THE USE OF MONTE CARLO TECHNIQUES TO STUDY YARN HAIRINESS FOR RING SPUN COTTON YARNS

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Abstract: The advent of high speed looms and knitting machines has elevated hairiness to be one of the important yarn quality parameters. The factors which affect yarn hairiness include raw materials and processing parameters. Apart from affecting the processing and quality of yarn, hairiness also affects the subsequent yarn processing and fabric quality. In this paper a study of the effects of cotton fiber properties on yarn hairiness has been undertaken. Studies of yarn quality parameters previously reported used classical and modern techniques. Classical methods give low prediction efficiency but provide a model which can easily explain the factors affecting yarn parameters. On the other hand the modern techniques give very high prediction efficiency but are unable to explain the effect of the factors on yarn quality parameters in a manner that is easy to understand. In this paper the relationship between fiber and yarn hairiness was undertaken using statistical modeling and Monte Carlo simulation. The results indicated that yarn count (tex), fiber length, maturity and trash have a negative correlation with yarn hairiness, while yarn twist, fiber micronaire, strength, length uniformity and elongation exhibited a positive correlation.

Keywords: Cotton, fiber, hairiness, yarn, regression, Monte Carlo techniques

1. Introduction

Yarn hairiness can be defined as the amount of fibers protruding out of the general body of the yarn. Hairiness is one of the important yarn properties, which affects the quality and subsequent processing of the yarn. Important fabric properties which include pilling and abrasion properties are affected by the yarn hairiness [1]. The importance of yarn hairiness cannot be overemphasized. The factors which affect yarn hairiness include raw materials and processing parameters. The selection of ring traveler weights and spindle speed are also important factors which must be considered in order to optimize yarn hairiness [2]. A high level of hairiness coupled with high spindle speed may lead to higher air drag. This may lead to unnecessarily higher level of energy consumption during spinning [3-4]. The efficiency of weaving machines can also be adversely affected by yarn hairiness especially in airjet weaving machines [5]. Many researchers have undertaken investigations concerning the effect of fiber properties on yarn hairiness with an aim of optimizing the processing efficiency and product quality. Therefore the effect of fiber properties on ring spun yarn hairiness is one key area that has been widely reported. According to a study conducted by Ahmad et al [6], for a given set of machine parameters, the hairiness of ring spun yarn is affected by fiber length and fiber micronaire. This is in agreement Viswanathan et al [7] reports, which stated that fiber fineness, length and maturity have considerable effect on yarn hairiness. In another research, yarn linear density was reported as the most important factor that affects yarn hairiness, followed by fiber micronaire [8]. The use of regression models to study yarn quality properties is a popular research technique. Ureyen and Kadoglu [9] designed regression models using fiber properties of drawframe sliver so as to eliminate the effect of the processing parameters on yarn properties. The samples were spun into different counts and twist. The regression models indicated that increasing fiber strength, length, yellowness, uniformity index, yarn twist and yarn count (finer yarn) will reduce yarn hairiness. The interpretation of regression models needs a high level of mathematical skills. Monte carlo techniques can however be used to simulate the regression models and hence simply the results produced by the regression models. This will enable easier and more accurate interpretation of the yarn models, which is likely to lead to a increase in the optimization of the yarn spinning process. The aim of this study was to investigate the effect of yarn and fiber properties on ring spun yarn using regression models. The designed regression models were simulated using monte carlo techniques, and hence provided a better understanding of the yarn hairiness models.

2. Experimental

In this research work, cotton lint and yarn samples were collected from spinning mills in Kenya. A summary of the tested characteristics for yarn and fiber samples is given in Table 1. Since the yarn manufacturing system is assumed to be an ergodic system, for every fiber sample collected, the yarn made from that lot was also collected from the ringframe.

Table 1*: Fiber properties and yarn parameters*

Variable	Minimum Value	Mean value	Maximum Value
Yarn Count (Tex)	20	22	27
Yarn Twist (Tpi)	20	22	24
Micronaire (Mic)	3	4	6
Maturity (Mat)	1	1	1
Length (Len)	25	29	33
Length Uniformity (Unf)	78	83	86
Short fiber index (SFI)	6	8	10
Strength (Str)	24	29	37
Elongation (Elg)	4	6	8
Trash cent (Cnt)	1	14	36

The collected samples were tested under standard testing conditions. The cotton lint were tested for; micronaire (mic), maturity (mat), length (len), uniformity (un), short fiber index(sfi), strength(str), elongation (elg) and Trash (cnt). Machine setting and yarn parameters considered included, yarn count (tex) and yarn twist (tpi). Due to the large number of variables, linear multiple regression analysis method was chosen in order to establish a quantitative relationship of yarn hairiness with respect to fiber and yarn properties. Statistical models were designed. The designed models were used to simulate the relationship between yarn hairiness and the independent variables (yarn and fiber properties). Monte Carlo technique was used for the simulation.

3. Results and Discussion

3.1 Yarn Hairiness model

The data collected in this research work was used to design statistical models. Monte Carlo simulation was used to study the influence of selected fiber properties, yarn parameters and machine settings. A linear multiple regression model (Equation 1) was designed. The designed equation was statistically significant and can therefore be used to study the factors affecting yarn hairiness.

$$H = 435 - 5.42Tex + 2.54Tpi + 48.9Mic - 511Mat - 5.86Len + 3.16Unf - 10.2SFI + 3.31Str + 0.74\,Elg - 1.08Cnt \quad (1)$$

Using Monte Carlo simulation a model of the hairiness data was designed. The simulated data was represented using a histogram as shown in Figure 1, which gave a range of 214 to 224 for 80% of the hairiness values.

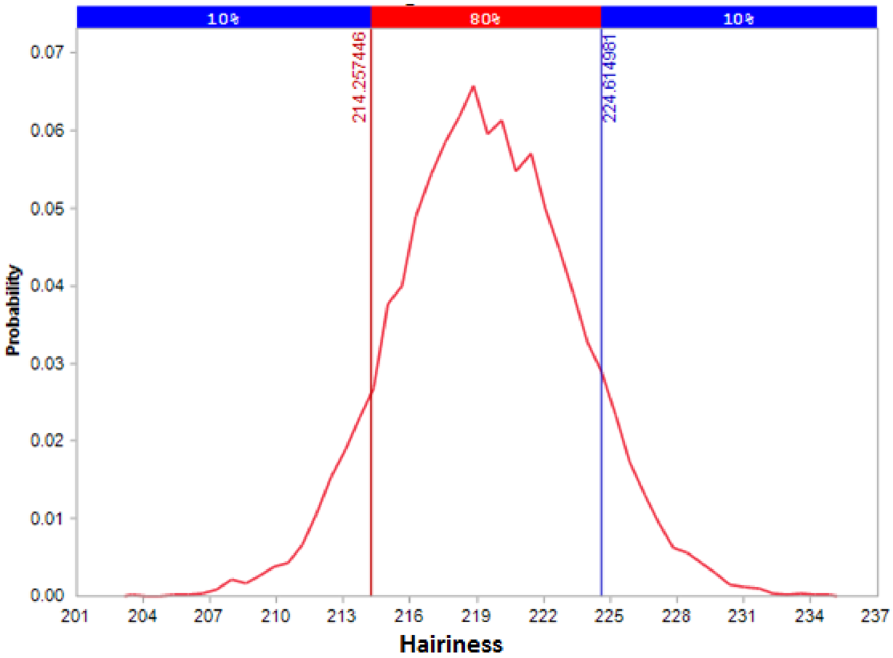

Figure 1: *Histogram for Simulated yarn Hairiness values*

A mean sensitivity analysis of the hairiness data was done to establish the effect of the independent variables of yarn hairiness. According to the results of mean sensitivity analysis as shown in Figure 2 the factor with the highest impact was yarn count (tex) followed by fiber microinare (Mic), length (Len), maturity (Mat), fiber strength (str), short fiber index (sfi), trash (cnt), length uniformity (Unf), twist (tpi) and elongation (Elg). From the above results it can be concluded that some of the most important factors affecting yarn hairiness are yarn count (tex), fiber fineness (micronire), fiber length, and maturity. This is in total agreement with results obtained by other researchers [6-9].

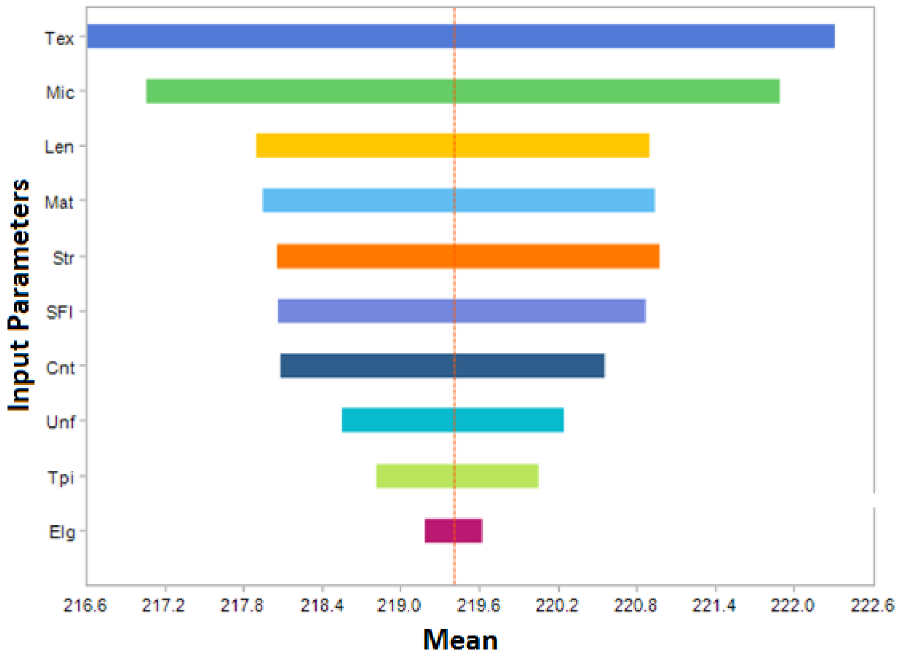

Figure 2: *The mean sensitivity of yarn hairiness*

3.2 Effect of yarn properties on yarn hairiness

To enhance an understanding of the factors affecting yarn hairiness, a rank sensitivity analysis was done. The results are given in Figure 3. The relationship between yarn hairiness and yarn count (tex), shows that yarn hairiness increases with a decrease in yarn linear density.

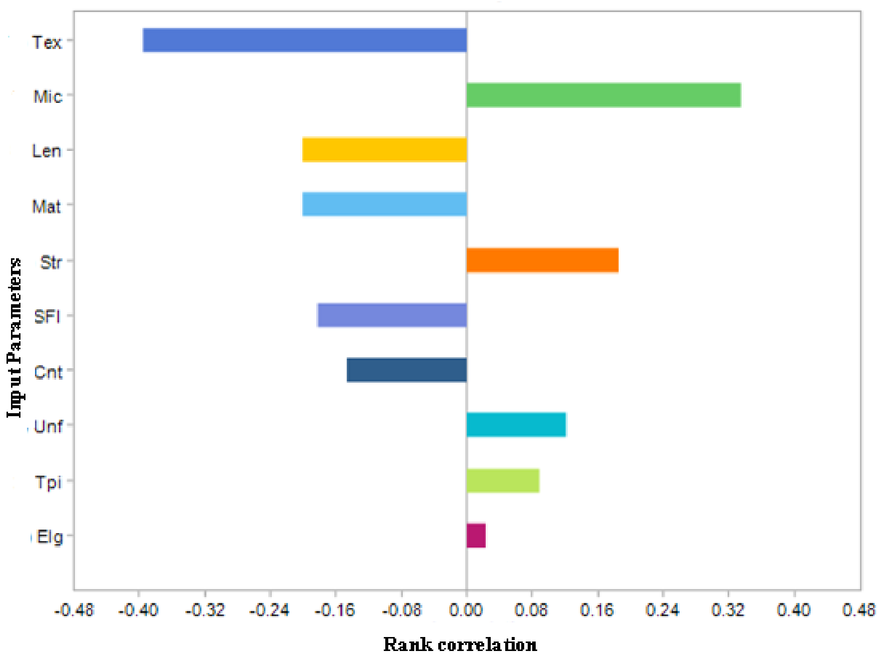

Figure 3: *Rank sensitivity plot*

Similar results were reported by Debnath and Sengupta [10], when studying jute yarns. But Tyagi et al [11] and Ureyen and Kadoglu [9] reported a converse result. That is to say yarn hairiness decrease when yarn linear density decreased. Hairiness is dependent on the number of fibers present in the cross section of the yarn. Hence coarser yarns are expected to have more hairiness compared to finer yarns. According to the sensitivity plot (Figure 3) twist has a positive correlation with yarn hairiness. Palaniswamy [12] reported an indirect relationship. As twist increase the extra twist tends to bind the protruding fibers ends and hence reduce yarn hairiness. Increase in twist also cause fibers to be re-oriented due to changes in the spinning triangle which cause more fiber ends to be exposed. Therefore the decrease of yarn hairiness has a limiting level, after which yarn hairiness starts to increase as twist increases.

3.3 The Effect of fiber properties on yarn hairiness

While yarn hairiness is affected by several factors, the effect of fiber properties on yarn hairiness could shed light on the processing of the Kenyan ring spun yarn. According to the mean sensitivity plot given in Figure 3, micronaire, strength, length uniformity and elongation showed a positive correlation with yarn hairiness. Fiber length, maturity, short fiber index and trash showed a negative correlation with yarn hairiness.

3.3.1 The Effect of fiber micronaire on yarn hairiness

Fiber micronaire was the most significant fiber property affecting yarn hairiness, with a positive correlation. This has been shown graphically in Figure 4. Except for the values towards the high level of micronaire, yarn hairiness generally increased with increase in fiber micronaire.

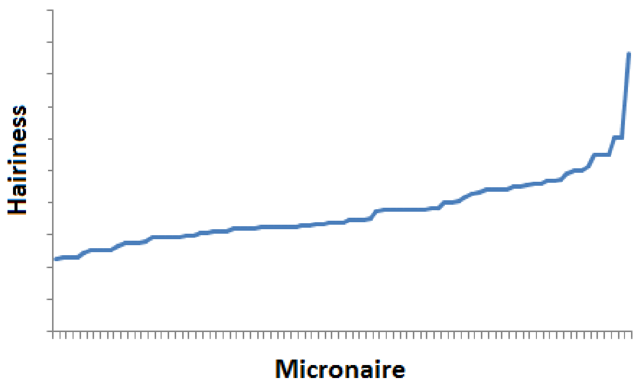

Figure 4: *The Effect of micronaire on yarn hairiness*

This is in agreement with the results obtained by Altas and Kadoglu [8]. For a given yarn linear density, an increase in fiber microniare implies an increase in fiber diameter, hence few number of fibers will be needed to pack a given fiber diameter. Fewer fibers will translate to fewer fiber ends, hence reduced yarn hairiness.

3.3.2 The effect of fiber length on yarn hairiness

The results for the effect of fiber length indicated that hairiness decreases as length increase (Figure 5). This is in total agreement with the results reported by other researchers [7-8, 13]. Longer fibers will produce yarn with fewer fiber ends, therefore it will be expected that yarn hairiness will decrease with increase in fiber length.

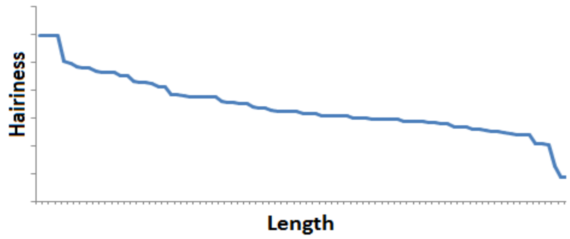

Figure 5: The effect of fiber length on yarn hairiness

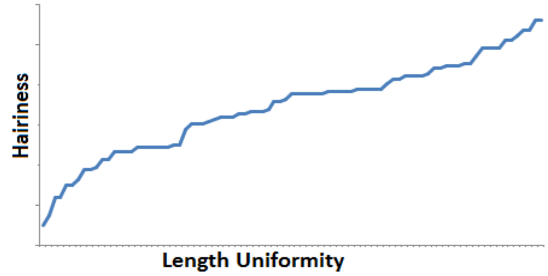

Figure 6: The effect of Length uniformity on yarn hairiness

Fiber length uniformity has a positive correlation with yarn hairiness (Figure 6). The same argument (as discussed earlier concerning fiber length) should hold true for length uniformity, since an increase in length uniformity is equivalent to increase in effective fiber length.

3.3.3 The effect of fiber tensile properties on yarn hairiness

The study of the effect of fiber strength on yarn hairiness revealed that fiber strength was positively correlated with yarn strength. This is shown graphically in Figure 7. Fiber elongation another important fiber property also exhibited a positive correlation with yarn hairiness (Figure 8).

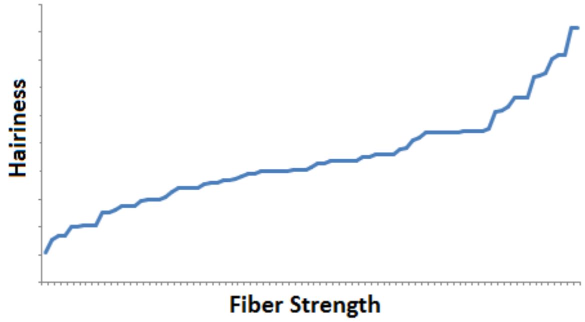

Figure 7: Effect of fiber strength on yarn hairiness

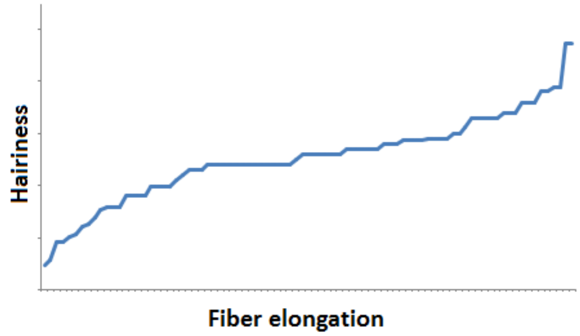

Figure 8: Effect of fiber elongation on yarn hairiness

3.3.4 The effect of short fiber index and fiber trash on yarn hairiness

A study of the effect of short fiber Index on yarn hairiness indicated that short fiber index was negatively correlated with yarn hairiness. This implies that as short fiber index increased yarn hairiness increased (Figure 9). The shorter the fiber the higher the number of fiber ends in a given length of yarn. More fiber ends will lead to higher hairiness. The effect of fiber trash on yarn hairiness as shown in Figure 10, showed a negative correlation. As trash increased yarn hairiness decreased. This could be an indirect implication due to the fact the higher the fiber trash, the short the fiber, a phenomena common to Kenyan cotton which is hand picked. Kenya farmers who are not keen enough to take good care of their cotton crop are also more likely to be careless when storing the cotton, leading to a high level of trash.

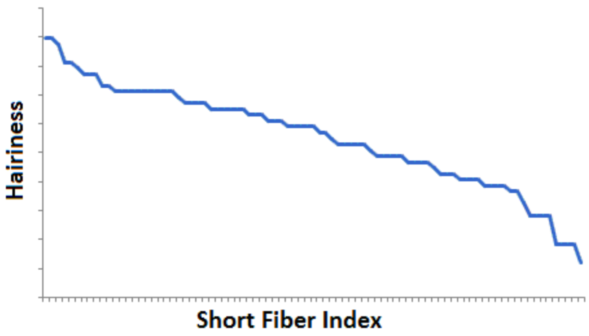

Figure 9: *Effect of short fiber index on yarn hairiness*

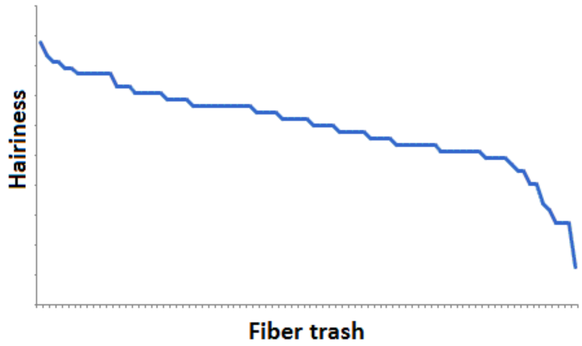

Figure 10*: Effect of fiber trash on yarn hairiness*

4. Conclusion

A study of the effect of fiber and yarn properties on yarn hairiness was undertaken using samples collected from spinning mills in Kenya. Regression models were design and Monte Carlo techniques used to simulate the hairiness model. The designed models indicated that yarn count (tex), fiber length, maturity and trash have a negative correlation with yarn hairiness, while yarn twist, fiber micronaire, strength, length uniformity and elongation exhibited a positive correlation with yarn hairiness.

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