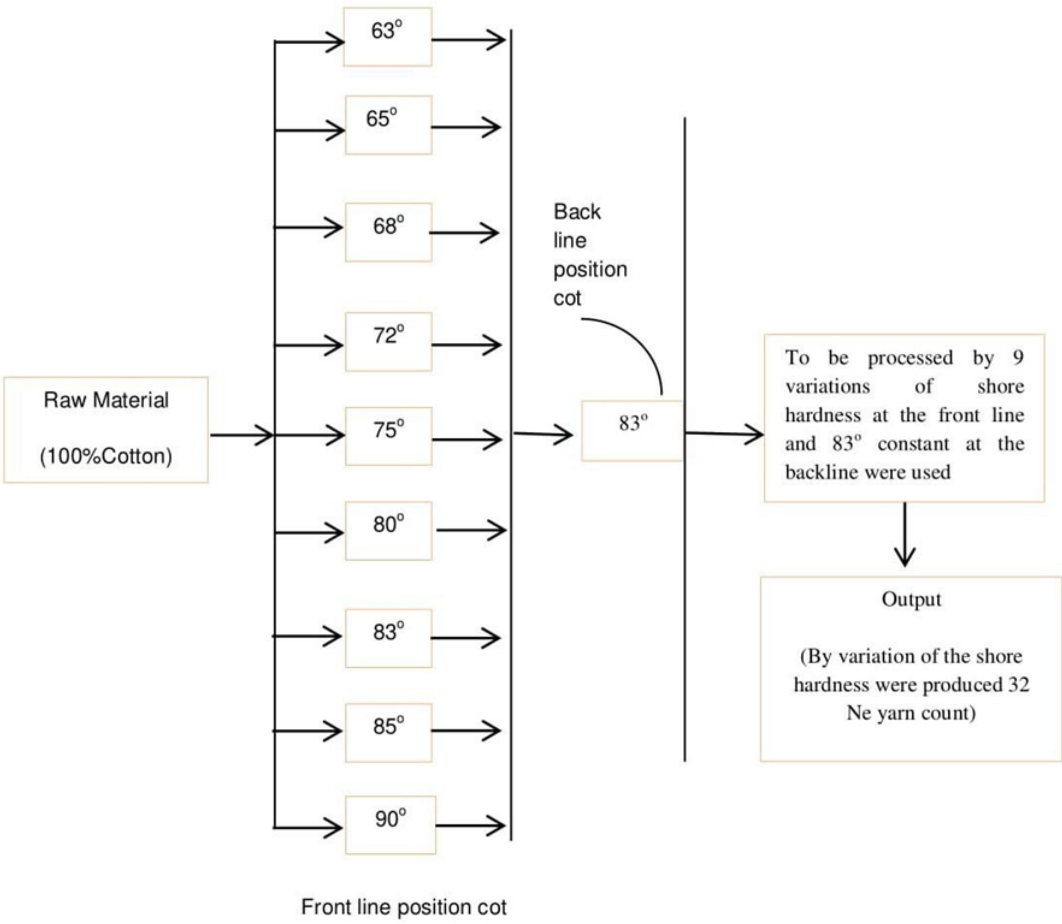

Figure 1. Ring frame cot positioning

For this investigation, only Alufitt Cot was chosen for both the front and backline positions. Nine top roller bare shells (Figure 2) were carefully selected for every shore hardness, and mounting was carried in a Vertical Pneumatic Mounting Machine. For the backline position standard, an 83° shore hardness cot was used throughout the study.

Figure 2. Roller bar shells after mounting and different degrees of rubber cots

Yarn Preparation

32s Ne carded yarn was produced using a Reiter ring spinning machine (G-35, Switzerland) and the machine specifications used in the course of this study are shown in Table 2. Figure 3 shows a schematic of the process flow diagram of carded yarn preparation used for this study.

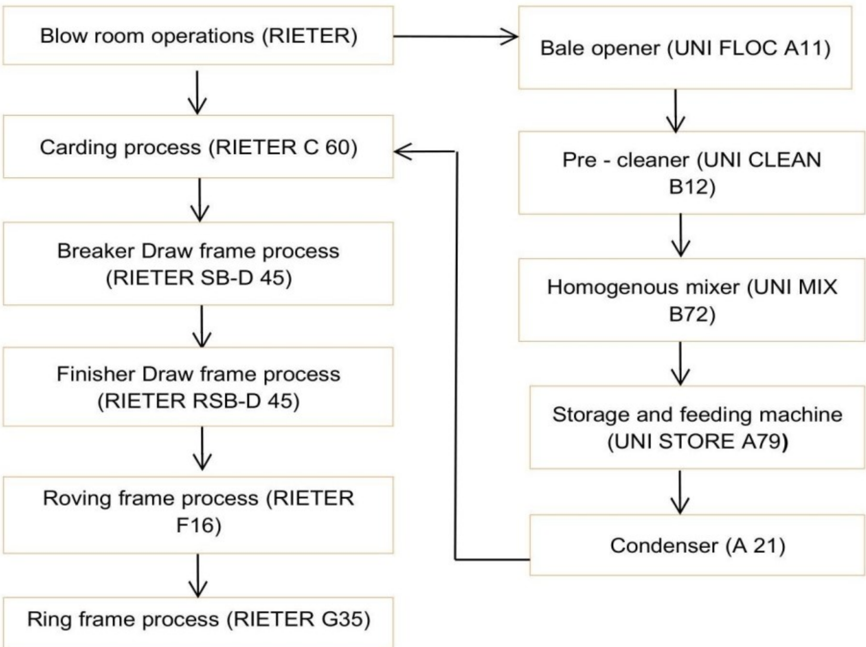

Figure 3. The sequence of machinery for raw material processing (carded process)

Table 2. Machine parameters

Parameters	Average value	Parameters	Average value
Make of ring frame	Rieter G-35	Material processed	100% Cotton
Drafting type	3/3	The pressure of the presser arm (Pa)	300,000
Spacer size (mm)	3.5	Total draft	40
Yarn count in Ne	32s	Break draft	1.09
Roving hank	0.8	Spindle speed (Rpm)	14000
Roving twist multiplier	1.3	Front roller speed (Mpm)	15.2
Bottom roller gauge (mm)	47	Ring frame twist multiplier	4.14
Roller Diameter (mm)	32	Twist Per Inch (TPI)	22.5

Sample Preparation and Testing Condition

For all yarn samples prepared, their yarn evenness, imperfection (thin place, thick place and neps), hairiness, strength and elongation characterizations were conducted in a controlled laboratory environment (relative humidity of 65±2% and temperature of 20±2 °C).

Fibre Parameters Testing

The physical properties of cotton fibre were tested using a high-volume instrument (USTER® HVI 1000) according to ASTM D 5867-2012 [21] Standard Test Methods.

Yarn Evenness, Imperfection and Hairiness Testing

Yarn evenness, imperfection and hairiness were assessed using USTER Tester (5-S800, Switzerland) according to ASTM D1425-96 [22] standard test method at testing the speed of 400 m/min and the test mode is normal.

Tensile Strength and Elongation Testing

The tensile strength and elongation of the yarns were tested on USTER TensoRapid 4 single yarn strength tester (USTER TensoRapid 4-C, Switzerland) as per ASTM D2256-2015 [23] standard test method at clamp speed of 5000mm/min, pre-tension force 0.5 CN/Tex, test length 500mm, clamp pressure 30% and absorber pressure 50%.

Statistical Analysis

Linear regression analysis was applied to establish a quantitative relationship between the yarn qualities concerning shore hardness. Due to the frequent yarn quality, a linear relationship between Shore hardness and yarn quality was assumed. The input parameters for the simple linear regression models were shore hardness while the output parameters were yarn quality and between shore hardness of the cot and yarn quality parameters linear regression equations were developed to predict the yarn quality parameters concerning shore hardness. Minitab 17 was used to statistically model to predict the effect of shore hardness on yarn properties and the developed linear regression equations of the yarn properties and shore hardness are as shown in equations 1-6. A linear regression line has an equation of the form Y = a + bX, where X is the explanatory variable (shore A hardness) and Y is the dependent variable (yarn quality parameters). The slope of the line is b, and a is the intercept. Therefore, simply by substitution from the formula on X values of the unused shore hardness degrees it can predict the yarn quality parameter results.

$$\text{Unevenness U (m) \% (Y)} = 9.995 + 0.05952X \text{----} R^2.0.973\ (97.3\%) \quad (1)$$

$$\text{Unevenness CV (m) \% (Y)} = 12.56 + 0.07915X \text{----} R^2.\ 0.974(97.4\%) \quad (2)$$

$$\text{Normal sensitivity imperfection levels (IPI/Km)}\ (Y) = -1075 + 34.18X \text{----} R^2.\ 0.947\ (94.7\%) \quad (3)$$

$$\text{Tenacity (cN/Tex) (Y)} = 18.80 - 0.08165X \text{----} R^2.\ 0.834\ (83.4\%) \quad (4)$$

$$\text{Elongation (\%)}\ (Y) = 7.321 - 0.03857X \text{----} R^2.\ 0.95\ (95\%) \quad (5)$$

$$\text{Hairiness index}\ (Y) = 4.482 + 0.02412X \text{----} R^2.\ 0.943(94.3\%) \quad (6)$$

RESULTS AND DISCUSSION

Nine full cops of 32s Ne carded cotton yarns were manufactured in Bahir Dar Textile Share Company by using G-35 RF (Ring Frame) RIETER, Winterthur, Switzerland. After yarn preparation, the yarns were verified by testing to ensure their properties. Table 3 shows the properties of the manufactured yarns. Yarn unevenness (Um%), coefficient of mass variation (CVm%), normal sensitivity imperfection levels (IPI/Km), yarn strength, elongation, and hairiness (H) were evaluated according to standard methods. Uster tester 5 and Uster Tensorapid 4 were used to determine the yarn properties.

Table 3. Yarn characteristics

S.No	Shore A Hardness (Front line)	Um (%)	CVm (%)	IPI/km	Tenacity (CN/Tex)	Elongation (%)	Hairiness (H)
1	63^0	13.68	17.45	977.4	14.37	5.05	5.92
2	65^0	13.91	17.76	1191.6	13.30	4.80	6.09
3	68^0	14.19	18.15	1347.2	13.15	4.65	6.21
4	72^0	14.24	18.27	1421	12.47	4.45	6.23
5	75^0	14.38	18.38	1472.4	12.38	4.33	6.25
6	80^0	14.60	18.69	1549.2	12.27	4.28	6.43
7	83^0	15.01	19.14	1718.4	11.96	4.10	6.42
8	85^0	15.12	19.37	1926.6	11.92	4.03	6.51
9	90^0	15.36	19.75	1999	11.75	3.93	6.70

Effect and Prediction of Shore Hardness on Yarn Evenness Um % and CVm%

Yarn evenness defined as the variation of mass per unit length can affect several properties of textile materials especially, the final appearance of the fabric. Irregularity or unevenness of yarn is defined as the variation in mass per unit length along the yarn it is expressed as U% and CV% [25-27]. Figures 4 and 5 summarize that among the nine shores A hardness optimum yarn result was obtained at front 63° and back 83°. This is mainly because low shore hardness on the front top roller encloses the fibre more completely and provides better gripping of fibres while processing finer yarns, and soft covers have a larger contact surface and therefore enclose the fibre bundle more fully [17,24]. Thus, provides more effective guidance even though softer cots under normal spinning conditions produce yarn with a better CV (m) and U (m) percentage. The graph also shows that, as the shore A hardness values increase from lower shore hardness (63°) to higher shore hardness (90°), the yarn U (m) % and CV (m) % increase proportionally.

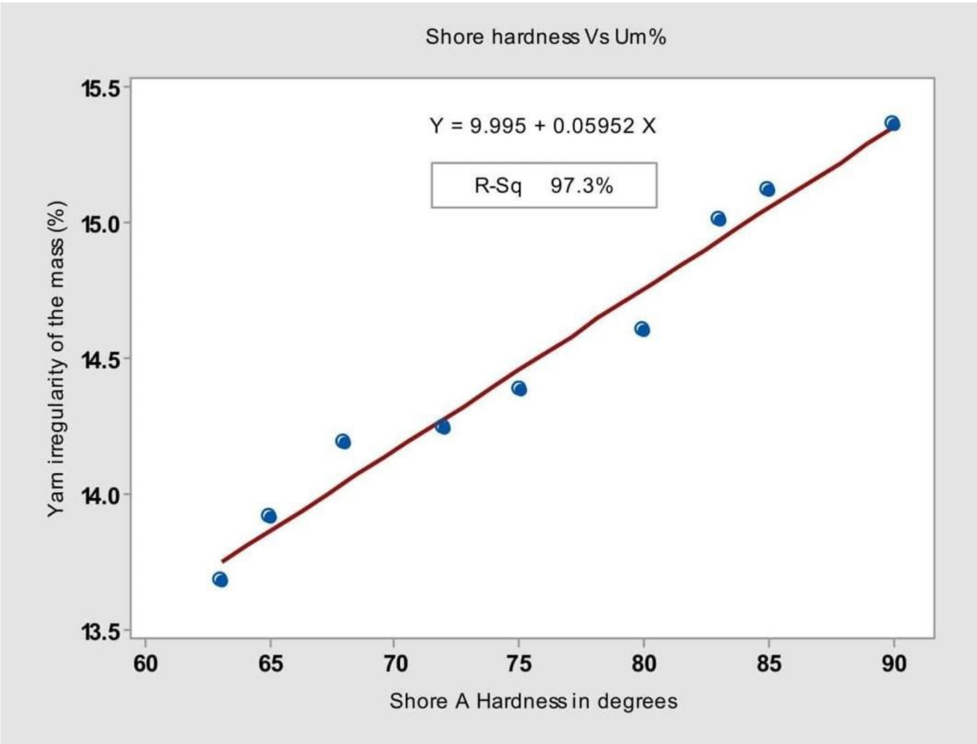

Figure 4. Shows the relationship between shore hardness and unevenness (Um %)

Figure 4 shows that there is a positive correlation between the shore hardness of the front-line cot and Um % (unevenness) of the produced yarn. The value of R^2=0.973 which is almost 97.30%. This signifies that one can have a definite prediction about the U (m) % with different shore hardness. In this investigation, it is not used 76° cots in the front line. If shore hardness A 76° were used in the front line then U (m) could be about 14.518% and Y=9.995+0.0595X, where X is shore hardness 76° and Y is U (m) %.

Figure 5 shows that there is a positive correlation between the shore hardness of the front-line cot and CVm % (yarn coefficient of variation percentage) of the quality of produced yarn. The value of R^2=0.974 which is almost 0.97 or 97.4%. This signifies that one can have a definite prediction about the CV (m) % with different shore hardness. The result from this study shows that there is a practical significance of the linear regression technique, and if 76° cot is used in the front line then the CV (m) would be around 18.575% and Y=12.56+0.07915X, where X is shore hardness 76° and Y is CV (m) %.

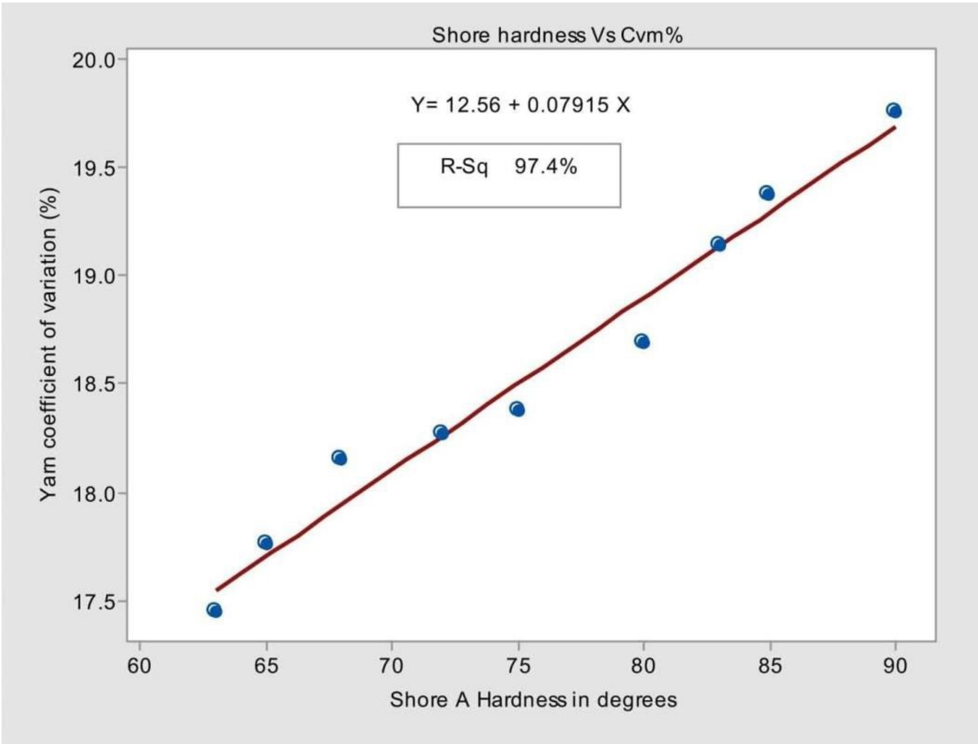

Figure 5. Shows the Relationship between shore hardness and CVm%

Effect and Prediction of Shore Hardness on Normal Sensitivity Imperfection Levels

Thin places, thick places and neps are known as imperfections. These undesired events are defined as a mass increase of +50% for thick places, -50% for thin places, +200% for ring-spun yarn neps. Figure 6 summarizes that among the nine shores A hardness optimum yarn result was obtained front 63° and back 83°. This is because soft covers have a larger contact surface and therefore enclose the fibre bundle more fully, thus providing more effective guidance, even though softer cots under normal spinning conditions produce yarn with a lower sum of thin -50%, thick +50%, and neps +200% per Km. Softer cots at the front line and harder cots at the back line reduce the imperfection level of yarn [17].

As shown in Figure 6 the shore A hardness value increases from lower shore hardness (63°) to higher shore hardness (90°), and the yarn imperfection per Km of the produced yarn increases proportionally.

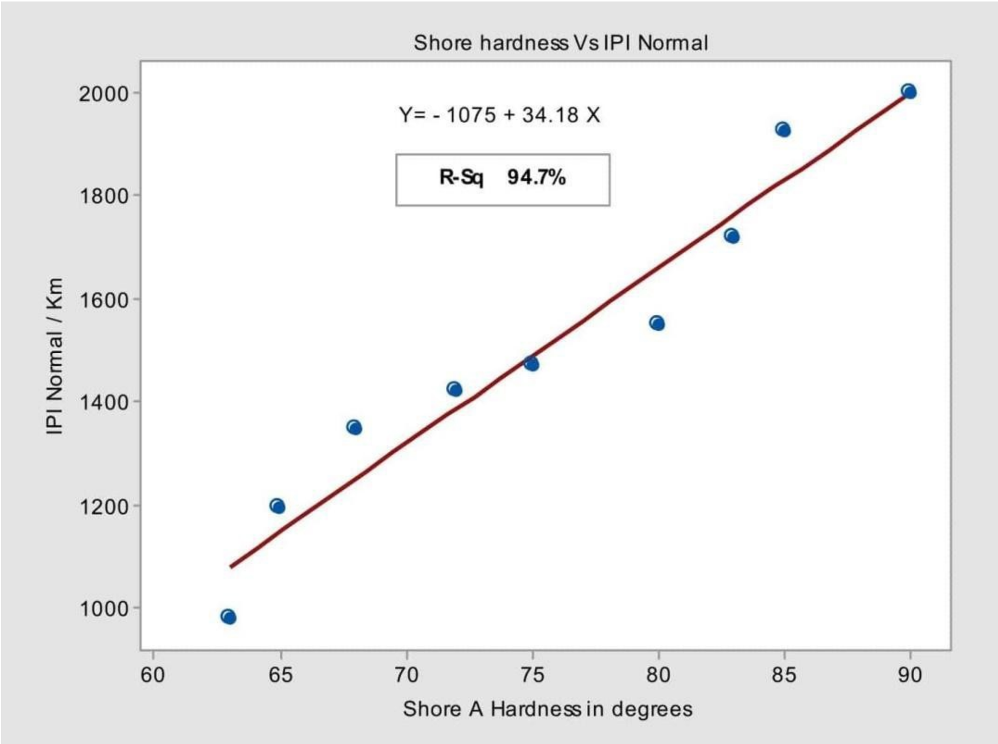

Figure 6. Shows the relationship between shore hardness and IPI normal

Figure 6 clearly explains that there is a positive correlation between the shore hardness of the front-line cot and normal imperfection level (sum of Thin –50%, Thick +50% & Neps +200% per Km of the produced yarn). The value of R^2=0.947 is about 94.7% and this signifies that one can have a definite prediction about the IPI level with different shore hardness. The result from this study shows that, if 76° cots in the front line are used, then the IPI level could be around 1522.68/Km and Y=34.18X–1075, where X is Shore Hardness 76° and Y is IPI/Km.

Effect and Prediction of Shore Hardness on Yarn Strength and Elongation

Tensile testing is used to determine the breaking force, elongation and toughness properties of the produced yarn. Figures 7 and 8 summarize that among the nine shores A hardness, optimum yarn tenacity (cN/Tex) and elongation %, the result was obtained at front 63° and back 83°. This is because soft covers have a larger contact surface and therefore enclose the fibre bundle more fully. Thus providing more effective guidance even though softer cots under normal spinning conditions have better yarns gripping and twist realization in yarn which results in an increase in strength

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and produces yarn with better elongation percentage and tenacity (CN/Tex) and on the other hand harder cots at front line increase the possibility of fibre breakage due to the spinning triangle. This triangle bundle of fibres will remain without twist during twisting and create a weak point in the yarn and hence breakage rate of the yarn during spinning increases. Therefore, to overcome this problem the front top roller should be cots by soft synthetic rubber. The results from Figures 7 and 8 also show that as the shore A hardness values increase from lower shore hardness (63°) to higher shore hardness (90°), the yarn tenacity and elongation values decrease gradually.

Figure 7 clearly shows that there is a positive correlation between the shore hardness of the front-line cot and the tenacity (cN/Tex) of the produced yarn. The value of R^2 = 0.834 or 83.4%. This signifies that one can have a definite prediction about the tenacity with a different shore A hardness. If a 64° cot is used in the front line then the tenacity values would be around 13.57 CN/Texand Y=18.80-0.08165X, where X is shore hardness 64° and Y is tenacity cN/Tex.

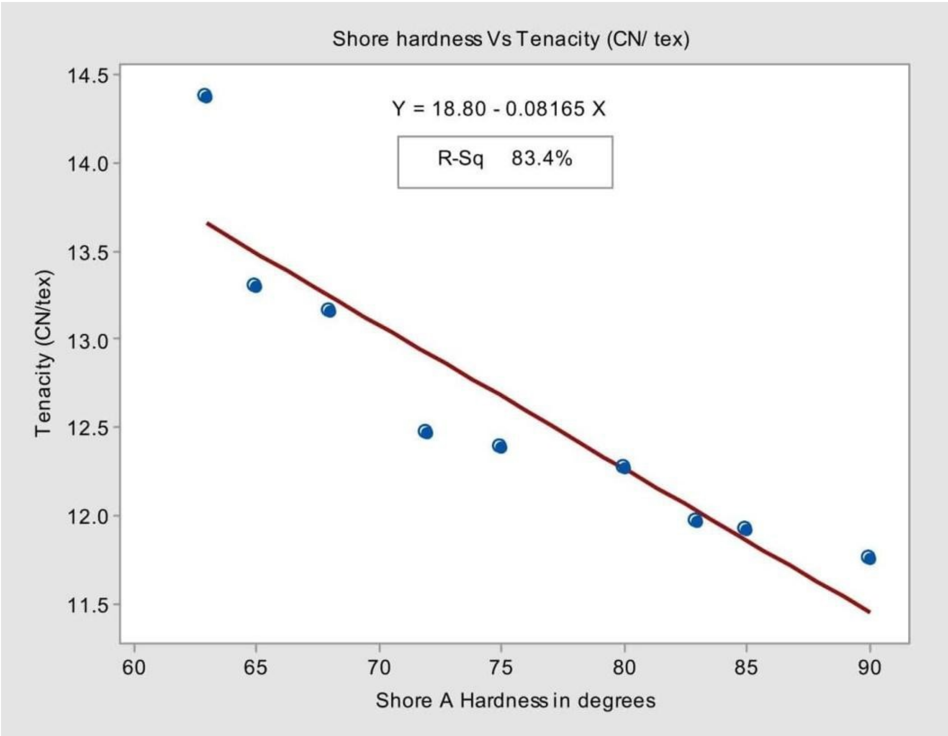

Figure 7. Shows the relationship between shore hardness and tenacity (cN/Tex)

Figure 8 shows that there is a positive correlation between the shore hardness of the front-line cot and the elongation of the produced yarn. The value of R^2=0.95 or 95% and this signifies that one can have a definite prediction elongation values will be around 4.853% and Y=7.321- 0.03857X, where X is shore hardness 64° and Y is elongation %.

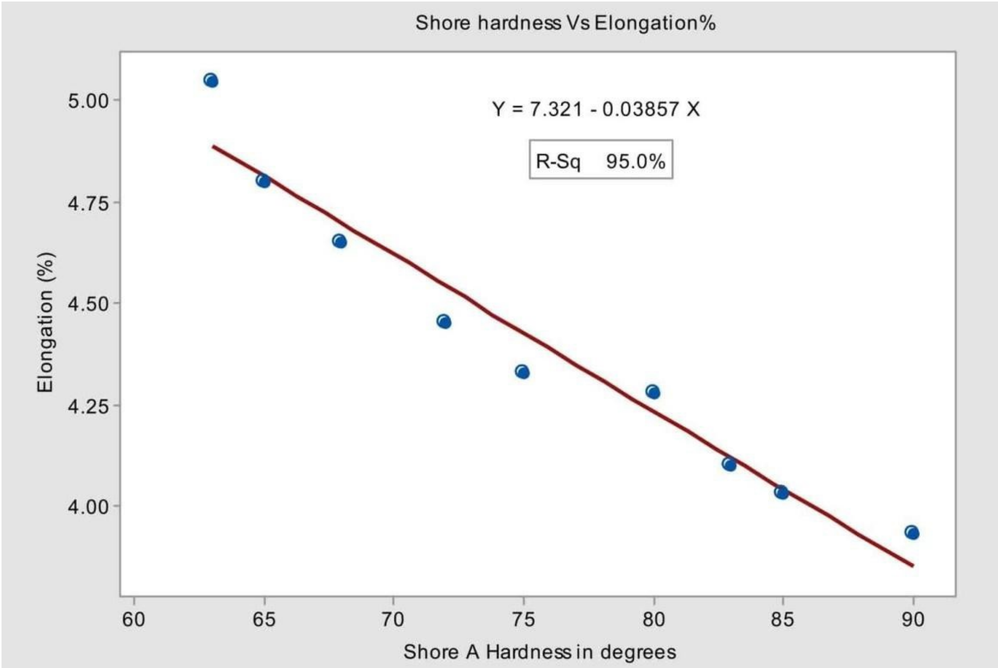

Figure 8. Shows the relationship between shore hardness and elongation (%)

Effect and Prediction of Shore Hardness on Yarn Hairiness (H)

Yarn hairiness significantly influences the characteristics of yarn, fabric appearance and working performance of spinning to its downstream processes. The hairiness of the index 'H' measurement unit of the USTER tester examines the hairiness of approximately 1cm length of the yarn it is specified as the average value of hairiness over the total test length. As can be seen in Figure 9, among the nine shores A hardness optimum yarn hairiness index result was obtained at front 63° and back 83°. This is because soft covers have a larger contact surface and therefore enclose the fibre bundle more fully. This provides more effective guidance even though softer cots under normal spinning conditions produce yarn with a better hairiness index. And also, it can be further explained that the hairiness was also increased with increasing front roller cot hardness. Soft coverings at the front line shift the nipping point of front rubber rollers slightly forward, due to the increased cross-sectional area. It reduces the spinning triangle, which causes the twist to be inserted in a better way. Better twist insertion reduces the hairiness of yarn. On the other hand, harder cots increased the fibre breakage which caused a higher value of hairiness [17]. Due to this reason figure 9 shows that as the shore A hardness value increases from lower shore hardness (63°) to higher shore hardness (90°), the yarn hairiness index values increase proportionally.

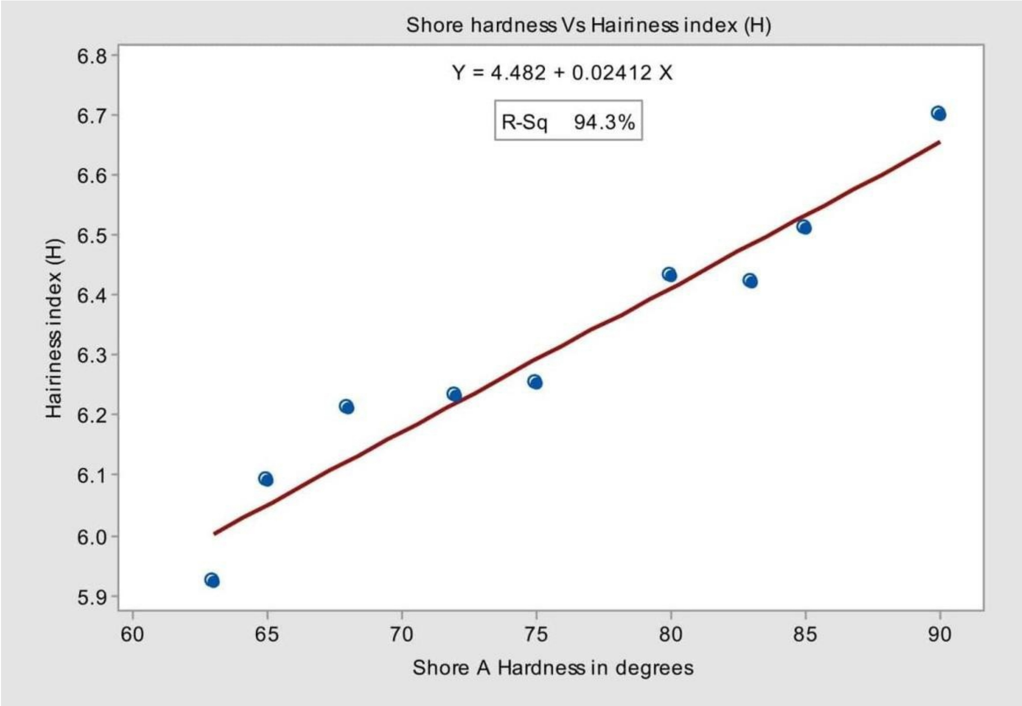

Figure 9. Shows the relationship between Shore hardness and hairiness index (H)

Figure 9 indicates that there is a positive correlation between the shore hardness of the front-line cot and the hairiness index of the produced yarn. The value of R^2=0.943 or 94.3%, signifies that one can have a definite prediction about the hairiness with different shore hardness. The result from this study shows that at 76° cot in the front line will have a hairiness value of 6.315 and Y=4.482+0.02412X, where X is shore hardness 76° and Y is the hairiness index.

CONCLUSION

This research focused on the prediction of the consequences of the ring spinning machine front roller rubber cot shore hardness on 100% cotton and 32s Ne ring spun yarn quality. Based on the results, an increase of 1° in shore hardness or the prediction values corresponds to an increase in imperfection levels in normal sensitivity (thin -50%, thick +50%, and neps +200%), hairiness, and evenness (Um% and Cvm%) by about 50.28/Km, 0.065 index, 0.138 Um%, and 0.195 Cvm%, respectively, and also the yarn strength and elongation are decreased by about 0.796 cN/Texand 0.197%, respectively. A linear regression analysis result showed that for U (m), CV (m), IPI values normal sensitivity levels, tenacity, elongation, and hairiness index of the yarn, there is a positive correlation between the shore hardness and yarn quality parameters with R^2 values of 0.973, 0.974, 0.947, 0.834, 0.95, and 0.943, respectively. So, almost in all cases, the value of R^2 was above 0.834, which signifies one can make a definite prediction about the yarn properties with different shore hardness. In cotton yarns, with an increase in shore hardness from 63° to 90°, the coefficient of variation of yarn mass CV (m)%, yarn unevenness

U (m)%, normal sensitivity imperfection/Km, and hairiness index increase by about 2.3 CV (m)%, 1.68 U%, 1021.6/Km, and 0.78 Index, respectively. On the other hand, in cotton yarns, with an increase in shore hardness from 63° to 90°, the elongation% and tenacity CN/Tex decreased by about 1.12% and 2.62 CN/Tex, respectively. The best result has been obtained in the case of using shore A hardness of 63° to 65° at the front top roller. This is because lower shore hardness cots help increase the area of contact with the fluted bottom roller, which significantly shortens the uncontrolled area between aprons and the cot nipping point.

Author Contributions

Conceptualization - Ferede E, Wagaye BT; methodology – Ferede E, Atalie D, Ayele M; formal analysis – Ferede E, Ayele M, Tesfay T; investigation – Ferede E; resources – Ferede E, Ayele M, Wagaye BT; writing-original draft preparation – Ferede E; writing-review and editing – Ferede E, Tesfay T, Ayele M, Atalie D, Wagaye BT; visualization – Ferede E, Tesfay T, Atalie D; supervision – Tesfay T, Wagaye BT, Ayele M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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