THE USE OF STATISTICAL TECHNIQUES TO STUDY THE RELATIONSHIP BETWEEN COTTON FIBERS AND YARN PROPERTIES - A CASE STUDY OF UGANDA ROTOR SPUN YARN

BY

MIREMBE JACQUIRINE
(BSc. Textile and Clothing Tech (Hons) Kyambogo University, Kampala – Uganda)

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN TEXTILE ENGINEERING, DEPARTMENT OF MANUFACTURING, INDUSTRIAL AND TEXTILE ENGINEERING, SCHOOL OF ENGINEERING, MOI UNIVERSITY- ELDORET KENYA

NOVEMBER, 2016

DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or Moi University.

Mirembe Jacquirine …………………………………… DATE: …………………..
TEC/PGMT/02/14

Declaration by Supervisors

This thesis has been submitted for examination with our approval as University Supervisors.

Prof. Josphat Igadwa Mwasiagi.…………………………….. DATE...………………
Moi University, Eldoret, Kenya

Dr. Nzila Charles …………………………………… DATE……………………
Moi University, Eldoret, Kenya

Dr. Eric Oyondi Nganyi ……………………………….... DATE……………………
Moi University, Eldoret, Kenya

DEDICATION

I hereby dedicate this thesis report to the European Commission and Mobility for Enhancing Training of Engineering Graduates in Africa (METEGA) for having awarded me a study scholarship and all the support provided towards accomplishing this master's programme.

I also dedicate this work to my family especially my mother and fiancee for the tireless support, sacrifice and words of encouragement they have given me throughout my whole study.

ABSTRACT

Due to current stringent customer demand for consistent, fast and better quality textile materials, Uganda's textile industry has lost ground to the competition coming from European textile produced products. Also, cotton being a natural fiber, its properties varies from fiber to fiber, season to season, and bale to bale due to changes in climatic conditions, soil type, growing regions, harvesting and ginning methods, which ultimately affects processing and consistency in yarn quality as per customer requirements. Selection of suitable cotton fibers and spinning parameters for a particular yarn quality requirement can thus reduce on this inconsistency. The objectives of this study were to test the mechanical and physical properties of cotton fibers using a High Volume instrument (HVI), spinning and testing of cotton rotor spun yarns for both mechanical and physical properties and to model the effect of cotton properties and spinning parameters on rotor yarn properties using statistical techniques. Yarns were spun using a rotor machine at Nytil factory in Jinja Uganda. Using Taguchi experimental design, different machine speeds were selected. For every yarn sample spun, the cotton used for the spinning process was characterized using High Volume Instrument (HVI). The cotton fiber properties measured included fiber length 28.54 mm, uniformity Index 83%, short fiber content 6.7%, fiber strength 28.6 mm, fiber elongation 7%, micronaire 4.3, trash content 26, trash area 0.46%, reflectance 74.6% and yellowness 10.91. The resulting yarns were tested for properties of strength, elongation, evenness, imperfections, count and twist. From the experimental data, multiple regression analysis employing Analysis of Variance was used to establish the relationship between cotton and yarn parameters. Regression models were developed and used to predict yarn properties. The model results showed that micronaire, maturity and count had the most significant influence on yarn strength at an adjusted R-Square (R^2) value of 0.8094. For yarn elongation, yarn count, fiber elongation, length uniformity and short fiber content were the most significant factors at an adjusted R^2 of 0.5720.Yarn evenness was mostly affected by count, reflectance, short fibre content and trash content at an adjusted R^2 value of 0.8955. Thin places were significantly affected by count, rotor speed, roller speed and trash content at an adjusted R^2 value of 0.9396. Thick places were mostly affected by count,maturity and rotor speed at an adjusted R^2 of 0.7656 while neps were mostly affected by yellowness, short fibre content, twist and rotor speed at an adjusted R^2 of 0.7616. This work has thus proposed models which can predict yarn strength, elongation, evenness, thin places, thick places and neps. Therefore, given fiber properties, the spinner can save time and material by carrying out fewer pre-spinning tests. As a recommendation, using the developed models could aid in the selection of suitable cotton fiber properties and spinning parameters for different yarn properties in order to attain desirable productivity and quality levels of the resulting rotor spun yarns.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This research wouldn’t have been successful without the efforts and support of various people and organizations among whom/ which are acknowledged here.

My first thanks go to the Almighty God for the protection, guidance and good health provided throughout my study and during the compilation of this report. To Him be the glory.

I am so thankful to the METEGA Project for the study scholarship granted and all the support provided throughout my studies. Thank you so much for having made this Master’s study dream come true.

I am greatly indebted to my supervisors Prof Josphat.Igadwa Mwasiagi, Dr. Charles Nzila and Dr. Eric Oyondi for their tireless support, advice, guidance, suggestions and comments given throughout this research study and in compilation of this report. Thank you so much. I would also like to thank my other lecturers; Dr. David Njuguna, Prof John Githaiga and Dr. Diana Madara for having dedicated their time for us to complete our studies promptly. Thank you so much.

I would also like to thank Madam Ann Cherus and Mr. Elluid Meli for the administrative duties done that made this scholarship a success. Thank you

I am so thankful to Dr. Nibikora of Busitema University, Prof. Aaron Wanyama and Mr. Gudoi Davis of Kyambogo University for the words of encouragement offered throughout this study journey.

My sincere gratitude goes to the management and staff of Southern Range Nyanza Limited textile factory especially the General Manager Mr. Viny Kumar for having allowed me carry out this research study and experiments from their factory. Former spinning manager Mr. Jacob Ochola, quality control manager Mr. Okecho Joseph and all machine operators for the guidance provided during sample processing and testing. Thank you so much for having made this research come through.

I am also grateful to Cotton Development Organization (CDO) for the HVI instrument provided during cotton sample characterization. I am also thankful to Fine Spinners Uganda Limited for the testing equipment provided during yarn characterization.

I am so thankful to my family members especially my mother Mrs. Esther Kalagi, my fiancee Mr. Luminsa Apollo, my lovely daughter Ms. Esther Katasi and my sisters and brothers for the love, care, words of encouragement, prayers and tireless support offered throughout this study. I will forever be grateful.

Last but not the least, my other gratitude goes to my classmates; Ms. Karen Desta Agulei, Mr. Mwesigwa Ronald, Mr. Nkosilathi Zinti Nkomo, Mr. Khafafa John and Mr. Wetaka Charles for the friendship, words of encouragement, suggestions and advice offered throughout this study and during the compilation of this report. Thank you so much

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Cotton is an annual cash crop that is produced commercially in over 80 countries located in the tropics and subtropical climatic zones. Cotton fibre is a natural cellulosic/ vegetable fiber among sisal, linen, pine, jute. Cotton fibers normally grow in a boll or protective capsule, from the epidermal cells on the seed surface of Gossypium plants which belong to the Malvaceae family. In terms of production, cotton fibers are mainly grown in developed countries all contributing about 85% to the global cotton production (Phundan., 2014). Among these include; China currently producing about 4.9 million metric tons, India about 5.8 million metric tons, United States with 2.8 million metric tons, Pakistan with 1.5 million metric tons and Brazil with 1.3 million metric tons according to (United States Department of Agriculture (USDA), Cotton Incorporated., (2016). Cotton is the most widely used natural textile fiber because of its excellent softness, comfort, strength, dye absorption, retention and washability properties.

In Africa, Tanzania, Zimbabwe, Zambia, Uganda, Benin, Burkina Faso, Cameroon, Mali are among the main cotton growing countries as reported by (United Nations Industrial Development Organization (UNIDO)., (2011), the leading producers being Burkina Faso, Zimbabwe, Tanzania and Zambia (International Cotton Advisory Committee (ICAC)., 2014). Africa’s regional cotton production was about 249,000 metric tons per season from the late 1980s to early 1990s, but for the last seasons from 2008/09-2013/14, production reached an average of 380,000 metric tons per season due to an increase in area planted and a slight rise in yield. In Africa, its estimated that only about 15% of the whole cotton production is transformed into yarn or other value-added textiles and the rest is exported as a raw material with no value addition (United Nations Industrial Development Organization (UNIDO)., 2011).

Uganda being among Africa’s main cotton growing countries, it was the largest Sub-Saharan Africa’s cotton producer during the 1960s. However, the sector failed due to high political and economic instabilities, improper ginnery management policies in addition to low cotton prices of the 1970s, which led to a drastic fall in production to values below 20,000 bales per annum (Baffes., 2009, Uganda Investment Authority (UIA)., 2014). However, in 1994, cotton prices peaked which promoted restoration policy to the industry which is still in effect today as the government has encouraged production and investment in the cotton and textile industry from both private and public sector. Current works done by Cotton Development Organization (CDO), a statutory body regulating and promoting cotton growth, processing and marketing in addition to other donors’ interventions have thus improved production significantly per hectare.

Uganda currently produces about 15,000 metric tons of cotton International Cotton Advisory Committee (ICAC)., (2014) mainly grown in the Northern, Eastern, lower West Nile and South Western part of the country on over 0.5-1.0 hectares of land. Cotton production is done manually by about 150,000 subsistence farmers (Uganda Investment Authority (UIA)., 2014). Initially, two cotton varieties were grown that is: Bukalasa Pedigree Albar (BPA) and Serere Albar Type Uganda (SATU). However, only BPA is currently grown which has excellent fiber characteristics for spinning (yields finer fibers of medium to long staple length). However, SATU which is a coarser fiber of short to medium staple length is set aside purely for research at the National Semi-arid

Agriculture and Animal Resources Institute (NaSAARI) (Cotton Development Organisation (CDO)., 2011)

Due to the current stringent customer demand for consistent and better quality textile materials, Uganda's textile industry has lost ground to the competition coming from European produced products and second hand clothing (Cotton Development Organisation (CDO)., 2011). As a result, about 5 % of the total cotton produced is consumed locally and the rest is exported with no value addition to countries like to Singapore (55%), Switzerland (23%), United Kingdom (17%) and to a lesser extent China, Japan and Kenya (Ahmed 2012). There is however, one private enterprise that adds value to cotton lint by making absorbent cotton wool for the domestic market but its capacity is still low as more than 50% of the country's sanitary products are imported. Besides textile production, the remaining cotton seed is processed into edible oil, soap and cotton seed cake for feeding live-stock (UIA 2014).

In simple terms, cotton is the raw material for the textile manufacturer who transforms cotton fibers into yarn and then into fabric for apparel, household goods or industrial products. Cotton fibre like all commodities is differentiated by quality parameters for the purposes of trade thus consistency in the final product quality is paramount. This is because any difference in quality affects the price as well as the value that manufacturers get from that cotton. In addition, quality and performance demands are being placed on the entire textile mill right from raw material processing to the end product because the cost of fiber raw material accounts for about 50-70% of the total yarn cost (Estur., 2008, Lawrence., 2003). However, cotton being a natural fiber, its properties keep varying from fiber to fiber, bale to bale and season to season due to changes in climatic conditions, growing areas, harvesting and ginning methods, thus consistently affecting yarn and fabric quality properties (Iftikhar et al., 2005).

Research has revealed that the quality of yarn and resulting fabric mainly depend on fiber parameters of: fiber length, uniformity Index, short fiber content, fiber strength, fiber elongation, micronaire value, trash content and colour. In addition to fiber properties, yarn twist, yarn count, spinning techniques and processing conditions also have been found to have profound effects on both yarn and fabric quality. These fore-mentioned factors affect yarn strength, elongation, hairiness, evenness and imperfection properties which are very desirable in the subsequent post spinning processes of winding, knitting and weaving (Iftikhar et al., 2005).

During weaving, yarns are subjected to high frictional and abrasion forces leading to increased warp yarn breakages, machine stoppages hence low productivity and poor quality fabrics (Kusum et al 2012). In the past 20-30 years, 15 non-reparable faults per 100 meters of cotton fabric were acceptable, in 2007 only 5 were accepted and the number is anticipated to become 3 in the near future as reported by International Trade Center (ITC)., (2007). To reduce on this occurrence, selection of suitable cotton fibers for a particular yarn and fabric quality requirement is paramount (Majumdar et al., 2004). However this has remained a great challenge to Ugandan spinners since theoretical methods and rule of thumb are used during textile processing.

Research efforts are therefore continuously being directed towards improving the desirable properties of cotton fibers, since these properties affect yarn and fabric quality. Such efforts are aimed at improving breeding, farming and ginning practices as well as textile processing systems and conditions. Prediction models have therefore been developed capable of predicting spun yarn properties from constituent fibers properties prior to fiber processing. Among these include: Mathematical models by (Morris et al., 1999, Frydrych., 1992.), Statistical models by (Ethridge et al., 1982, Hunter., 1988), Empirical models by (Hunter., 1988) and Artificial Neural Network models by (Ethridge et al.,1996, Deogratias and Wang., 2010).

Mathematical models provide a better understanding of the interrelationship between different fiber and yarn properties but they require solving a lot of assumptions to make the mathematics involved easy to understand (Anindya et al., 2005). Empirical models assume that fiber properties are independent of and that they exert an exclusive influence on the yarn properties, which is not always true (Mogahzy et al., 1990). Currently, Artificial Neural Network (ANN) and Adaptive Neuro- Fuzzy Inference System (ANFIS) are used because they give very reliable results (Deogratias and Wang., 2010). However, these results are stored in opaque/unclear fashion making it difficult to interpret and understand by some manufacturers (Furferi and Gelli, 2010). To the contrary, statistical models are easy to develop and use, give good results thus are among the most widely used models during yarn prediction (Erol and Sagbas., 2009). These mainly use regression analysis in estimating the quantitative relationship between textile material properties. This approach is used to investigate the interdependence of different fiber properties and to estimate their relative contribution to the overall yarn properties. Several researchers have therefore developed regression models using this method. However, most of these models have been developed for ring spun yarns and little has been done on rotor spun yarns (Farooq et al., 2012, Halimi et al, 2009, (Khalilur et al., 2015a, Khalilur et al., 2015b). In order to design a cotton cloth with an optimum combination of properties for a given end use, it is desirable to know how the properties in question are affected by the changes in constituent fibers, yarn properties and machine settings. This study therefore aimed at using statistical techniques employing multiple regression analysis to study the relationship between cotton fibers, yarn and spinning parameters on cotton rotor spun yarn properties.

1.2 PROBLEM STATEMENT

Uganda produces about 15,000 Metric tons of cotton but only 5% is used locally and the rest is exported with no value addition. This has resulted from limited research and infrastructure, use of modest technology and availability of a few domestic textile industries in the country. Due to the current stringent customer demand for consistent and better quality textile materials, Uganda's textile industry has thus lost position to the competition coming from European produced products. Generally, cotton fibers being natural, their properties vary from fiber to fiber, season to season and bale to bale due to changes in climatic conditions, soil type, growing regions, harvesting and ginning methods, which ultimately affects consistency in yarn quality as per customer requirements. For Uganda to therefore compete favorably with the western markets on similar products, there is need to improve the quality of its yarns. This can be achieved through selection of suitable cotton fiber properties and spinning parameters as per desired customer requirement. However, with theoretical means of production used in these textile industries, this has remained a great challenge to most spinners. The use of statistical modelling tools can however aid in the selection of the desired parameters according to specification. These models also have the potential to reduce on raw material wastage, maintain production consistency, improve on productivity and quality of yarns produced, as well as meeting customer demands on time.

1.3 JUSTIFICATION OF THE PROJECT

i. Southern Range Nyanza Limited spins yarn from cotton fibers grown from different regions in the country. Cotton fibers being natural, its variation in properties ultimately affects consistency in yarn quality as per customer requirements. To reduce on this inconsistency, the industry blends several bales of cotton from each of the regions to be processed and spun into yarn of the required count. However, due to an inbuilt relationship that exists between fiber properties, process parameters and yarn properties, this method is inefficient because theoretical methods and rule of thumb are used during both bale selection and processing..

ii. The use of statistical modelling tools can however aid in the selection of better cotton fibre properties and spinning parameters as per the desired yarn quality customer requirement. The developed predictive models may therefore provide a clear understanding of the impact of any changes in fiber properties and process parameters on the whole textile processing performance. This will reduce on raw material wastage, maintain production consistency, improve on productivity and quality of yarns produced hence meeting customer demands on time.

1.4 SIGNIFICANCE OF THE PROJECT

i. Using the developed models could result into better rotor spun properties, thus high quality cotton cloth. This will improve sells and hence more returns on investment.

ii. Carrying out this study could therefore promote better cotton utilization and processing hence generating income to the local population and textile manufacturers.

1.5 OBJECTIVE OF THE PROJECT

The main objective of this research work was;

To study the relationship between cotton fibers, yarn and spinning parameters on rotor spun yarn properties using statistical techniques.

1.5.1 Specific objectives of the project

The specific objectives of this research work were;

i. Testing of mechanical and physical properties of cotton fibers using a High Volume instrument (HVI)

ii. Spinning and testing of cotton rotor spun yarns for both mechanical and physical properties

iii. Modelling the effect of cotton fibre properties, yarn and spinning parameters on rotor yarn properties using Analysis of Variance (ANOVA) and multiple regression analysis statistical techniques

1.6 SCOPE OF THE STUDY

This research was limited to 100% cotton rotor spun yarns manufactured in Southern Range Nyanza Limited, Jinja-Uganda. Modelling of the relationship between fibers, yarn and spinning parameters on rotor spun yarn properties was done using Analysis of Variance (ANOVA) and multiple regression analysis.

CHAPTER 2 LITERATURE REVIEW

2.1 COTTON FIBER PROPERTIES

Cotton like all other textile fibers has properties required for the manufacture of yarn to be used in spinning, weaving, knitting and dyeing operations. These are grouped into physical and chemical properties. Among the chemical properties, cotton has a good resistance to alkalis, fair resistance to acids and good resistance to organic solvents especially during laundry. It is however affected by mildew or microorganisms during hot and humid conditions. According to Brandrup and Immergut., (1989), cotton swells in a high humidity environment, in water and in concentrated solutions of certain acids, salts and bases. The swelling effect is usually attributed to the sorption of highly hydrated ions making cotton to have a moisture regain of about 7.1~8.5% and the moisture absorption is 7~8%. Chemical properties mainly affect the dyeing, printing, finishing and daily use of the cotton fabric where acids, alkalis and solvents are applied. On the contrary, physical characteristics of raw cotton fibers affect the manufacturing efficiency and/or quality of the finished product. These properties mainly affect the spinning, weaving, knitting and dyeing operations of textile manufacturing.

2.1.1 Physical and mechanical properties of cotton fibers

Selection of proper fibre raw materials has become every spinner's interest because of the fiber cost and quality. Researchers have reported that the cost of fiber raw materials accounts for about 50-70% of the total yarn cost (Estur., 2008, Lawrence., 2003). During raw material selection, important consideration is put on the quality of the end product coupled with the processing requirements for producing the desired yarn. The selection of good cotton quality fibers leads to a good quality yarn and hence the resulting fabric.

However, the interaction of fibers with machine processing differs from one spinning system to another hence making it essential to know how fiber parameters affect both yarn quality and the spinning performance. There are a number of properties that are considered useful by both the spinner/yarn manufacturer in order to produce high quality products. These fiber properties however, vary in importance according to the spinning system used and the product to be made. Research works relating cotton fiber properties and resulting rotor spun yarns have been done from which predictive models have been developed (Deogratias and Wang., 2010, Farooq et al., 2012, Hanen et al., 2015). This section therefore explains some of the cotton physical properties that are considered very influential during textile processing.

2.1.1.1 Fiber length

Fiber length is described as the average length of the longer one-half of the fibers and is termed as the Upper Half Mean Length (UHML) from the Uster HVI instrument. Cotton length and length distribution are affected by agronomic and environmental factors during fiber development and mechanical processes at and after harvest. Cotton fiber length is a genetic feature thus varies considerably across different cotton species and varieties. Upland cotton has a medium fiber length of 15-30 mm and width of approximately 20 µm. Egyptian/American Pima is 20-4 0mm with a width of 22 µm and the longer Sea Island cotton is 60 mm (Cook., 2006). For Bukalasa Pedigree Albar type in Uganda, the length is between 27-30 mm (Cotton Development Organisation (CDO)., 2011). Fiber length is a very important property in textile processing as it determines the draft settings of machines in a spinning mill depending on whether it’s short or long. In some spinning systems like ring spinning, fibre length has a great contribution towards yarn strength as it allows fibers to twist around each other for a number of times compared to short fibers. This prevents fibre slippage hence contributing to yarn strength. In addition, longer fibers have higher frictional/cohesion forces between them which prevents fibre slippage during processing and hence contributing to yarn strength.

However, in rotor spinning, the importance of fiber length is less significant compared to the ring spinning process. Studies done by Lawrence., (2010) revealed that during fiber processing in rotor spinning, the extent of opening action imposed by the opening/combing roller depends on the fiber length, in that as the fiber length increases, the force acting on the fiber beard increases significantly resulting in fiber damage and wastage. Also, during fiber passage through the transportation tube, long fibers are more vulnerable to airstream disturbance than medium to short fibers hence causing poor fiber orientation and ultimately a reduction in yarn quality. Steadman et al., (1989) added that long staple cottons contribute less to strength due to the formation of wrapper fibers. Louis., (1981) also concluded that the number of wrapper fibers in the yarns increased with increase in length (31.8 mm) than in short cottons (25.1 mm) which affected yarn quality. It was added that longer lengths are more important when spinning finer counts than coarse counts with rotor machines. With this, careful control of fiber length is therefore required for rotor spinning than ring spinning because the forming yarn is more able to withstand tension fluctuations caused by spinning long staple fibers than short staple fibers in ring spinning. It is therefore important to determine the fiber length distribution of the cotton fibers to be processed since the distribution and transfer of tension among fibers in the yarn depends on the length and frictional contact of the overlap of their ends.

2.1.1.2 Length uniformity Index

Length uniformity index (LUI) is yet another important property in textile processing. It refers to the ratio of mean length to UHML length expressed as a percentage. LUI gives an indication of short fiber content, since cottons of low length uniformity index are likely to contain a high percentage of short fibers. Short fibers require a greater level of twist than longer fibers so as to hold together to form a yarn of useful strength and this increases costs. LUI values greater than 85% are considered very high, 83-85% is high, 80-82% is intermediate, 77-79% is low and below 77% is very low and undesirable (Lawrence., 2003). Length uniformity index is therefore important to yarn production efficiency as well as yarn strength and evenness. (Majumdar wet al., 2004) reported that higher LUI values increase yarn elongation by hindering fiber slippage during spinning thereby ensuring greater translation of fibre elongation to yarn elongation which improves on subsequent processes of weaving and knitting. It was added that better uniformity ratio gives a higher fibre to fibre friction which prevents fibre slippage and hence improving on yarn properties. Cook., (2006) reported that LUI is an important parameter influencing yarn evennes and spinning performance of finer counts in rotor spinning thus must be kep consistent since variations in length can lead to an increase in waste, deterioration in processing performance and yarn quality. On the contrary, (Kaushik et al., 1987a) reported that fiber length characteristics play only a minor role in rotor spinning since they can adversely affect yarn strength and evenness due to the greater incidence of wrapper fibers and poor fiber orientation.

2.1.1.3 Fiber tensile properties

Fiber strength and elongation are the mainly considered fiber tensile properties in terms of quality. Fiber strength is measured in grams per tex or denier and is determined as the force required to break the beard of fibers, clamped in two sets of jaws placed 12.5mm apart. Fiber elongation on the other hand is an increase in the original length of the fiber before breakage expressed as a percentage. Cotton fibre tensile properties are also affected by agronomic and environmental factors during fiber development and mechanical processes at and after harvest. Among the good attributes of cotton that favor is wider commercial use is strength. Cotton strength in the range of 30 g/tex is considered to be very strong, 29-30 g/tex strong, 26-28 g/tex average, 24-25 g/tex intermediate and 23 g/tex weak. Cook., (2006) and Brandrup et al., (1989) found that, the breaking strength of cotton is about 3.0-4.9 g/denier, while the breaking elongation is about 8-10%.

Tensile properties are highly important since they determine the work of rupture used to withstand the stress of various stages of fiber and yarn production. Tensile properties also affect the winding and knitting efficiency as well as warp and weft breakages during weaving operations. The use of strong fibers produces strong yarns hence improving on fabric strength and durability. Final yarn strength depends on how well its constituent fibers can easily share the load applied to the yarn. It is believed that the more the fibers in the yarn cross section, the higher the strength since the strength translation efficiency from fibers to yarns is about 40-65% (Lawrence., 2010). Louis., (1981) reported that in rotor spinning, fiber strength has a higher influence on yarn strength than fiber length.

2.1.1.4 Fiber linear density

Fiber linear density or fineness refers to the mass per unit length of a fiber and is measured in micronaire or denier. Fiber fineness determines the minimum yarn linear density or count that is spun from a particular fiber basing on the minimum number of fibers that are required to physically hold a twisted yarn assembly together. Cotton fibers with a micronaire value of 3.7- 4.2 are said to be fine and termed as premium quality while values in the range of 4.3-4.9 are coarse and called base range. Generally, fiber fineness affects the processing performance and the quality of the end product in several ways. In the opening, cleaning, and carding processes, low-micronaire or fine-fiber cottons require slower processing speeds to prevent damage to the fibers. In ring spinning, yarns made from finer fibers result in more fibers per cross section, which in turn produces stronger yarns. Dye absorbency and retention also varies with the maturity/fineness of the fibers where the greater the maturity, the better the dye absorbency and retention (Lawrence., 2003). Fineness is believed to affect the hairiness and evenness of yarns and hence the resulting fabric quality properties like pilling and abrasion resistance (Candanet al., 2000).

Studies have showed a relationship between fiber micronaire, fineness and maturity (Brandrup., 1989 and Montalvo., 2005). Micronaire is related to fibre maturity because during measurement, the rate of airflow depends on the resistance offered by the total surface area of fibers which is related to linear density and fibre cell wall thickness/maturity. According to Heap., (2000), micronaire is among the most important fiber characteristics for international cotton classers and spinners. This is because micronaire is an indication of both fineness (linear density) and maturity (degree of cell-wall development) which are important cotton quality properties. An increase in fiber micronaire implies an increase in fiber diameter thus few fibers will be needed to pack a given yarn. To spinners, a low micronaire value may indicate the presence of immature fibers while high micronaire values may indicate that fibers are coarse and mature (www.Cottoncrc.Org. Csiro). On the contrary, Montalvo., (2005) when studying the relationship between fiber micronaire, fineness and maturity reported that a low micronaire value may also indicate fine fibers with adequate maturity. Fiber maturity refers to the degree of cell wall development/thickening.

Maturity is also a very important parameter which affects the overall process ability of the fibers since mature fibers are known to be stronger which facilitates better processing. Immature fibers on the other hand cause excess waste through breakages, lowers yarn strength, affects yarn appearance through formation of neps and uneven dye penetration due to improper development of the active sites. Fibre immaturity results from a number of factors among which include; poor soils, plant pests and diseases and adverse weather conditions. Mwasiagi et al., (2011) when studying the quality of Kenyan rotor spun yarns reported that the cotton fibers used had a high yellowness value which was an indication of increased fibre immaturity. According to Balasubramanian.,(2011), fiber fineness has the most significant influence on the properties of rotor spun yarns compared to ring spun yarns. This is because it depicts the number of fibers in the yarn cross section. In rotor spinning a great number of fibers per cross section is required in order to withstand the high tensions resulting from high rotor speeds.

2.1.1.5 Fiber trash content/ non-lint content

Trash content refers to the amount of impurities contained in a cotton sample. These impurities result from factors, such as cotton growing environment, planting practice, harvesting methods and ginning procedures. Trash in form of husks, leaves, stalk and seed-coat fragments have a detrimental effect on fiber, yarn and fabric quality. Boykin et al., (2010) reported that during cleaning especially with the saw gin type, fiber quality parameters like fiber length and trash content are significantly affected. With less cleaning, excessive trash remains in fibers causing spinning difficulties and hence affecting yarn quality. However, over-cleaning also affects fiber quality by creating short fibers. These may lead to excessive yarn breakages, more defects, and less spinning efficiency. In addition, the presence of short fiber in cotton increases processing waste, fly generation which can cause deterioration in spinning performance due to increased machine stoppages and hence affecting yarn quality in terms of evenness, hairiness and strength.

In rotor spinning, any fine trash and vegetable matter left in the feed sliver can accumulate in the rotor groove which obstructs the yarn formation process or causes fiber agglomeration at this point. This leads to more yarn defects and end breakages which affect the overall yarn quality. In addition, very fine trash particles in the sliver can also lead to black spots in the yarn which deteriorates the fabric appearance. It is therefore vital for the input sliver to have a very high level of cleanliness. A maximum trash level of 0.1-0.2% is thus recommended for rotor and air jet machines (Lawrence., 2010). Generally, high trash content in raw cotton is undesirable as removing trash is a direct cost to a spinning mill in terms of maintenance and yarn costs (Rogers et al., 2005).

However, trash content is helpful in estimating the net amount of manufactured textile product obtainable from raw cotton. The amount of trash in cotton fibre raw material also aids in adjusting ginning and textile processing machinery for maximum trash removal.

2.1.1.6 Colour grade

Colour is a primary factor used in cotton grading by visual judgment. Cotton colour is described by two parameters: the degree of reflectance (Rd) and yellowness (+b). The reflectance value ranges between 40% which means dark cotton to 85% meaning lighter/brighter cotton while yellowness values range from 4% to 18% where, 18/% indicates an increasing degree of yellow saturation (Rogers et al., 2005). The degree of reflectance shows the brightness and dullness of the sample while yellowness depicts the degree of cotton pigmentation (Raghavendra et al., 2004). Cotton fibers are known to have a creamy white color but this is usually affected by climatic conditions, type of soil, storage conditions, insect secretions and fungi, trash and dust content, Ultra Violet radiation exposure, heat (Raghavendra et al.,2004) and harvesting and ginning operations (Rogers et al., 2005). Porter et al., (1996) reported that the planting date and genotype also significantly affect the fiber’s reflectance (Rd) and yellowness (+b). The results showed that late planting (mid-June) had the most consistent negative effect on both Rd and +b t and thus should be avoided. According to USDA, there are five recognized groups of color which include: white, grey, spotted, tinge, and yellow-stained. The general white color of cotton gives it excellent performance in processes like dyeing but as the color deteriorates the dyeing ability of the fibers decreases (Cook., 2006 and Raghavendra et al., 2004). In addition, (Gamble, 2007) reported that high yellowness values influence the hue and depth of dye shade. Colour is an element of cotton quality and raw stock colour measurements are useful in controlling the colour of manufactured undyed, bleached or dyed yarns and fabrics.

2.1.1.7 Short fiber content

Short fiber content (SFC) is defined as the percentage by weight of cotton fibers equal to or less than 12.7 mm length. Short fiber content like fiber neps usually results from mechanical processing of the cotton lint during harvesting, ginning, opening and cleaning actions (Garner., 2006). Picking and stripping are the two major mechanical methods of cotton harvesting that greatly influence SFC. During picking, immature cotton bolls are either not opened or partly opened, thus contributing to short fibers as the picker cannot pull the cotton fibers from such bolls. Harvesting with strippers results in more immature and weaker fibers besides producing cotton lint with more foreign particles but is preferred because of its high production efficiency. SFC has been found to have a negative effect on the spinning efficiency and yarn quality. With respect to rotor spinning, Lawrence., (2003) stated that short fibers have a less detrimental impact on rotor yarn strength compared to long fibers due to cyclic aggregation of fibers during yarn formation. However, presence of excess amounts of short fibers in cotton can cause significant problems like excess waste, loss of yarn strength, increased ends-down, and more yarn defects.

2.2 COTTON FIBER CHARACTERISATION

It is a requirement that spinners test the quality properties of the raw material in question prior to processing so that good material is put to use and the low grade material downgraded. According to International Cotton Advisory Committee (ICAC)., (2006) report, cotton testing is crucial to both cotton buyers/sellers and spinners since it helps in assessing the true value of cotton for better pricing by ginners and in making the best use of the fiber quality by spinner. Initially, raw cotton fiber properties were measured using conventional methods namely: Suter-Webb array method (comb sorter), Fibrograph and Peyer AL101 for fiber length, stellometer and Pressley tester for fiber strength, gravimetric method for fiber fineness/micronaire, caustic soda swelling method for maturity, Shirley analyzer for trash content (International Cotton Advisory Committee., 2006, Patwardhan et al., 2009) and color measurement using both a spectrometer CIE-based average color measurement and a color uniformity measurement (Duckett., 1999).

However, studies done by Patwardhan et al., (2009) indicated that the above conventional methods are tedious, time consuming in addition to requiring good expertise for the results to be reproducible and accurate. This led to the advent of testing technologies, namely: High Volume Instrument (HVI) in the late 1960s (Ramey et al., 1999) and Advanced Fiber Information System (AFIS) in the 1980s (Shofner et al., 1988). These instruments are fully automated thus produce less operational errors and can test a number of parameters within a short time. However, AFIS Instruments have been found to provide the spinners with both average fiber values and distributions but are incapable of measuring fiber strength which is a very important factor for yarn tenacity (Mustafa et al., 2007). Limited research is thus available relating to the use of AFIS tests in estimating the relationship between fiber and yarn properties probably due to the above mentioned reason. Zhu and Ethridge., (1997) used AFIS test results to predict yarn hairiness for both rotor and ring machines. Chanselma et al., (1997) used the results to predict yarn evenness and imperfections and Mustafa et al., (2007) to predict cotton ring yarn properties using Linear Regression Models.

The United States Department of Agriculture (USDA) thus highly recommends and has made the use of an HVI instrument shown in Figure 2.1 in quality testing of cotton fibers mandatory (Patwardhan et al, 2009). This has been attributed to the following advantages: (i) HVI measuring system can determine a particle count of the cotton trash that is directly related to textile processing waste, (ii) it determines micronaire, a factor that is correlated with cleaning efficiency, neppiness, yarn strength, uniformity and dyeing of fibers, yarns, and fabrics, (iii) it provides a reproducible and economical procedure to measure length and length uniformity of fibers, (iv) it can rapidly and objectively determine the color of cotton that is an important factor in determining the cotton end use and (v) it also determines various stress-strain parameters that are useful for research and for relating fiber characteristics to processing performance and quality of end products (American Socity for Testing and Materials (ASTM)., 2005).

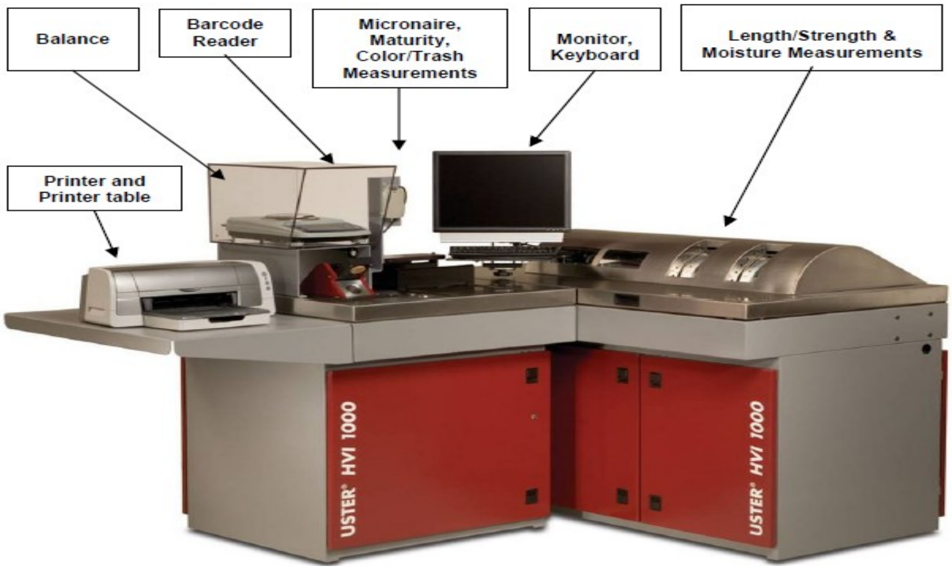


Figure 2.1: HVI Instrument (Uster Technologies).

The HVI instrument employs the use of a programmable microprocessor system with a memory for controlling internal operations and performing the required calibration, calculation and data presentation while measuring the fiber properties. According to the user guide report released by International Textile Manufacturers Federation, ITMF (2001), Standard Test Methods for Measurement of Physical properties of cotton fibers designated as ASTM D 5867-2005 is recommended when measuring these quality properties. Before doing any test, the machine must be calibrated for the specific parameters to be tested at relative humidity (RH) of 65% ± 2 and temperature of 21^0C ± 2^0C using the principles given in Table 2.1. Several works relating fiber and yarn properties using this machine have thus been published (Farooq et al., 2012, Hanen et al., 2015, Khalilur et al., 2015, Muhammad et al., 20

Table 2.1: Cotton properties and HVI testing procedures

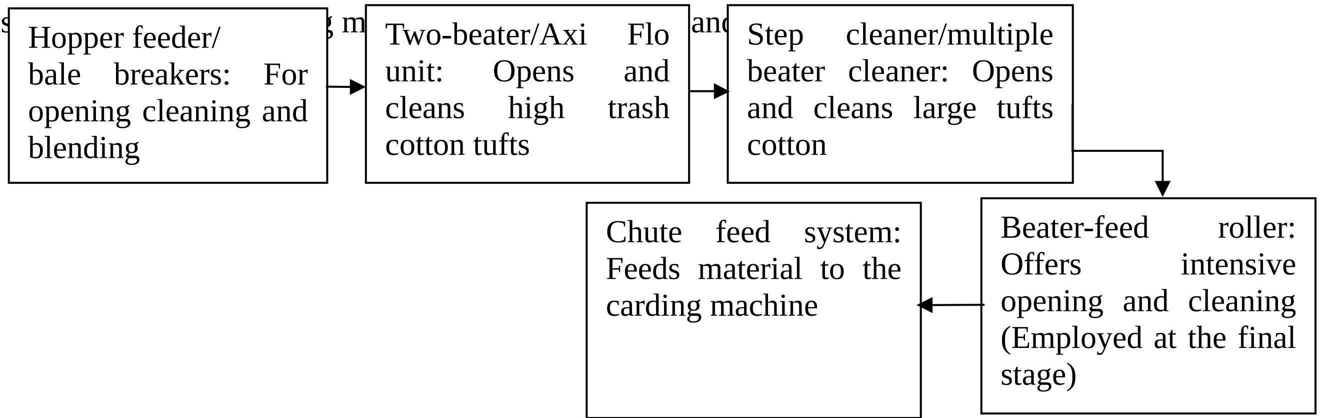
Fibre property	**Testing method**
Fiber fineness	Measured by relating airflow resistance to the specific surface of fibers
Fiber maturity	Calculated using an algorithm based on several HVI measurements
Upper Half mean length (mm)	Measured optically using a Fibrograph. A tapered beard of fibers is automatically prepared, brushed and then tested.
Uniformity Index (%)	
Short fibre Index (%)	
Strength (g/Tex)	Uses the same beard of fibers used for length measurements and is measured physically by clamping a fibre bundle between 2 pairs of clamps spaced at 1/8inches. These pull away at a constant speed until the fibre bundle breaks
Elongation (%)	
Reflectance (%)	Measured optically different colour filters, converted to USDA upland or Pima colour grades or regional customized colour chart
Yellowness	
Trash area (%)	Measured optically by using a digital camera and converted to USDA trash grades or customized regional trash standards
Trash count	

2.3 COTTON FIBER PROCESSING

In the conversion of baled cotton into finished yarn, the primary purpose of the preparatory processes is to open, clean and parallelize the fibers in preparation for spinning. These processes convert a three-dimensional bale of compressed, entangled and matted fiber mass into an orderly arrangement of fibers in a one-dimensional continuous strand length through a series of processes/stages, namely; Stage I: Fiber opening and cleaning (blow room), Stage II: Fibre disentangling and further cleaning (carding), Stage III: Fiber straightening and parallelizing / short fiber removal and additional cleaning (drawing I), Stage IV: Additional fiber straightening, parallelizing and attenuation (drawing II) and Stage V: Spinning (Yarn formation).

2.3.1 Blow room process

The early stages of material preparation generally involve the removal of impurities from the fiber mass by mechanical or chemical means and blending/mixing of that mass to produce a homogeneous feed to carding. Since blending progresses through to the spun yarn, at any cross section, the relative proportions of the different fibers grades or types should remain constant so as to obtain consistent yarn properties. Several machines are usually placed sequentially in a cleaning line in order to progressively intensify the degree of opening, cleaning and blending of the tufts. The fiber tufts are usually transported from one machine to another by airflow through connected ducting. At the end of the cleaning line, 40% to 50% of impurities are removed and the opened material is m and



Cleaning is a very crucial stage in fiber processing because too much cleaning affects the fibers causing severe breakages in subsequent processes while insufficient cleaning leaves a lot of trash in the material that also affects machine performance and yarn quality (Boykin et al., 2010). In order to achieve optimum rates, a predetermined sequence of opening units with coarse openers positioned in the early stage and finer openers positioned toward the final stage are used. Coarse opening units consist of short or thin fingers, or partially pinned blades while fine openers typically consist of medium to fine saw-tooth wires. Figure 2.2 and Figure 2.3 illustrate the blow room sequential machine arrangement.

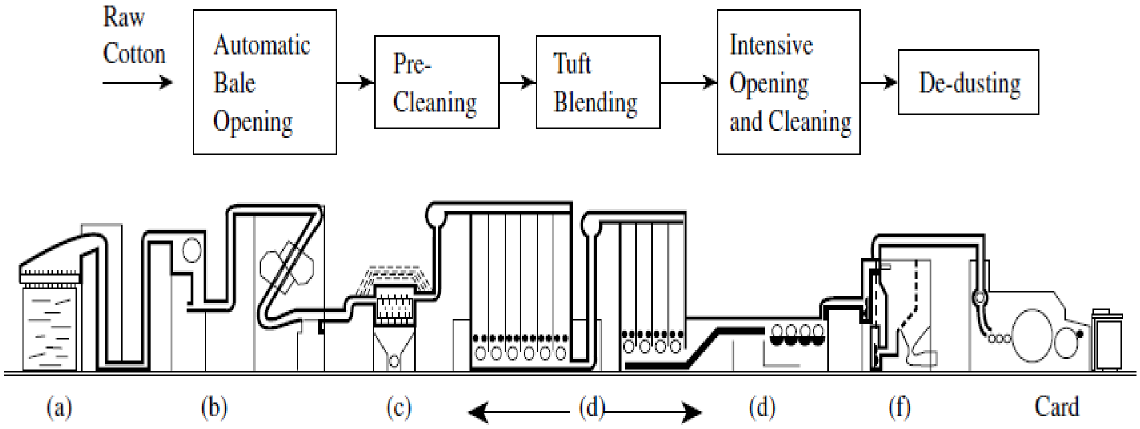


Figure 2.2: Blow room sequential machine arrangement for cotton fiber processing (Courtesy of Trutzschler GmbH).

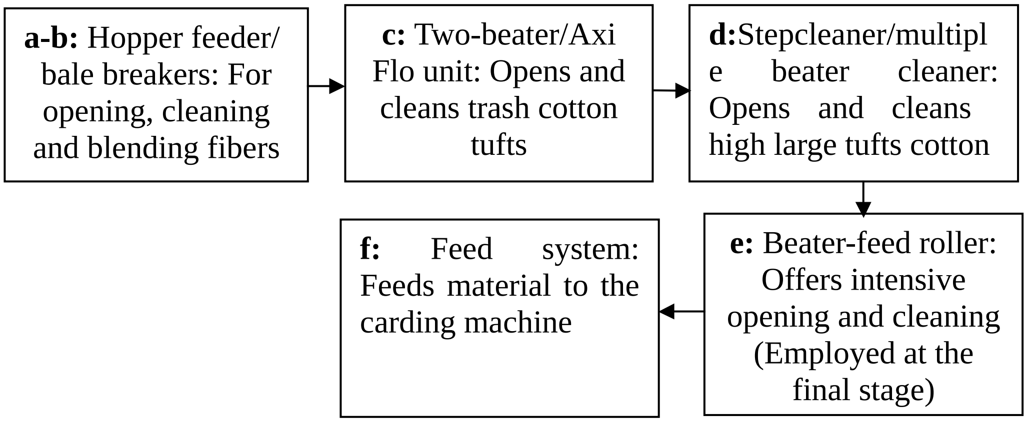


Figure 2.3: Flow chart for blow room sequential machine arrangement.

2.3.2 Carding process

Carding is the action of disentangling fiber tufts into a collection of individual fibers/a filmy web of individual fibers which is then consolidated into a strand length of sliver or slubbing of the required count. This is achieved by working the tufts between closely spaced surfaces clothed with opposing sharp points. Carding is an important stage in processing because unless the fibers are separated into individuals, they neither be spun into smooth and uniform yarns nor can they be blended properly with other fibers. Carding therefore helps in fiber individualization, fiber orientation, cleaning, neps disentanglement, short fiber removal and silver formation. Depending upon the staple length of the fibers to be processed, three types of carding machines are used in the processing of cotton, wool and man-made fibers. These include: Revolving flat card, woolen card and worsted card

Lawrence (2003) stated that in carding technology, trash and dust content, neps and short fiber content resulting from fiber breakage, fiber individualization and level of irregularity of the sliver are the main key performance indicators as regard to the sliver as well as yarn quality. Leifeld F., (1997) added that, with cotton fibers, a low level of neps and trash particles in the sliver is a prerequisite since the impurity content of cotton slivers increases almost linearly with carding production rate. Since trash and neps removal takes place in the licker-in, fixed and revolving flats, and the cylinder, attention should be given to their speeds and settings during operation, especially for the flats, cylinder and doffer. Leifeld F., (1997) studies indicated that over a range of 300 to 600 rpm, high cylinder speeds will reduce trash content by more than 50%, but can also cause more fiber breakage than high taker-in speeds. Van., (1980) added that, increased cylinder speed causes more fiber breakage than increased taker-in speed, a problem reflected in yarn strength. Studies reported that rotor yarn tenacity reduced by 5% with increasing cylinder speeds between 480 rpm and 600 rpm, whereas ring spun yarns showed a 5% reduction for speeds between 260 rpm and 380 rpm and 10% at 600 rpm (Van 1980). In order to achieve a fixed sliver count, an increase in the doffer speed and a decrease in the cylinder-doffer speed ratio can be used. Figure 2.4 illustrates the basic features of a revolving flat card used for cotton production.

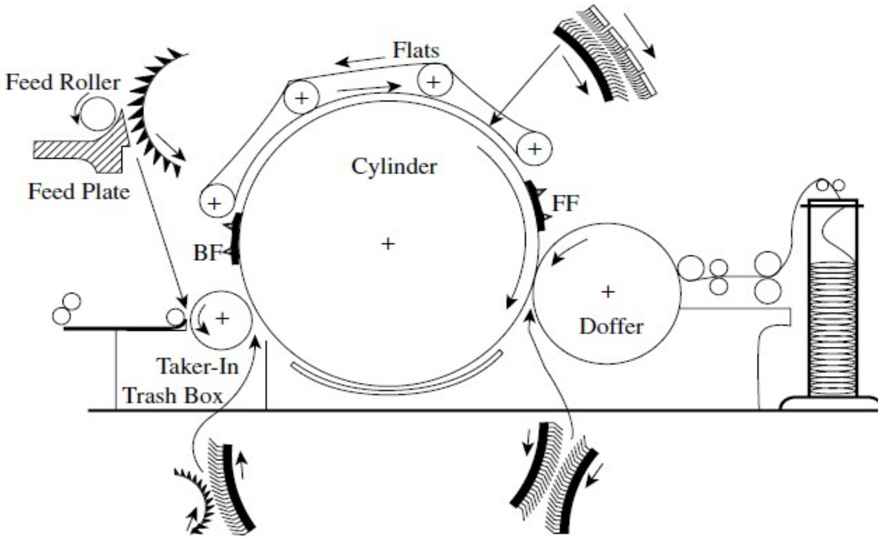


Figure 2.4: Basic features of a revolving flat card (Lawrence 2010).

2.3.3 Drawing process

The third stage in fiber processing involves drawing, combing and roving production, the later being prepared for ring spinning. This stage is very critical since in order to produce yarns of desired counts and with acceptable properties, fibers in a card sliver have to be straightened, aligned, and parallelized so that the sliver count can be appropriately reduced to obtain the required yarn count during spinning. Drawing involves doubling and roller drafting of slivers where several slivers (usually 6 or 8) are placed in parallel, combined and then reduced in diameter by a draft equal in number to the slivers combined as shown in Figure 2.5. This is done so as to produce a sliver that is properly blended with reduced irregularity but uniform count which results into an even and regular yarn.

King., (1991) stated that the use of six or eight doublings depends on fiber length and the size of draft. However, cotton lengths are found to process better from the use of six doublings with a draft of six while eight doublings may be used for longer staples. According to Lord., (2003), a sliver is often passed through two draw frames for better results; the first passage, called ‘breaker drawing’ and the second ‘finisher drawing’ both usually consisting of a 3/3 or 4/4 drafting system. The sliver leaving the drafting rolls passes through a condenser containing a sharp contraction designed to produce lateral fiber migration to improve sliver cohesion. It finally passes through the trumpet which further condenses it and by the action of the take-up rolls, the sliver is pushed through the sliver passage and deposited in the can. A linear speed of 457m/min (500yd/min) is recommended though lately speeds of about 730 m/min (800 yd/min) are possible with modern machines (Lord., 2003).

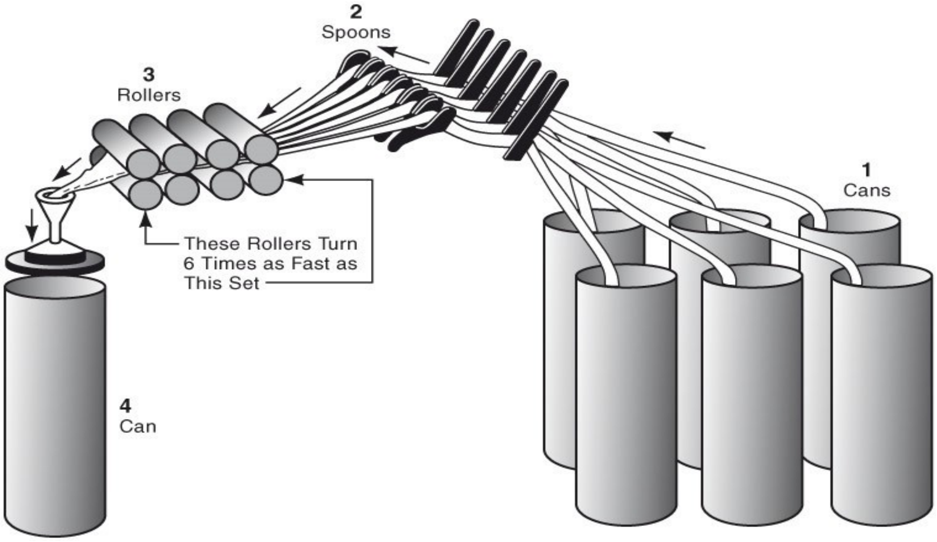


Figure 2.5: Main features of the drawframe (www.cottonguide.org).

2.3.4 Spinning process

Spinning is the final stage in raw material processing. Initially, yarn spinning was purely done by hand but the process later became mechanized after industrial revolution. Spinning refers to the conversion of natural or man-made fibers into yarns by applying twist. There are quite a number of spinning systems available though not all of them are commercially in use. The conventional ring spinning method is the most widely used system accounting for an estimated 90% of all spinning machines on the world market. Besides the ring spinning system, other systems include; Open-End spinning systems (rotor spinning, friction spinning and vortex spinning), Siro, electrostatic, self - twist, wrap and twistless spinning systems all popularly termed as unconventional spinning processes. Among these, rotor spinning has the largest market share but due to techno-economic considerations, it is restricted to production of coarse and medium yarn counts.

Further research into high production technologies revealed that the air jet/vortex system showed some commercial success because of its technological superiority to conventional systems with a finer yarn count range of 7.5 tex to 12 tex. Friction spinning, on the other hand, produced yarns of more acceptable quality used for technical fabrics and filters due to their pliability imparted by real twist. The ring spinning system had therefore, remained unchallenged since its introduction in 1832 by John Thorp till the late 1960s when other spinning systems were invented. This system gave the most effective application of continuous drafting, twisting and winding, flexibility in spinning a range of fiber types, capability of spinning finer count yarns and very importantly, production of yarns with good tensile properties. However, due to its low production speeds and production of irregular and hairy yarns, spinners sought technologies with greater productivities but without change in yarn desirable properties. This led to the invention of Rotor Open-End spinning techniques which created great interest all over the world since yarn counts could be spun with suitable properties. Rotor spinning machines spin a range of fibers like cotton, cotton waste, cotton blends, polyester and polyacrylonitrile fibers. Rotor spinning has several advantages over ring spinning, such as increased production rates which is about 5-8 times that of ring spinning, separation of twisting and winding operations, possibilities of full automation of yarn spinning due to elimination of roving processes, limited labor and floor space requirement (Lawrence 2010).

In addition, rotor spun yarns are more uniform in appearance and in linear density, have a better evenness and are more extensible, fuller and less hairy. However, the yarns are not as strong as ring spun yarns with a maximum tenacity of about 10% –30%, and in some cases even up to 40% lower than that of ring spun yarns. This is due to limited fiber migration and lower packing densities during yarn formation. However, because the yarns were acceptable for some uses and the increased economy of operation, rotor spinning emerged successful despite its difficulties and by the year 1969, it was commercially in use (Lawrence 2010). Rotor spun yarns find application in leisure wear, jeans, beddings, dresses, industrial wear, towels, denims among others.

2.4 ROTOR SPINNING SYSTEM

The volume of rotor spinning production has increased in recent years considering the present trend in the consumption of textile products. This is attributed to its increased production rates compared to other spinning technologies.

2.4.1 The principle of rotor yarn spinning

Unlike in ring spinning, the input material fed into the rotor machine is sliver. For satisfactory and consistent short staple spun yarn properties, Salhotra., (1992) revealed that, the feed sliver should be free from impurities as possible to avoid clogging the rotor machine and blocking the twist flow into the fiber ribbon which affects yarn quality in addition to the maintance costs. Lord (2003) also added that the sliver should be as free from hooks and tangles as possible in order to reduce fiber damage which affects yarn quality. During spinning, the input sliver is fed to the system and by the help of the feed roller and plate, it is pushed to the opening roller with saw tooth or pins that separates it into individual fibers under a high draft ratio. The separated fibers are removed from the opening roller by air suction through the fiber transport channel where they are further drafted and drawn into the rotor. This suction is generated externally to the rotor which is under a partial vacuum. These fibers are then individually deposited onto the internal wall of the rotating rotor and then slide down into the rotor groove, where they accumulate to form a ribbon of fibers. For proper spinning, the fibers must be completely removed from the combing roll and transported to the rotor without being crumpled or disoriented as this effects yarn quality. Figure 2.6 shows the main features of the rotor spinning system

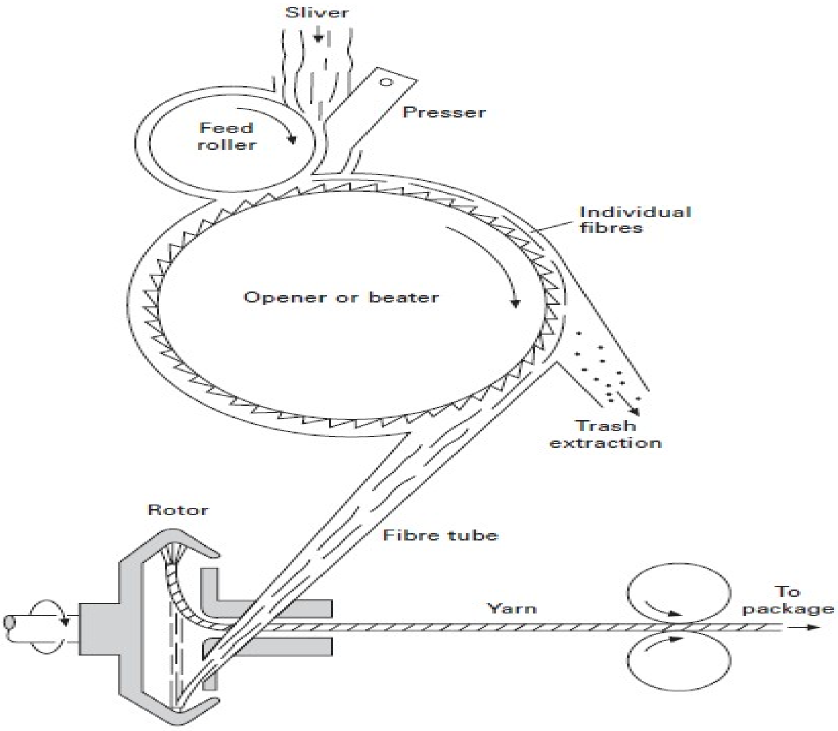


Figure 2.6: Main features of rotor spinning system (W.Schlafhorst AG &Co.).

At the spinning point, the tail end of the yarn already wound on to the package is threaded through the nip of the delivery rollers and into the doffing tube. The partial vacuum in the rotor sucks the tail end of the yarn into the rotor whose rotation develops an air drag and centrifugal forces on the yarn. In so doing, the yarn end is pulled in contact with the collected deposited fiber ribbon as shown in Figure 2.7. At the same time, the tail end is twisted with each revolution of the rotor.

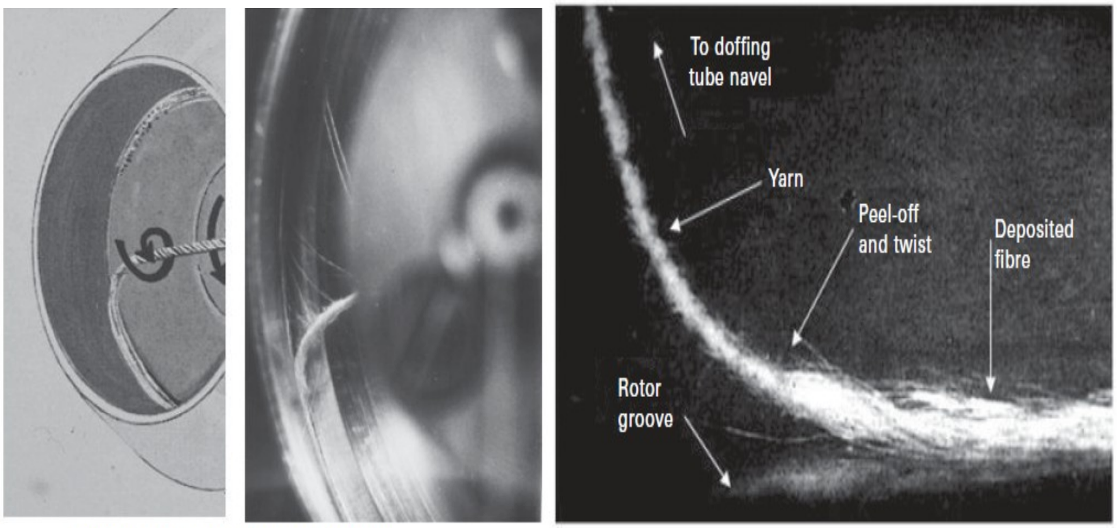


Figure 2.7: Yarn formation in the rotor (W.Schlafhorst AG &Co.).

To insert twist into the fiber ribbon so as to produce the yarn, sufficient twist torque must be present at the peel off point so as to avoid yarn breakages resulting from the high tension induced in yarn tail by centrifugal forces. The rotor thus generates the twist torque as it carries the yarn tail through each revolution. This twist propagates towards the tail end of the yarn and binds the ribbon into the yarn end. Once the yarn tail enters the rotor, the delivery rollers are set in motion to pull it out. The amount of twist inserted in the tail will propagate into each length of ribbon peeled from the groove, thus forming the next length of yarn. After twisting, the output yarn is then wound onto ‘cheese’ or ‘cone’ packages of the required size (Lawrence 2003, Lawrence 2010). The rotor spinning action is continuous because of the conservation of mass flow of the sliver feed rate, buildup of the fiber ribbon to give a required count, rate at which the fiber ribbon is peeled from the groove and twisted to form the yarn as well as the rate at which the formed yarn is pulled from the rotor and wound onto the package. In other words, as the length of the fiber ribbon is removed and twisted to form the yarn, more fibers are collected to replace that length. Lord (2003) reported that to produce an open-end yarn, it is necessary to use a very high draft so that the fiber flow is reduced to just a few fibers in the cross-section. This prevents twist from running back into the fiber supply thereby producing false twist, which would distort the spinning process and hence affecting the resultant yarn.

2.5 ROTOR SPUN YARN PROPERTIES

Different spinning systems due to changes in the spinning geometry produce yarns with different properties. This section of the report therefore looks at the properties of rotor spun yarns of strength, elongation, irregularity/unevenness, imperfections and hairiness properties.

2.5.1 Yarn tensile properties

The strength and elongation of spun yarns governs its process-ability during spinning and post spinning operations like winding, weaving and knitting. Rotor spun yarns are believed to be less strong than the conventional ring spun yarn of the same count. These yarns are believed to have a maximum tenacity of about 10% - 30%, and in some cases even up to 40%, lower than that of ring spun yarns. This is due to the lower levels of fiber migration, less packing fiber density and the presence of non-load-bearing wrappers and belt fibers. However, even though the mean strength of the rotor yarn is generally lower, it has a better strength variation. That’s to say, for a given count, rotor spun yarns are more consistent in strength with a strength coefficient of variation (CV%) of 5.1 to 10.8 compared to 7.22 to 20.95 of the ring spun yarn. This is because rotor-spun yarns being made from sliver and with opening roller drafting, they are not affected by roller drafting waves as are ring spun yarns (Lawrence 2010). Balasubramanian., (2005) however stated that the difference in strength of rotor and ring spun yarns depends upon the type of strength test carried out. It was urged that the difference is more significant in single yarn tests than lea tests because of higher lea ratio in rotor yarns. With regards to elongation, rotor spun yarns are known to be more extensible due to the presence of many hooked, looped and disoriented fibers in the structure. However, the dense, more tangled structure of fibers in the core offers very little freedom of movement hence making rotor yarns less flexible than ring yarns.

The strength of spun yarns is affected by mass per unit length variations in the sliver, roving, fiber length, strength and machine settings used during spinning. In order to obtain sufficient strength in the yarn, constituent individual fibers must wholly or partly transfer their inherent strength from one fiber to another and then to the yarn. However, this cannot be fully achieved from the practical point of view and hence twisting of the whole or part of the fiber strand remains the only way of imparting strength in the final yarn. The failure mechanism of staple twisted yarns with respect to yarn tensile properties can be explained in relation to their nonlinear tensile behavior. When a load is applied to the yarn, tension is induced in each of the fibers through shear forces between the fibers themselves. This tension depends on how the load is distributed over the yarn cross section in relation to the amount of twist level inserted in the yarn, fiber position in the yarn and the spun-in length. Therefore, when a small load is applied onto the yarn, a linear behavior is experienced where increasing inter fiber friction prevents fibers from slipping past one another which prevents breakage. When the load is increased, fibers begin to slip as the helix angle begins to extend there by locking in the fibers and the yarn tightens to take further load. However, beyond this point, any further increase in the load increases with a combination in fiber slippage and the fibers eventually break. Proper selection of machine settings and optimization of twist results into better yarn processing and improvement on yarn strength quality.

2.5.2 Yarn evenness/Uneveness

Yarn evenness refers to the mass per unit length variation within the yarn. Yarn unevenness has influential impacts not only in fabric formation causing frequent yarn breakages and fabric faults but also in dyeing operations leading to uneven dye penetration. Rotor spun yarn evenness is mostly affected by fiber micronaire, longer fiber lengths, sliver count variations (Kaushik et al 1987a), yarn count and high trash content (Ishtiaque et al., 2004). In addition, low opening roller speeds and high rotor speeds have also been found to have detrimental effects on yarn evenness. Low opening speeds lead to insufficient fiber opening which results into fiber overlapping and ultimately increased irregularity and imperfections (Khalilur et al., 2015b-c, Farooq et al., 2012,Kong et al., 1996). Rotor spun yarns are however known to be more even as compared to conventional ring spun yarns. This is attributed to multiple doubling or back doubling of fibers in the rotor groove and ultimate thickness of many thin layers of fibers from which the rotor spun yarn is made (Rameshkumar et al., 2008). Lawrence (2010) added that this evenness is a result of the suppression of the drafting wave due to use of opening rollers and the large packages formed in rotor spinning unlike in ring spinning. The roller drafting employed in ring spinning prohibits the random distribution of fibers in the cross-section causing quasi-periodic variations. This is due to the phenomenon of the drafting wave formation in the drafted ribbon of fibers thus when the ribbon is twisted to form the yarn, the drafting wave adds to the ideal unevenness thereby increasing to the final yarn’s irregularity.

2.5.3 Yarn imperfections

Yarn imperfections result from the variation in the number of fiber ends per unit length of yarn and are in the form of thick places, thin places and neps. Thick places are yarn defects characterized by a diameter greater than that of the adjoining segments and extending 6 mm in length. These mostly result from poor drafting of fibers during yarn formation. Thin places are yarn defects characterized by a segment that is substantially at least 25 % smaller in diameter than the average diameter of the yarn and are normally caused by increase in count. Neps on the other hand are tightly tangled knot-like mass of unorganized fibers formed in the yarn. Imperfections are undesirable since they exhibit a poor fibre and yarn appearance, lowers yarn strength as well as increasing yarn breakages during winding, weaving and knitting operations. Yarns with increased neps besides producing a fabric with many faults also create light specks/spots on dyed or printed fabrics, which reduce the market value of the end product. Neps in cotton fibers mostly result from mechanical processes during processing such as harvesting, ginning, opening, cleaning, carding and combing. In rotor spun yarns, neps are a representation of high number of wrapper fibers and they result from increased rotor speeds, small rotor diameter, reduced rotor groove, increased yarn count, fiber length and fiber fineness as stated by Lawrence and Finikopulos., (1992).

Mangialardi and Meredith., (1990) in the study of the relationship between fineness, maturity and strength to neps and seed-coat fragments revealed that neps were highly correlated with maturity- fineness properties. Similar results were reported by Vander.,

(1999) where micronaire emerged as the most significant fiber property influencing nep levels and nep size. It was thus concluded that the number of neps per grams decreased as micronaire, length uniformity ratio, strength and span length increased. Ganatra et al., 1982) stated that the amount of neps formation in cotton fibers and yarns depends on fiber fineness/linear density, fiber maturity and trash content. Neps in yarns were found to decrease with increase in micronaire and maturity. Lawrence (2010) recommended that yarn irregularity and imperfections can be reduced by ensuring proper fiber individualization at the carding stage, minimization of inter-fiber contact by greater fiber parallelization at the drawing stage, control on the movement of short fibers by ensuring a proper drafting system and minimization on the short fiber content. Rotor yarns are found to have fewer irregularities and imperfections compared to carded ring-spun yarns. This is due to the mechanism of yarn formation which involves cyclic aggregation. This is a doubling effect of the deposited layers accumulating to form the ribbon of fibers within the rotor groove before twist insertion, which in the end eliminates irregularities.

2.5.4 Yarn hairiness

Yarn hairiness refers to the amount or length of fibers protruding on the yarn surface. Yarn hairiness is a desirable property in certain situations where thermal insulation of textiles is required but undesirable in other circumstances. For example, higher hairiness increases the cost of sizing as more size chemicals are consumed to coat/flatten the hairy yarn body. Rotor yarns are known to be less hairy than ring spun yarns due to the mechanism of yarn formation that doesn’t employ a spinning triangle which causes some fibers to remain protruding on the yarn surface during yarn formation. Also, in rotor spinning, fibers migrate in a different way and the mean fiber position and amplitude of migration are lower than those in conventional ring yarns. This causes less inter-fiber friction which prevents the formation of surface hairs. However, according to Barrela et al., (1999) the level of yarn hairiness depends on the number of fibers at the outer layer of the yarn that were not directly adhered to the yarn body.

2.5.5 Yarn bulkness

Rotor spun yarns are also bulkier than other yarns. Lawrence., (2010) concluded that these yarns are about 5% –10% bulkier than ring spun yarns due to greater buckling of fibers in the core. This is because their packing is concentrated nearer to the yarn axis and less towards the outer surface. Rameshkumar et al., (2008) added that this bulk is due to the more number of folded fibers, which provide extra volume and less spinning tension as compared to ring spinning.

2.6 CHARACTERISATION OF COTTON ROTOR SPUN YARNS

It is important for spinners to establish yarn properties prior to fabric manufacture in order to select best yarns for the smooth running of subsequent processes. During characterization, yarns are normally tested for; single yarn strength, skein/Lea/bundle strength, elongation and Uster parameter testing. The Uster parameters tested include; uniformity U%, irregularity CV% and imperfections. In addition, yarns are also tested for actual twist and yarn count so as to suit the intended application.

2.6.1 Tensile properties measurement

When evaluating the mechanical properties of staple yarns, most emphasis is put on the tensile strength and breaking elongation as these properties influence the efficiency of weaving and knitting machines. Low strength and elongation results into yarn breakage during fabric manufacture which affects the final fabric strength (Das et al., 2010). For research purposes; single yarn strength testing is preferred as it gives enough information on intrinsic properties of yarns. Various researchers have therefore tested for single yarn strength when predicting cotton fibers and yarn property relationship using different machines. A Uster Tensorapid strength tester at a gauge length of 500 mm, a pretension of 0.5 cN/tex and a rate of 500 m/min has been used by Farooq et al., (2012), Hanen et al., (2015) and Krupincova et al., (2013) while Khalilur et al., (2015) used a MAGElestretch testing machine. Conventional machines like Pendulum lever, Stellometer have also been used to test for yarn tensile properties. Iftikhar et al., (2003) used the pendulum lever principle machine when studying the influence of cotton fiber fineness and staple length on yarn lea strength. Most of these machines employ an average time-to-break of 20 ± 3 s at a rate of 300 ± 10 mm/min when using a 250 mm gauge length as reported by The International Standards Association test committee for standardizing tests for fibers, yarns, and fabrics (ISO TC) and ASTM D 2256-2002. A pre-tension of 5±0.1cN/tex is considered satisfactory to use as it removes any slack or kinks from most yarns without appreciable stretching as reported in (American Society for Testing and Mateials ASTM D2256., 2002) standard.

2.6.2 Evenness measurement

Yarn evenness is mainly measured by a Uster tester instrument. The Uster tester (UT) employs an electronic parallel plate air capacitor during testing as the measuring device. During testing, a strand of sliver or yarn is introduced into the space between the plates in order to change the capacity of the capacitor, the change being proportional to the weight of material present. The changes in capacity are then detected and translated electronically into meter readings which indicate the percentage coefficient of variation of yarn unevenness (CV **%)** (ASTM D1425)., 1996) standard. According to Lawrence., (2003), during evenness testing, two parameters are usually measured, that is; the irregularity (U %) and the percentage coefficient of variation (CV %). However, when handling large quantities of data, CV % is commonly used to define mass variability and is thus well-suited to the problem of expressing yarn evenness. This is because the irregularity U % is proportional to the intensity of the mass variations around the mean value only and the larger deviations from the mean value are taken into consideration in the calculation of CV% expressed in equation 2.1.

…………………………………………. Equation 2.1

The CV% value is measured at speeds of 100 m/mm, 200m/mm and 400m/min in a time of 1 minute as reported in ASTM D1425 (1996) standard but the later is found satisfactory hence has been used by a number of researchers during their predictions (Farooq et al., 2012, Hanen et al., 2015, Halimi et al., 2009).

2.6.3 Imperfection measurement in Uster tester

Yarn imperfections are defects expressed in terms of thin places, thick places and neps. During measurement, after detecting the CV%, signals from the main unit of the Uster tester are fed to the imperfection indicator which simultaneously measures the neps, thick places and thin places basing on the set sensitivity levels. Standard sensitivity levels for rotor yarn imperfections are: thin places (-50 %), thick places (+50 %) and neps (+280 %).

2.6.4 Yarn twist measurement

Twist refers to the number of turns per unit length of yarn. The optimum value of twist imparted in yarns is determined by fibre length, fineness, strength, coefficient of friction and yarn count being spun. Twist affects production performance and properties of the finished product like yarn strength, fabric luster, feel and weight. Twist is measured by either the direct method or Untwist-retwist method. According to ASTM D1422.,, (1999) standard, the untwist retwist method is preferred when measuring the twist of rotor spun yarns. With this standard, a pretension of 0.5 gf/tex and a gauge length of 250 mm is recommended for satisfactory results. The S.I units for twist are Turns Per Meter (TPM) or Turns Per Inch (TPI) depending on the yarn counting system used.

2.6.5 Yarn count/linear density measurement

Yarn count refers to the mass per unit length or length per unit mass of yarn. During count testing, the skein method of using a wrap reel and a weighing balance is used according to ASTM D1907., (2001)standard. With this method, specified lengths of yarn, usually 100 m or 120 yards are wound on a hand or motor driven wrap reel as reels or skeins. These skeins are removed from the reel and later weighed to obtain their mass on a balance. The linear density of the yarn is then computed from the average mass and length of the skeins obtained.

2.7 RELATIONSHIP BETWEEN COTTON FIBERS AND ROTOR SPUN YARN PROPERTIES

Cotton fiber parameters have been found to have greater impact on final yarn properties since they account for about 50-70% of the total yarn cost (Estur 2008, Lawrence 2003). This has therefore stimulated research into the development of prediction models such as statistical, empirical, mathematical, artificial neural network and adaptive inference-fuzzy models in order to predict the effect of these fiber properties on resulting yarns. However, most of these research works have been done on the conventional ring spun yarns and little research is available relating to the effect of fiber properties on rotor spun yarns. With respect to fiber parameters, tensile properties are always considered very important during yarn prediction since they are believed to have a direct relationship with yarn tensile properties. This is attributed to the strength translation efficiency from fibers to yarns of about 40-65% (Lawrence ., 2010).

Deogratias et al (2010) when predicting rotor spun yarn strength from cotton fibers using Adaptive Neuro Fuzzy Inference system concluded that fiber strength, fiber length, uniformity index and count had a positive impact on yarn strength while micronaire, yellowness and short fiber content had a negative impact. Ethridge et al., (1982) found quite similar results when estimating the functional relationship between fiber properties and the strength of Open-End spun yarns. The results found a linear empirical relationship between rotor yarn strength, fiber strength, fiber length uniformity ratio, micronaire and fiber grayness. For the Count Strength Product (CSP), the micronaire value had the highest significant impact on rotor yarns whereas grayness and yellowness had a slight negative impact.

According to Balasubramanian., (2011), fiber fineness has the most influence on the properties of rotor spun yarns compared to ring spun yarns since it depicts the number of fibers in the yarn cross section. Lawrence., (2010) also added that the use of finer fibers for spinning rotor yarns provides several advantages such as increased spinning limit, more even yarn and lower optimum twist.

Hanen et al., (2015) predicted Open–End yarn properties of strength, elongation and CV % using HVI fiber properties (fibre strength and short fibre content) and yarn processs parameters (twist and count). The results showed that rotor yarn strength and elongation were positively influenced by fiber strength and twist and negatively by count and short fiber index. Yarn unevenness was positively affected by fiber strength and short fiber index and negatively by count. It was concluded that the finer the count, the lower the strength and elongation but the higher the level of yarn unevenness in rotor spun yarns.

Lawrence., (2003) stated that in rotor spinning, increased fiber length leads to increased fiber breakage and the buckling of fibers during deposition onto the collecting surfaces during spinning and hence affecting yarn strength, evenness and imperfections. Kaushik et al., (1987a) added that fiber length and its characteristics have a limited significance in rotor spinning since longer lengths result into increased wrapper fibers and poor fiber orientation which adversely affects yarn strength and evenness.

Barella., (1988) manufactured cotton spun yarns from 34 staple stocks with both ring and rotor spinning processes at two values of yarn linear density at constant twist multiplier. For each spinning system, yarns were tested for hairiness using a Shirley hairiness meter. The results showed that fiber length and its uniformity had the greatest influence on the hairiness for both ring and rotor spun yarns, but fiber fineness had only a slight influence on the yarn hairiness of ring-spun yarns. Zhu and Ethridge., (1997) predicted hairiness for ring and rotor spun yarns and concluded that all HVI parameters have some influence on the hairiness of both ring and rotor spun yarns. Krupincova., (2013) in the study of yarn hairiness verses quality of cotton fibers concluded that the only significant factor affecting yarn hairiness was fiber length because it can change the spinnability of the fiber material.

When explaining the impact of fiber properties on rotor spun yarns, the prepared feed sliver is as equally important since it affects the overall spinning performance and quality of resulting yarns. The quality of feed sliver in terms of cleanliness, uniformity and orientation of fibers has a profound influence on end breaks during spinning and consequently on the resulting rotor yarn properties such as strength and irregularity (Lawrence., 2003). Any residual trash content left in the sliver reaches the rotor groove and accumulates there, leading to short-term yarn irregularity, strength variation and ultimately to end breakages.

Ishtiaque et al., (2004) stated that during fiber deposition, majority of the impurities lands onto the ribbon of fibers and since these particles are heavier, they cannot penetrate the ribbon’s thickness hence are twisted into the yarn structure. Other impurities in the sliver that land at the gap behind the peel-off point enter the rotor groove and as the ribbon of fibers is removed, they build up over time to form a sizeable ring of deposit in the grooved circumference of the rotor. These impurities in the end prevent the required close packing of fibers within the rotor groove. This deteriorates fiber configuration hence causing a constant decrease in yarn tensile properties and an increase in irregularity. In addition, a high level of impurities in the sliver may also lead to wearing of the opening roller, rotor walls and the groove which not only deteriorates yarn quality but also adds to machine maintenance costs (Rogers et al., 2005, Boykin et al., 2010).

2.8 RELATIONSHIP BETWEEN YARN, SPINNING PARAMETERS AND ROTOR SPUN YARN PROPERTIES

The effect of yarn and spinning parameters on rotor spun yarn parameters has been extensively researched by several researchers and the selected discussions are explained in this section. Kong et al., (1996) when studying the effect of fiber opening on the uniformity of count 34 tex (17.36 Ne) and 60 tex (9.84 Ne) rotor spun yarns reported that because rotor spinning machines operate at high speeds and have complex spinning aerodynamics, variations in the operating parameters could influence yarn properties. During the study, it was discovered that in order to minimize material variation in the final results, machine settings should be kept constant for all fibers used in the experiment. From the study, increased rotor speeds increased the CV% and imperfections in both yarn counts. The CV% and number of imperfections decreased as the opening roller speed increased from 5000 rpm-7000rpm but beyond these values, they instead increased. This was attributed to increased fiber separation which improves fiber orientation and alignment but excess speeds lead to end breakages which increases the yarn's CV%.

Khalilur et al., (2015a) studied the effect of blend ratio, blending technique, cylinder and rotor speed (80,000 rpm and 85,000 rpm) to statistically predict the properties of cotton/waste blended Open-End rotor yarn of count 16 Ne using Taguchi OA Design. Results revealed that a good quality rotor spun yarn in terms of yarn evenness, imperfections and strength is as a result of reduced rotor speeds. Higher rotor speeds resulted into increased number of wrapper fibers which disturb the fiber arrangement in the rotor groove leading to unevenness and imperfections. Also, fibers coming out of the combing roller cannot be straightened properly in rotor groove at high speeds because of short contact time before yarn formation which leads to lower yarn strength. Results also indicated that yarn elongation dropped at a drawframe blending ratio 67/33 (recycled/virgin) at higher rotor speeds but increased for a blend ratio of 83/17 probably due to the presence of more short fibers which create disturbance during drafting.

Bechir et al., (2015) studied rotor spun yarn quality and recycling of post-industrial cotton wastes at varying rotor speeds of 65,000 rpm, 70,000 rpm, 80,000 rpm and roller speeds of 7700 rpm, 8200 rpm and 8700 rpm. It was concluded that yarn strength increased with increase in rotor speed due to the increase in the number of wrapper fibers that bind the yarn together. However, excessive speeds led to a decrease in yarn strength due to increase in false twist. Yarn elongation was observed to decrease with increase in rotor speed because higher rotor speed creates a permanent strain in the yarn due to higher spinning tension which in return reduces the elongation. Increase in opening roller speed improved tensile properties and yarn irregularities but high speeds resulted into higher rotor deposition and deterioration of fiber orientation inside the transportation tube which causes higher end breakage and ultimately a reduction in yarn properties. Twist was found to have no significant effect on any properties. Higher rotor speeds also led to increase in yarn irregularity and imperfections.

Ahmed et al., (2014) characterised rotor spun yarns of count 30 tex (19.68 Ne), 35 tex (16.87 Ne) and 40 tex (14.76 Ne) at high rotor speeds. The study concluded that yarn strength increased with increase in rotor speed from 70,000 rpm to 90,000 rpm due to the increase in the number of wrapper fibers which tightened the yarn together but beyond 100,000 rpm, it decreased drastically for fine counts than coarse ones. This is because coarser yarns can withstand high tensions upto a certain limit compared to fine yarns due to a large yarn diameter and more numbers in the cross section. Results for yarn elongation were similar to those obtained by Bechir et al., (2015). However, yarn elongation increased with increase in twist and linear density. Yarn uneveness slightly improved with increase in rotor speed upto 90,000 rpm after which it deteriorated for all counts. For total imperfections, they increased with increase in rotor speeds.

Halimi et al., (2009) did a study on the influence of (yarn count, twist factor, opening roller speed, rotor speed and rotor type) and recovered fibers from cotton waste on imperfections, uniformity and hairiness of rotor spun yarn. Results indicated that yarn hairiness was mainly affected by the rotor type, yarn count, twist factor, opening roller speed and to a lesser extent by rotor speed and percentage of recycled fibers. Low opening roller speed (7000 rpm) and high speeds (88,000 rpm) gave low hairiness, irregularity and imperfection values. The irregularity (CV %) was most significantly affected by rotor type, rotor speed, yarn count and percentage of recovered fibers compared to opening roller speed and twist factor. An increase in any of the fore mentioned factors increased the yarn irregularity. Thin places, thick places and neps were mostly influenced by yarn count and rotor type, yarn count, rotor type and rotor speed and yarn count and rotor speed, respectively. The level of imperfections was found to increase with count values due to a direct relationship with the number of yarns in the cross section.

Farooq et al., (2012) studied the effect of rotor speed, yarn twist and linear density on production and quality characteristics of rotor spun yarn and found out the following: yarn production increased with increase in rotor speed and yarn linear density but decreased with increase in yarn twist. This is because yarn delivery speed is believed to increase by increasing the rotor speed and weight per unit length of the yarn. Yarn strength increased with increase in rotor speed, twist and linear density. High rotor speed increased the number of wrapper fibers per unit length which provide extra binding to the yarn hence increasing its strength. However, higher rotor speeds reduced fiber parallelization in the rotor groove causing disturbance in the fiber arrangement along the yarn axis and hence a reduction in yarn strength. Similar results were obtained by Bechir et al., (2015), Ahmed et al., (2014) and Erdem et al., (2005).

Yarn elongation increased with increase in yarn twist and linear density but decreased with increase in rotor speed. This was because the angle between the fiber spiral position and yarn axis increases due to increase in twist. This improves the springy behavior of fibers hence leading to higher elongation. The number of fibers per cross section was found higher for the yarn with increased linear density. This improved the cohesion force between the fibers and hence giving better elongation. Similar results were obtained by Richard., (2009). CV% increased with increase in rotor speed and decreased with increase in yarn linear density. Imperfections also increased with increase in rotor speed. These results were in agreement with other researchers (Halimi et al., 2009, Khalilur et al., 2015a-c, Bechir et al 2015). Yarn hairiness increased with increase in yarn count and decreased with the increase in twist. Higher twist means more compactness of yarn which improves the quality of yarn with respect to hairiness (Krupincova., 2013).

Ishtiaque et al., (2004) studied the effect of rotor speed (45,000 rpm, 50,000 rpm, 55,000 rpm), roller speed (7500 rpm, 8000 rpm), yarn count 29.5 tex (20.17 Ne), 38.9 tex (15,18 Ne), 59 tex (10.01 Ne) and trash content in draw frame sliver on cotton yarn end breakage in rotor spinning. Results showed that as the count of yarn became finer, the end breakage rate increased drastically. This resulted from the fact that, the finer the count, the lower the number of fibers in the yarn cross section reaching closer to the spinning limit, which causes an increase in end breakage. Increased rotor speeds increased the yarn breakage rate since they impose powerful centrifugal forces on the fibers in the rotor groove. This leads to poor spinning stability and an increase in yarn tension, which in turn causes high yarn breakages.

Muhammad et al., (2002a) studied the effect of multiple Open-End processing variables upon cotton yarn quality of counts 10 Ne, 16 Ne and 20 Ne. It was pointed out that yarn irregularity increased as the count increased. With respect to strength, finer counts gave a less value of lea strength as compared to coarser count yarns. Soliman., (1996) during the study of the influence of combing on open-end rotor spinning parameters, thus advised that incase fine-count rotor yarns are to be spun, combing should be a necessary part of the sliver preparation. From the study, higher opening roller speeds led to a good opening efficiency but at the same time weakened the fibers hence causing yarn breakages and deterioration in yarn strength and elongation. Kong (1996) added that a high opening roller speed results in higher rotor deposition hence deteriorating fiber orientation inside the transport tube which causes higher end breakage. Lawrence (2003) added that, at low opening-roller speeds, the degree of fiber separation will be lowered, and the yarn may become more irregular with increase in the number of thick and thin places. This was because a point reached at which the ratio of the airflow and the opening roller linear velocities was too low to give effective stripping of fibers from the opening roller.

Khalilur et al (2015b) again studied the effect of rotor speed, combing-roll speed and type of recycled waste on rotor yarn quality using Response Surface Methodology. It was concluded that rotor speed of 85000 rpm and combing roll speed of 8500 rpm gave the best result in terms of yarn strength and elongation percentage of 16 Ne rotor spun yarn produced from 100% recycled spinning waste. Ends breakage rate increased drastically at increasing rotor speed and combing roll speed but were minimized by using pneumafil waste in recycled fiber mixing of the blow room.

Khalilur et al., (2015b) did another study on the influence of cleaning intensity, card cylinder speed and opening roller speed on the quality of a rotor spun yarn from 100% recycled cotton waste using Box and Behnken experimental design. The results revealed that imperfections improved with increase in opening roller speed up to a certain limit when cleaning intensity setting at the card was low. But with high cleaning intensity setting, increasing opening roller speed resulted into increasing yarn thick places, neps and thin places. With strength, it was stated that if the feed silver is properly cleaned in the preparatory stages, then high roller speed wouldn’t affect the fibers hence contributing to their strength and vice versa.

In conclusion, several works have been done and cited in this chapter relating cotton fibre properties and spinning parameters on rotor spun yarn properties. However, no similar work has so far been reported studying Bukalasa Pedigree Albar cotton grown from Uganda. In addition more work still needs to be done in the related field especially on the relationship between cotton fibre properties and resulting yarn properties because most of the published works are too old to address the current issues in spinning mills considering the new changes and development in technology.

Furthermore, no comprehensive research study has so far been reported studying the combined effect of both cotton fibre properties, yarn processing parameters and machine speeds on rotor spun yarn quality. This should not be under estimated because in order for the textile manufacture to design a cotton cloth with an optimum combination of properties for a given end use, it is desirable to know how the properties in question are affected by the changes in constituent fibers, yarn properties and machine settings. This study therefore intends to use statistical methods to study the relationship between HVI cotton fibre properties, yarn processing parameters and machine speeds on rotor spun yarn properties. From this, prediction models will be developed and optimal settings for the different parameters used obtained. This will enable the spinner to clearly understand the impact of any given change in the fore mentioned factors on the produced yarns and hence improving the final yarn quality.

Chapter 3 : MATERIALS AND METHODS

3.1 MATERIALS AND METHODS

The materials used in this research work included raw cotton fiber samples and rotor spun yarns while the methods included fiber characterization, yarn spinning and characterization and statistical modelling techniques. Since Uganda grows only one type of cotton, the cotton sample type hence used in this study was Bukalasa Pedigree Albar (BPA).

3.2 CHARACTERISATION OF COTTON FIBERS

Cotton fiber samples were collected from Southern Range Nyanza Limited. This factory spins cotton obtained from different regions of the country. According to ASTM D1422., (1999) standard (Standard Practice for Sampling Cotton Fibers for Testing), a representative of ten bales was sampled. This standard recommends obtaining 100 gms of a cotton subsample from each opposite side of the bale and then combining the two subsamples to form a laboratory sample. However, due to a large number of tests required for the study, 500 gms were obtained from each side of the bale. From this about 10-12 kgs of cotton were obtained in different polythene bags in preparation for testing as shown in Figure 3.1.

The collected samples were conditioned for about 48 hours under standard atmospheric conditions at a relative humidity (RH) of 65% ± 2 and temperature of 21^0C ± 2^0C. The samples were later tested for quality parameters of; Spinning consistence index, fiber length, length uniformity index, short fiber content, fiber strength, elongation, micronaire, maturity, moisture content, trash content, trash area and colour grade (reflectance (Rd) and yellowness (+b)) using a High Volume Instrument (Uster HVI 1000 Series) as per ASTM D5867., (2005) standard.

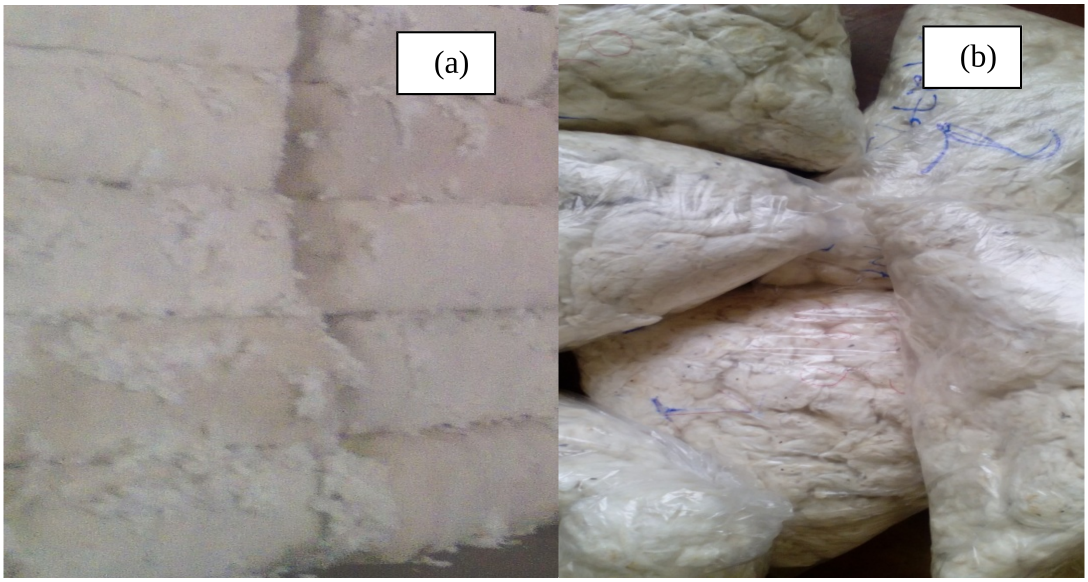


Figure 3.8: (a) Cotton bales and (b) respective samples

Testing was done at Cotton Development Organization’s laboratory in Kampala, Uganda. A total of 108 results were obtained and the averages considered for spinning. A summary of these results is given in section 4.11 and Appendix A. The HVI instrument employs the use of a programmable microprocessor system with a memory that controls the internal operations in so doing performing the required calibration, calculation and data presentation during cotton fiber testing as explained in the given principles.

3.2.1 Fibre length and Length Uniformity measurement

The machine after warming up and becoming electronically stable was calibrated to the required specifications four hours earlier using the available calibration cottons provided by USDA. A weight of 5 gms from a collected sample was prepared into a beard sample of parallel fibers to be fed in the machine for testing. The prepared specimen was then placed into the comb holder of the Fibrograph Plus inserted into the instrument. The instrument automatically brushed the fibers and transported the comb to the measuring head to make the necessary measurements. The bundle was scanned by a light source and the variation in light intensity of the different lengths of fibre was recorded and reproduced in the form of a length-frequency curve called the Fibrogram. From this, the Mean lengths/Upper half-mean length (UHML) and length uniformity were obtained. The measured values were displayed on the visual monitor from which a hard copy of results was printed. For upper half mean length (UHML), values were given to 2 decimal places in mm and length uniformity ratio to the nearest 0.1 %.

3.2.2 Fibre strength and elongation

During fibre strength and elongation testing, the same fibre sample or beard of cotton used when measuring fibre length is used. The samples to be tested were prepared by combing and brushing in order to remove crimp and loose fibers hence straightening them. The combed beard was then clamped in two sets of jaws, spaced 1/8" or 3.2mm apart. The second pair of clamps pulls away from the first pair at a constant speed until the fiber bundle breaks and the amount of force required to break the fibers measured in g/tex. The Elongation was measured directly from the displacement of the jaws during the bundle-breaking process. At the end, fiber bundle strength was given in g/tex and elongation in percentage to one decimal value.

3.2.3 Micronaire measurement

Micronaire was measured using the air flow resistance method to the specific surface of fibers. The machine was calibrated first with two calibration standards, one having a designated lower value of 3.0 and the other a higher value of 5.0 micronaire. Designated values of the laboratory control samples were entered into the machine as a control experiment. After testing each laboratory sample, the internal computer automatically performed the calibration. A sample free from large pieces of non-fibrous materials and knotty balls was prepared from which 10g were weighed to be inserted into the instrument's testing chamber. By closing the lid, the sample was compressed to a fixed volume and the instrument automatically performed the test. The resistance to air flow, using constant pressure compressed air was measured and the pressure drop across the plug of cotton was expressed as micronaire.

Trash content measurement

The instrument was left to warm up for at least 1 hour so as to become electronically stable for calibration. The surface of the specimen to be tested was placed and pressed flat over the colorimeter/trashmeter sample window by the plate to apply pressure to the specimen. The plate was held in position until the instrument displayed that the measurement was complete. Different surface areas of each sample were tested since trash within cotton is not uniformly distributed. With all calculations performed by the instrument, the test values were displayed directly from the visual monitor trash-meter indicating the average percentage trash area to the nearest 0.1 unit and the average number of trash pieces contained in the sample.

3.2.5 Color measurement

The instrument was calibrated by warming it up for a minimum of 4 hours until it became electronically stable. With the help of a key board, Reflectance (Rd) and yellowness (+b) calibration values of each calibration tile were entered. A smooth surface of the laboratory sample that is judged to be a representative for colour as the test specimen was selected. Later, the surface of the specimen to be tested was placed over the sample window and the instrument energized so as to cause a plate to apply pressure to the specimen. The surface of the sample was large enough to completely cover the instrument's viewing window and opaque enough to avoid any light transmission. A thickness of 50 cm or more has been found acceptable thus was used. The specimen was then held in position until the instrument displayed that the measurement was complete. After, other observations were made on the other side of the specimen in order to obtain a measure of the full range of colour. With all calculations being performed by the instrument's internal programmed microprocessor, the average Rd and +b values to the nearest 0.1 were determined by locating the point at which the Rd and +b values intersect on the Nickerson –Hunter cotton colorimeter diagram for cotton variety) A copy of the results were printed and kept for analysis. Table 3.1 gives the fibre properties tested and their coded values.

Table 3.2: Fiber properties and their coded values.

Fiber Property	Coded Value
Micronaire	X_1
Maturity	X_2
Upper Half Mean Length	X_3
Uniformity Index	X_4
Short Fiber Content	X_5
Strength	X_6
Elongation	X_7
Reflectance	X_8
Yellowness	X_9
Trash Content	X_{10}
Trash Area	X_{11}

3.3 COTTON FIBER PROCESSING

The raw cotton material was processed in five stages right from blow room to rotor spinning as shown in Figure 3.2 and Appendix B.

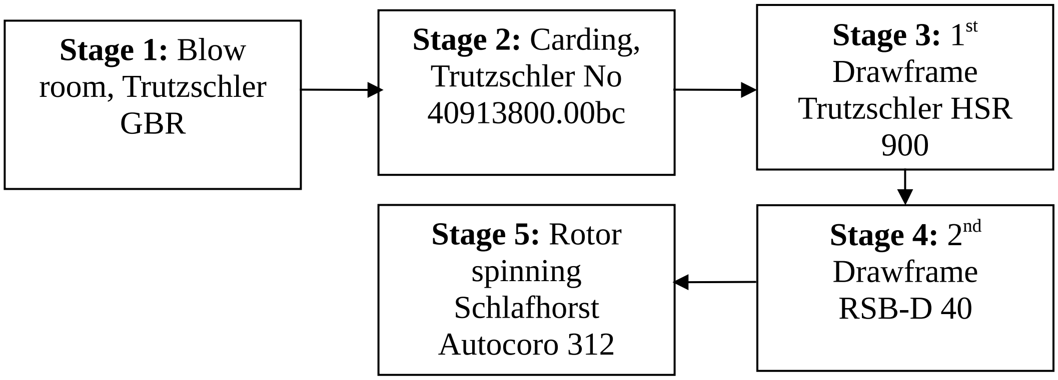


Figure 3.9: Flow chart showing cotton processing from blow room to rotor spinning

3.3.1 Blow room: Material preparation

Ten sampled cotton bales were manually opened and mixed up properly as shown in Figure 3.3. The opened material was then loaded on the bale braker in preparation for processing through the whole sequential blow room machine arrangement illustrated in Figure 3.4. With all machine settings kept constant, the sample was mechanically opened into small tufts, cleaned and blended with the action of rollers, spikes and beaters in the respective machines. The fiber tufts were transported from one machine to another for intensive cleaning by the action of airflow suction through connected ducting. At the end of the cleaning line, the opened material was then fed into the carding machine through the chute feed system.

Figure 3.10: (a) Bale opening and mixing and (b) sample on the breaker machine.

The process flow chart in Figure 3.4 shows the sequential machine arrangement that the raw cotton material underwent during processing.

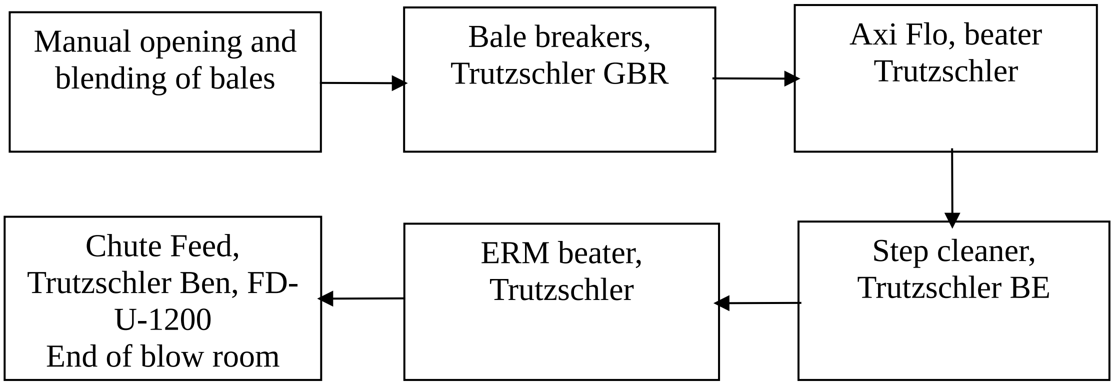


Figure 3.11: Material processing in the blow room sequential machine arrangement

3.3.2 Carding /Sliver formation

At this stage, three fully automated revolving flat cards (Trutzschler, 2009) were used to achieve fiber individualization, fiber orientation, further cleaning, neps disentanglement, short fiber removal and silver formation. Each of these cards had a production rate of

50.8 kg/hr. With all machines settings kept constant as given in Table 3.2, fiber tufts from the blow room were disentangled into a collection of a filmy web of individual fibers which was later consolidated into sliver of the required count 0.115 Ne. Since the input sliver properties affect the qualities of rotor spun yarns, autolevellers were fitted on the carding machines to ensure consistence in count, evenness and regularity of the output sliver. Sliver trash content also being a major problem in rotor spinning, optimal settings as given in literature were used at the licker-in, cylinder and the doffer where cleaning takes place from as shown in Table 3.2.

Table 3.3: Card settings

Parameter	Settings
Sliver count	0.115 Ne
Delivery speed	165 m/min
Draft	91
Starting speed	20 m/min
Flat speed	250 mm/min
Cylinder speed	450 mm/min
Licker-in speed	1200 mm/min
Target pressure	170 Pa
Can changing speed	30 m/min
Can filling quantity	7500 m

3.3.3 Drawing/ Fiber blending and straightening

The sample material was passed through two drawing passages for better results of blending, alignment and straightening**.** During the first passage or braker frame, an automatic Trutzschler HSR 900 drawing machine with a 4/3 drafting roller arrangement was used. At constant machine settings, six big sliver cans were placed in parallel, combined and then doubled into a single sliver using a draft of six. This was done in order to produce one sliver of a similar count with better blending and reduced irregularity. A speed of 400 m/min was used to produce a sliver count of 0.115 Ne to be fed to the 2nd finisher draw frame. About 30 small white sliver cans giving 2000 m were produced as shown in Figure 3.5.

Figure 3.12: First drawing passage where six doublings were done.

At the finisher draw frame, an automatic Rieter RSB-D 40, 2010 model drawing machine fitted with autolevellers was used to achieve the final alignment and straightening of the sliver. By keeping the machine settings for the entire processed sample constant, eight small white cans from the braker frame were combined which gave a sliver of 8 doublings. At a speed of 500 m/min, a sliver count of 0.115 Ne was produced to be fed in the rotor machine for yarn spinning. Ten small pink sliver cans were produced as shown in Figure 3.6. Both draw frame settings used during sample processing are given in Table 3.2.

Figure 3.13: Finisher draw frame processing sliver in pink cans for rotor spinning

Table 3.4: Draw frame settings

Parameter	Settings
Sliver count target	0.115 Ne
Delivery speed	360 m/min
Total draft	5.65
Doubling	6 and 8
Distance between back and middle roller	10 mm
Distance between front and middle roller	4 mm
Can filling quantity	2000 m and 3000 m

3.3.4 Rotor spinning

Yarns were spun at varying values of count, twist, opening roller speed and rotor speed using an automatic rotor spinning machine for which the specifications and settings are given in Table 3.4. To clearly investigate the relation between spinning parameters and spun yarns, Design of Experiments (DOE) was employed. Here Taguchi experimental Design according to Khalilur et al., (2015a) was used to design the experimental runs that were used during yarn production. Appendix C gives the main feaures of the Schlafhorst rotor machine used during yarn formation.

Table 3.5: Rotor spinning specifications and machine settings

Parameter	Settings
Rotor machine	Schlafhorst Autocoro 312
Rotor type	Hybrid G.333/T.333
Rotor diameter	34.5 mm
Input sliver count	0.115 Ne
Yarn counts	15Ne and 24 Ne
Count drafts	130.42 and 208.73
Twist multiplier	4.4 TM, 5.0 TM, 5.5 TM
Opening roller speeds	7000 rpm, 8000 rpm,9000 rpm
Rotor speeds	80,000rp, 90,000 rpm, 100,000 rpm

3.4 DESIGN OF EXPERIMENTS - TAGUCHI EXPERIMENTAL DESIGN

Taguchi Experimental Design is an engineering method for product or process design that focuses on minimizing variation in the output (Taguchi., 1987). The primary goal of the design is to find factor settings that minimize response variation in order to keep the process on target. After determining which factors cause the variation in the response, the next step is to find settings for controllable factors that will reduce the variation. It is thus urged that a product designed with Taguchi designs delivers more consistent performance which is a requirement to most spinners. In addition, this design ensures that all factors are balanced and weighed equally thus during analysis, the effect of one factor does not influence the estimation of the other since each is evaluated independently (Peace., 1993, Crevelinget al., 1995, Park., 1996, Fraleyet al., 2006). Taguchi design was thus used because instead of having to test all possible combinations like in the factorial design, the method tests a fraction or pairs of combinations. With this, it was possible to collect the necessary data to determine which factors most affect product quality with a minimum amount of experimentation hence saving on time and resources. Therefore, 4 factors at 3 levels were studied using the design. The values were chosen upon request by the industry and in comparison to literature. A mixed design of 1 Factor at 2 levels and 3 factors at 3 levels was used, (L18 = 2^1, 3^3). With respect to this design, it was possible to study only two counts at three varying levels of twist, opening roller speed and rotor speed whose coded and real values are given in Table 3.4. A total of 18 experimental runs (L18) given in Table 3.5 and Appendix C were thus used during yarn production.

Table 3.6: Factors levels with coded and real values

	Roller speed (rpm), X_{12}	Rotor speed (rpm), X_{13}	Count (Ne), X_{14}	Twist (TM), X_{15}
Levels and values	7000	80000	15	4.4
	8000	90000	24	5.0
	9000	100000	-	5.5

Table 3.7: Taguchi experimental design Runs

Expt No	X_{12}	X_{13}	X_{14}	X_{15}
1	1	1	1	1
2	2	2	1	1
3	3	3	1	1
4	1	1	1	2
5	2	2	1	2
6	3	3	1	2
7	1	2	1	3
8	2	3	1	3
9	3	1	1	3
10	1	3	2	1
11	2	1	2	1
12	3	2	2	1
13	1	2	2	2
14	2	3	2	2
15	3	1	2	2
16	1	3	2	3
17	2	1	2	3
18	3	2	2	3

A sliver count of 0.115 Ne was therefore fed into the rotor machine from which yarns were spun. Ten cones each having about 1500 m were spun for each experimental run hence giving a total of 180 cones. After spinning, the cones were packed in boxes per experiment and taken to the laboratory in preparation for testing as shown in Figure 3.7. The properties tested were yarn strength, elongation, evenness, thin places, thick places and neps/km.

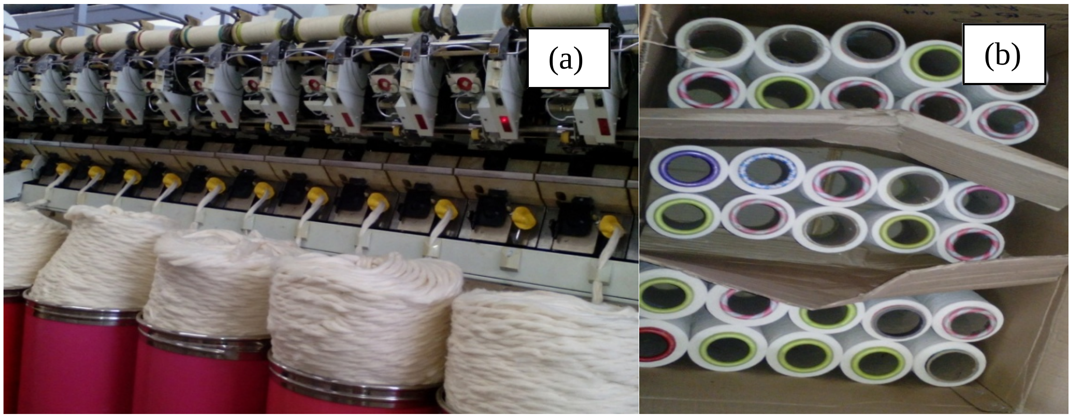


Figure 3.14: Yarn production on a rotor machine and spun yarns in a box.

3.5 CHARACTERIZATION OF ROTOR SPUN YARNS

The yarn samples were conditioned under constant standard atmospheric conditions at a relative humidity (RH) of 65% ± 2 and temperature of 21^0C ± 2^0C for 48 hours and later tested for single yarn strength (Y1), elongation (Y2), unevenness (Y3), thin places/km (Y4), thick places/km (Y5) and neps/km (Y6).

3.5.1 Yarn tensile properties (Strength and Elongation)

Single yarn strength testing was done using a pendulum testing machine given in Figure 3.8. The machine was first calibrated to the right scale using a standard yarn of known strength and elongation. A yarn specimen was then carefully gauged at a gauge length of 500 mm between the upper and lower jaws at a pre tension of 0.5cN/tex. This removes any slack or kinks in the yarn without appreciable stretching according to ASTM D2256 (2002). The machine was started and run until the yarn broke approximately after 20 ± 3 seconds. At this point, the breaking force in grams was read from the curved scale and elongation percentage from the vertical scale with the help of respective scale pointers. The machine was then stopped and reset to the initial gauge position for another test. The experiment was repeated for each ten cones per the 18 experiments. The breaking force was given in grams and in order to calculate the breaking tenacity, the following formula was used;

$$B = \frac{F}{T}$$ ……………………………………………………………………… Equation 3.2

Where; B = Breaking tenacity in g/tex

F = Breaking force in grams

T = Linear density in Tex

Figure 3.15: Single yarn strength and elongation testing machine.

3.5.2 Yarn evenness test

Yarn evenness testing was done using a Uster Evenness Tester 3 machine shown in Figure 3.9 as per ASTMD 1425- 96 standard**.** The machine was calibrated by allowing it to warm for about an hour so as to become electronically stable and after which, it was set to the following testing conditions: Testing speed 400 m/min, testing time 1min, measuring slot 3 for yarn testing and a 25% tension. The yarn package was mounted on a holder and the free end of the specimen passed through the sensing elements and take-up mechanism of the tester. Continuous drawing of the material through the capacitor causes changes in the capacity which follows the variation in the weight per unit length of the strand, the unit length being the length of the capacitor. The changes in capacity are then detected and translated electronically into meter readings which indicate the average irregularity either as percentage mean deviation U% or coefficient of variation unevenness (CV %). Ten cones per experiment were tested and the average CV% was thus used for analysis.

Figure 3.16: Uster tester evenness and imperfections testing machine.

3.5.3 Imperfections test (Thin places/km/ Thick places/km and neps/km)

The same Uster tester 3 given in Figure 3.9 was used. During testing, signals from the main testing unit are fed to the imperfection indicator which simultaneously measured the, thin places, thick places and neps/km at sensitivity values of -50%, +50% and +280% respectively. Ten cones were tested per each experiment and the mean average of results used for analysis.

3.5.4 Yarn twist measurement

Twist was tested using the twist testing machine in Figure 3.10 by using the untwist-retwist method as per ASTM D 1422 (1999) standard. With the counter set at Zero and reading in Turns Per Inch (TPI), the specimen was mounted in between the clamps at a gauge length of 250 mm under a tension of 0.25 ± 0.05 gf/tex. One end of the specimen was secured in the non rotatable clamp while the other in the rotatable clamp that was left open temporarily to allow yarn passage. The yarn was pulled extending through the open clamp until the pointer attached to the non rotatable clamp reached a predetermined position for the required tension and then tightened. At this point, the sensor also lightened which confirmed the clamping accuracy. The rotatable clamp was revolved in the direction that untwisted the specimen hence increasing its length. The rotation was continued until all the original twist was removed. Immediately, twist was re-imparted back into the specimen in the opposite direction so as to attain the original twist. At this point, the specimen is assumed to have its original length and tension. Ten cones were tested for each experiment and the averages were used for analysis. The final twist was then calculated from the following Equation 3.2.

$T = \frac{R}{2L}$... Equation 3.3

Where; T=Twist (TPI),

R = Counter reading,

½= Correction for twist-retwist,

L=Specimen length

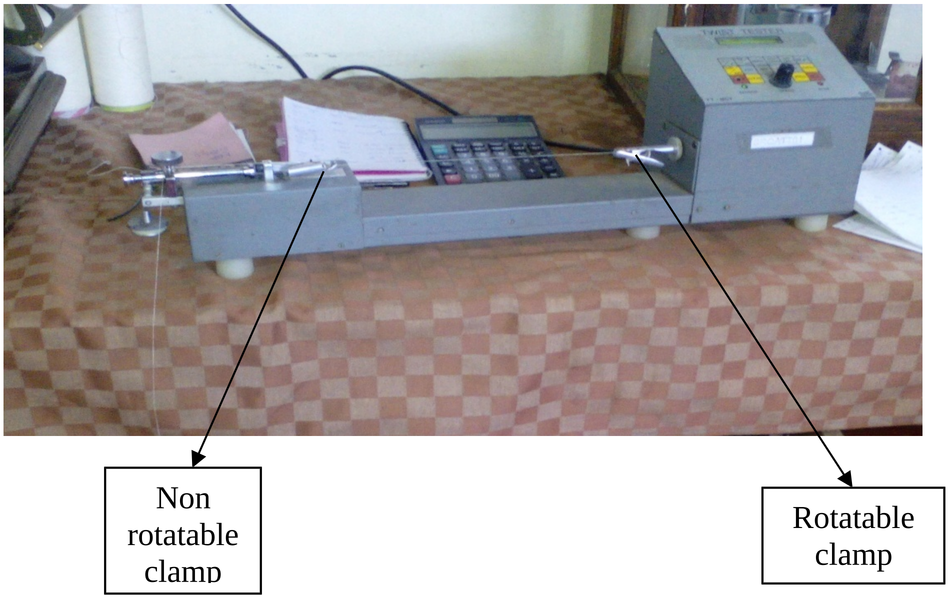


Figure 3.17: Twist measuring equipment.

3.5.5 Yarn count or linear density

This test was carried out using the skein method of wrap wheel and balance system given in Figure 3.11 as per ASTMD1907., (2001) standard. Having adjusted the wrap reel accordingly, yarn samples were passed through the guides and wrapped around the wheel of 120 yards. After achieving the required length of 109.7 m, the bell rang and the machine was stopped. The samples were removed carefully from the reel and weighed. Ten different cones were tested for each experiment after which the weights were used to calculate the average actual count (Ne) using the following formula.

$$\text{Yarn Count (Indirect system)} = \frac{L}{M} \times \frac{B}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Equation 3.4}$$

Where; M = Mass in grams

L = Length of skein as read from the skein gage 109.7 m

A = Constant in indirect yarn numbering system

B = Constant of mass in grams for indirect system

Therefore, Yarn count was calculated using = (120/M) X (453.6/840) = (64.8/ M)

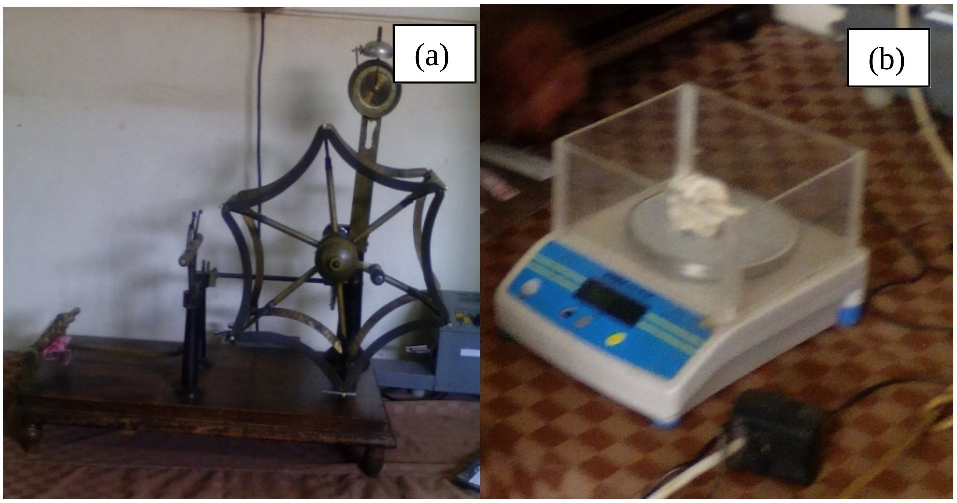


Figure 3.18: Yarn count testing equipment (a) wrap reel and (b) analytical balance.

3.6 DATA PRE-PROCESSING

Data pre-processing is the preparation of data for analysis. It includes data cleaning, normalization or standardization so as to improve its quality before being used for any analysis. This improves on data accuracy and hence minimizing errors. In most cases, the data is normalized/ standardized where it is scaled to fall within a small specified range such as -1.0 to 1.0 or -2 to 2. The data used in this study was thus standardized before developing the regression models. Using Minitab statistical software tool, the mean value of the variables is subtracted from each single variable and then the value obtained is divided by the standard deviation. In addition, the factor variables were also checked for multicolinearity in order to ensure that none is correlated to each other as this affects the coefficient of determination (R-square, R^2), sign of coefficients and P-significance value in the regression models.

3.7 STATISTICAL MODELLING OF RESULTS

Statistical modelling refers to the simplified mathematical way of approximating reality and making predictions from that approximation using the generated data. As mentioned in chapter 1, statistical modelling techniques were the first and still the most widely used models during yarn prediction. This is because they are easy to develop, easy to understand in addition to giving good yarn prediction results. Statistical techniques mostly employ regression analysis to estimate the relationship between a dependent variable and one or more independent variables. The regression results indicate the direction, size and statistical significance of the relationship between predictors and the responses.

During multiple regression analysis, there are number of assumptions that must be considered in order to obtain better regression models. Among these include the following;

i. Multiple linear regression analysis requires that the relationship between the independent and dependent variables be linear. This can be tested using scatter plots

ii. Multiple linear regressions also assumes that there is little or no multicolinearity in the data. Multicolinearity occurs when the independent variables are not independent from each other. Multicolinearity can be checked using the correlation matrix, VIF and Tolerance values. When considering the VIF method, values obtained below 5 signify little or no multicolinearity and the reverse is true for values beyond 5 (Jim., 2013).

Due to a large number of variables involved in this study, linear multiple regression analysis method was used in order to establish a quantitative relationship between fiber properties, spinning parameters and respective yarn properties. The input parameters were fiber properties, yarn parameters and spinning parameters while the responses were resultant yarn properties as illustrated and coded in Figure 3.12.

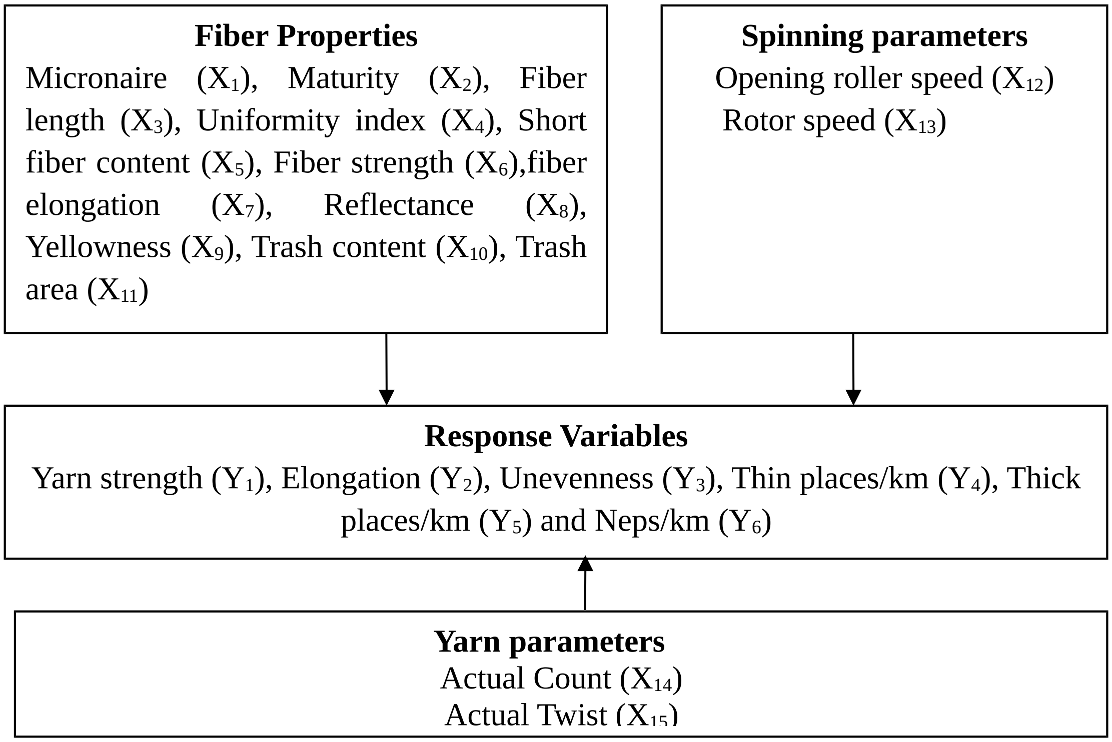


Figure 3.19: Input and responses variables with their coding values.

During statistical analysis, the coefficient of determination or coefficient of multiple regression (R-squared, R^2) and the alpha P-Significance value ($p<0.05$) are used as an indication for a perfect model (Farooq et al., 2012, Hanen et al., 2015). R-squared is a statistical measure of how close the data are to the fitted line and is always in the range of 0% –100%. Zero, 0% indicates that the model explains none of the variability of the response data around its mean while 100% indicates that the model explains all the variability of the response data around its mean. R-square is calculated using a ratio of residual sum of squares to total sum of squares thus it falls within a range of 0-1. Normally, a high R-squared value close to 1 is considered as a perfect fit for the developed model. However, the R-squared value is somehow misleading since it cannot determine whether the coefficient estimates and predictions are biased or not. In addition, it does not also indicate whether a regression model is adequate or not. This is because R-squared value gives the percentage variation explained as if all independent variables in the model affect the dependent variable. This is so since every predictor added to a model increases the R-squared value and never decreases it. Thus, a model with more terms may seem to have a better fit just for the fact that it has more terms. On the contrary, adjusted R-squared value gives the percentage of variation explained by only those independent variables that in reality affect the dependent variable. The adjusted R-squared compares the descriptive power of regression models that include diverse numbers of predictors. This compensates for the addition of variables and only increases if the new term enhances the model above what would be obtained by probability and decreases when a predictor enhances the model less than what is predicted by chance (Jim., 2013).

Therefore, during analysis, Analysis of Variance (ANOVA) results were used to check the fit for the model. Adjusted R-squared value, R-square value, P- statistical significance value ($p<0.05$), F- statistical value, standard error of regression/estimate (S), Variance Inflation Factor ($VIF<5$) and percentage contributions of each predicting factor to the whole model were given and thus used. The F- statistical value determines whether the relation obtained in the model is significance. By default, Minitab statistical software uses a confidence interval of 95% which equates to declaring statistical significance at

$P<0.05$ (Everett et al., 2004). The developed statistical models therefore took the form given in equation 3.4.

$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \cdots b_kX_k$ ……………………………......... Equation 3.5

Where; Y = Dependent/predicted variable (Yarn properties) b_0 = Constant or intercept

b_1, b_2….. b_k = Regression coefficients which indicate the change in the predicted value (Y) due to 1 unit change in the value of X (the predictor)

X_1, $X_{2\ldots\ldots}$ X_k = Independent/predictor variables (fiber properties, yarn parameters and spinning parameters.

Chapter 4 : RESULTS AND DISCUSSIONS

4.1 CHARACTERISATON OF UGANDAN COTTON FIBERS AND YARNS

Cotton fiber samples were collected from Southern Range Nyanza Limited factory in Jinja- Uganda and later tested for physical and mechanical properties using an HVI instrument. The tested sample was then processed and spun into yarn using a rotor spinning machine from the same factory. The resulting yarns were conditioned and tested for quality parameters under standard conditions for textile testing (RH of 65% ± 2 and temperature of 21^0C ± 2^0C). A summary of results for both the cotton fiber and resulting yarn properties is discussed in sections 4.1.1 and 4.1.2, respectively.

4.1.1 Cotton fiber quality characterisation

The quality of cotton fibers is defined in terms of their physical and mechanical parameters due to their significant influence on both spinning and post spinning processes of winding, weaving and knitting. Among these, fiber length, length uniformity index, short fiber content, fiber strength, elongation, micronaire, maturity, trash content, trash area and Colour grade (Reflectance (Rb) and yellowness(+b) were considered in this study. The summary of results for these properties is given in Table 4.1. The mean values of results were compared to those obtained in literature by Farooq et al., (2012) and Uster internationally accepted standards.

Table 4.8: Raw cotton fiber properties

Fiber Property	Coded Value	Min value	Max value	Mean value	CV % value	Literature value (Farooq et al., 2012)	Uster standard
Micronaire	X_1	3.87	5.46	4.3	5.88	4.7	50%
Maturity	X_2	0.85	0.88	0.86	0.86	0.9	50%
Upper Half Mean Length	X_3	27.43	30.17	28.54	2.45	28.04	50%
Uniformity Index	X_4	80.3	85.3	83	1.28	83.3	50%
Short Fiber Content	X_5	4.9	9.3	6.7	12.75	8.3	50%
Strength	X_6	26.7	31.7	28.6	3.64	30.5	50%
Elongation	X_7	6.1	7.8	7	5.49	-	25%
Reflectance	X_8	71	76.5	74.6	1.72	74.7	50%
Yellowness	X_9	10.5	11.5	10.91	2.06	8.9	50%
Trash Content	X_{10}	12	43	26	22.69	33	50%
Trash Area	X11	0.15	0.99	0.45	40.9	-	50%

Table 4.1 shows that the mean values for the cotton sample used in this research are almost similar to those obtained by Farooq et al., (2012). The small variation in results may be attributed to the fact that cotton being a natural fibre, its properties vary from fiber to fiber, season to season, and bale to bale due to changes in climatic conditions, soil type, growing regions, harvesting and ginning methods as reported by Iftikhar et al., (2003). In comparison to the Uster standards, the Uster level for the studied cotton was at 50% for almost all properties except elongation at 25%. This therefore meant that the cotton used in the study was of average quality.

In rotor spinning, the most influential fiber properties towards yarn quality are micronaire, fiber length and its characteristics, strength and trash content (Balasubramanian., 2011). High trash content and trash area in the raw material is very detrimental in rotor spinning. This is because a lot of trash in the feed sliver requires more opening and cleaning at the opening point which results into fiber rupture and ultimately a deterioration in yarn strength and evenness. In addition, any fine trash and dust content left in the feed sliver can accumulate in the grooves thus obstructing the yarn formation process and in the end causing warp breakages which affect the overall yarn quality. Boykin et al (2010) reported that during cleaning especially with the saw gin type, fiber quality parameters like fiber length and trash content are significantly affected which may have contributed to a high trash content value in this study. However, with less cleaning, excessive trash remains in fibers causing spinning difficulties and a reduction in yarn quality thus optimum speeds should be selected for better results.

Rotor spinning can work well with short fibers since longer lengths have been found to contribute to formation of wrapper fibers (Kaushik et al, 1987a). However, presence of excess amounts of short fibers in cotton can lead to excess waste, loss of yarn strength, increased ends-down and more yarn defects. The CV% of short fiber content like with trash content might have resulted from mechanical processing of the cotton lint during picking, harvesting, ginning, opening and cleaning actions. Since cotton grown in Uganda is handpicked during harvesting, some cotton bolls may have become wrongly or partly opened, thus contributing to short fibers as the picker cannot properly pull them out. Fiber fineness depicts the number of fibers in the yarn cross section. During rotor spinning, a high number of fibers per cross section (about 100 fibers) are required in order to withstand high tensions induced by the rotor machine. The mean value of 4.3 obtained in this study is in the range of coarse fibers.

4.1.2 Rotor spun yarn quality characterization

Rotor spun yarns were produced at varying values of count, twist, opening roller speed and rotor speed following the Taguchi experimental design. This was done so as to clearly investigate the effect of change in these fore mentioned factors on the resulting yarn properties. The spun yarns were tested for quality parameters of strength, elongation, evenness, thin places/km, thick places/km and neps/km as summarized in Table 4.2.

Table 4.9: Summary of rotor spun yarn properties

Yarn property	Coded value	Count 15Ne			Count 24Ne		
		Min	Max	Mean	Min	Max	Mean
Tensile Strength (g/tex)	Y_1	10.59	12.31	11.29	10.24	11.3	10.79
Elongation (%)	Y_2	4.42	6.49	5.18	3.99	5.5	4.55
Unevenness (CVm %)	Y_3	15.56	16.92	16.14	16.69	17.49	17.03
Thin places (-50%)	Y_4	0	6	3	12	23	16
Thick places (+50%)	Y_5	83	202	121	131	232	187
Neps (+280)	Y_6	65	131	83	70	151	121

From Table 4.2, the yarn results obtained in this study were in range with those obtained by Farooq et al., (2012b) where strength was in the range between 9.5- 13.3 cN/tex, CV % was in the range of 12.8-14.4 % and total imperfections (thin places, thick places and neps) were in the 51-391 range. However, since the yarns were spun using a designed experiment for the intended study, it was a challenge for the results obtained to be compared with the Uster standard values. Theoretically, it can be concluded from Table 4.2 that count 15 Ne exhibited better properties compared to count 24Ne. This may be attributed to the reasons that count 15 Ne being coarser; it can withstand high spinning tensions more during spinning than the finer count. This improves the spinning stability and hence yarn quality due to reduced end breakages (Ishtiaque et al., 2004).

4.2 MODELLING THE RELATIONSHIP BETWEEN COTTON FIBERS, SPINNING PARAMETERS AND RESULTING YARN PROPERTIES

Modelling was done using Minitab 17 statistical software tool and due to a large number of variables involved in the study, linear multiple regression analysis was employed to investigate the relationship between cotton fibre properties, yarn processing parameters and machine speeds on the spun yarns. Models were developed at a 95% confidence interval (CI) and 95% prediction interval (PI) which is a default setting by the software. The data was first standardized and made to fall within a given range of scale so as to improve on its accuracy and hence the reliability of the models.

4.2.1 Modelling yarn Strength

Yarn strength is one of the most important yarn quality parameters since it affects the manufacture and usability of both woven and knitted fabrics. During model development, several runs were done while checking the P-value, F-value, Adjusted R-squared value, standard error of estimate (S) value and variance Inflation Factor (VIF)/multicolinearity test value as shown in Tables 4.3 and 4.4. Predictor variables that had high P and VIF values were removed and hence giving a regression model shown in equation 4.1 with few but significant influencing factors.

Table 4.10: Regression statistics for yarn strength

R-squared	0.8451
Adjusted R-squared	0.8094
Standard error (S)	0.231929
Model P-value	0.000

Table 4.11: Analysis of Variance for yarn strength

Factors	DF	Factor contribution (%)	F-Value	P-Value	VIF-Value
X_{14}	1	77.59	65.13	0	1.44
X_2	1	6.52	14.91	0.002	1.67
X_1	1	0.4	34.56	0	2.24
	3				

Tables 4.3 and 4.4 gives the regression statistics/ANOVA results used during model development. The symbol ‘DF’ in Table 4.4 represents the degrees of freedom for the factors. From Table 4.3, the yarn strength regression model recorded an adjusted R-squared value of 0.8094. This means that 80.94% variation in yarn strength can be explained by the adjusted number of terms in the regression model Equation 4.1. The significant P–Value was 0.000 ($P<0.05$) which indicates that the developed model was significant. The standard error of estimate (S) was small at 0.231929 which means that the observations are closer to the fitted line hence the model is significant. From Table 4.4, all the predictor variables in the model were significant with no multicollinearity since the P and VIF values were below 0.05 and 5, respectively. In addition, the F-statistical values were also higher than the P-values which mean that the model was significant with a good fit and hence may be used to predict rotor spun yarn strength as given in the regression equation 4.1. From Table 4.4, yarn count is seen to have the strongest relationship to yarn strength since it contributes a percentage of 77.59 % to the

entire model. Count was followed by maturity at 6.52 % and finally micronaire at 0.40 %. A regression model given in Equation 4.1 was thus obtained for yarn strength.

$$Y_1 = 11.1239 + 0.5056X_1 - 0.3441X_2 - 0.5622X_{14}$$ …………………… Equation 4.6

Where; Y_1 = Yarn strength, X_1= Micronaire, X_2= Maturity and X_{14} = Yarn count

With reference to Equation 4.1, yarn strength (Y_1) was observed to increase with increase in micronaire (X_1) but reverse results were observed for count (X_{14}) and maturity (X_2). The regression model shows that for each unit increase in micronaire (X_1), yarn strength is expected to increase by a coefficient value of 0.5056 while for count (X_{14}) and maturity (X_2), any unit increase is expected to cause a decrease in yarn strength (Y_1) by a coefficient value of 0.5622 and 0.3441, respectively. Research has it that the first significant raw material parameter controlling the characteristics of a rotor spun yarn is fiber fineness/micronaire since the finer the fibers, the more their number in the yarn cross-section hence the higher the strength (Balasubramanian 2011). Lawrence (2010) added that fine finers increase the spinning limit and lead to production of more even yarns. In this study, yarn strength increased with micronaire probably because micronaire is related to fineness and maturity. Research states that low micronaire values mean that the fibers are fine and immature while high micronaire means that they are coarse and mature. As a result, strength might have increased due to reduced end breakages which might have resulted from improved fiber maturity. In addition, very fine fibers are known to work well with low processing speeds hence if spun with rotor machines, frequent yarn breakages are expected to occur resulting from high spinning tensions due to the fact that rotor machines operate at higher speeds. This will in the end cause reductions in yarn strength. Similar results were observed by Hanen et al (2015) where it was revealed that increase in micronaire means that the fibers are coarse thus will produce thick sliver which results into stronger yarns.

Increase in maturity (X_2) increases yarn strength but excessive maturity leads to increased fiber crimp which is undesirable in rotor spinning. High levels of crimp can hinder proper fiber opening by the opening roller hence affecting the smooth flow of fibers in the transportation tube and deposition in the rotor groove. This causes improper fiber individualization and hence low yarn strength. Increase in count (X_{14}) reduced yarn strength probably due to reduced number of fibers in the yarn cross section. In rotor spinning, unlike ring spinning, increasing count reduces on the number of fibers in the yarn cross section reaching the spinning point during yarn formation. This affects the spinning stability causing yarn breakages and poor fiber orientation which ultimately affects yarn strength. These results were in agreement with Hanen et al., (2015) and Ishtiaque et al., (2004). Research shows that the more the number of fibers in the yarn cross section, the more the strength because all the fibers are assumed to transfer at least 40-50% of their strength to the final yarn (Lawrence., 2010). Balasubramanian., (2011) concluded that fine count yarns have fewer fibers in the yarn cross section thus should be produced from fine and longer fibers. In rotor spinning, a minimum of 100 fibers per yarn cross section is required for better spinning in order to withstand the high tensions resulting from high rotor speeds. It can thus be stated that increased number of fibers in the yarn section coupled with an optimum twist can yield good strength results in rotor spinning.

Since the data fit the model relatively well at an adjusted R-squared value of 0.8094, the developed model thus was used to obtain optimal settings for the contributing factors. This was achieved using the statistical response optimiser in Minitab. To confirm the accuracy of the model, composite desirability ‘d’ was used. This evaluates how the settings optimise the overall set of responses using a range of values from zero to one (0-1), where 1 or values close to 1 represent the ideal case while zero indicates that one or more responses are outside their acceptable limit. Table 4.5 gives results of the predicted strength value, confidence and prediction interval and optimal settings for the prediction variables. The figures in brackets under optimal setting indicate the real values for the data used before it was normalised for analysis.

Table 4.12: Predicted strength, confidence and prediction interval and optimal settings

Goal : Maximizing strength		Variables	Optimal settings
Predicted strength (Y_1)	12.6299g/tex	X_{14}	-1 (14.39)
95% Prediction interval	(11.948, 13.312)	X_2	0.569 (0.85)
95% Confidence interval	(12.168,13.092)	X_1	1.479 (4.22)

The goal in this study was to maximize strength. From Table 4.4, the model predicted a yarn strength value of 12.6299 g/tex (12.3823cN/tex) which lies within the prediction interval (PI) range of (11.948 and 13.312) and a confidence interval (CI) of (12.168 and 13.092). The value obtained in this study is in the range of strength values meant for weaving purposes (9-12 cN/tex for the weft and 12-16 cN/tex for warp yarns). The optimal settings for the predictor variables in Table 4.5 were achieved at a composite desirability of 1 which meant that they may be used to predict rotor spun yarn strength.

4.2.2 Modelling yarn elongation

Yarn elongation is also a very important parameter in textile manufacturing. Yarns with high elongation values can withstand tensile forces impacted on them for a longer period before breakage which facilitate better spinning and post spinning operations. Yarn elongation was predicted using the same predictor variables used in section 4.2.1. A summary of the statistical results is given in Tables 4.6 and 4.7.

Table 4.13: Regression statistics for yarn elongation

R-squared	0.6790
Adjusted R-squared	0.5720
Standard error (S)	0.446607
Model P-value	0.006

Table 4.14: Analysis of Variance for yarn elongation

Factors	DF	Factor contribution (%)	F-value	P-value	VIF-value
X_{14}	1	33.18	12.4	0.004	1.03
X_7	1	14.15	8.24	0.014	1.33
X_5	1	12.3	5.41	0.038	2.75
X_4	1	8.27	2.55	0.137	3.17
	4				

Table 4.6 shows that the adjusted R-squared obtained for the yarn elongation model was 0.5720. This means that 57.20 % variation in yarn elongation could be explained by the adjusted terms in the regression Equation 4.2. The P-significance value of the model was 0.006 which means that the model was significant since ($P<0.05$). The standard error of estimate (S) was small at 0.446607 which means that the observations are closer to the fitted line. From Table 4.7, the F-statistical values and P- values for the factors revealed that the predictor variables were significant and with recommended VIF values below 5 representing no multicollinearity. The percentage contribution of each independent variable to the response showed that yarn count (X_{14}) had the highest influence on yarn elongation, followed by fiber elongation (X_7), short fiber content (X_5) and finally uniformity index (X_4). A regression model given in equation 4.2 was thus obtained for yarn elongation.

………………... Equation 4.7

Where; Y_2 = Yarn elongation, X_4 = Length uniformity index, X_5 = Short fiber content, X_{14} = Yarn count

Equation 4.2 shows that yarn elongation (Y_1) increased with increase in fiber elongation (X_7) and uniformity index ratio (X_4) but decreased with increase in short fiber content(X_5) and count (X_{14}). For each unit increase in fiber elongation (X_7) and uniformity ratio (X_4), yarn elongation is expected to increase by a coefficient value of 0.308 and 0.371 while for short fiber content (X_5) and count (X_{14}), any unit increase is expected to cause a decrease by a coefficient value of 0.422 and 0.399, respectively. Higher length uniformity ratio values hinder fiber slippage during spinning which improves on the yarn elongation. This was in agreement with studies done by (Deogratias et al., 2010).

According to Lawrence (2003) and Lord (2003), length uniformity index (X_4) is an indication of short fiber content (X_5) where the lower the percentage, the more the percentage of short fibers present in the sample. Increase in short fiber content reduced yarn elongation in this study which is in agreement with studies done by Hanen et al., (2015). Short fibers have been found to work well with rotor spinning machines due to reduction on poor fiber orientation and the formation of wrapper fibers resulting from longer lengths during spinning (Kaushik et al 1987a). However, excess amounts of short fibers is also undesirable since it can lead to increased ends-down at the opening stage and hence a deterioration in yarn properties of strength, elongation and uniformity. In addition, short fiber spinning needs higher twist levels to be inserted into the yarn in order to hold it very tightly together which lowers the production rate. Since short fiber content (SFC) results from mechanical processing of the cotton lint during harvesting, ginning, opening and cleaning actions, careful control at these stages should thus be administered so as to keep the (SFC) level minimum.

Yarn elongation decreased with increase in count probably due to the reason explained in section 4.2.1. Increase in yarn count reduces on the number of fibers in the cross section reaching the spinning point. This leads to disturbances in yarn formation hence causing frequent yarn breakages resulting into reduced yarn elongation. Hanen et al (2015) concluded that yarn count was among the most influential factors affecting rotor yarn elongation but in negative manner. Similar results were also obtained by Ishtiaque et al (2004).

The developed model was used to obtain optimal settings for the factor variables used during yarn elongation prediction and are as given in Table 4.8.

Table 4.15: Predicted elongation, confidence and prediction interval and optimal settings

Goal : Maximizing yarn elongation		Variables	Optimal settings
Predicted Elongation (Y_2)	7.30292%	X_{14}	-1 (14.39)
		X_7	1.655 (7.7)
95 % Prediction interval	(5.342, 9.264)	X_5	-1.602 (4.9)
95 % Confidence interval	(5.600, 9.006)	X_4	-2.145 (80.3)

From Table 4.8, the model predicted yarn elongation of 7.30292 % which is within the prediction interval range of (5.342 and 9.264) and a confidence interval range of (5.600 and 9.006). This predicted value is in the recommended range of 6.5 - 8% for better yarn subsequent applications (Lawrence et al., 2003). The optimal settings in Table 4.8 were achieved at a composite desirability of 1, hence could be used to predict yarn elongation.

4.2.3 Modelling yarn evenness

Yarn evenness is affected by quite a number of factors among which include; fiber fineness, variations in sliver count, yarn count and machine parameters (Lawrence 2010, Hanen et al., 2015, Halimi et al., 2009). The evenness statistical model was thus developed using fiber properties, yarn parameters and spinning parameters as the predictors and the results are summarized in Table 4.9 and 4.10.

Table 4.16: Regression statistics for yarn unevenness

R-squared	0.9233 %
Adjusted R-squared	0.8955 %
Standard error (S)	0.181580
Model P-value	0.000

Table 4.17: Analysis of Variance for yarn evenness

Factors	DF	Factor contribution (%)	F-value	P-value	VIF -value
X_{14}	1	69.48	99.69	0.000	1.02
X_8	1	14.95	16.18	0.002	1.09
X_{10}	1	6.27	5.29	0.042	1.07
X_5	1	1.64	3.47	0.089	1.06
	4				

Table 4.9 shows that the achieved adjusted R-square value for the yarn evenness model was 0.8955 and a P-value of 0.000. This means that 89.55 % variation in yarn evenness could be explained by the adjusted terms in the regression Equation 4.3. The standard error of estimate 0.181580 means that the data points were close to the fitting line and hence significant in the model. The predictor variables being significant with no multicollinearity between meant that the model fit the data well as given in Table 4.10.

The same table shows that under factor contribution, yarn count (X_{14}) had the most significant effect on the developed evenness model, followed by reflectance (X_8), trash content (X_{10}) and lastly short fiber content (X_5). The model given in equation 4.3 was hence developed and used to explain the relationship between yarn evenness and the predictor variables.

………. Equation 4.8

Where; Y_3 = Coefficient of mass variation (yarn unevenness), X_5 = short fiber content,
X_8 = reflectance, X_{10} = trash content and X_{14} = yarn count.

From Equation 4.3, yarn mass variation (Y_3) increased with increase in short fiber content (X_5), trash content (X_{10}) and yarn count(X_{14}) but decreased with increase in reflectance (X_8). For each unit increase in short fiber content (X_5), trash content (X_{10}) and count (X_{14}), yarn unevenness (Y_3) is expected to increase by a coefficient value of 0.0855, 0.1056 and 0.4755, respectively. With respect to reflectance (X_8), any unit increase is expected to cause a decrease in yarn mass variation by a coefficient value of 0.1946. Increase in short fibers as explained in section 4.2.2 deteriorates yarn evenness due to increased ends-down at the opening stage. This results into improper fiber straightening through the transportation channel and during deposition on the grooves which ultimately affects the yarn’s uniformity. In rotor spinning, fine trash and dust content can accumulate in the grooves leading to more end breakages and hence an increase on the level of yarn irregularity. Any vegetable matter present in the cotton sliver also gets caught in the rotor groove and obstructs the yarn formation process. This results into increased fiber agglomeration at the collection point which causes a reduction in the overall yarn uniformity according to Lawrence., (2010).

Ishtiaque et al., (2004) stated that during fiber deposition, majority of the impurities lands onto the ribbon of fibers and since these particles cannot penetrate the ribbon’s thickness, they are twisted into the yarn structure and hence deteriorating on the level of evenness. It is therefore vital for the input sliver to have a very high level of cleanliness so as to maintain yarn quality. A maximum trash level of 0.1-0.2% is thus recommended for rotor and air jet machines (Lawrence., 2010 King et al., 1991).

Increase in count as mentioned in the previous sections means that the yarn is finer and hence susceptible of causing yarn irregularity due to poor spinning stability and increment in the number of weak places in the yarn. This result is in agreement with Hanen et al., (2015) and Ishtiaque et al., (2004). Since rotor machines operate at high speeds, its expected that the level of the yarn’s evenness would decrease due to increased end breakages resulting from the weakness of the yarn.

The model having fit the data well at an adjusted R-squared value of 0.8955, it was thus used to obtain the optimal settings for the influencing factors as given in Table 4.11.The values in brackets indicate the real data values used before data was normalized for analysis.

Table 4.18: Predicted mass variation, confidence and prediction interval and optimal settings

Goal: Minimizing yarn mass variation (CV %)	Variables	Optimal settings

Predicted Evenness (Y_3)	15.4984%	X_{14}	-0.983 (14.47)
		X_8	1.408 (75.6)
95% Prediction interval	(14.987, 16.010)	X_{10}	-1.466 (17)
95% Confidence interval	(15.179, 15.818)	X_5	-1.602 (4.9)

Since a high yarn mass variation has detrimental effects on the final yarn quality, the goal on this study was to keep it to minimum levels. The model predicted a yarn mass variation percentage (Y_3) of 15.4984 % which falls within the prediction range of (14.987, 16.010) and confidence interval range of (15.179, 15.818). The optimal setting values obtained in this section were also within the accepted limit since they indicated a composite desirability of 1.This therefore means that the variables could be used to predict the level of yarn mass variation in the spun yarns.

4.2.4 Modelling thin places/km

Thin places are weak places in the yarn and are undesirable since they exhibit a poor yarn appearance, lower strength and increased breakages during spinning and subsequent spinning processes. Thin places are affected by fiber properties, yarn count and twist variation and machine parameters/settings (Halimi et al.2009, Kong et al., 1996, Farooq et al., 2012). Therefore, the predictor variables used to predict thin places/km formed in the rotor yarns were; fiber properties, yarn count and twist and machine parameter settings Table 4.12 and 4.13 give a summary of the statistical results for thin places/km.

Table 4.19: Regression statistics for thin places/km

R-squared	0.9585 %
Adjusted R-squared	0.9396 %
Standard error (S)	1.73635
Model P-value	0.000

Table 4.20: Analysis of Variance for thin places

Factors	DF	Factor contribution (%)	F-value	P-value	VIF-value
X_{14}	1	75.04	198.72	0.000	1.02
X_{13}	1	9.18	8.28	0.004	1.09
X_{12}	1	6.68	11.72	0.006	1.04
X_{10}	1	4.03	12.99	0.015	1.01
X_4	1	0.92	3.16	0.103	1.1
	5				

Tables 4.12 and 4.13 gives the regression statistics results for thin places/km. An adjusted R-squared value of 0.9396 and a P-value of 0.000 ($P<0.05$) were obtained for the model. Table 4.13 shows that the predictor variables were significant without multicolinearity effect due to low P and VIF values. Also the P-value being less than the F-value, it means that the model was significant and fit the data well. Yarn count (X_{14}), was observed to have the greatest influence on the number of thin places/km (Y_4) in the spun yarns. This was followed by rotor speed (X_{13}), roller speed (X_{12}), trash content (X_{10}) and finally length uniformity index (X_4). A regression model given in Equation 4.4 was thus obtained.

$Y_4=9.254-0.805X_4+1.219X_{10}+1.538X_{12}+1.660X_{13}+6.173X_{14}$ .... Equation 4.9

Where; Y_4 = Thin places/km, X_4 = Length Uniformity Index, X_{10} = Trash content,
X_{12} = Roller speed, X_{13} = Rotor speed and X_{14}= Yarn count

Equation 4.4 shows that the number of thin places (Y_4) formed in the yarn increased with increase in trash content (X_{10}), roller speed (X_{12}), rotor speed (X_{13}) and yarn count (X_{14}) but decreased with increase in length uniformity index (X_4). Any unit increase in the fore mentioned factors will cause a significant increase in thin places by the coefficients given in equation 4.4 except for length uniformity index. High trash content values increase thin places/km due to fiber agglomeration into the rotor groove which causes frequent breakages and hence weak places in the resulting yarn. Ishtiaque et al., (2004) found out that any impurities landing at the gap, behind the peel-off point enter the rotor groove and as the ribbon of fibers is removed, they build up over time to form a sizeable ring of deposit in the grooved circumference of the rotor. These in the end prevent the required close packing of fibers within the rotor groove which deteriorates fiber alignment and hence causing a constant decrease in yarn tensile properties and an increase in irregularity and imperfections.

Low opening roller speeds lead to poor fiber opening by the opening roller. This is because a point can be reached at which the ratio of the airflow and the opening roller linear velocities is too low to give effective stripping of fibers from the opening roller. High speeds contribute to better opening and hence proper straightening and individualization of fibers which contributes to a reduction in thin places/km. However, excessive speeds result in higher rotor deposition and deterioration of fiber orientation inside the transportation tube which causes higher end breakage and ultimately a reduction in yarn properties such as strength, evenness and imperfections (Bechir et al., 2015, Khalilur et al., 2015a-c, Ahmed et al., 2014). A roller speed of 7000 rpm obtained in this study for the formation of low thin places/km in the yarn is similar to that obtained by Kong et al., (1996) and Halimi et al., (2009) where it was concluded that the coefficient of variation (CV%) and number of imperfections decreased as the opening roller speed increased from 5000 rpm -7000 rpm but beyond these values, the number instead increased.

The number of thin places/km was also observed to increase with increase in rotor speeds. This may have been attributed to increase on the yarn breakage rate resulting from powerful centrifugal forces imposed on the fibers in the rotor groove. Similar results were obtained by Ahmed et al., (2014), Farooq et al., (2012) and Halimi et al., (2009) where it was concluded that high speeds lead to poor spinning stability and an increase in yarn tension, which in turn leads to formation of thin places in the yarn. Ahmed et al., (2014), Farooq et a.,l (2012 and Halimi et al., (2009) concluded that a good quality rotor spun yarn with reduced imperfections was obtained in the rotor speed ranges of 70,000 rpm- 90,000 rpm.

Increase in yarn count as explained earlier disturbs the yarn formatiom process and hence affecting yarn quality. Since thin places are termed as weak places in the yarns, it’s expected fine yarns gets have more weak or thin places.

The adjusted R^2 being close to 1, means that the model fit the data well thus may be used to predict the value of thin places/km in the rotor spun yarns. The results are given in Table 4.14

Table 4.21: Predicted thin places, confidence and prediction interval and optimal settings

Goal : Minimizing Thin places/km		Variables	Optimal settings
Predicted Thin places	- 4.09365/Km	X_{14}	-1 (14.39)
		X_{13}	-1.1903 (80,000)
		X_{12}	-1.1904 (7000)
95% Prediction interval	(-9.27, 1.08)	X_{10}	-1.466 (17)
95% Confidence interval	(-7.58, -0.61)	X_4	1.963 (85.3)

The model predicted thin places/km as -4.09365/Km which lies within the prediction interval of (-9.27, 1.08) and confidence interval of (-7.58, -0.61). The predicted value in this study might be attributed to the mechanism of cyclic aggregation during yarn formation. Rotor spun yarns generally have a lower level of thin places/km due to a doubling effect of the deposited layers that accumulate to form a ribbon of fibers within the rotor groove before twist insertion and hence ultimately eliminating irregularities. Similarly, the optimal settings in this section where also obtained at a composite desirability of 1 hence the optimal settings obtained may be used to predict the number of thin places/km.

4.2.5 Modelling thick places/km

Thick places are also detrimental to yarn and fabric quality hence should be minimised. The selection criteria for the independent variables used in this section was similar to that used in sections 4.2.1- 4.2.4. The regression statistics and ANOVA results are given in Tables 4.15 and 4.16, respectively.

Table 4.22: Regression statistics for yarn thick places/Km

R-squared	0.8095 %
Adjusted R-squared	0.7656 %
Standard error (S)	22.8881
Model P-value	0.000

Table 4.23: Analysis of Variance for thick places

Factors	DF	Factor contribution (%)	F-value	P-value	VIF-value
X_{14}	1	69.99	47.77	0	1.12
X_{13}	1	10.86	14.33	0.002	1.07
X_2	1	0.11	8.6	0	1.16
	3				

The regression model from Table 4.15 recorded an adjusted R-squared value of 0.7656 and a P-significance value of 0.000 ($P<0.05$). Since the F-values were greater than the P-values, this means that model was significant and thus 76.56 % variation in thick places may be explained by the adjusted terms in the model Equation 4.5. From Table 4.16, the predictor variables were significant with higher F-values but low P and VIF values. Just like in the previous models, yarn count (X_{14}) was observed to have the greatest influence on the number of thick places/km (Y_5) with a percentage contribution of 69.99 %. This was followed by rotor speed (X_{13}) at 10.86 % and finally maturity (X_2) at 0.11 %. This resulted into a regression model Equation 4.5.

$Y_5 = 162.10 - 21.44X_2 + 22.79X_{13} + 41.74X_{14}$ …………………………… Equation 4.10

Where Y_5 = Thick places/km, X_2 = Fiber maturity, X_{13} = Rotor speed and X_{14} = count

From Equation 4.5, it was observed that the number of thick places/km (Y_5) formed in the yarn increased with increase in rotor speed (X_{13}) and yarn count (X_{14}) but decreased with increase fiber maturity (X_2). This means that for a given unit increase in rotor speed (X_{13}) and count (X_{14}), thick places (Y_5) will significantly increase by coefficient values of 22.79 % and 41.74 % respectively. However, with maturity (X_2), any unit increase is expected to cause a decrease on thick places by a value of 21.44 %. Thick places usually result from a group of badly drafted fibers that are twisted together to a form a relatively short length of yarn which is several times that of the yarn diameter. Maturity reduced on the level of thick places in yarns since mature fibers exhibit good strength thus are less likely to break during processing. This minimises the formation of short fibers which may end up being twisted into the yarn and hence forming thick places. Lawrence (2010) thus advices that in order to minimise on the level of irregularity and imperfections, it’s necessary to ensure proper fiber individualisation at the carding stage, proper fiber drafting system especially with short fibers and minimisation on the level of short fiber content.

Thick places were also observed to increase with increase in rotor speed. This may have been attributed to the fact that at very high rotor speeds, fibers cannot be properly opened by the opening roller and straightened in the rotor groove due to short contact time before yarn formation. As a result of improper fiber individualization some fibers will tend to be twisted together hence creating thick places in the yarn. Similar results to those obtained by Khalilur et al., (2015a-c) were observed where rotor speeds in range of 80,000 rpm -85,000 rpm gave good quality yarns. In addition, high rotor speeds demand for a high feed rate in order to maintain the yarn count for a given twist value. This in the end can cause poor fiber opening and individualization and hence leading to formation of thick places in the yarn. The developed regression model was used to determine the variable optimal settings given in Table 4.17. The values in brackets indicate the real data values used before data was normalized for analysis.

Table 4.24: Predicted thick places, confidence and prediction interval and optimal settings

Goal : Minimizing thick places/Km		Variable	Optimal setting
Predicted thick places	68.794/Km	X_{14}	-1 (14.39)
95% PI	(9.0, 128.6)	X_{13}	-1.190 (80,000)
95% CI	(35.2, 102.4)	X_2	1.139 (0.86)

Table 4.17 shows the optimal settings for thick places/Km formed in the spun yarns. With the goal to minimise on the level of thick places formed, the prediction model gave a value of 68.794/Km. At a composite desirability of 1, the optimal settings were; maturity (X_2) at 1.139 rotor speed (X_{13}) at -1.190 and yarn count (X_{14}) at -1. This means that the factor variables can be used to predict the number of thick places formed in the spun yarns.

4.2.6 Modelling neps/km

Neps in rotor spun yarns are a representation of high number of wrapper fibers and they result from increased rotor speeds, small rotor diameter, reduced rotor groove, increased yarn count, fiber length and fiber fineness as stated by Lawrence and Finikopulos (1992). This section discusses the relationship between fiber properties, yarn parameters and spinning parameters on the number of neps/Km formed in yarns. The regression statistics results are given in Tables 4.18 and 4.19.

Table 4.25: Regression statistics for neps/Km

R-squared	0.8212 %
Adjusted R-squared	0.7616 %
Standard error (S)	15.5740
Model P-value	0.000

Table 4.26: Analysis of Variance for Neps

Factors	DF	Factor contribution (%)	F-value	P-value	VIF-value
X_9	1	50.13	16.58	0.002	1.30
X_{15}	1	15.82	10.63	0.007	1.27
X_{13}	1	11.25	9.25	0.010	1.03
X_5	1	4.92	5.73	0.034	1.09
	4				

From Table 4.18, the adjusted R^2 value for the model was 76.16 % (0.7616) and the P-value was 0.000 which is less than the statistical ($P<0.05$). Table 4.19 also shows that all the predictor variables in the model were significant and not correlated to each other since the VIF values were all below 5. The F-statistical values were also higher than the P-values. This means that the regression model was significant and thus 76.16 % variation in neps/Km formed in the yarns may be explained by the adjusted terms in the regression Equation 4.6. Unlike in the previous models, it was observed that yellowness (X_9) had the most significant influence on neps/km (Y_6)at a percentage contribution of 50.13 % to the whole regression model. This was followed by twist (X_{15}), rotor speed

(X_{13}) and lastly short fiber content (X_5). A regression model Equation 4.6 was thus obtained and used to predict the level of neps/km.

.... Equation 4.11

Where; Y_6= Neps/km, X_5 = short fiber content, X_{13} = rotor speed and X_{15} = twist factor

From Equation 4.6, it was observed that the number of neps/km (Y_6) formed in the yarn increased with increase in yellowness (X_9), rotor speed (X_{13}) and yarn twist (X_{15}) but decreased with increase in short fiber content (X_5). This means that for a given unit increase in yellowness, rotor speed and twist, neps in the yarns are expected to increase by coefficient values of 17.96, 12.19 and 14.40 respectively. With respect to short fiber content any unit increase is expected to cause a decrease on the level of neps/km by a coefficient value of 9.74. From Equation 4.6, neps/km reduced with increase in short fiber content (X_5). Similar results were obtained by Lawrence (2003) where increased fiber length was observed to increase fiber breakages and the buckling of fibers during deposition on to the collecting surfaces which affected yarn quality in terms of evenness and regularity. Kaushik et al (1987a) added that increasesd fiber length adversely affected yarn strength and evenness due to the greater incidence of wrapper fibers and poor fiber orientation.

Neps/Km increased with increase in yellowness probably due to the relationship established between fibre maturity and colour. Mwasiagi et al., (2015) when studying the quality of Kenyan cotton rotor spun yarn stated that the cotton fibers used had a high yellowness value possibly due to climatic conditions. It was concluded that the cotton is rain fed throughout the season in uncontrolled proportions thus making the cotton turn yellow before it is actually mature. During processing therefore, these immature fibers are expected to break resulting into entanglements that form neps. Mangialardi & Meredith., (1990) found quite similar results that neps were highly correlated with maturity and fineness properties when studying the relationship between fineness, maturity, strength to neps and seed-Coat Fragments in fibres. Ganatra et al., (1982) stated that the amount of neps formation in cotton fibers and yarns depends on fiber fineness, fiber maturity and trash content. It was observed that neps in the yarns decreased with increase in fibre fineness and maturity.

Several researchers have reported on the influence of rotor speed on neps/km and imperfections as a whole. As stated in section 4.2.4 and 4.2.5, increase in rotor speeds increases on the level of neps formed in the yarns due to increase on the number of wrapper fibers formed on the yarn’s surface. Khalilur et al., (2015) reported that higher rotor speeds result in increased number of wrapper fibers which disturb the fiber arrangement in the rotor groove hence leading to yarn unevenness and imperfections. These wrappers are usually counted as neps by the Uster evenness tester machine as stated by Lawrence., (2010), and Farooq et al., (2012).

The number of neps/km was also observed to increase with increase in twist levels. High twist causes poor twist propagation into the yarn since the fibers making up the yarn loose contact with the twist angle during yarn formation. This results into fibre breakages which are likely to entangle with time forming knots that are termed as neps in yarns. Also, high twist levels lower the production rate during spinning. As a result, fibers stay at the opening stage for a prolonged time which results into fiber injury and thus breakages which may increase on the number of neps in the resulting yarn.

Since the model was significant, it was thus used to obtain the predicted value of neps/km and the variable optimal settings are as given in Table 4.20. The values in the brackets indicate the real data values for the independent variables used before it was normalised.

Table 4.27: Predicted neps, confidence and prediction interval and optimal settings

Goal : Minimizing Neps/Km		Variables	Optimal settings
Predicted Neps	25.5903/Km	X_9	-1.422 (10.6)
		X_{15}	-1.385 (17.62)
95%PI	(-19.1, 70.2)	X_{13}	-1.190 (80,000)
95% CI	(-3.4, 54.6)	X_5	2.293 (9.5)

From Table 4.20, the model predicted neps of 25.5903/Km which falls within the prediction and confidence interval ranges of (-19.1, 70.2) and (-3.4, 54.6), respectively. Since a composite desirability of 1, represents an ideal case for the predicted response, it therefore means that the optimal settings for the predictor variables may be used to predict the number of neps formed in the rotor spun yarn.

Chapter 5 : CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

This research aimed at investigating the relationship between cotton fiber properties, yarn processing parameters and machine speeds on Ugandan cotton rotor spun yarns using statistical techniques. The study was carried out at Southern Range Nyanza Limited (Nytil-Factory) in Jinja-Uganda and it mainly focused on the physical and mechanical properties of fibers and yarns as well as rotor spinning parameters. The main fiber parameters considered included; fiber length, length uniformity index, short fiber content, fiber strength, elongation, micronaire, maturity, trash content, trash area, reflectance (Rd) and yellowness (+b). For yarns properties; strength, elongation, evenness, thin places, thick places and neps/km were considered while yarn count, yarn twist, rotor speed and roller speed were the spinning parameters selected for the study.

Characterization of Ugandan cotton fibers using the HVI instrument revealed that the fibers had mean values of 4.3, 0.86, 28.54 mm, 83 %, 6.7 %, 28.6 g/tex, 7.0 %, 74.6 %, 10.9, 26, 0.46 % for micronaire, maturity, upper half mean length, length uniformity index, short fibre content, strength, elongation, reflectance, yellowness, trash content and trash area, respectively. In comparison to the Uster standards, the cotton fibers used were of an average grade since they were among the 50 % Uster level basing on staple length.

The yarns used in this study where spun following the Taguchi Experimental Design at varying values of count (15 Ne, 24 Ne), twist multiplier (4.4 TM, 5 TM, 5.5 TM), opening roller speed (7000 rpm, 8000 rpm, 9000 rpm) and rotor speed (80,000rpm, 90,000rpm, 100,000 rpm) on a Schlafhorst rotor spinning machine. In terms of characterization, a coarser count 15 Ne exhibited better properties than count 24 Ne under similar spinning conditions. This count gave a mean strength of 11.29 g/tex, elongation of 5.18 %,, evenness (CV%) of 16.14%, thin places of 3/Km, thick places of 121/Km and neps of 83/km compared to 10.79 g/tex, 4.55%, 17.03 %, 16/km, 187/km and 121/km values of count 24, Ne respectively.

From the experimental results, yarn property prediction models were developed using HVI fibre properties, yarn count, yarn twist and machine speeds.

- Yarn strength model was developed using fibre micronaire, fibre maturity and yarn count as the most significant factors. These exhibited a relatively high significance and data fit at an adjusted R-squared value of 0.8094 and a p-value of 0.000.
- Yarn elongation model was developed using fibre length uniformity index, fibre elongation, short fibre content and yarn count as the most significant factors. These exhibited a relatively low significance and data at an adjusted R-squared value of 0.5720 and a p-value of 0.006.
- Yarn evenness model was developed using fibre reflectance, trash content, short fibre content and yarn count as the most significant independent variables. These exhibited a relatively high model significance and data fit at an adjusted R-squared value of 0.8955 and a p-value of 0.000.
- Yarn thin places model was developed using fibre length uniformity index, rotor speed, opening roller speed, trash content and yarn count as the most significant independent variables. These exhibited a high model significance and data fit at an adjusted R-squared value of 0.9396 and a p-value of 0.000.

- Yarn thick places model was developed using fibre maturity, rotor speed and yarn count as the most significant factors These exhibited a relatively high model significance and data fit at an adjusted R-squared value of 0.7656 and a p-value of 0.000.
- Yarn neps model was developed using fibre yellowness, short fibre content, rotor speed and yarn twist as the most significant factors. These exhibited a relatively high model significance and data fit at an adjusted R-squared value of 0.7616 and a p-value of 0.000.

A general conclusion can be made that yarn count had the most significant influence on almost all rotor spun yarn properties. Increase in yarn count negatively affected yarn strength, elongation, evenness, thin places and thick places/Km. With respect to fiber properties, short fiber content, length uniformity index, trash content, maturity, micronaire, fiber elongation, reflectance and yellowness emerged as the factors that had a significant relationship with the rotor spun yarn propeties. Fibre strength, fibre length and trash area were insignifant. For spinning paramaters, increase in yarn twist, rotor speed and opening roller speed negatively affected the yarn properties.

This study thus developed prediction models for rotor spun yarn strength, elongation, evenness, thin places, thick places and neps. Therefore, given fiber properties, the spinner can save time and material by carrying out fewer pre-spinning tests. In addition, using the developed models may aid in the selection of suitable cotton fiber properties and spinning parameters for different yarn properties in order to attain desirable quality levels of the resultant rotor spun yarns.

5.1 RECOMMENDATIONS

The fore mentioned yarn properties in this study are very important since they affect the yarn’s quality and application. From the current work, further research is recommended in the following areas.

- Model validation is needed to determine the efficiency of the proposed models
- Current predictions should be compared with predictions based on different techniques like mathematical, empirical and Neuro network models
- Universality of the models should also be ascertained
- Optimization of specific processes in spinning to improve the performance of the developed models
- More models should be developed using cotton fibers grown for more than one year’s season to establish their performance with the developed models.

5.2 RESEARCH LIMITATIONS

- Statistical modelling requires a lot of trials in order to come up with the most adequate and useful model.
- Statistical models are also specific on conditions under which they are developed hence modifications have to be done on them if they are to be used for another factory.

REFERENCES

Abhijit M., Prabal, K.M., Bijon, S. (2004). Selecting Cotton Bales By Spinning Consistency Index And Micronaire Using Artificial Neural Networks. *Autex Research Journal*, 4,1.

American Society for Testing and Materials (ASTM D1425). (1996). Standard Test Method for Unevenness of Textile Strands Using Capacitance Testing Equipment.

American Society for Testing and Mateials (ASTM D2256). (2002). Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method.

American Society for Testing and Materials (ASTM D1422). (1999). Standard Test Method for Twist in Single spun Yarns by the Untwist-Retwist method.

American Society for Testing and Materials (ASTM D1422). (1999). Standard practice for sampling cotton fibres for testing.

American Society for Testing and Materials (ASTM D1907). (2001). Standard Test Method for Linear Density of Yarn Count (Number) by the Skein Method.

American Standard Testing Method (ASTM). (2005). *International Standard Test Methods For Measurement Of Physical Properties Of Cotton Fibers By High Volume Instruments.*

Anindya, G., Sayed, I., Seenivasan, R., Prithwiraj, M., Asis, P. (2005). Predictive Models For Strength Of Spun Yarns: An Overview. *Autex Research Journal* 5 (1).

Balasubramanian, N. (2005). Merits of Lea CSP and Lea Ratio. *Journal of Textile Association* 94.

Balasubramanian, N. (2011). Rotor spinning-Influence of fibre properties, yarn quality compared to ring spinning preparatory and post spinning.

Baffes, J. (2009). Comparative Analysis Of Organization And Performance Of African Cotton,The Cotton Sector of Uganda.

Barella, A. (1988). The Influence of the Spinning Process, Yarn linear density and Fiber Properties on Hairiness of Ring-spun and Rotor-spun Cotton Yarns. *Journal of Textile Institute* 79 (2): 189–190.

Barrela, A. T. (1999). Belts in open-end yarns: Influence of rotor diameter and statistical distribution. *Textle Research Journal* 6, 389–393.

Boykin, J. C. (2010). Predicting Fibre Quality after Commercial Ginning basing on Fibre Obtained with Laboratory-Scale Gin Standards. *Journal of Coton Science* 14(1): 34-45.

Brandrup, J., Immergut, E.H. (1989). *Polymer Handbook* .

Candan, C. A. (2000). Performance Of Open-End And Ring Spun Yarns in Weft Knitted Fabrics. *Textille Research Journal* 70: 177-181.

Chanselma J.L., Hequet, E. and Frydrych (1997). Relationship Between Afis Fiber Characteristics And Yarn Evenness And Imperfections. In Proceedings Of The Beltwide Cotton Conference. 1:512-516.

Cook G. J. (2006). *Hand Book Of Textile Science* . Abington Hall: Wood Head Publishing Ltd.

Cotton Development Organisation (CDO) and Uganda Investiment Authority. (2011). *Cotton from Uganda.*

Cotton Development Organisation (CDO). (2012). The Cotton Industry in Uganda. Production trends and earnings.2000 www.cdo.org .

Creveling, W. Y. (1995). E*ngineering Methods for Robust Product Design.* Addison-Wesley Publishing Company.

Das, B.R. (2010). Tensile Behavoiur of Spun yarns under Static state. *Journal of engineered fibres and fabrics* 5 (1).

Deogratias, N., Xin H. W. (2010). Prediction of rotor spun strength from cotton fibre properties using Adaptive Neuro fuzzy inference sysytem. *Journal of Fibres and Polymers* 1:97-100.

Duckett K. E. (1999). Color grading of cotton-measurement", Beltwide cotton conference, Orlando.

Erdem, C. A. (2005). Wrapper Fibers in Open-End Rotor-Spun Yarns: Yarn Properties and Wrapper Fibers. *Fibers & Textiles in Eastern Europe* 13 (2): 8-15.

Erol, R., Sagbas, A., 2009). Multiple Response Optimisation of the Staple-Yarn Production Process for Hairiness, Strength and Cost. *Fibres and Textiles in Eastern Europe* 17:40-42.

Estu, G. (2008). Comparative Analysis Of Organization And Performance Of African Cotton Sectors. *Quality And Marketing Of Cotton Lint In Africa*.

Ethridge, M. D. (1982). Estimating Functional Relationship Between Fibre Properties and the Strength of Open-End Spun Yarns'. *Textile Research Journal* 35-44.

Ethridge, M. D. (1996). Prediction of Rotor Spun Cotton Yarn Quality: A Comparison of Neural Network and Regression Algorithms in *Proceedings of the Beltwide Cotton Conference* 2: 1314–1317.

Everitt, S. L. (2004). *A handbook of statistical analysis using SPSS.* London New York Washington, D.C: Chapman & Hall/CRC Press LLC.

Farooq, A. A. A., Hafiz, U.R. (2012). Statistical Modelling for the Effect of Rotor Speed, Yarn Twist and Linear Density on Production and Quality Characteristics of Rotor Spun Yarn. *Research Journal of Engineering and Technology* 31, (1): 119.

Farooq Ahmed Arain, A. T. (2012). Multiple Response Optimization of Rotor Yarn for Strength, Unevenness, Hairiness and Imperfections. . *Journal of Fibers and Polymers.* , 13: 1, 118-122.

Fraley, S. (2006). *Fraley, Stephanie, et al. "Design of experiments via Taguchi methods: orthogonal arrays." The Michigan chemical process dynamic and controls open text book.* USA.

Frydrych,I., (1992). A New Approach for Predicting Strength Properties of Yarns. *Textile Research Journal* 62: 340-348.

Furferi, R. A. (2010). Yarn Strength Prediction: A Parctical Model Based on Artiicial Neural Networks. *Journal of Mechanical Engineering* 10: 1155.

Gamble, G. R. (2007). The Effect of Bale Ageing on Cotton Fiber Chemistry, Processing Performance, and Yarn Quality. *The Journal of Cotton Science* 11: 98–103.

Ganatra, S. R. (1982). Nepping Potential of Cotton Blends, Cotton Technology Research Laboratory Publication. *Indian Council of Agricultural Research* 197.

Garner, W. E. (2006). Fibre Quality and Ginning Performance of Machine Picked and Stripped Cotton, USDA Report and ERS Marketing Research Report. No. 852.

Halimi, M. T., Azzour, B., Ben, H.M., Sakli, F. (2009). Influence of Spinning Parameters and Recovered Fibers from Cotton Waste on the Uniformity and Hairiness of Rotor Spun Yarn. *Journal of Engineered Fibers and Fabrics* 4 (3).

Hanen, G., Adel, G., Tarek, B. (2015). Open-End Yarn Properties Prediction using HVI Fibre Properties and Process Parameters. *Autex Research Journal* 1 1-6.

Heap, S. (2000). The Meaning Of Micronaire. *International Cotton Conference. Bremen, Germany*, 97-113.

Hunter, L. (1988). Prediction of Cotton Processing Performance and Yarn Properties from HVI Test Results. *Melliand Textilberichte* 69: 123-124.

Iftikhar, A., Sheikh, M.N.,Muhammed, T., (2005). Influence of Cotton Fibre Fineness and Staple Length Upon Yarn Lea Strength. *International Journal of Agriculture and Biology* 4: 642-644.

International Cotton Advisory Committee (ICAC). (2006). *Survey of the Fibre Testing Equipment.* Washington DC USA.

International Cotton Advisory Committee (ICAC). (2014). Cotton: Review of the World Situation. July-August, Vol 67, No 6.

International Trade Center (ITC). (2007). *The Impact of Cotton Fibre Properties on Textile Processing, Performance, Quality and Costs.* www.cottonguide.org.

International Trade Centre (ITC), Cotton Development organisation (CDO). (2011). *Cotton fom Uganda*.

Ishtiaque, S.M., Apurba, D. (2004). End Breakage in Rotor Spinning: Effect of Different Variables on Cotton Yarn End Breakage. *Autex Research Journal* 4 (2): 52-59.

Jim Frost. (2013). Multiple Regression Analysis: Use Adjusted R-Squared and Predicted R-Squared to Include the Correct Number of Variables. *Retrieved* June 13th 2015 *from Minitab. com.*

Josphat I. M, Lusweti,K., Mbwana, S.N.,Simiyu,S.,Ambrose, K. (2015). A study of the Quality of Kenyan Cotton rotor Spun Yarn. *African Journal of Textile and Apparel Research* 1, (1) 13-17.

Kaushik, R.C., Salhotra, K.R., Tyagi, G.K. (1987a). Contribution of Fiber Length and Fiber Denier to Characteristics of Ring- and Rotor-spun yarns. *Indian Journal of Fiber Textile Research* 12: 146–148.

Khalilur, R.K., Habibur, R. (2015). Study of Effect of Rotor Speed, Combing-Roll Speed and type of Recycled Waste on Rotor Yarn Quality Using Response Surface Methodology. *Journal of Polymer and Textile Engineering* 2, (1) 47-55.

Khalilur, R. K., Mohammed, M.H., Ronobir, C. S. (2015). Statistical Analyses and Predicting the Properties of Cotton/Waste Blended Open-End Rotor Yarn Using Taguchi OA Design. *International Journal of Textile Science* 4(2) 27-35.

Khalilur, R. K., Ronobir, C. S. (2015). The Influence of Some Process Parametres on Rotor Spun Yarn Quality Produced from Recycled Cotton Spinning Wastes Using Box Behken Experimental Design. *International Journal of Textile Science* 4(1): 9-19.

King, E. (1991). The Role of the Modern Drawframe, International Textile. Bulletin., Yarn Forming 1: 35–45.

Kong L. X., Platfoot, R. A., Wang, X. (1996). Effects of Fiber Opening on the Uniformity of Rotor Spun Yarns. *Textile Research Journal* 66 (1): 31-36.

Krupincova, G. (2013). Yarn hairiness verses quality of cotton fibers. *Indian Journal of Fibers and textile Research* 38: 223-229.

Lawrence, C. A., Finikopulos, E. (1992). Factors effecting changes in the structure and properties of open-end rotor yarns. *Indian Journal of Fibre Textile Research* 17: 201–208.

Lawrence, C. A. (2003). *Fundamentals of Spun Yarn Technology.* London New York Washington: D.C.: CRC Press LLC.

Lawrence C.A. (2010). *Advances in yarn spinning technology.* Oxford Cambridge Philadelphia Ne/w Delhi: Woodhead Publishing Limited.

Leifeld, F. (1997). Meeting the challenge of the future: The holistic approach. *International Textile Bulletin* 4: 34–38.

Lord, P. R. (2003). *Handbook of yarn production Technology, science and economics.* New York Washington, DC: Woodhead Publishing Ltd.

Louis, G.L. (1981). Some factors affecting open end cotton yarns. *Textile Research Journal* 51, 674.

Mangialardi, G. W. (1990). Relationship of Fineness, Maturity, and Strength to Neps and Seed-Coat Fragments in Ginned Lint. Transaction of the ASAE 33 (4).

Mogahzy, Y. E. (1990). A Statistical Approach for Determining the Technological Value of Cotton Using HVI Fibre Properties. *Textile Research Journal* 60: 497–500.

Montalvo, J. G. (2005). Relationships Between Micronaire, Fineness and Maturity. *Journal of Cotton Science* 9:81-88.

Morris, P. J., Merkin, J.H., Rennel, R.W. (1999). Modelling of Yarn Properties from Fibre Properties. *Journal of the Textile Institute* 90: 322-335.

Muhammad, N., Nisar, A.J., Muhammad, I., Bilal, F. (2002). Effect Of Multiple Open-End Processing Variables Upon Yarn Quality. *International Journal Of Agriculture & Biology* 4, 2.

Mustafa, E., Ureyen, H.K. (2007). The Prediction of Cotton Ring Yarn Properties from AFIS Fibre Properties by Using Linear Regression Models. *Fibres & Textiles in Eastern Europe 15 (4): 63*.

Park, S. (1996). *Robust Design and Analysis for Quality Engineering. Chapman & Hall.* Chapman & Hall.

Patwardhan, A. U. (2009). Comparativ Comperative Study Of Different Test Methods Used For The Measurement Of Pysical Properties Of Cotton. *Indian Journal of Fibre and Textile Research* 34: 52-358.

Peace, G. (1993). *Taguchi Methods.* Addison-Wesley Publishing Company.

Phundan, S. (2014). Cotton Varieties and Hybrids. *India: Central Institute for Cotton Research (CICR).*

Porter, P. M. (1996). Cotton cultivar response to planting date on the southeastern coastal plain. *Journal of Production Agriculture* 9:223–227.

Raghavendra, R., Hegde, A. D Atul Dahiya, M.G.Kamath,Xiao.G and Praveen K.J (2004). Cotton Fibers: 1-15

Rameshkumar, C Anandkumar, P., Senthilnathan, P., Jeevitha. R., Anbumani, N. (2008). Comparitive studies on ring, rotor and vortex yarn knitted fabrics. *Autex Research Journal* 8 (4).

Ramey, H. C. (1999). Classing of fiber Cotton: Origin, History, Technology, Production. New York: John Wiley & Sons, Inc.

Richard, F. (2009). *Physical Properties of Spun Yarns.* Uster Technology Application report, 36.

Rogers, D. D. (2005). Engineering and Ginning: The Effect Of Harvesting Procedures on Fibre and Yarn Quality of Ultra-Narrow-Row Cotton. *Journal of Cotton Science* 9: 25-23.

Salhotra, K. R. (1992). An Overview of spinning technologies: Possibilities, applications and limitations. *Indian Journal of Fibre and Textile Research* 17: 255-262.

Shofner, F. G. (7-8 Dec. 1988.). Advanced fiber information system: A new technology for evaluating cotton. . *Conference of The Textile Institute.* Coventry, Uk: Textile institute.

Soliman, H. A. (1996). Influence of Combing on Open-End Rotor Spinning Parameters. *International Textile Bulletin, Yarn and Fabric Forming* 2: 39–44.

Steadman, J. R. 1. R.G (1989). Factors affecting rotor spinning of fine cotton yarns,. *Textile Research Journal.*, 59, p 371.

Taguchi, G. (1987). *System of Experimental Design.* New York: UNIPUB, Kraus International Publications.

Uganda Investment Authority (UIA). (2014). *Cotton Sector Profile.*

United Nations Industrial Development Organization (UNIDO). (2011). *A Feasibility Study for a Spinning Mill in 11 Sub Saharan countries.* Vienna Gherzi.

United states Department of Agriculture (USDA), Cotton Incorporated. (2016). Wold cotton Production.

Van, Alphen, W. F., (1980.). The card as a dedusting machine. England: Melliand Textilberichte 12 (80) 1523- 1528

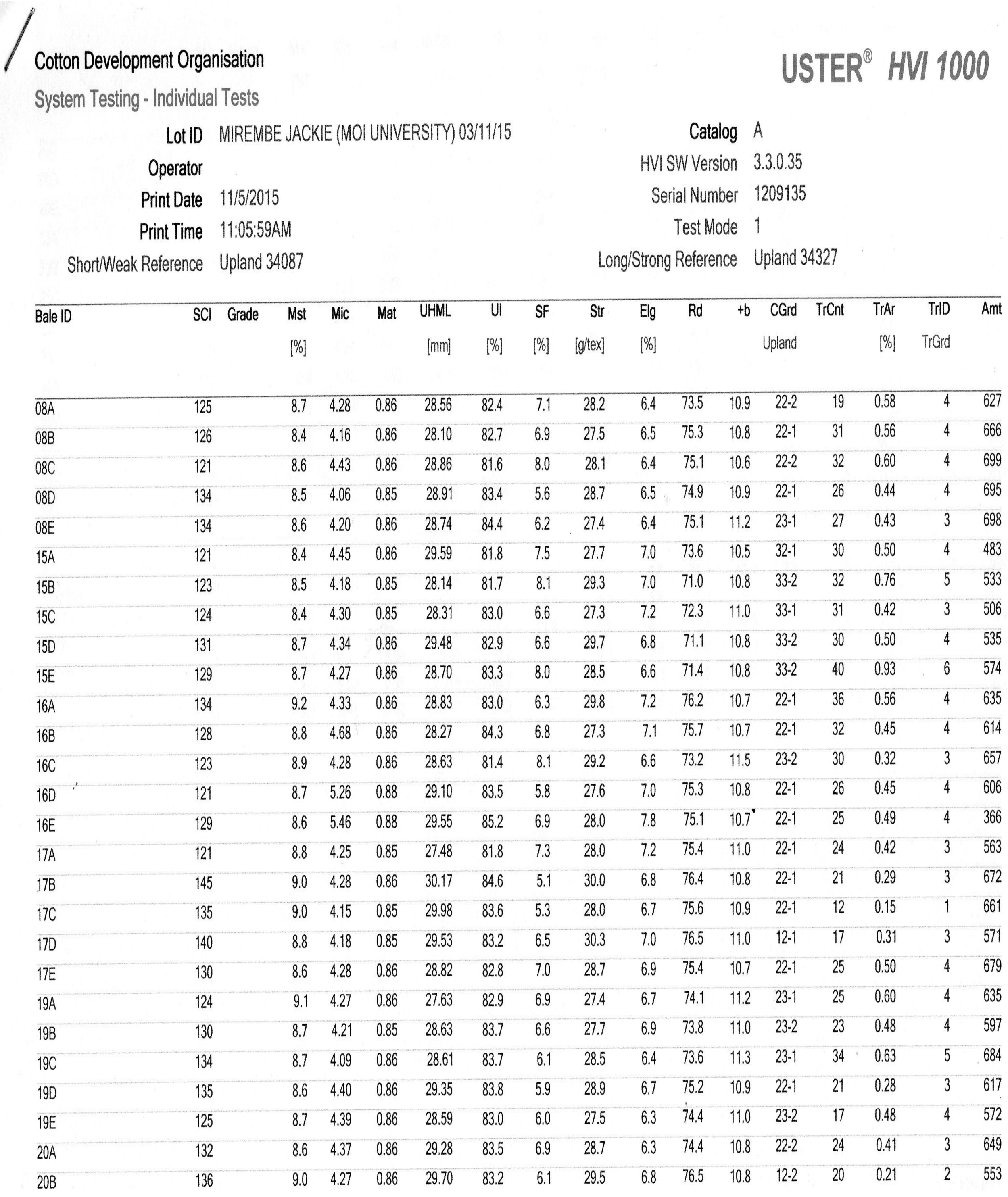
Van der Sluijs, M. L. (1999). Neps in Cotton Lint. Textile Progress 28 (4).

Www.Cottoncrc.Org. Csiro. (2000). *The Importance Of Quality Fibres.*

Zhu, R., Ethridge, D. (1997). Predicting hairiness for ring and rotor spun yarns and analyzing the impact of fibre properties. *Textile Research Journal* 67: 694-698.

APPENDICES

Appendix A: Sample of HVI cotton results



Cotton Development Organisation

System Testing - Individual Tests

USTER® HVI 1000

Lot ID	MIREMBE JACKIE (MOI UNIVERSITY) 03/11/15	Catalog	A
Operator		HVI SW Version	3.3.0.35
Print Date	11/5/2015	Serial Number	1209135
Print Time	11:05:59AM	Test Mode	1
Short/Weak Reference	Upland 34087	Long/Strong Reference	Upland 34327

Bale ID	SCI	Grade	Mst [%]	Mic	Mat	UHML [mm]	UI [%]	SF [%]	Str [g/tex]	Elg [%]	Rd	+b	CGrd Upland	TrCnt	TrAr [%]	TrID TrGrd	Amt
08A	125		8.7	4.28	0.86	28.56	82.4	7.1	28.2	6.4	73.5	10.9	22-2	19	0.58	4	627
08B	126		8.4	4.16	0.86	28.10	82.7	6.9	27.5	6.5	75.3	10.8	22-1	31	0.56	4	666
08C	121		8.6	4.43	0.86	28.86	81.6	8.0	28.1	6.4	75.1	10.6	22-2	32	0.60	4	699
08D	134		8.5	4.06	0.85	28.91	83.4	5.6	28.7	6.5	74.9	10.9	22-1	26	0.44	4	695
08E	134		8.6	4.20	0.86	28.74	84.4	6.2	27.4	6.4	75.1	11.2	23-1	27	0.43	3	698
15A	121		8.4	4.45	0.86	29.59	81.8	7.5	27.7	7.0	73.6	10.5	32-1	30	0.50	4	483
15B	123		8.5	4.18	0.85	28.14	81.7	8.1	29.3	7.0	71.0	10.8	33-2	32	0.76	5	533
15C	124		8.4	4.30	0.85	28.31	83.0	6.6	27.3	7.2	72.3	11.0	33-1	31	0.42	3	506
15D	131		8.7	4.34	0.86	29.48	82.9	6.6	29.7	6.8	71.1	10.8	33-2	30	0.50	4	535
15E	129		8.7	4.27	0.86	28.70	83.3	8.0	28.5	6.6	71.4	10.8	33-2	40	0.93	6	574
16A	134		9.2	4.33	0.86	28.83	83.0	6.3	29.8	7.2	76.2	10.7	22-1	36	0.56	4	635
16B	128		8.8	4.68	0.86	28.27	84.3	6.8	27.3	7.1	75.7	10.7	22-1	32	0.45	4	614
16C	123		8.9	4.28	0.86	28.63	81.4	8.1	29.2	6.6	73.2	11.5	23-2	30	0.32	3	657
16D	121		8.7	5.26	0.88	29.10	83.5	5.8	27.6	7.0	75.3	10.8	22-1	26	0.45	4	606
16E	129		8.6	5.46	0.88	29.55	85.2	6.9	28.0	7.8	75.1	10.7	22-1	25	0.49	4	366
17A	121		8.8	4.25	0.85	27.48	81.8	7.3	28.0	7.2	75.4	11.0	22-1	24	0.42	3	563
17B	145		9.0	4.28	0.86	30.17	84.6	5.1	30.0	6.8	76.4	10.8	22-1	21	0.29	3	672
17C	135		9.0	4.15	0.85	29.98	83.6	5.3	28.0	6.7	75.6	10.9	22-1	12	0.15	1	661
17D	140		8.8	4.18	0.85	29.53	83.2	6.5	30.3	7.0	76.5	11.0	12-1	17	0.31	3	571
17E	130		8.6	4.28	0.86	28.82	82.8	7.0	28.7	6.9	75.4	10.7	22-1	25	0.50	4	679
19A	124		9.1	4.27	0.86	27.63	82.9	6.9	27.4	6.7	74.1	11.2	23-1	25	0.60	4	635
19B	130		8.7	4.21	0.85	28.63	83.7	6.6	27.7	6.9	73.8	11.0	23-2	23	0.48	4	597
19C	134		8.7	4.09	0.86	28.61	83.7	6.1	28.5	6.4	73.6	11.3	23-1	34	0.63	5	684
19D	135		8.6	4.40	0.86	29.35	83.8	5.9	28.9	6.7	75.2	10.9	22-1	21	0.28	3	617
19E	125		8.7	4.39	0.86	28.59	83.0	6.0	27.5	6.3	74.4	11.0	23-2	17	0.48	4	572
20A	132		8.6	4.37	0.86	29.28	83.5	6.9	28.7	6.3	74.4	10.8	22-2	24	0.41	3	649
20B	136		9.0	4.27	0.86	29.70	83.2	6.1	29.5	6.8	76.5	10.8	12-2	20	0.21	2	553

Appendix B: Cotton processing flow chart

Figure A1: Cotton fibre processing adopted in this study: (a) manual bale opening, (b) blow room stage, (c) Carding stage, (d) Breaker drawframe stage, (e) Finisher drawframe stage and (f) rotor spinning stage

Appendix C: Real values of the spinning parameters used

Opening roller speed (rpm)	Rotor speed (rpm)	Yarn count (Ne)	Yarn twist (TM)
9000	80000	14.69	17.62
8000	90000	14.58	17.75
7000	100000	14.48	18.41
9000	80000	14.51	20.01
8000	90000	14.54	19.99
7000	100000	14.49	19.35
9000	90000	14.47	22.38
8000	100000	14.39	20.33
7000	80000	14.53	20.29
9000	100000	23.89	25.16
8000	80000	24.21	25.77
7000	90000	23.84	24.99
9000	90000	23.84	28.57
8000	100000	23.94	27.37
7000	80000	23.92	30.11
9000	100000	23.85	25.8
8000	80000	23.97	25.51
7000	90000	23.94	26.66

Appendix D: Spinning features of a Schlafhorst rotor machine

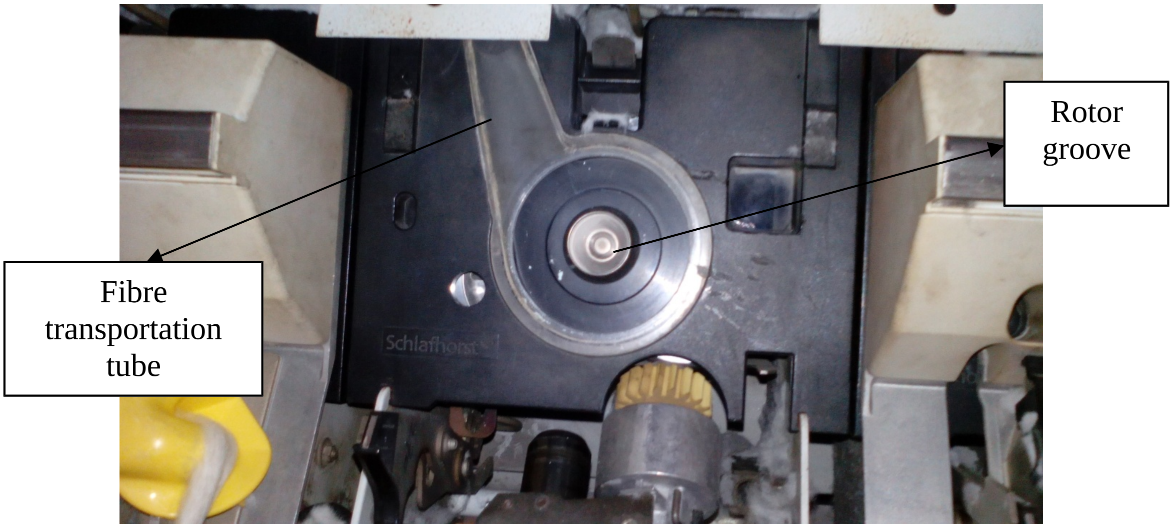


Figure A2: Spinning parts for the Schlafhorst rotor spinning machine

Appendix E: Conference paper

Mirembe Jacquirine, Josphat Igadwa Mwasiagi, Eric Oyondi, Charles Nzila. (2016). *The Use of Statistical Techniques to Study the Effect of Spinning Parameters on Rotor Spun Yarn Strength*. Sino-Africa International Symposium on Textiles and Apparel & Sino-Africa Cultural Exchange Forum, 2-3/ August/2016, Mombasa Kenya