Optimization of Cotton Mélange Yarn Manufacturing for Better Quality and Productivity

Thesis Submitted

By

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CERTIFICATE FROM THE SUPERVISOR/S

This is to certify that the thesis entitled "**Optimization of Cotton Mélange Yarn Manufacturing for Better Quality and Productivity**" submitted by **Shri Suchibrata Ray**, who got his name registered on **06/03/2014** for the award of Ph.D.(Engg.) degree of Jadavpur University is absolutely based upon his own work under the supervision of **Dr. Debamalya Banerjee,** Jadavpur University, Kolkata and **Dr. Anindya Ghosh**, Department of Textile Technology, Government College of Engineering and Textile Technology, Berhampore and that neither his thesis nor any part of the thesis has been submitted for any degree / diploma or any other academic award anywhere before.

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ABSTRACT

Yarn is the basic raw material for weaving and knitting industry. The mélange yarn is gaining popularity over conventional yarn as the mélange yarn has a touch of ecstasy in the knitwear spinning. Mélange yarn manufacturing has the advantages of energy saving, emission reduction and environmental protection and therefore it is apparent that the mélange yarn will be the dominant product of textile spinning industry. The quality of the yarn determines its application in the further processes. With the gradual increase in market share, achieving the desired quality level of mélange yarn remains a challenge for yarn manufacturing industry. Productivity of ring frame is a key indicator of the performance of a spinning industry. Therefore, achieving desired yarn quality at higher ring frame productivity level remains a real challenge for any spinner. There should be a balance between the ring frame productivity level without deteriorating yarn quality. Hence, designing and manufacturing of cotton mélange yarn with optimal quality parameters and productivity level is an important aspect in yarn manufacturing industry. To start with such an optimization problem, it is required to find out the decisive controllable parameters affecting quality parameters of cotton mélange yarn. After intensive literature review, it was observed that hardly any work has been reported on the combined effect of raw material, spinning process parameters and productivity on cotton mélange yarn qualities. Therefore, in this work initially a 3-factor-3-level L9 orthogonal array Taguchi experimental design in presence of two unavoidable noise parameters has been used to determine the significant factors affecting mélange yarn quality parameters (evenness, tenacity, elongation at break, imperfection and hairiness index) for 20’s Ne cotton mélange yarn. Shade depth (%), twist multiplier (TM) and ring frame spindle speed (rpm) are chosen as three controllable factors and for each factor 3 levels are considered. Shade depth (%) and spindle speed are found to be the major parameters affecting evenness, tenacity, elongation at

break, imperfection and hairiness of cotton mélange yarn. However, only yarn strength and elongation at break are found to be affected by TM.

One of the main disadvantages of the Taguchi method is that the results obtained are only relative and do not able to draw exact relationship between the response and factors. Further, Taguchi method has some difficulty in accounting for interactions between factors. Hence, a response surface methodology was opted in this study. The effect of the controllable parameters and their interactions on the responses (evenness, tenacity, elongation at break, imperfection and hairiness) are checked using 3- factor-3-level Box and Behnken response surface design for both blow room and draw frame blended cotton mélange yarn. Shade depth (%), spindle speed (rpm) and twist multiplier (TM) are chosen as three different controllable factors and for each factor 3 levels are considered. Quadratic regression equations are developed for the response variables for both types of blended mélange yarn. Beta coefficient (β) and percentage contribution of the significant factors are calculated. Shade depth is found to be the most dominating factor controlling yarn evenness, tenacity, elongation at break, imperfection and hairiness followed by spindle rpm and yarn twist multiplier (TM) which is in conformation with the study conducted using Taguchi experimental design.

A comparison between blow room and draw frame blending techniques was made. The quality results of blow room blended and draw frame blended cotton mélange yarns are used for the comparison. Better yarn quality with respect to yarn evenness, imperfections, tenacity, elongation at break and hairiness index was achieved with the draw frame blending methodology as compared to the blow room blending methodology. The mélange yarn quality was found to be deteriorated with the increase of shade depth (%) for both the blending methodologies.

To start an optimization problem, it is prerequisite to find out the decisive controllable factors affecting objective functions and derive mathematical relationships among them. The

quadratic regression equations of response surface design are used to formulate the optimization problems. To optimize multiple objectives simultaneously, multi-objective optimization of cotton mélange yarn properties has been attempted using the desirability function approach. The optimization problem is formulated to maximize the overall desirability by satisfying the multiple properties of mélange yarn such as yarn evenness, tenacity, imperfection and hairiness to their respective target values for both blow room and draw frame blended 20's Ne cotton mélange yarns of three different shade depths (%). The optimum values of the controlled factors i.e. spindle rpm and twist multiplier for the maximum overall desirability are obtained. Multi-objective optimization using desirability function approach is experimentally validated and the optimized and achieved values are found to be in good agreement.

Dedicated to My Parents, Wife & Daughter

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Chapter 1

Introduction

CHAPTER 1

INTRODUCTION

In this introductory chapter, the fancy yarn and its classification, fibre dyed mélange yarn and its importance have been introduced. The aims / objectives behind the research work have also been discussed. Finally, the structure of the thesis has been outlined.

1.1 Mélange yarn manufacturing: Opportunities and Threats

Growing world population and ever changing fashion demand for the change of textile raw materials. Fancy yarns exist on the textile market as a main raw material for knitting and weaving products. The textile industry is presently capable to produce various kinds of fancy yarns. Present trend in modern fashion has increased the popularity of fancy yarns. The use of fancy yarns creates a unique aesthetic appeal in the fabrics and that find applications in normal and high fashion clothing, curtains, upholstery and many other areas. Yarns, in which some decorative discontinuity or interruption in either yarn structure or colour or both are introduced deliberately with the intention of producing an enhanced aesthetic effect, are known as fancy yarns. The classification of fancy yarns is made based on method of manufacturing process for getting the fancy effect. The production of fancy yarn with the help of specialized equipmentis known as direct method whereas in indirect method, fancy yarn is produced my modifying the conventional processing techniques both upstream and downstream of spinning. Therefore, indirect method of fancy yarn production remains a great challenge for a yarn manufacturer.

Fibre dyed mélange yarn is a product of indirect method of fancy yarn manufacturing and it is the most important and popular member of the fancy yarn family because of its various advantages and superiority over conventional yarns as well as other category of fancy yarns. Fibre dyed mélange yarns are known for their attractive colour and appearance and it is classified as special effect yarns. Such fancy yarns enhance the fabric appearance and they are best suited to be used as underwear textiles, innerwear textiles, casual wear, sportswear, T-shirts and all sorts of cloth products, as well as bed linens, towels, decorative fabrics and other home fabric products. The application of fibre dyed mélange yarn enabled the fashion industry to create various kinds of structure and appearance, especially in hosiery fashion products with ease. The gradual increase in market share and wide range of application has made the mélange yarn a point of attention to the fashion industry.

Among all the fibres used by apparel industry, cotton is considered as one of the best fibres due to its superior physical and mechanical properties. Due to their specific properties of aesthetics and comfort, cotton mélange yarns are mostly used in the production of a variety of fabrics for knitwear apparel. In case of traditional yarn formation process, grey cotton fibres are passed through various stages of mechanical processing and then converted into grey yarn which is used in fabric formation either at grey form or after dyeing. In case of grey yarn application, fabric is dyed for further use by the apparel industry. In case of dyeing of either yarn or fabric, essentially the whole quantity of the textile material needs to be dyed or chemically processed for further application. Whereas in order to spin cotton mélange yarn, the cotton fibres are dyed first and then blended with other grey cotton fibres, thus it reverses the process of the traditional yarn formation. Hence, mélange yarns or fabrics produced with mélange yarns need not to be dyed or chemically processed for further applications. Fibre dyed mélange yarn is made of two or more different coloured fibres which are spun after fully mixing, therefore creating a unique mixed colour effect. The ratio of dyed cotton fibre to grey cotton fibre in the mixing may be anything ranging from 0.5 to 99.5. This is the beauty of the mélange yarn manufacturing. Once the mélange yarn is spun, there is no need of dyeing anymore. Thus dyeing of huge amount of undyed grey cotton can be avoided by the textile industry. Partial omitting of chemical processing or dyeing directly leads to saving of natural resources like water, energy saving, emission reduction and reduces the use of chemicals, which in turn help to protect the environment. Such advantages have made the mélange yarn an important and future potential product of textile spinning.

But, the manufacturing complexities of fibre dyed cotton mélange yarn has created few limitations for this elegant product. The chemical processing, especially dyeing causes change in physical and chemical properties of cotton fibre. There is a significant strength loss of cotton fibres after dyeing. During chemical treatments like scouring and dyeing, the natural wax present in the cotton fibre got removed and dyed cotton becomes more prone to damage compared to grey cotton. Furthermore, due to the changes in surface characteristics of cotton fibre after dyeing, the possibilities of fibre entanglement and cohesion increase. Thus dyed fibres are more prone to damage during the mechanical processing in spinning. The fibre damage during dyeing and further mechanical processing not only affects the efficiency of the spinning process but also the mechanical properties of the final yarn and fabric are also affected. Therefore, achieving desired quality and production efficiency together for cotton mélange yarn is a hilarious task for the spinner.

The average margin level for a spinning industry ranges from 7 – 10% only. The ring frame productivity is a key performance indicator for any yarn manufacturer. Introduction of cotton mélange yarn has potential to increase the profitability of the spinning unit and this is the reason, many yarn manufacturers are venturing into mélange yarn production. Therefore, certain increase in ring frame productivity will benefit the industry engaged in cotton mélange yarn manufacturing.

1.2 Motivations behind this research work

In the textile industry, spinning process is one of the important production processes. Yarn is the basic raw material for weaving and knitting industry. The quality of the yarn determines its application in the downstream processes. There are various spinning process parameters which affect yarn quality. Many studies have been performed to understand the effect of spinning process parameters on ring spun yarn (Lee and Ruppenicker, 1978; Barella and Manish, 1988; Ahmad et al., 2002; Ishtiaque et al., 2004a, 2004b; Ishtiaque et al., 2005; Kumar et al., 2006a, 2006b; Tyagi et al., 2010; Lawal et al., 2011; Hasanuzzaman et al., 2015; Rokonuzzaman et al., 2017).Yarn quality is a concept defined by customer demands for several properties simultaneously. Yarn evenness deals with the variation in yarn fineness. This is the property commonly measured as the variation in mass per unit length along the yarn. It is important quality of yarn because it can influence so many other properties of yarn and of fabric made from it (Shahzad, 2003; Mahmood et al., 2009; Kostanjnsek and Dimitrovski, 2016). Researchers have described the yarn strength as one of the most important quality parameters of yarn and yarn unevenness, thin and thick places, neps, elongation are other major properties for spun yarn (Sheikh, 1991; Karapinar and Erdem, 2003; Ghosh et al., 2005).

Over the years, many researchers (Clegg, 1940; Williams et al., 1950; Grant et al., 1952; Wakeham, 1955; Rebenfeld, 1957; Brushwood, 1988; Balasubramanian et al., 1995; Koo and Suh, 2005) have investigated the effect of mechanical processing involved in cotton fibre spun yarn manufacturing process on fibre damage, short fibre generation and reduction in staple length. Some researchers (Graham et al., 1977; Goynes et al., 1984; Berberi, 1991; Behera et al., 1997; Ishtiaque and Das, 2003a, 2003b; Koo et al., 2003; Selvan and Raghunathan, 2004; Karim et al.,2007; Moghaseem, 2007, 2008; Naik and Bhat, 2008; Zou, 2014; Khan et al., 2014; Hafeezullah et al., 2015) also tried to study the effect of washing process, dyeing processes, spinning processes and various spinning technologies on cotton fibre mechanical properties such as strength loss, fibre damage, short fibre generation and their subsequent effect on cotton mélange yarn qualities. Dyeing of cotton fibres leads to greater fibre entanglement and cohesion. During the scouring and dyeing process of cotton fibres, a large portion of wax present on the surface of cotton fibres is removed, therefore the surface characteristics of the fibres change. Due to the more propensity of fibre rupture, the average length of dyed cotton fibres decreases with a higher rate than that of grey cotton fibres while going through the blending, carding and drawing processes. It is noted that the fibre rupture not only affects the efficiency of the spinning process, but also affects the mechanical properties of the final yarn and fabric. The processing complexities of fibre dyed mélange yarn have created its own limitations. Thus, it has become a challenging task to engineer cotton mélange yarn with desired quality at optimum productivity level. Engineering of cotton mélange yarn require selection of important controllable parameters to achieve desired level of yarn quality parameters.

There is hardly any published literature which reports the individual as well as the interactive effect of raw material, spinning process parameter and productivity on mélange yarn qualities i.e. yarn evenness, tenacity, elongation at break, imperfections and hairiness index of cotton mélange yarn. Even there is hardly any work which has tried to find out the effect of blending method on cotton mélange yarn quality parameters. Therefore, a thorough investigation on the individual and interactive effects of raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) on mélange yarn properties is required for both the blending techniques. After analyzing the parameters which significantly affects the cotton mélange yarn qualities, an attempt will be made to manufacture mélange yarns with desired quality parameters and optimum productivity.

1.3 Objectives

The broad objective of this research endeavour is to study the effects of some selected process parameters on mélange yarn quality and engineering cotton mélange yarn for desired yarn properties at optimum productivity level.

The specific objectives will be as follows:

1. To understand the influences of raw material, spinning process parameters and productivity level on yarn evenness, tenacity, elongation at break, imperfection and hairiness index of cotton mélange yarn for both the blending methods. Taguchi experimental design and Box and Behnken experimental design will be used for this purpose.
2. To understand the effect of blending methodology on cotton mélange yarn quality.
3. Engineering cotton mélange yarn for optimum quality parameters and productivity level using desirability function.

1.4 Structure of the thesis

This thesis has been divided into eight chapters. A brief summary of the thesis is provided below:

Chapter 1 gives an introduction to the research work and summarizes the objective of the research.

In **Chapter 2**, an exhaustive literature review on fancy yarn and its application, mélange yarn manufacturing techniques, yarn quality parameters and different process parameters affecting yarn qualities, damage of dyed cotton fibre and its impact on cotton mélange yarn qualities, effect of different process parameters on mélange yarn qualities, various design of experiments and optimization processes have been discussed.

In **Chapter 3**, the effect of raw material and various spinning process parameters on yarn evenness, tenacity, elongation at break, imperfection and hairiness index of cotton mélange yarn considering noise factors has been discussed.

The effect of raw material and various spinning process parameters on yarn evenness, tenacity, elongation at break, imperfection and hairiness index of blow room blended and draw frame blended cotton mélange yarn has been discussed in **Chapter 4** and **5** respectively.

Chapter 5 reports a comparative study of different blending methodologies used to produce cotton mélange yarn on yarn evenness, tenacity, elongation at break, and imperfection and hairiness index of cotton mélange yarn.

In **Chapter 6**, cotton mélange yarn quality optimization with target yarn quality parameters for both the blow room blended and draw frame blended cotton mélange yarn using desirability approach have been presented.

Conclusion of the thesis is made in **Chapter 7.**

Chapter 8 describes the scope of further work, which can be explored in future.

Chapter 2

Literature Review

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

In this chapter a comprehensive overview of fancy yarns, mélange yarn, manufacturing process of mélange yarn, important process parameters affecting yarn quality parameters and the decisive factors affecting the mélange yarn properties have been discussed. Thereafter, brief overviews about design of experiments and optimization processes adopted in this research work have been discussed.

2.2 Fancy yarns

The search for new textile products in terms of fashion and appearance has been continuously leading to the design of new types of fancy yarns with impression of lively colour, exclusivity in effect’s structure, flamboyant effects of texture, etc. Nowadays, yarns with structural effect like loops, waves, snarls, chenille pile, etc. and/or optical effects like colour and lustre /dull outcomes are among the most important products of spinning, twisting, wrapping, texturing, printing, knitting, etc. The demand for fancy yarns is due to the special aesthetic appeal they impart to fabrics, which find applications in normal and high fashion clothing, curtains, carpets, upholstery, and many other areas (Pouresfandiari, 2003). Fancy yarns are found to be up-to-date as there is no alternative to them because of their unique aesthetic and decorative impact to the woven, knitted or nonwoven materials (Petrulyte, 2007).The fancy yarns are the big classification of yarns that are used for being pleasing to the eye and have something special than conventional yarn (Oxtoby, 1987; Gong and Wright, 2002). Fancy yarns exist on the textile market as a main raw material for knitting and weaving products and they are very popular in the focus of modern fashion (Grabowska, 2008). Fancy yarns are special products of spinning with deliberately introduced irregular characteristics in either diameter, bulk or in colour (Nisarahmed, 2012). Among fancy yarns the majority of the yarns come under the category of mélange yarn (Memon et al, 2015). Mélange yarns are well known for their gorgeous colour and look (Moghaseem, 2008).

2.3 Definition of mélange

The literary meaning of the word “Mélange” is an unorganized mixture of various dissimilar items. In textile process, mélange yarn is made of two or more different colour fibres which are spun after fully mixing, therefore creating a unique mixed colour effect. It may be defined as “a type of spun yarn made from two or more fibre groups with different colours or dye affinities” (Moghassem, 2008; Regar et al., 2017). Figure 2.1 depicts the visual appearance of mélange and dyed yarns. Visual appearance of knitted fabrics made from mélange and dyed yarns are depicted in Figure 2.2.

(a) (b)

Figure 2.1Visual appearance of mélange yarn (a) and dyed yarn (b)

(a) (b)

Figure 2.2 Visual appearance of knitted fabrics made from mélange yarn (a) and dyed yarn (b)

2.3.1 Definition of mélange shade depth

Mélange yarn is characterized by the amount of dyed fibre present in the yarn. Technically that is known as depth of the mélange colour or shade. Mixing dyed and un-dyed fibres with varying degrees is a common method of producing a variety of fancy mélange yarns. If we mix 10% dyed fibre with 90% grey fibre then the depth of that particular mélange color is 10%. Broadly mélange colour is categorized based on their depth of the shade and noted as below:

(a) Shade depth of 0.2% - 20% is under “Light shade” category,

(b) Shade depth of 21% - 40% is under “Medium shade” category,

(c) Shade depth of 41% - 90% is under “Dark shade” category

2.3.2 Benefits of mélange yarn

Mélange yarn is popular for all good reasons. It’s the yarn of the modern textile industry. It’s an environment-friendly yarn and dyeing of fibre is carried out before spinning process which ultimately preserves the energy and adds to environmental safety. Using of mélange yarns is the latest trend in the fashion industry. An enduring brightness and opulence in the fabric colour can be achieved through mélange yarns. Mélange yarns are mainly used in the textile industry to manufacture a selection of commercial items that are used in knitting, weaving, socks, shirts, sportswear, decorative fabrics, towels etc.

2.4 Manufacturing process of mélange yarns

(a) (b)

Figure 2.3 Dyed cotton fibres (a) and grey cotton fibres (b)

Cotton mélange yarn is spun from a number of cotton fibres with different colours. Figure 2.3 illustrates dyed and grey cotton fibres. Mixing dyed and grey fibres in various ratios produces a variety of mélange yarn. This mixing of fibres (dyed and/or grey), could be done in the blow room at the start of spinning preparation, or it could be done when putting fibres in the draw frames to create the cotton mélange effect.

2.4.1 Blow room blend

Such shades which are blended through blow room are called “Blow Room blends”. Normally darker shades and shades consisting of variety of coloured fibres are run as blow room blend shades. This is done to achieve the maximum blending and uniformity in the shade.

2.4.2 Draw frame blend

Such shades which are blended on draw frame in form of alteration in sliver doublings are termed as “Draw Frame blends”. Mostly lighter shades are blended on draw frame, as they are easy to blend and provide ease in balancing the process.

Naik and Bhat (2008) made an attempt to study the production techniques used for producing different mélange yarns including the synthetic mélange yarns. They also emphasized on process difficulties, utilities and limitations of mélange yarns. In their study four different types of mélange yarn production techniques have been explored, viz., tuft blended mélange yarn, sliver blended mélange yarn, synthetic mélange yarn and twisted/plied mélange yarn. First two techniques are mostly used for cotton mélange yarn production with dyed cotton fibre, third technique is used to produce synthetic filament mélange yarn and the fourth one is used to produce moulinee (different coloured continuous filament yarns) and jaspe mélange yarn by twisting different coloured yarns in the doubling / plying process. The paper has indicated that dyeing process of cotton fibres lead to greater entanglement and cohesion among them and further mechanical processes lead to fibre damage which makes the mélange yarn manufacturing process more difficult. Hence increasing the proportion of dyed fibres in the mélange yarn degrades the effectiveness of the specialty yarn and also restricts the ability to make finer yarn.

2.5 Yarn quality

Spinning process is one of the important production processes in the textile industry and the quality of the yarns produced is very important in determining their applications further (Subramanian, 2007). In staple yarn manufacturing, it is a recognized fact that currently more than 60% of world yarn production is based on ring spinning method (Tarafder, 2002; Ishtiaque et al., 2004b). The quality for any production process is usually inversely proportional to quantity (Rokonuzzaman et al., 2017). Karapinar and Erdem (2003) pointed out that the main yarn properties which are important for yarn manufacturing are described as structural properties (yarn count, yarn twist), unevenness properties (CV% values of unevenness, thin and thick places, neps, hairiness) and physical and mechanical properties (strength, elongation). The required yarn qualities for the high-efficiency knitting and weaving machines are linear density and its coefficient of variation, twist, strength, elongation at break, irregularity (CVm%) and hairiness (Jackowski et al., 2002; Kostajnsek and Dimitrovski, 2016). Yarn breaking strength and elongation at break are the major parameters that affect the bursting strength of the knitted fabric (Ertugrul and Nuray, 2000).The strength of a spun yarn is recognized as one of the most important quality parameters of yarn (Ghosh et al., 2005). Imperfections in yarns are serious flaws that greatly affect the yarn quality. In carded yarn, more than 75% of the imperfections are due to the presence of fibre clusters and fibre clusters entangled with foreign matter, whereas in combed yarn, both fibre clusters and fibre clusters with fly seem to contribute to more than 85% of the thick places (Padmanabhan and Balasubramanian, 1990). Imperfections adversely affect yarn and fabric quality for ring spun yarn (McCreight, 1997; Grosberg and Iype, 1999; Hebert et al., 1986). Yarn imperfection (neps, thick and thin places) is an important parameter which affects both yarn and fabric processing as well as quality (Ochola et al., 2012).

2.5.1 Effect of spinning process parameters on yarn quality

Extensive research has been carried out to find out the effect of different spinning process parameters on ring spun yarn properties. It has been established that beside raw material, various spinning process parameters like spindle speed, twist multiplier, total draft, top roll pressure, traveller mass, speed frame parameters, etc. are the decisive factors affecting the yarn properties. Karapinar and Erdem (2003) explained that fibre properties (raw material), process parameters such as yarn count, yarn twist, blend ratio and preparation processes like spinning systems (types and adjustments) are the main factors which affect the yarn properties. Lee and Ruppenicker (1978) studied the effects of carding rate, total spinning draft, and spindle speed on the properties of ring-spun cotton knitting yarn. The yarn quality parameters like strength, uniformity and imperfection were measured for both the varieties of carded and combed yarns. They found that yarn strength and uniformity were improved by increasing the total spinning draft. Increased carding rate improved fibre orientation and produced stronger and more uniform yarn. They also noted that lower spindle speeds resulted in slightly uniform and stronger yarns with fewer imperfections. Ahmad et al. (2002) investigated the effect of twist multiplier and spindle speed on ring spun 30^s carded cotton yarn strength and irregularity. Yarn samples of 30^s count were prepared from 1.27 roving hank for four levels of spindle speed and three levels of twist multiplier. They found the best results of yarn lea strength and evenness at the lowest spindle speed of 15600 rpm and lowest twist multiplier of 4.1. Ishtiaque et al. (2004b) optimized the ring frame process parameters for better yarn quality and production. Three important ring frame process parameters, namely spindle speed, top roller pressure and traveller mass have been optimized. The actual levels of variables were taken within the range of industrially acceptable limits. The yarn quality parameters like yarn irregularity, imperfections, hairiness index, tenacity and elongation at break were measured for all the samples. Yarn breakage rate at ring frame was also studied for three different traveller masses. Experimental results and analysis concluded the optimized values of spindle speed to be 15000 rpm, top roller pressure 2.5 kg/cm^2 and traveller mass 50 ISO No. They found that with the increase in spindle speed, the end breakage rate increased and yarn elongation at break decreased. According to them, the yarn imperfections, hairiness index and strength initially improved and then deteriorated at higher speed. They also concluded that yarn U%, imperfections, hairiness index and tenacity improved with the increase in traveller mass but breaking elongation reduced significantly. Furthermore, the higher traveller mass at higher spindle speed increased the end breakage rate marginally. Similar kinds of observations were made by Jackowski et al. (2002) and Mahmmod et al. (2004). In another study, Ishtiaque et al. (2004a) investigated the effect of speed frame process parameters on yarn quality and production. They studied the influence of flyer speed, top roller pressure and middle condenser size in the drafting region on various characteristics of roving and yarn. The yarn samples were tested for various properties like yarn irregularity, imperfections, hairiness index, tenacity and elongation at break. The roving samples were tested for roving irregularity and roving breakage rate. They concluded that the roving U% and breakage rate increased with the increase in flyer speed but imperfection and yarn tenacity initially decreased and then increased. They concluded that the roving irregularity, roving breakage rate and yarn imperfections initially decreased and then increased with the increase of top roller pressure. Kumar et al. (2006a) studied the effect of spinning process variables on tensile properties of ring, rotor and air-jet yarns. They found that the ring yarn has the highest breaking elongation whereas the air-jet yarn has the lowest. It was also found that yarn spun at higher speed frame draft and corresponding lower ring frame draft has better tenacity and breaking elongation compared to yarn spun at lower speed frame draft and corresponding higher ring frame draft. Kumar et al. (2006b) in another study investigated the effect of spinning process variables on physical properties of ring, rotor and air-jet yarn and the ring yarn was found to be highly even and had the least number of thin places and neps but thick places were the least in rotor yarn. Tyagi et al. (2010) studied the effect of spinning conditions like spinning draft, twist factor, yarn count and spindle speed on mechanical and performance characteristics of cotton ring and compact spun yarns. They found that regularity characteristics such as yarn uniformity, thick places and neps get much better when spinning draft and twist factor reduced. The lower spindle speed resulted into better yarn uniformity and imperfection. They also concluded that yarns with less hairiness, better abrasion resistance and sufficient structural integrity can be spun by using appropriate twist factor and varying spindle speed. In another study, Tyagi et al. (2013) studied the influence of twist and blend ratio on characteristics of ring spun tencel blended yarns. They observed an initial increase in yarn strength initially and then decrease with the increase in twist factor. They also found the consistent increase in breaking elongation with the increase in twist factor for tencel blended yarn. Influence of spindle speed on quality of flax/cotton blended ring spun was investigated by Lawal et al. (2011). In their study, yarns of 39 tex and 59 tex were produced with four different flax/cotton blend ratios at three different spindle speeds. They observed that the tenacity and total imperfections (neps, thin and thick places) of flax/cotton blended yarns increased whereas, the breaking extension decreased with the increase in spindle speed for all the yarn counts and blend proportions. The effects of spinning process parameters namely, spindle speed, roving twist multiplier (roving TM) and yarn twist multiplier on yarn properties were studied and optimized by Hasanuzzaman et al. (2015). Carded cotton yarn samples were produced and measured for different yarn properties like yarn hairiness, evenness, breaking strength and breaking extension, imperfection and breakage rate. They found that with increased spindle speed, the yarn imperfection increases and the yarn breaking extension decreases. Yarn strength and uniformity initially improved with increase in spindle speed but thereafter deteriorated with further increase in speed. With increased yarn TM, the yarn strength, uniformity and hairiness index improved but the effect of yarn TM on imperfection was not significant. The best optimal values for the process parameters were spindle speed of 17000 rpm, yarn TM of 4.1 and 1.3 roving TM. Barella and Manich (1988) studied the influence of spinning process, yarn count and fibre properties on the hairiness of ring-spun and rotor-spun cotton yarns. They confirmed higher hairiness of ring-spun yarns compared to rotor-spun yarns and hairiness increases with the increase in yarn linear density. A detail study on the effect of fibre to fibre friction along with the carding parameters on the openness of fibre has been carried out by Ishtiaque et al. (2005). The fibre openness has been correlated with the drafting force of rovings and properties of sliver, roving and yarn. They concluded that the nep count and short fibre content of card sliver, mass irregularity of card sliver, draw frame sliver, roving and yarn, total imperfections and yarn tenacity were significantly influenced by the fibre openness. The influence of process variables on characteristics of modal siro-spun yarns has been studied by Gowda et al. (2004). Yarn samples of 30 tex were produced by varying key process variables, viz. strand spacing, traveller mass and spindle speed. All the yarn samples were evaluated for unevenness, imperfections, strength and elongation at break. They observed that the increase in strand spacing from 6 mm to 10 mm increases the unevenness and decreases the hairiness, strength and extension of modal siro-spun yarns. Based on experimental results, the strand spacing of 8 mm, traveller mass of 1/0 and spindle speed of 17000 rpm were optimized for optimum yarn quality. Abbasi et al. (2012) observed that the amount of twist plays a vital role on physical and mechanical properties like yarn tenacity, breaking elongation, mass variation and hairiness of low twist yarn. Basu (2009) made an attempt to analyze the yarn structure – properties relationship. According to him the importance of this subject has increased due to the need of yarn with best possible quality at optimum cost and the diversification of textiles in various products, where performance is the main criteria, necessitating better yarn engineering. He has pointed out that beside the fibre properties, yarn structure is the most important factor which influences the properties. If the relationship is understood, the yarn structure can be modified for changing the yarn properties. Based on various research publications made on yarn structure-properties relationship it was concluded that the yarn structure changes with the yarn production technology, process parameters and fibre parameters.

2.5.2 Effect of mechanical processing on fibre damage and its impact on spun yarn quality

Many researchers investigated the effect of mechanical processing involved in cotton fibre spun yarn manufacturing process on fibre damage, short fibre generation and reduction in staple length. It has been established that the mechanical processes involved in spinning, causes fibre damage and the changes of fibre properties due to mechanical action affects the yarn properties. Therefore, in manufacturing a spun staple yarn, it is essential to have optimum selection of processing conditions and component fibres in order to achieve optimum yarn properties. Clegg (1940) observed that 5% proportion of damaged fibres in a cotton bale was increased to 59% in the spun yarn. They also noted a significant drop in the mean breaking load of the fibres in the yarn compared to those in the bale. Grant et al. (1952) investigated the effect of mechanical processing on the cotton fibre properties after ginning to final yarn formation stage. Fibres for the test of unprocessed cotton were collected from ginned cotton bale and fibres for the test of processed cotton were taken from $16/2^s$ yarns by untwisting. They found that the effects of processing on length, weight-fineness, tenacity and crystallite orientation were within experimental errors in the test method. Williams et al. (1950) studied the effect of manufacturing processes on fibre length distribution and staple length of the original cotton used in grey yarn and grey cloth. They reported that changes in a typical portion of fibre length distribution of fibre arrays of 50 samples of raw cotton and corresponding grey yarn and cloth are not of such a character as to affect the reliability of the estimates of staple length. Wakeham (1955) described that the cotton fibre length distribution is an important quality factor from both the processing and yarn quality points of view. They made a point that the higher amount of short fibres present in cotton causes appreciable increase in waste %, excessively uneven rovings and yarns, less efficient spinning, and weaker yarns. A detail study was carried out by Rebenfeld (1957) to evaluate the effect of processing on cotton fibre properties. The mechanical properties were evaluated on fibres taken from the bale, the yarn, the scoured fabric, bleached and mercerized fabric, and from fabric that had been bleached, mercerized and then resin finished. They concluded that all the processing stages affect the mechanical properties of cotton fibre and their extent is process dependent. The extent of alteration in fibre properties is more in case of wet finishing operations like scouring, bleaching and mercerizing compared to mechanical operations such as carding, spinning and weaving. They also reported that changes in cotton fibre properties are reflected in fabric characteristics. Brushwood (1988) studied the effect of heating on chemical and physical properties and processing quality of cotton. They concluded that processing and yarn quality problems sometimes occur through over drying practices. Excessive heating of cotton resulted into strength loss and increased fibre breakage. The changes in fibre properties due to heating caused increased neps, reduced strength and uniformity in the yarn. An investigation was made to study the changes in cotton fibre properties at different stages of spinning by Balasubramanian et al. (1995). 30^s carded and 40^s comber mixings were chosen and samples were collected randomly from various stages of spinning. All the fibre samples were tested for various fibre properties. They observed significant improvements in 50% span length, uniformity ratio and bundle tenacity from card to drawing sliver for both the mixing varieties. Koo and Suh (2005) studied the effects of spinning processes on cotton fibre characteristics and spun yarn properties. They concluded that each processing stage in spun yarn manufacturing changes both the single fibre properties and the bundle tensile and other quality characteristics. They also observed no significant correlation between yarn tensile strength and single fibre tensile properties and fineness.

2.5.3 Effect of chemical processing on cotton fibre properties and its effect on spun yarn quality

Graham et al. (1977) studied the processing efficiency of chemical treated cotton fibre. The cotton fibres were chemically treated for two hours at ambient temperature and then spun into $24^s/1$ yarn through normal spinning process. To compare the quality performance of chemically treated cotton, yarn samples of combed variety and 95/5 cotton/polyester blend with untreated cotton were prepared. The fibre length, strength, elongation and fineness were determined for treated cotton samples. Uniformity was tested for sliver, roving and yarn samples. Knittability was also tested for the yarn samples. They observed that the chemical treatment was detrimental to carding action and yarn strength. They also concluded that the treatment increased fibre friction which subsequently improved fibre parallelization and reduced twist requirement for roving but not for yarn. A change in cotton fibre surface characteristics due to washing was studied by Goynes et al. (1984). Cotton fibres from 10 different washing methods were studied microscopically. They observed a reduction in the number of loose surface particles on the fibre surface. They also found that natural coatings appeared to have been removed in some cases and heavier deposits were found on some surfaces.

2.5.4 Effect of blending methods on spun yarn quality

In practice, blow room blending and draw frame blending are the two general blending methods used in yarn spinning. Normally, blow room blending is known as fibre-blending and draw frame blending is known as sliver-blending. Both the blending methods have their own advantages and disadvantages. Many researchers investigated the effect of blending techniques on final yarn quality parameters. Chollakup et al. (2008) studied the effects of blending parameters on fibre migration of silk/cotton blends. The blending factors studied were the blending methods, intimate blending (blow room blending) and draw frame blending. For intimate blending, silk fibre waste was opened and manually mixed with the same quantity of cotton fibres, then introduced into the card feeding system. To produce draw frame blend, the same number of pure component silk and cotton card slivers were mixed at draw frame. After being blended by two methods and passed through the drawing and roving frames, the material was finally spun into a 30 tex yarn in ring spinning machine. They found that the blended fibres in the draw frame blending tend to migrate more towards the yarn core as compared to the intimate blending. The intimate blending gave a more homogeneous fibre distribution, with no radial migration tendency. Lam et al. (2017) investigated the effect of fibre length and blending method on the tensile properties of ring spun chitosan-cotton blend yarns. Yarn samples of 20’s Ne were produced with both types of blending, i.e., fibre blending and sliver blending methods. The strength, elongation, linear density, twist and evenness of all the yarn samples were investigated. Researchers pointed out that the blending method of fibre components (fibre or sliver blending) directly influences the yarn tenacity. They also found that fibre blending offers more evenness in the fibre distribution in the spinning process as opposed to the sliver blending method. Tanveer et al. (2010) pointed out that, the most popular method used for blending natural fibres, which required different opening and cleaning treatment, is draw frame blending. Subramanian et al. (2015) compared the quality of polyester-cotton blended yarn produced with two different blending methodologies. They found that the yarns produced with blow room blending method showed better yarn quality in comparison to that of draw frame blending with respect to yarn evenness, imperfections, classified faults and tensile strength. Anandjiwala and Goswami (1999) studied the effect of fibre properties and yarn structure on the tensile properties of ring spun cotton yarns made from 50:50 blend of high and low tenacity fibres. They produced the yarns by using blow room blending and draw frame blending techniques. They observed better tensile strength for blow room blended yarn compared to draw frame blended yarn in spite of positioning more high strength fibres in the core of the draw frame blended yarn. The effect of blend percentage on blend irregularity for both the blow room and draw frame blended polyester /viscose air-jet spun yarn was studied by Punj et al. (1999). They prepared the blow room blended yarn by stack blending method and draw frame blended yarn by blending the sliver at first draw frame. They achieved minimum index of blending irregularity for 67/33 polyester/ viscose blow room blended yarn and draw frame blended yarn showed higher index of blending irregularity compared to blow room blended yarn for all the blends.

2.6 Mélange yarn and fabric quality

2.6.1 Properties of dyed cotton fibres and its effect on mélange yarn quality

Ishtiaque and Das (2003a) investigated the properties of grey and dyed cotton fibres including the waste materials at different stages of rotor spinning process. In case of dyed fibres both reactive dyed and natural dyed cotton fibres were studied. They reported that fibre length and related parameters consistently deteriorate in each mechanical processing stage and the effect is more prominent in case of natural dyed cotton fibres where the frictional co-efficient is very high. They also concluded that pin type opening roller shows less fibre breakage and better dust separation than saw toothed type opening roller. In case of natural dyed cotton where the fibre friction is high, the fibre length drops and short fibre content increases with the increase in opening roller speed. The damage of cotton fibre and its effect on cotton mélange yarn properties in production of rotor and ring mélange yarns were studied by Gharchaghaji et al. (2007). They had produced the yarn by mixing grey and dyed cotton fibres in draw frame. To study the effect of fibre damage on the dyed and grey cotton fibre assemblies in yarns, 100% dyed and grey yarns were also produced. It has been observed that dyeing and mechanical process lead to decrease of effective length and increase of short fibre content. According to them increasing short dyed fibres in rotor mélange yarn caused a drop in tenacity and elongation at break, increased imperfections, unevenness and hairiness in mélange yarn. Also fibre damage in rotor mélange yarn was more than ring mélange yarn due to further opening by opening roller. These variations were indicative of fibre damage in dyed cotton fibres on mélange yarn manufacturing. Selvan and Raghunathan (2004) investigated the effect of dyeing, drying, opening and carding during mélange yarn preparation on length and tensile properties of fibres using three different varieties of Indian cottons, viz., S6, DCH32 and MCU5. They concluded that there is a reduction in strength and length of fibres after dyeing, drying, opening and carding i.e. the preparatory processes up to carding for mélange yarn. The intensity of length reduction is higher in case of longer length fibres. This reduction in length reduces the cohesive force, which leads to poor performance of mélange yarn. The reduction in strength affects the tensile properties of mélange yarn. Hence, a clear insight can be obtained for choosing the proportion of grey and dyed fibres within the same variety or in the different varieties for producing particular quality of mélange yarn. The influence of dyeing and spinning on the characteristics of cotton fibres and its impact on the properties of cotton mélange yarn has been investigated by Moghaseem (2007, 2008). Grey cotton fibres were pre-treated, scoured and dyed before using for mélange yarn spinning. Three ring spun yarns were produced separately from 100% grey cotton, 50:50 dyed and grey cotton blends and 100% dyed cotton. The extent of fibre damage was assessed by measuring the length and the mechanical characteristics of cotton fibres after passing the fibres through the lap machine and the draw frame II. The yarn properties were examined for all the three types of yarn produced. The results showed that the fibre length, in terms of number and weight of grey cotton was longer than that of dyed cotton, while the amount of fibre nep and short fibre content (fibre length having less than 0.5 inch) of dyed cotton were more than those of grey cotton. In terms of tenacity and elongation at break, grey and dyed cotton fibres were very similar. It was concluded that the influence of dyeing and spinning processes on the fibre length characteristics and entanglement was more than that on the tensile properties of the fibre. In case of mélange yarn properties it was found that all the three yarns were the same in terms of elongation at break but the tenacity was highest for 100% grey cotton yarn and lowest for 100% dyed cotton yarn. The CVm%, thin places, thick places and amount of neps were lowest for 100% grey cotton yarn and highest for 100% dyed cotton yarn. The yarn hairiness was highest for 100% dyed cotton yarn and very similar for 100% grey cotton yarn and 50:50 dyed/grey cotton blended yarn. Koo et al. (2003) made a study on damage of dyed cotton fibres and its relation to the properties of specialty yarns (mélange yarns). Effects of dyeing process on some properties of cotton fibres were analyzed. They observed that the average tenacity, elongation at break and fibre length of cotton fibres decrease after pre-treatment and dyeing. Eleven yarn samples of 30’s Ne were produced with grey cotton and ten different ratio of grey cotton and dyed cotton blends. The effects of blend ratio of dyed cotton on some properties of specialty yarns were studied. They found that the tenacity of specialty yarns with changing blend ratio decreases significantly by increasing the blend ratio to 40%, but shows no important change above 40%. The unevenness of the specialty yarn decreases at a blend ratio of more than 20% due to the disparity of the component fibres. The spinnability of specialty yarns also decreases as the blend ratio increases. They concluded that there are constraints of producing cotton specialty yarn and achieving desired properties of a fine cotton mélange yarn because of spinning difficulties. During production of mélange yarns by blending dyed and grey cotton fibres, fibres get damaged by dyeing and spinning processes, leading to degradation in the properties of specialty yarn. A detailed study of the damage caused to dyed cotton fibres and its effect on the properties of rotor and ring spun mélange yarns were made by Karim et al. (2007). To study the damage of cotton fibre after dyeing, 2.5% span length, strength and elongation at break were measured for dyed fibre samples. Scanning electron microscope (SEM) photographs were used to investigate the physical appearance of the damage fibres. Three kinds of ring and rotor spun cotton yarns (29.5 Tex) viz., 100% white, 50% white and 50% dyed (mélange) and 100% dyed were produced. Two kinds of each ring and rotor spun mélange yarns were produced. For one type, flocks of dyed and white fibres were mixed in the blow room and for the other, dyed and white slivers were mixed in the draw frame. The study concludes that dyeing of cotton leads to an increased amount of fibre damage in comparison to dyed fibres.The samples containing dyed fibres suffered a noticeable reduction in the effective length. This reduction increases from mélange yarn to the yarn with 100% dyed cotton fibres. The quality of the mélange yarn depends considerably on the blending stage as well as the spinning system. The higher number of drawing stages when blending white and dyed fibres in the draw frame results in better mechanical properties, but greater hairiness in the yarn. The presence of dyed fibres in the mélange leads to a considerable decrease in the mechanical properties of rotor spun yarns, but ring spun yarns do not seem to be significantly affected. The effect of dyeing parameters on physical properties of dyed cotton fibres and mélange yarn was investigated by Hafeezullah et al. (2015). They dyed cotton fibres at four different times i.e., 70, 80, 90 and 100 minutes and three different dye fixation temperatures i.e., 50°C, 60°C and 70°C. The 20's Ne ring spun cotton mélange yarns were prepared using dyed fibre produced with 12 different combinations of dyeing time and temperature. The 2.5 % span length and short fibre index were measured for dyed cotton fibre and various quality parameters of mélange yarn such as yarn tenacity, elongation%, evenness, nep count and hairiness were studied. It was concluded that the effective span length of cotton fibre became worse in case of increasing dyeing temperature and further decreased with increasing dyeing time. Short fibre index of cotton fibre increased with increased dyeing temperature. Overall the effect of increasing dyeing time on yarn evenness was more than the effect of increasing dyeing temperature whereas dyeing time did not affect the yarn tensile properties significantly. Mahmood et al. (2009) made a study to evaluate the interaction of coloured polyester and multi bleached cotton blends for the tensile properties of rotor spun mélange yarn. Six blends of black dyed polyester and bleached cotton were used to produce 10's Ne rotor mélange yarns. The prepared rotor mélange yarns were then bleached with sodium hypochlorite and hydrogen peroxide. They concluded that the yarn tensile properties improved gradually as the share of polyester in the blend is increased. Ishtiaque and Das (2003b) studied the effects of moisture content and linear density of feed sliver on rotor spinning performance and yarn quality of grey and dyed cotton. They observed that the yarn quality in terms of strength, irregularity and imperfections deteriorates with the increase in moisture content and linear density of feed sliver for both grey and dyed cotton. They also noted that the cotton dyed with natural indigo showed poor running performance and yarn quality compared to grey and reactive black dyed cotton.

2.6.2 Effect of process variables on mélange yarn and fabric quality

The effect of percentage of dyed fibre, spacer size and spinning system on mélange yarn properties were studied by Regar et al. (2017). The normal ring spinning and compact ring spinning system were used to produce cotton mélange yarn. Two different dyed fibre percentages (30% and 60%) and two different spacer sizes (3mm and 3.5mm) were used. They concluded that dyed fibre component and spacer size have a direct impact on the yarn quality parameters. Compact mélange yarn has shown better yarn properties over the normal ring spun mélange yarn. Zou (2014) studied the effect of process variables on properties of viscose vortex coloured spun yarn. Box and Behnken design of experiment with three process variables viz., nozzle pressure, yarn delivery speed and yarn count were used to prepare the samples. It was observed that yarn tenacity was significantly affected by yarn delivery speed, yarn count and nozzle pressure. Yarn delivery speed has a nonlinear and marked effect on yarn elongation at break while yarn count has a linear effect on yarn elongation at break. Yarn evenness was significantly influenced by nozzle pressure, yarn delivery speed and yarn count. Also it was noted that yarn hairiness was significantly influenced by nozzle pressure and yarn delivery speed. Compared to yarn delivery speed, yarn count and nozzle pressure have significant effect on yarn diameter. Khan et al. (2014) investigated the interactive effect of blend proportion and process parameters on ring spun cotton/viscose mélange yarn properties and fabric GSM. Four variables viz., dyed viscose percentage, spindle speed of ring frame, twist multiplier (TM) of yarn and a knitting parameter namely stitch length with three levels of Box and Bhenken design of experimental method was used for the study. They found that with the increase of dyed viscose proportion, yarn unevenness and total imperfection improve but the yarn strength and elongation decrease. As the spindle speed increases total imperfections and strength of the mélange yarn increase and elongation decrease for all blend ratios. The best yarn evenness was achieved at spindle speed of 15500 rpm. They also concluded that fabric GSM increases with higher viscose percentage and lower stitch length. Zou (2015) studied the influence of yarn formation process variables such as nozzle pressure, yarn delivery speed and yarn count on the properties of viscose fabric produced from vortex mélange yarn. Three variables, three levels Box and Bhenken design of experiment was used to produce the viscose mélange yarn samples. They observed that the air permeability rate and dynamic drape coefficient of the fabric decrease with the increase in yarn delivery speed while the fabric mass loss rate reaches to peak and then decreases with the increase in nozzle pressure. The fabric breaking strength was significantly affected by the reciprocal of the yarn count. They also concluded that the fabric breaking strength and air permeability do not get affected by nozzle pressure.

2.6.3 Effect of blending methods on mélange yarn quality

Effect of different blending methods and blending stages on mélange yarn properties were studied by Behera et al. (1997). Both dyed and grey fibres with different degrees of opening and cleaning were mixed at blow room and draw frame stage to measure the yarn properties. The extent of fibre damage and the uniformity of fibre distribution have also been evaluated. They concluded that the mélange yarn properties are significantly influenced by blending methods and blending stages. Highest strength was achieved with draw frame blending. The study showed that the number of broken and damaged dyed cotton fibres in spun yarn is more than the number of damaged fibres in cotton bale. Also the strength of dyed fibres in yarn decreases in comparison with that of cotton fibres in bale. Yarn imperfections are low in the case where mixing of dyed cotton and grey cotton fibres take place in the drawing stage. Excessive mechanical action by repetitive blow room and carding causes fibre damage and loss in fibre tenacity, resulting in loss of yarn tensile properties. With mixing at blow room, better shade uniformity is produced. Hence, blending methods and blending stages should be decided, taking into account the end use of the mélange yarn. Pre opening of dyed component should be carried out properly to improve blend homogeneity and better yarn quality.

2.7 Design of experiments

A designed experiment is a test or series of tests in which purposeful changes are made to the input variables of a process so that we may observe and identify corresponding changes in the output response. A schematic diagram of a standard manufacturing process is shown in Figure 2.4.

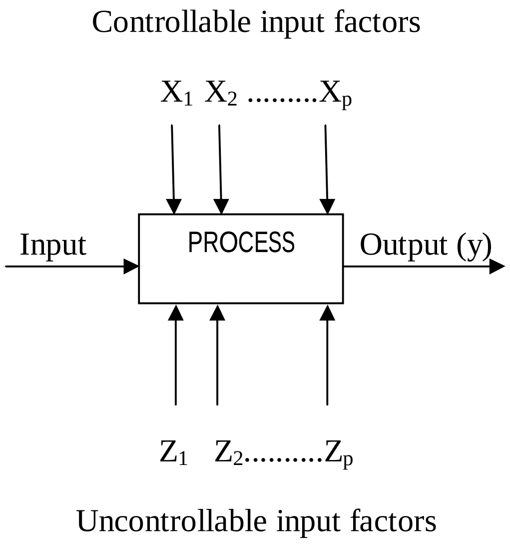


Figure 2.4 Schematic diagram of a normal manufacturing process

In engineering experiments, the independent parameters are changed deliberately to certain extent to observe the effect of changes on ‘response’ or ‘objective’ variable. Experimental design is a critically important engineering tool for improving a manufacturing process. It is essential to design the experiments so that the data yielded can be analyzed to draw a valid conclusion. The various designs of experiments (DOE), which are practiced in industry, are given below:

- Completely randomized design
- Block design
- Full factorial design
- Fractional factorial design
- Response surface design
- Taguchi design

2.7.1 Completely randomized design

This type of DOE is used when the objective of the experimentation is to choose the best method from several alternatives. In this type of design, one primary factor is considered with different treatments. For example, “which is the best fibre that affects the thermal conductivity most?”

In completely randomized experimental design, the treatment e.g. the primary factor is randomly assigned from random number tables or by some other physical mechanism.

2.7.2 Block design

Block designs are used to reduce or eliminate the ‘nuisance factors’ or ‘experimental errors’. In experimentation, apart from the primary factor, other factors (controllable or uncontrollable factors but which are not of primary interest) may affect the response variable and hence are known as ‘nuisance factors’. The nuisance factors that affect the response variable most, need to be controlled by a technique known as ‘blocking’ to eliminate (or reduce) the contribution of nuisance factors towards experimental error. In these design of experimentations, homogeneous blocks are created in which the nuisance factors are kept constant and the primary factor is varied. Different types of randomized block designs are cited below:

- Randomized block design
- Latin square designs
- Graeco-Latin square designs
- Hyper-Graeco-Latin square designs

2.7.2.1 Randomized block design

This type of experimental design is used when single factor is of primary interest with only one nuisance factor. A randomized block experimental design is shown in Figure 2.5. In the figure cited below A, B, C and D are the treatments where as I, II, III and IV are different blocks.

I	D	B	C	A
II	B	D	A	C
III	C	A	D	B
IV	A	C	B	D

Figure 2.5 A randomized block experimental design

2.7.2.2 Latin square design

This type of experimental design is used when single factor is of primary interest with two different nuisance factors. A Latin square experimental design is shown in Figure 2.6, in which A, B, C and D is the treatments while two blocking factors are shown along the rows and columns.

	Nuisance factor 1			
Nuisance factor 2	D	B	C	A
	B	D	A	C
	C	A	D	B
	A	C	B	D

Figure 2.6 A Latin square experimental design

2.7.2.3 Graeco-Latin square design

This type of experimental design is used when single factor is of primary interest with three different nuisance factors. A Graeco-Latin square experimental design is shown in Figure 2.7.

	Nuisance factor 1			
Nuisance factor 2	B_γ	A_β	D_δ	C_α
	A_δ	B_α	C_γ	D_β
	D_α	C_δ	B_β	A_γ
	C_β	D_γ	A_α	B_δ

Figure 2.7 A Graeco-Latin square experimental design

The symbols A, B, C and D in Figure 2.7 are the treatments. Two blocking factors are shown along the rows and columns, whereas the third blocking factor is indicated by the prefix symbols α, β, γ and δ.

2.7.2.4 Hyper-Graeco-Latin square design

This type of experimental design is used when single factor is of primary interest with four nuisance factors. A Hyper-Graeco-Latin square experimental design is shown in Figure 2.8. In the figure cited below the symbols A, B, C and D are the treatments. Two blocking factors are shown along the rows and columns, whereas the third and forth blocking factors are indicated by the prefix symbols α, β, γ, δ and m, n, o, p respectively.

	Nuisance factor 1			
Nuisance factor 2	$B_{\gamma m}$	$A_{\beta n}$	$D_{\delta o}$	$C_{\alpha p}$
	$A_{\delta n}$	$B_{\alpha m}$	$C_{\gamma p}$	$D_{\beta o}$
	$D_{\alpha o}$	$C_{\delta p}$	$B_{\beta m}$	$A_{\gamma n}$
	$C_{\beta p}$	$D_{\gamma o}$	$A_{\alpha n}$	$B_{\delta m}$

Figure 2.8 A Hyper-Graeco-Latin square experimental design

2.7.3 Full factorial designs

Full factorial design of experimentation is used when the objective of the experimentation is to extract the most important factors from large list. Therefore, the number of factors in this case is at least 2 and each factor having 2 or more level.

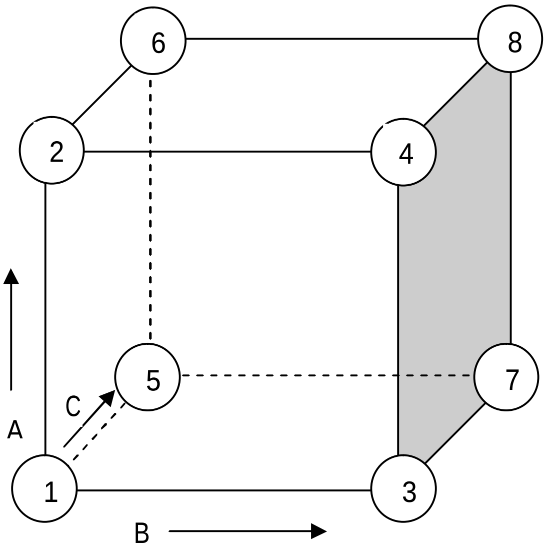


Figure 2.9 A 3 factor 2 level (2^3) full factorial design with factors A, B and C

Table 2.1 Runs of a 3 factor 2 level (2^3) full factorial experimental design

Experimental runs	A	B	C
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

A 3 factor 2 level (2^3) full factorial design is illustrated in Figure 2.9. The experiment runs are shown at the corners of the cube. Table 2.1 shows the ‘runs’ of a 3 factor 2 level full factorial design in a ‘standard order’.

2.7.3.1 Blocking of full factorial design

Alike ‘randomized block design’, the effect of nuisance factors that contribute to the experimental error in ‘full factorial design’ experimentation is eliminated by ‘blocking’. A blocked 3 factor 2 level (2^3) full factorial design is depicted in Figure 2.10. The first block is dark shaded corners and the other block is white filled corners. Table 2.2 shows the ‘runs’ of a blocked 3 factor 2 level (2^3) full factorial design in a ‘standard order’.

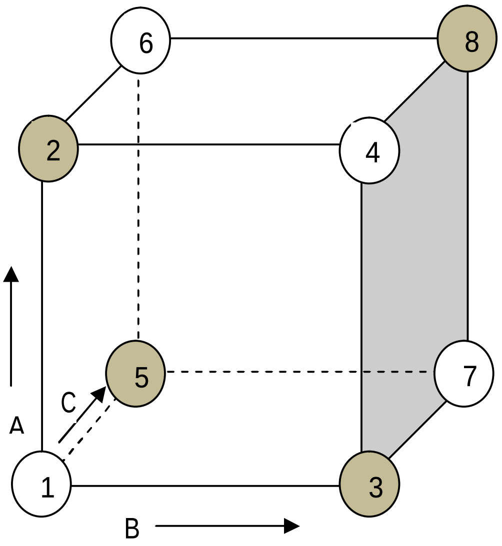


Figure 2.10 A blocked 3 factor 2 level (2^3) full factorial designs with factors A, B and C

Table 2.2 Runs of a blocked 3 factor 2 level (2^3) full factorial experimental design

Block	Experimental runs	A	B	C
I	1	-1	-1	-1
	2	+1	+1	-1
	3	+1	-1	+1
	4	-1	+1	+1
II	5	+1	-1	-1
	6	-1	+1	-1
	7	-1	-1	+1
	8	+1	+1	+1

2.7.4 Fractional factorial designs

The number of runs for ‘full factorial design’ increases with the increase of factors and the DOE remains no longer efficient. A ‘fractional factorial design’ is a better solution in such cases where the experimental runs are more due to large number of factors. In ‘fractional factorial design’ only a fraction of the runs specified in ‘full factorial design’ are considered. Hence, a fractional factorial design is a variant of the basic factorial design in which a subset of the runs is made. A 3 factor 2 level (2^3) full factorial design vs fractional factorial design has been illustrated in Figure 2.11. The experimental runs are shown in the corners. Table 2.3 shows the runs of a 3 factor 2 level (2^3) full factorial vs fractional factorial experimental design in a standard order. It is seen from the table that while a 3 factor 2 level (2^3) full factorial design requires 8 runs, a fractional factorial design requires only 4 runs.

Table 2.3 A 3 factor 2 level full factorial vs fractional factorial design of experiment

No. of runs	Full factorial design			Fractional factorial design		
	A	B	C	A	B	C
1	-1	-1	-1	-1	-1	+1
2	+1	-1	-1	+1	-1	-1
3	-1	+1	-1	-1	+1	-1
4	+1	+1	-1	+1	+1	+1
5	-1	-1	+1			
6	+1	-1	+1			
7	-1	+1	+1			
8	+1	+1	+1			

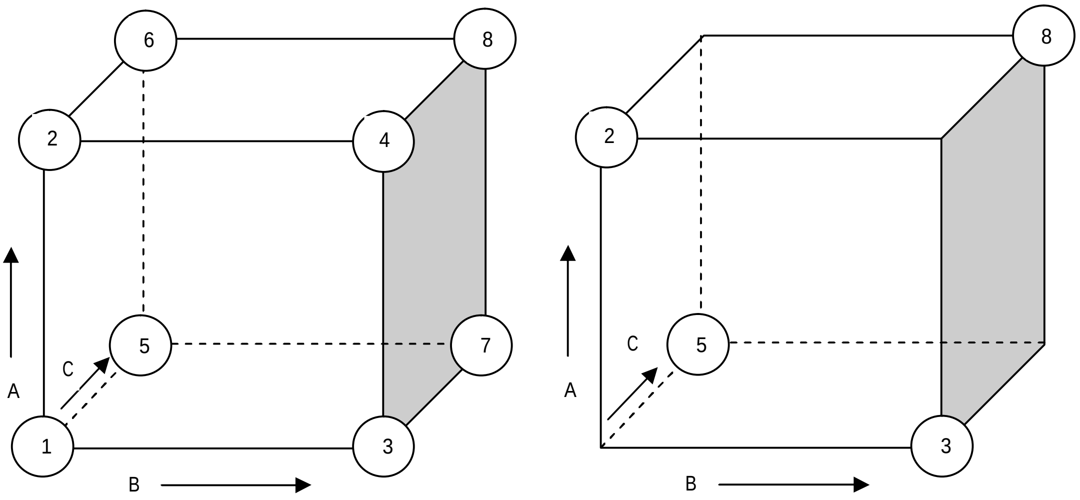


Figure 2.11 A 2^3 full factorial vs fractional factorial DOE with factors A, B and C

2.7.5 Response surface designs

Response surface methodology (RSM) is a collection of statistical and mathematical techniques that are useful for analysis and modelling in applications where a response of interest is influenced by number of variables and the objective is to optimize this response. Response surface designs help the experimenter to estimate the interaction effects of the prime factors and provide us the contour of the response surface. The response surface contour helps to find the optimal process setting, model a relationship between the response variable and prime factors, troubleshoot process problems. Further, it helps to make a process more robust against external non-controllable influences. The most commonly used response surfaces are ‘Central Composite design’ and ‘Box-Behnken design’.

2.7.5.1 Central Composite design

A ‘Box-Wilson Central Composite design’, commonly known as ‘Central Composite design’ is a full factorial or fractional factorial design with ‘center points’ that is augmented with group of axial points known as ‘star points’. If the distance between the ‘center point’ to the factorial points are ±1, the distance between the ‘center point’ and the ‘star points’ in the design space is $|\alpha| > 1$. The 'star points' correspond to extreme values for each factor. The value of α depends on the number of factors in the factorial portion of Central Composite design and is calculated by the following equation:

$$\alpha = [2^{number\ of\ factors}]^{1/4} \qquad (2.1)$$

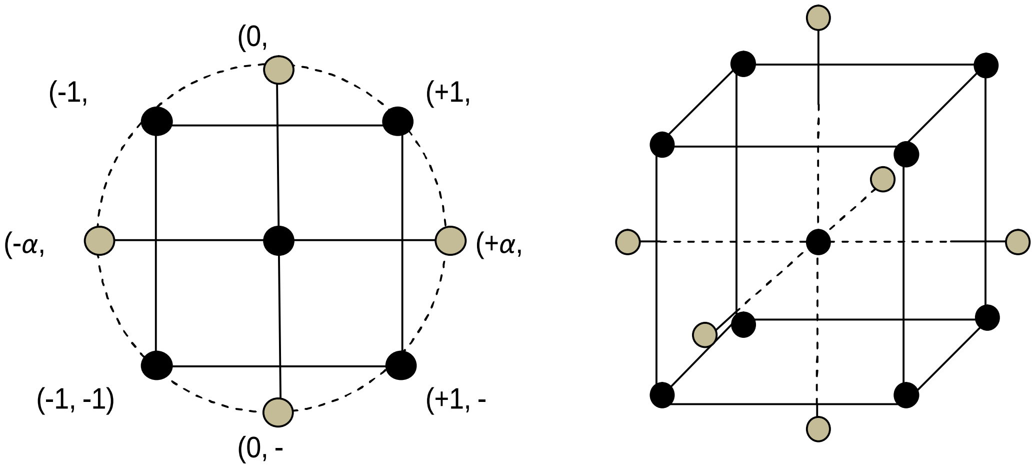


Figure 2.12 Central Composite design for 2 and 3 factors

Figure 2.12 shows a Central Composite design for two and three factors, respectively. Table 2.4 shows some values of α as a function of the number of factors.

Table 2.4 'α' values of Central Composite designs of various factors

Number of Factors	α value
2	$2^{2/4} = 1.414$
3	$2^{3/4} = 1.682$
4	$2^{4/4} = 2.000$

2.7.5.2 Box-Behnken design

The Box-Behnken design is an independent quadratic design. Unlike Central Composite design, the treatment combinations are at the midpoints of edges of the process space and at the center. Box-Behnken designs are rotatable and require three levels of each factor. Figure 2.13 shows a Box-Behnken design for three factors.

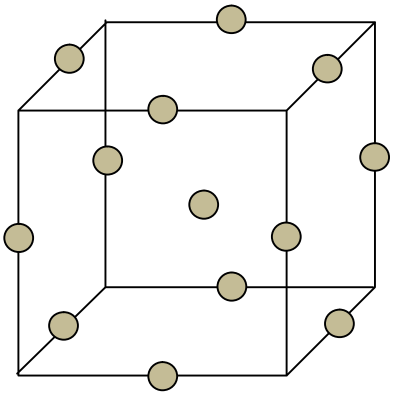


Figure 2.13 A Box-Behnken design for 3 factors

Unlike Central Composite design, the Box-Behnken design does not contain any treatment combinations at the extremes of the cubic regions. The points on the corners of cube in Central Composite design represent factor level combinations that are very expensive or difficult to test due to physical constraints on experimentation, which is avoided in Box-Behnken design. Also, the number of runs in Box-Behnken design is less in comparison to Central Composite design.

Table 2.5 contrasts the structures of Central Composite design and Box-Behnken design with three factors, while Table 2.6 compares the number of runs required for a given number of factors for Central Composite and Box-Behnken designs.

Table 2.5 Structural comparison of Central Composite design and Box-Behnken designs for three factors

Central Composite design				Box- Behnken design			
Rep	A	B	C	Rep	A	B	C
1	-1	-1	-1	1	-1	-1	0
1	+1	-1	-1	1	+1	-1	0
1	-1	+1	-1	1	-1	+1	0
1	+1	+1	-1	1	+1	+1	0
1	-1	-1	+1	1	-1	0	-1
1	+1	-1	+1	1	+1	0	-1
1	-1	+1	+1	1	-1	0	+1
1	+1	+1	+1	1	+1	0	+1
1	-1.682	0	0	1	0	-1	-1
1	+1.682	0	0	1	0	+1	-1
1	0	-1.682	0	1	0	-1	+1
1	0	+1.682	0	1	0	+1	+1
1	0	0	-1.682	3	0	0	0
1	0	0	+1.682				
6	0	0	0				
Total runs = 20				Total runs = 15			

Table 2.6 Number of runs for Central Composite designs and Box-Behnken designs

Number of factors	Central Composite design	Box-Behnken design
2	13 (including 5 center points)	-
3	20 (including 6 center points)	15 (including 3 center points)
4	30 (including 6 center points)	27 (including 3 center points)

2.7.5.3 Application of Box-Behnken design in textile engineering

Box-Behnken design has become popular in textile industry in the context of process optimization. This method is often employed after identification of controllable factors that affects the responses of prime importance. Investigations were conducted largely in spinning sector using the Box-Behnken designs. Effect of structural parameters of injected slub yarn on its tensile properties and abrasion resistance was studied by Mukhopadhyay et al. (2017) by using Box-Behnken design of experiment. Chandrasekaran et al. (2016) applied Box-Behnken design of experiment to optimize the spinning parameters, such as twist multiplier, spindle speed and polyvinyl alcohol (%), influencing the characteristics of structurally modified viscose yarn. Response surface method was used by Senthilkumar and Kuthalam (2015) to study the influence of vortex spinning parameters on the tensile properties of polyester/cotton vortex yarn. The influence of fibre friction, front zone roller setting and front top roller pressure at speed frame and ring frame on cotton /milkweed blended yarn properties was studied by Karthik and Murugan (2016) by using Box and Behnken design of experiment. Orthogonal block Box and Behnken design of experiment was applied by Banerjee et al. (2018) to study the effect of yarn fineness and various knitting parameters on ultraviolet resistance of knitted fabrics. Effect of carding parameters, namely card cylinder speed, card production rate, and draw frame doubling on the ring spun yarn properties was studied by Jabbar et al. (2013) by using Box-Behnken design of experiment. Optimizations of the controlled factors were done for better yarn quality. Box-Behnken response surface design was applied by Gowda et al. (2004) to study the influence of process variables like strand spacing, traveller mass and spindle speed, on quality of modal siro-spun yarns. Ishtiaque et al. (2006) applied Box-Behnken factorial design to study the influence of fibre friction, top arm pressure at various drafting stages namely draw frame, speed frame and ring frame on yarn properties. Gokarneshan et al. (2006) investigated the influence of critical ring frame parameters on the fibre cohesion in yarns. They optimized the spindle speed, traveller mass and twist multiplier for achieving minimum twist of cohesion in the yarns. Application of Box-Behnken factorial designs are also reported in post-spinning and other unconventional spinning processes. Rengasamy et al. (2005) optimized the jet angle, jet diameter, yarn linear density and winding speed to minimize yarn hairiness using Box-Behnken factorial design. Palta and Kothari (2002) investigated the effect of overfeed, air-pressure and texturing speed on various properties of air-jet textured polyester yarns using Box-Behnken design methodology. Studies on comfort of textiles using Box-Behnken response surface design are also notified. Singh et al. (2010a) studied the effect of sheath fibre proportion, fibre fineness and yarn fineness of DREF III friction spun yarns on various physiological comfort properties of a fabric viz. air permeability, water vapour permeability and thermal conductivity using Box-Behnken response surface design. Singh et al. (2010b) further studied the effect of sheath fibre proportion, fibre fineness and yarn fineness on physiological comfort related properties affecting the liquid transmission behaviour i.e water absorbency and wicking ability using 3-factor 3-level Box-Behnken design.

2.7.5.4 Application of Box-Behnken design in mélange yarn manufacturing

There have been very few reports on the application of Box-Behnken experimental design methodology in mélange yarn manufacturing process optimization. Khan et al. (2014) studied the effect of dyed viscose percentage, spindle speed of ring frame, twist multiplier and knitting stitch length on viscose mélange yarn properties and fabric GSM using 4-factor-3 level Box-Behnken experimental design. They observed that with the increased percentage of dyed viscose in mélange yarn, yarn irregularity, imperfections, strength and elongation were decreased but the fabric GSM was increased with increased percentage of viscose fibre in mélange yarn. They also noted that with increased spindle speed, the yarn elongation decreased and yarn imperfection increased. Twist multiplier has shown positive effect on yarn strength.

2.7.6 Taguchi design

Taguchi et al. (2005) developed a statistical approach to improve the quality of manufactured products by minimizing the effect of causes of variation, known as Taguchi Method and it has become an important tool in engineering. A special set of arrays known as orthogonal arrays and signal to noise ratio (S/N) are used in Taguchi method. In orthogonal array, a special set of arrays of factor and level combination are used to conduct minimum number of experiments to provide full information of all the factors that influence the response. A typical L9 orthogonal array is shown in Table 2.7 with three factors with three levels each. The value “9” indicates nine prototypes that need to be tested. A, B and C in the table are the controllable factors. The noise factors are denoted by X and Y with two levels of each.

Table 2.7 L9 (3^3) orthogonal array

Experimental Run	Controlled parameters			Uncontrolled parameters	
	A	B	C	X	Y
1	-1	-1	-1	± 1	± 1
2	-1	0	0	± 1	± 1
3	-1	+1	+1	± 1	± 1
4	0	-1	0	± 1	± 1
5	0	0	+1	± 1	± 1
6	0	+1	-1	± 1	± 1
7	+1	-1	+1	± 1	± 1
8	+1	0	-1	± 1	± 1
9	+1	+1	0	± 1	± 1

The experimental outputs are then transformed into a signal to noise ratio (S/N ratio) that represents the ratio of sensitivity to variability. A higher S/N ratio indicates better quality. The S/N ratio needs to be maximized which eventually minimize the effect of uncontrolled random noise factors that may influence the process performance at significant level.

S/N ratio can be calculated using the following equations depending on the response as: ‘larger-the-better’, ‘smaller-the-better’ or ‘nominal-the-best’ (Ross, 1996; Roy, 2001; Taguchi, Chowdhury and Wu, 2005).

a) Nominal the best

$$\frac{S}{N} = 10\log\left[\frac{\bar{y}}{S_y^2}\right] \qquad (2.2)$$

b) Larger the better

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \qquad (2.3)$$

c) Smaller the better

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \qquad (2.4)$$

where, $\bar{y}$ is mean of observed data, S_y^2 is the variance of y, n is the number of experiments in the orthogonal array and y_i is the i^{th} value measured.

Optimum process can be determined from the S/N ratios. For each significant factor, the level corresponding to the highest S/N ratio is the optimum level.

2.7.6.1 Application of Taguchi design in textile

Application of Taguchi experimental design methodology is becoming popular day by day in various sectors of textile industry. Khan et al. (2015) used Taguchi experimental design in predicting the cotton/waste blended rotor yarn properties. For the experiment, two levels of four independent variables were selected. Kumar and Ishtiaque (2009) investigated the effect of process variables on packing density parameters of ring, rotor and air-jet spun yarns using Taguchi method. Salhotra et al. (2006) studied the effect of lap hank, card draft and draft / doublings on fibre orientation parameters and tenacities of slivers and rovings using Taguchi experimental design. In this experimentation speed frame draft was considered as noise variable. Ishtiaque et al. (2006) considered doff position, spindle to spindle variation of spinning machines and material conditioning before testing yarn properties as noise variables and investigated the effect of final machine parameters on fibre orientation and properties of ring, rotor and air-jet yarns using Taguchi experimental design. Kumar et al. (2006a, 2006b) studied the effect of spinning process variables namely, lap hank, card draft, draft / doublings at drawframe, speed frame draft, ring frame draft, rotor draft and air-jet draft on yarn tensile properties, unevenness, imperfections and hairiness of various spinning systems using Taguchi design. The noise variables selected for the investigation were spindle-to-spindle variation, doff position and material conditioning before testing yarn properties. Cheng and Li (2002) examined the effects of various spinning parameters on yarn hairiness in jet-ring spinning system using L_{16} orthogonal design and optimized spinning condition for different fibre materials. Cho and Jeong (2006) used Taguchi method to predict the yarn tenacity of dyed spun yarn from the spinning conditions and analyzed various yarn properties. Webb et al. (2007) studied the effect of air blast duration, air blast pressure, chamber design and cutting synchronization and their interactive effects on splice strength of Nylon 66 yarns and optimized the splicing parameters using Taguchi design. The noise factors considered were temperature, humidity, fibre density, splice length, blast hole position, testing and recording equipment tolerances. Tascan (2014) applied Taguchi method to optimize the process parameters of wet-spun solid PVDF fibers for maximizing the tensile strength and applied force at break and minimizing the elongation at break. Applications of Taguchi design to study effect of various process parameters on woven and knitted fabrics and optimization of those various fabric properties are also reported. Oinuma (1990), Maramarali (2003), Wilbik et al. (2006), Benltoufa et al. (2007), Dias and Delkumburewatte (2008), Mavruz and Ogulata (2009) used Taguchi design method to correlate air permeability and fabric structural parameters like stitch length, wales per inch, courses per inch, fabric thickness, pore size etc. Mavruz and Ogulata (2010) also optimized the bursting strength of knitted fabrics by using Taguchi experimental design. Ogulata and Mavruz (2011) optimized yarn and fabric factors to maximize air permeability of knitted fabrics using Taguchi L_9 orthogonal design technique. The modelling of the colour yield of 100% cotton fabric dyed was done by Fazeli et al. (2012) by applying Taguchi experimental design. Optimum conditions of dyeing process on cotton knit fabric were obtained by Wahyudin et al. (2017) by using Taguchi method.

2.8 Optimization process

2.8.1 Linear and quadratic programming

The linear programming is the simplest optimization technique to minimize or maximize a linear function of decisive variables whereas quadratic programming is the optimization technique to minimize or maximize a quadratic function of decisive variables. Linear problems are solved using the Simplex method. Quadratic programming can be solved by a smooth nonlinear optimization method such as GRG (Generalized reduced gradient) or SQP (Sequential quadratic programming) method.

2.8.2 Multi-objective optimization

Whenever an optimization problem involves two or more objective functions, the task of finding optimum solutions is known as multi-objective optimisation. The optimization solution may be one or more depending upon the type of objective functions. Whenever the objectives are non-conflicting in nature, a single optimization solution may possible. But, when the objectives are conflicting in nature, more solutions may be possible and a trade-off is then required. A solution that is extreme with respect to one objective needs to compromise with other objective and vice-versa.

Desirability function is one of the examples of classical approach to solve multi-objective optimization problems. Harrington (1965) developed the concept of desirability in 1965 and it was developed by Derringer and Suinch (1980). A desirability function (*di*) is defined individually for each objective with goal and boundaries. The goals could be either maximize or minimize or target an objective. The individual desirability functions are then combined together to calculate the “overall desirability”. Both the individual desirability and overall desirability have a range from ‘0’ to ‘1’. A desirability of 0 corresponds to completely undesirable property whereas a value of 1 means completely desirable. The corresponding solution for the maximum overall desirability is the solution for a multi-objective optimization problem. Some works have been reported on use of desirability function to optimize multiple responses in the textile field. Souid et al. (2008) used desirability function for comparative quality optimization between ring spun and slub yarns. Souid et al. (2012) estimated denim fabric quality using desirability function. Desirability function was used by Mal et al. (2016) to engineer a knitted cotton fabric for optimum comfort in a hot climate. Asim et al. (2011) optimized the process parameters for simultaneous fixation of reactive printing and crease resistant finishing using desirability function. Taieb and Msahli (2013) used desirability function to optimize knitted fabric quality which comprises various mechanical quality viz. areal density, bursting pressure, extensibility, dimensional stability, abrasion resistance etc.

2.9 Summary

Having scrutinized research literatures of yarn quality parameters, mélange yarn manufacturing processes, cotton mélange yarn quality parameters, the decisive factors affecting cotton mélange yarn properties along with various optimization process, it is found that there is hardly any published literature which reports the effect of individual and interactive effect of raw material, spinning process parameter and productivity on mélange yarn qualities i.e. yarn evenness, tenacity, elongation at break, imperfections and hairiness index of cotton mélange yarn. Even there is hardly any work which has tried to find out the effect of blending method on cotton mélange yarn quality parameters. It was also noticed that no attempt was made to engineer cotton mélange yarn, which is supposed to be the future of the yarn industry, for optimum quality parameters.Therefore, it was felt that a thorough investigation on the individual and interactive effects of raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) on mélange yarn qualities is required for both the blending techniques.Effect of blending methodology on mélange yarn quality parameters is to be compared for finding suitable manufacturing process. After analyzing the parameters which significantly affect the cotton mélange yarn qualities and developing their empirical formulae, suitable optimization algorithms may be utilized to engineer cotton mélange yarn with desired quality parameters for optimum productivity.

Chapter 3

Analysis of Influence of Spinning Process Variables and Shade Depth on Quality Parameters of Blow Room Blended Cotton Mélange Yarn using TAGUCHI Experimental Design

CHAPTER 3

ANALYSIS OF INFLUENCE OF SPINNING PROCESS VARIABLES AND SHADE DEPTH ON QUALITY PARAMETERS OF BLOW ROOM BLENDED COTTON MÉLANGE YARN USING TAGUCHI EXPERIMENTAL DESIGN

3.1 Introduction

Yarn is the product of spinning process which is one of the important production processes of textile industry. The basic raw material of knitting and weaving industry is yarn. The performances of knitting and weaving machines as well as the quality of fabrics made by them are largely governed by the yarn quality. Yarn quality is a concept defined by customer demands for several properties simultaneously. Researchers have studied on various important yarn quality parameters which can influence so many other properties of fabric made from it. Various research studies have reported that yarn evenness, strength, yarn twist, thin and thick places, neps, elongation are main yarn properties for spun yarn (Shahzad, 2003; Mahmood et al., 2009; Kostanjnsek and Dimitrovski, 2016; Sheikh, 1991; Karapinar and Erdem, 2003; Ghosh et al, 2005).Technological advancement has enabled the textile industry to produce various kinds of yarns and fabrics with special appearance by varying product mix and structure. The increasing trend in the demand of fancy yarns is observed in the era of modern fashion (Grabowska, 2008). Mélange yarn is one of the important members of the fancy yarn family and it is known for its attractive colour and appearance. Mélange yarn is made out of two or more different coloured fibres which are spun after mixing, therefore creating a unique mixed colour effect. Such type of fancy yarns have advantages for fabric appearance and they can be used in casual wear, sportswear, shirts, business suits, socks and all sorts of cloth products, as well as bed linens, towels, decorative fabrics and other home fabric products. With the gradual increase in market share and application in different field of textiles, achieving desired quality as well as productivity is now becoming a challenge for a spinner while manufacturing mélange yarn. Nevertheless, the quality of the mélange yarn is a key parameter for the success of this speciality yarn. Hence, to achieve a cotton mélange yarn with optimum evenness, strength, elongation at break, imperfection (thick places, thin places and neps) and hairiness, it is required to optimize multiple properties simultaneously. An optimization problem requires objective functions and constraint functions. Therefore for optimization, selection of important controllable parameters affecting the objective functions and constraint functions are necessary so that mathematical relationships between the objectives, constraints and controllable parameters can be developed. Undoubtedly, the objective functions for a cotton mélange yarn are yarn evenness, strength, elongation at break, imperfection and hairiness. Therefore, as a prerequisite to start an optimization problem, it is required to find out the decisive controllable parameters affecting these objective functions and Taguchi design of experiment is best suited for this purpose.

Researchers have studied on various spinning parameters affecting ring spun yarn quality. It has been reported in various studies that yarn quality parameters are largely affected by fibre properties, changes in fibre properties during mechanical processing involved in spinning, blend ratio, yarn count, spindle speed, amount of twist, drafting roller pressure, drafting forces, roller gauges, total draft, etc. (Lee and Ruppenicker, 1978; Barella and Manish, 1988; Ahmad et al., 2002; Ishtiaque et al., 2004a, 2004b; Ishtiaque et al., 2005; Kumar et al., 2006a, 2006b; Tyagi et al., 2010; Lawal et al., 2011; Hasanuzzaman et al., 2015; Rokonuzzaman et al., 2017).

Most of the researchers, who have worked on the quality and manufacturing processes of cotton mélange yarn, have tackled the problem in isolation. Those researches were primarily concerned with the effect of washing process, dyeing processes, spinning processes and various spinning technologies on cotton fibre mechanical properties such as strength loss, fibre damage, short fibre generation and their subsequent effect on cotton mélange yarn qualities, lacking a holistic approach (Graham et al., 1977; Goynes et al., 1984; Berberi, 1991; Behera et al., 1997; Ishtiaque and Das, 2003a, 2003b; Koo et al., 2003; Selvan and Raghunathan, 2004; Karim et al., 2007; Moghaseem, 2007, 2008; Naik and Bhat, 2008; Zou, 2014; Khan et al., 2014; Hafeezullah et al., 2015).

However, no study has been reported on the effect of individual and interactive effect of raw material, spinning process parameters and productivity on mélange yarn qualities. Therefore, in this study an attempt has been made to study the effect of raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle speed of ring frame) on mélange yarn qualities. Also, it is noted that, there exists certain unavoidable noise factor that may affect the properties of cotton mélange yarn. In an industrial set up, these noise factors could be enormous in number. Some of these noise factors could be temperature, humidity, machine number, machine vibration, cop position, machine sides, operator etc. Therefore, prior to the optimization of cotton mélange yarn quality parameters, it is necessary to incorporate the unavoidable noise factors along with controlled factors (shade depth %, yarn TM and spindle speed) and study their effect on mélange yarn properties. Therefore, in this part of research, Taguchi experimental design (Ross, 1996; Taguchi et al., 2005) has been used to study the effects of shade depth %, yarn TM and spindle speed on yarn unevenness (U %), strength, elongation at break, imperfection and hairiness for 20’s Ne cotton mélange yarn. Two noise parameters namely spinning position in the ring frame and yarn position at ring frame bobbins have been considered.

3.2 Materials and method

3.2.1 Preparation of yarn samples

In this study, combed grey and combed black dyed sankar-6 cotton fibres were used to produce 20’s Ne mélange yarn samples. The cotton fibre properties used to produce the yarns are summarized in Table 3.1. Black dyed cotton fibres were opened using Mixing Bale Opener (MBO) and were then blended by weight with combed grey cotton fibres in a Blender. After mixing at Tuft Blender, fibre mixture was passed through a unimix for better randomization. After that the layering of fibres was done. In order to improve the processing of dyed cotton fibres in the subsequent operations, 6% water and 0.15% lubricant (LV-40) were sprayed over the layering. The layering was then conditioned for 8 hours before feeding it to the blow room. The stages of cotton mélange yarn production are shown in Figure 3.1.

Table 3.1 Fibre properties

Cotton Fibre	HVI (High Volume Instrument) test results				Bare sorter analysis	
	2.5% Span length (mm)	Bundle strength (g/tex)	Fineness (micronaire)	Short fibre index (SFI)	Effective length (mm)	Short Fibre (%)
Grey combed S-6	27.59	32.6	4.1	6.6	33	10.32
Dyed Combed S-6	27.47	20.43	4.2	6.7	33	10.73

Table 3.1 indicates that there is a drop in fibre strength after dyeing. Also cotton fibres become slightly coarser after dyeing. The surface properties of cotton fibre are affected by dyeing process. Chemicals and dyes used during scouring and dyeing lead to eroding and

degrading the fibres which result reduction in fibre strength after chemical processing. Moreover, a large portion of the wax present on the cotton fibre surface is removed during scouring and dyeing and that leads to cotton fibre damage. In dyeing process, dyes and chemicals are being deposited / penetrated on the fibre and that causes the cotton fibre slightly coarser.

(a) Black dyed cotton fibre

(b) Layering after mixing

(c) Feeding at Blow room

(d) Carding

(e) Breaker Draw frame (f) Finisher draw frame

(g) Speed frame (h) Ring Frame

Figure 3.1 Stages of cotton mélange yarn manufacturing process

In case of mélange yarn production, the dyed fibre percentage in the mixing is commonly known as shade percentage or shade depth (%). Mixing of dyed and grey fibres was done at blow room stage to produce ‘blow room blended mélange yarn’. Figure 3.2 depicts the process flowchart for producing mélange yarn by blow room blend method.

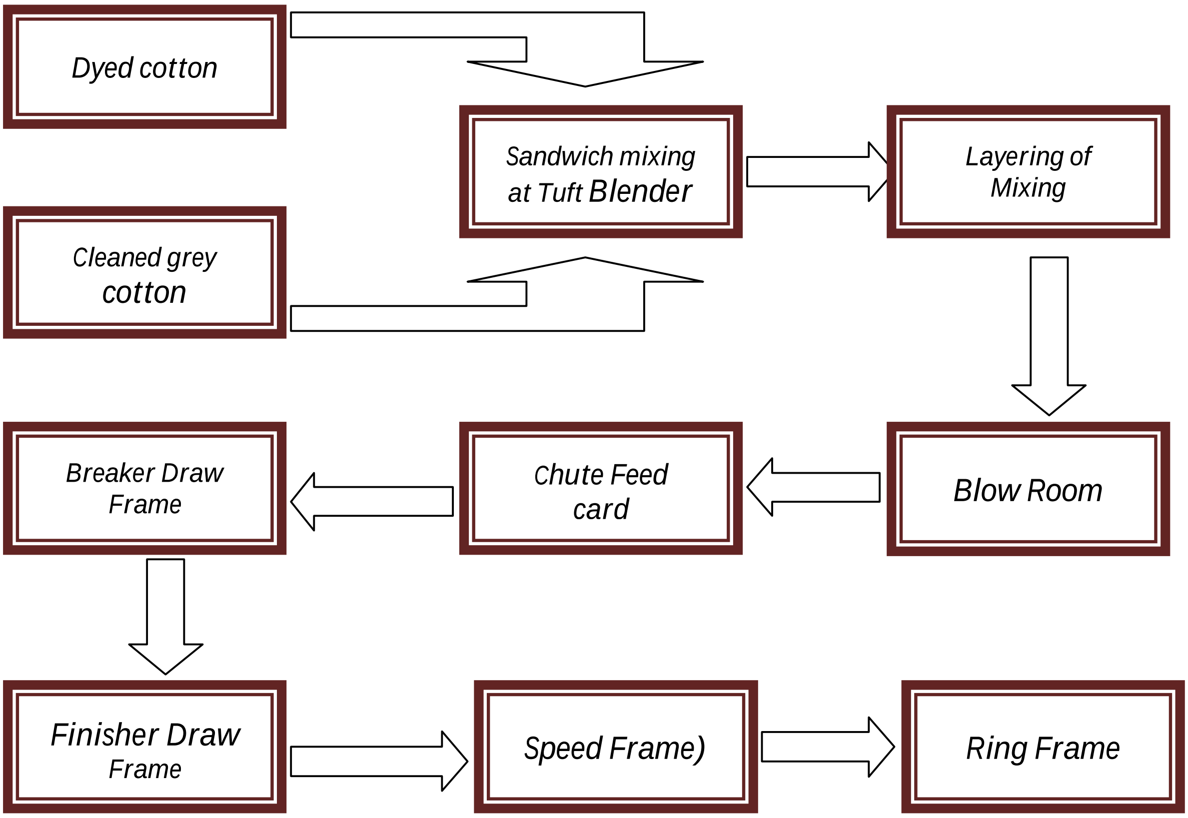


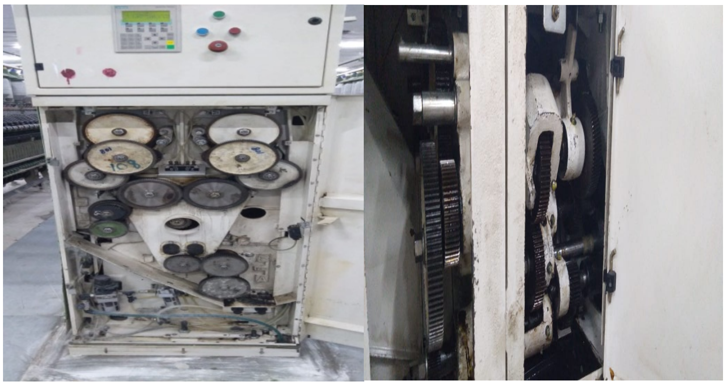
Figure 3.2 Process flow chart for blow room blend mélange yarn

Table 3.2 Controlled factors and their levels

Controlled factors	Coded level		
	-1	0	+1
Shade depth (%), X_1	10	40	70
Spindle speed (rpm), X_2	12500	13500	14500
Twist multiplier (TM), X_3	3.5	3.7	3.9

Three controlled factors, namely shade depth (%), yarn twist multiplier (TM) and ring frame spindle speed (rpm) were chosen and for each factor three levels were selected based on expert's opinion. Table 3.2 shows the actual values of controlled factors corresponding to their coded levels. The controlled factors X_1, X_2 and X_3 correspond to shade depth (%), spindle speed (rpm) and TM respectively.

It is essential to plan the experiments in such a way that the data yielded can be analyzed to draw a valid conclusion. Therefore, an experimental design was chosen to prepare the yarn samples to analyze the effect of controllable factors on responses with minimum number of experimental runs. Along with controllable factors, there exist certain unavoidable noise factors that may affect the yarn properties. Therefore, it is necessary to incorporate the unavoidable noise factors along with controlled factors and study their effect on mélange yarn quality parameters. Accordingly, Taguchi experimental design has been used to prepare the yarn samples. Two different noise parameters were considered in this study i.e. samples were made at two different positions of the ring frame (gear side and fan side) as shown in Figure 3.3 and at two positions of the bobbin (top and bottom) as shown in Figure 3.4. Yarn samples were prepared in a LR/6 (Laxmi Reiter) conventional ring spinning system according to the L9 orthogonal array as shown in Table 3.3. For each of the experimental run, two noise factors each at two levels produced four repetitions. Therefore, total numbers of samples were 36 (9 × 4). The actual values of the noise factors corresponding to their coded levels are shown in Table 3.4.



(a) (b)

Figure 3.3 Position of ring frame gear side (a) and fan side (b)

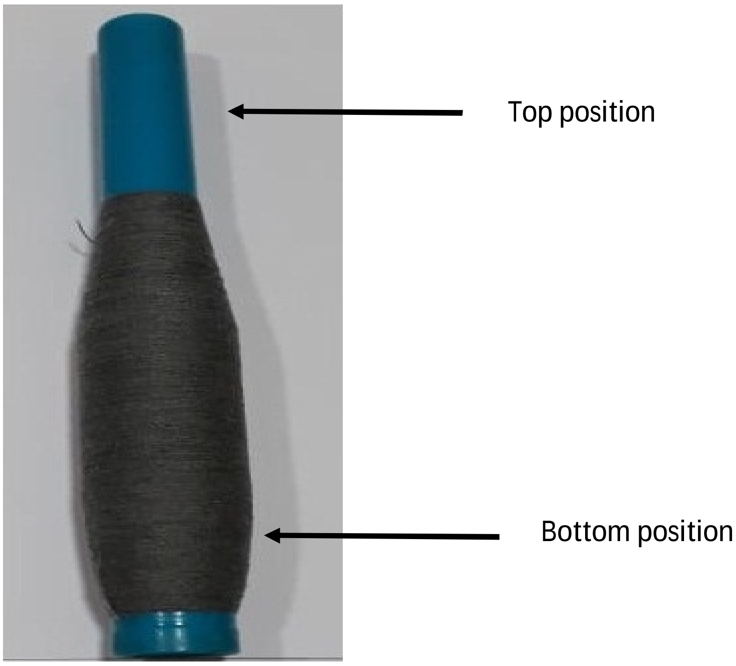


Figure 3.4 Position of bobin bottom (a) and top (b)

Table 3.3 L9 (3^3) orthogonal array

Experimental run	Controlled factors			Noise factors	
	X_1	X_2	X_3	Machine End	Bobbin position
1	-1	-1	-1	±1	±1
2	-1	0	0	±1	±1
3	-1	+1	+1	±1	±1
4	0	-1	0	±1	±1
5	0	0	+1	±1	±1
6	0	+1	-1	±1	±1
7	+1	-1	+1	±1	±1
8	+1	0	-1	±1	±1
9	+1	+1	0	±1	±1

Table 3.4 Noise factors and their levels

Noise factors	Coded level	
	-1	+1
Machine end	Motor end	Gear end
Bobbin position	Top position	Bottom position

3.2.2 Testing of samples

All the thirty six yarn samples were conditioned at standard temperature of 27±2°C and 65±4% relative humidity for 24 hours. Subsequently, the samples were evaluated for yarn unevenness (U %), imperfections (IPI), hairiness index (HI), strength (cN/tex) and breaking elongation (%) using suitable testing instruments and methods. For each of 36 yarn samples, 10 readings were taken for measuring the average U%, IPI and HI. Average yarn strength and breaking elongation were estimated for each type of yarn based on 1000 tests.

3.2.2.1 Yarn unevenness (U %)

The variation of mass per unit length of yarn is generally known as irregularity or unevenness. It is the percentage mass deviation of unit length of material which is caused by uneven fibre distribution along the length of the strand. The yarn evenness is described as U % = Mean deviation / Mean ×100.

Yarn U % is proportional to the intensity of the mass variations around the mean value. Higher the U% more is the yarn unevenness. Yarn U% was investigated by a capacitance based evenness tester (USTER TESTER-4) with yarn withdrawal speed of 400 m/min and testing time of 1 min. The working principle of capacitance based URTER TESTER-4 is described as mentioned below:

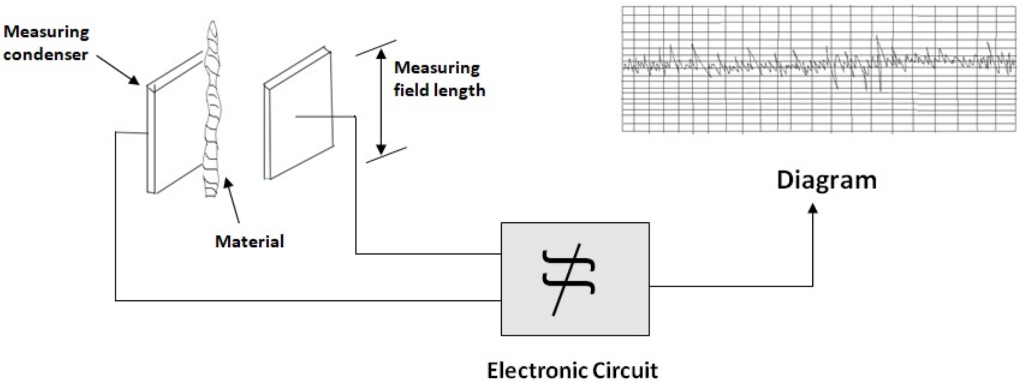


Figure 3.5 Schematic diagram of working principle of yarn evenness tester

If a dielectric material such as yarn is introduced into the space between the parallel plate capacitor, the capacitance of the capacitor changes which is proportional to the mass of the material present. Thus if a yarn is drawn at constant speed through the parallel plate capacitor as shown in Figure 3.5, the changes in capacitance will follow the variation in weight/unit length of the yarn. This signal is then processed by digital processor to get mass variation. A USTER TESTER-4 of yarn evenness tester is shown in Figure 3.6.

Figure 3.6 Uster tester 4 – yarn evenness tester

3.2.2.2 Yarn imperfections (IPI)

IPI stands for imperfection index of yarns. The imperfections in the yarn refer to the total number of thin places (-50%), thick places (+50%) and neps (+200%) present per 1000 meter of yarn. The definitions of thin places (-50%), thick places (+50%) and neps (+200%) are given below:

- A thin place (-50%) means the cross section of the yarn at the thin place is only 50% of its mean cross section or less.
- A thick place of (+50%) means the cross section of the yarn at the thick place is 150% of its mean cross section or more.
- +200% neps indicates the cross section at nep is 200% of the mean cross section of the yarn or more.

The imperfections are referred to the frequently occurring yarn faults. Yarn imperfections are measured by capacitance based evenness tester USTER TESTER-4 with the same principle as described in 3.2.2.1.

3.2.2.3 Hairiness index (HI)

Yarn hairiness denotes the amount of hairs (protruding fibres) above the surface of the yarn. Especially, in case of staple fibre spun yarns, fibres tend to protrude outside the yarn body even though proper twisting is done. Usually hairiness is denoted in terms of Hairiness Index (HI) which represents the total length of hairs (in centimetre) measured over one centimetre yarn length. In most circumstances hairiness is an undesirable yarn property, giving rise to problems in fabric formation. An attachment mounted with USTER TESTER-4 evenness tester measures yarn hairiness index simultaneously with the yarn evenness measurement. In this instrument the yarn is illuminated by a parallel beam of infra-red light as it runs through the measuring head. Only the light that is scattered by fibres protruding from the main body of the yarn reaches the detector as is shown in Figure 3.7. The direct light is blocked from reaching the detector by an opaque stop. The amount of scattered light is then a measure of hairiness and it is converted to an electrical signal by the apparatus. The instrument is thus monitoring the total hairiness only.

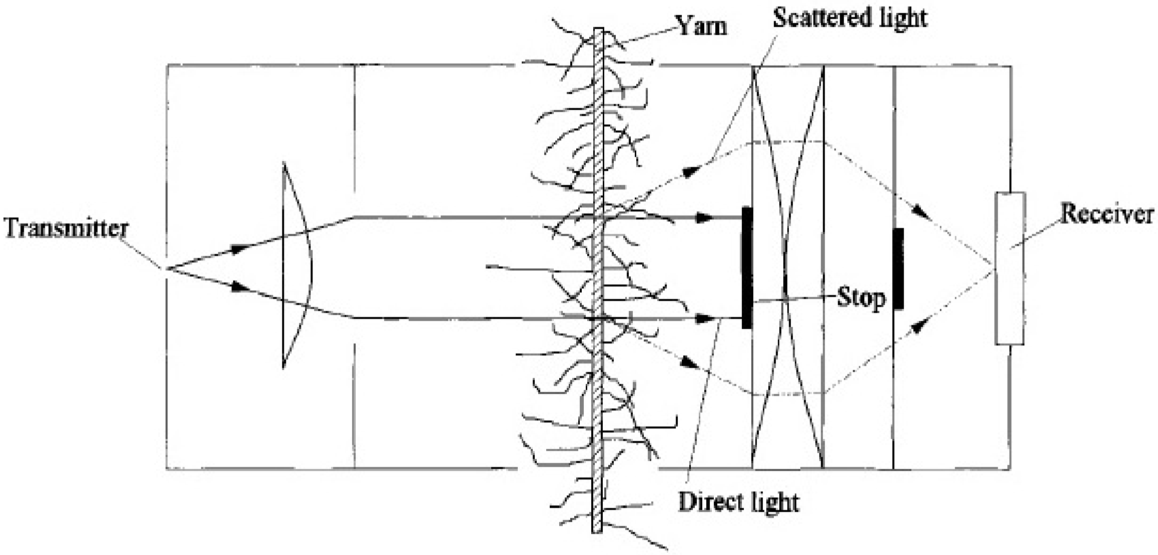


Figure 3.7 Schematic diagram of measurement of hairiness by scattered light

3.2.2.4 Yarn strength (cN/tex) and breaking elongation (%)

Yarn tensile property is a parameter of vital importance because it directly influences a number of mechanical properties of fabrics. Some importance terms related to yarn tensile property are defined below:

- Breaking force (cN) – the maximum force required to break the specimen.
- Breaking elongation (%) – elongation of the specimen at breaking load expressed as a percentage of testing length.
- Tenacity (cN/tex) – the breaking force per unit linear density of the unstrained specimen.

USTER TENSOJET instrument was used to measure the tensile properties of all the yarn samples using a specimen length of 500 mm, extension rate of 400 m/min and pre-tension of 0.5 cN/tex. This instrument works with the principle of CRE (constant rate of extension), where the rate of elongation of the specimen is kept constant. In this instrument, the strain-gauge principle is employed for measuring the load. A metallic wire is used as a strain gauge which changes its resistance under loading due to the change in its length and cross-sectional area. If the length of the wire increases from l to $l + \Delta l$ under loading, its resistance increases from R to $R + \Delta R$. The resistance changes linearly with the strain. The strain gauges are bonded to a cantilever metallic beam. The yarn specimen is clamped between two jaws. The upper jaw is attached to the free end of the cantilever beam and a lower jaw is lowered at a constant velocity which develops tensile loading in the specimen. Under this loading, the cantilever beam bends such that outer strain gauges subject to tension while the inner gauges undergo compression. Thus the applied load in the specimen causes changes in dimensions of the strain gauges which in turn cause changes their resistances. The magnitude of the load applied can be obtained by measuring the changes in resistances of the strain gauges. Basically the strain gauges are connected to form a Whetstone bridge. Before the application of load, the bridge is balanced, thus the voltage output becomes zero. An application of load causes the changes in resistances of the strain gauges, therefore the bridge becomes unbalanced. The unbalancing of the bridge causes an output voltage which is proportional to the applied load. The output voltage is amplified with a suitable electric circuit and converted into a digital signal.

The yarn tenacity is calculated from the peak force which occurs anywhere between the beginning of the test and the final rupture of the specimen. The breaking elongation is calculated from the clamp displacement at the point of peak force. A USTER TENSOJET tester is shown in Figure 3.8.

Figure 3.8 Uster Tensojet – yarn tensile properties tester

3.2.3 Analysis of the Response

The Taguchi method is a statistical approach developed by (Taguchi et al., 2005). This method has become an important tool in engineering for improving the quality of manufactured products by minimizing the effect of causes of variation. In this method a special set of arrays known as orthogonal arrays and signal to noise ratio (S/N) are used. In orthogonal array, combination of a set of arrays of parameters and levels are used to conduct minimum number of experiments to provide complete information of all the parameters that influence the response. A typical L9 orthogonal array is shown in Table 3.3 with three parameters, each having three levels. The outputs of the experiments are then transformed into a Signal to Noise ratio (S/N ratio) that represents the ratio of sensitivity to variability.

Maximum S/N ratio signifies minimum effect of noise factors and vice versa. Therefore, the higher S/N ratio indicates better quality. The S/N needs to be maximized in order to minimize the effect of noise. The S/N ratio is calculated using the following equations (Ross, 1996; Taguchi, et al., 2005; Zeydan, 2008) based on whether the response parameters are 'nominal-the-best', 'larger-the-better', or 'smaller-the-better'.

a) Nominal the best

$$\frac{S}{N} = 10 \log \left[\frac{\bar{y}}{S_y^2} \right] \qquad \text{... (3.1)}$$

b) Larger the better

$$\frac{S}{N} = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right] \qquad \text{... (3.2)}$$

c) Smaller the better

$$\frac{S}{N} = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \qquad \text{... (3.3)}$$

where $\bar{y}$ is the mean of observed data, S_y^2 is the variance of y, n is the number of experiments in the orthogonal array and y_i is the i^{th} value measured.

In the present work, S/N ratios of the yarn U%, IPI and HI have been calculated using Equation (3.3) for 'smaller-the-better', whereas that of yarn strength and breaking elongation (%) have been calculated using Equation (3.2) for 'larger-the-better'. The optimum level for each response is the level at which the S/N ratio is maximum. An ANOVA analysis of the S/N ratio is also done to understand the percentage contribution of each controlled parameter.

3.3 Results and discussion

The experimental values of yarn quality parameters like yarn strength, elongation at break (%), U%, imperfections and hairiness index, for 20’s Ne cotton mélange yarn are shown in Table 3.5. The yarn samples have a strength ranging from16.70 cN/tex to 20.75 cN/tex, elongation at break (%) ranging from 3.82 to 4.97, U % ranging from 8.67 % to 9.72%, imperfection ranging from 25.2 to 59.50 and hairiness index ranging from 4.47 to 5.89.

3.3.1 Yarn strength and breaking elongation

The experimental results of average yarn strength and breaking elongation with their calculated S/N ratios (larger-the-better) are shown in Table 3.6. It is observed from Table 3.6 that the maximum S/N ratio for yarn strength is 26.24 cN/tex and that for breaking elongation is 13.24 %. The optimum combination of parameters for maximum S/N ratio of yarn strength is 10%, 3.9 and 14500 rpm for shade depth, TM and spindle speed respectively, and that for the breaking elongation is 40%, 3.9, 12500 rpm for shade depth, TM and spindle speed respectively.

Table 3.5 Parameters and properties of 20’s Ne cotton mélange yarn

Sl. No.	Controlled factors			Noise factors		Yarn properties				
	X_1 (Shade depth, %)	X_2 (Spindle speed , rpm)	X_3 (Twist multiplier, TM)	Machine end	Bobin position	U %	Tenacity (cN/tex)	Imperfection (IPI)	Elongation at break (%)	Hairiness index
1	-1	-1	-1	-1	-1	8.67	19.11	25.2	4.41	4.58
2	-1	-1	-1	-1	+1	8.72	18.73	27.3	4.40	4.88
3	-1	-1	-1	+1	-1	8.69	19.11	25.6	4.46	4.56
4	-1	-1	-1	+1	+1	8.75	18.77	28.4	4.39	4.76
5	-1	0	0	-1	-1	8.68	20.10	25.8	4.22	4.47
6	-1	0	0	-1	+1	8.75	19.97	29.3	4.71	4.63
7	-1	0	0	+1	-1	8.71	20.05	30.5	4.14	4.49
8	-1	0	0	+1	+1	8.78	19.80	27.4	4.77	4.67
9	-1	+1	+1	-1	-1	8.91	20.37	32.3	4.21	4.70
10	-1	+1	+1	-1	+1	8.88	20.27	35.6	4.45	4.79
11	-1	+1	+1	+1	-1	8.83	20.68	33.6	4.35	4.60
12	-1	+1	+1	+1	+1	8.92	20.75	36.8	4.46	4.86

Sl. No.	Controlled factors			Noise factors		Yarn properties				
	X_1 (Shade depth, %)	X_2 (Spindle speed , rpm)	X_3 (Twist multiplier, TM)	Machine end	Bobin position	U %	Tenacity (cN/tex)	Imperfection (IPI)	Elongation at break (%)	Hairiness index
13	+1	0	-1	-1	-1	9.54	17.35	40.1	4.15	5.12
14	+1	0	-1	-1	+1	9.51	18.39	41.5	4.96	5.45
15	+1	0	-1	+1	-1	9.47	17.69	40.6	4.28	5.34
16	+1	0	-1	+1	+1	9.49	17.99	42.7	4.87	5.59
17	+1	+1	0	-1	-1	9.46	18.45	44.6	4.44	5.36
18	+1	+1	0	-1	+1	9.55	18.58	45.6	4.71	5.59
19	+1	+1	0	+1	-1	9.51	18.53	40.8	4.53	5.31
20	+1	+1	0	+1	+1	9.49	18.50	50.1	4.70	5.54
21	+1	-1	+1	-1	-1	9.56	16.70	45	3.82	5.62
22	+1	-1	+1	-1	+1	9.62	16.97	47.3	4.14	5.74
23	+1	-1	+1	+1	-1	9.67	17.21	57.6	4.33	5.46
24	+1	-1	+1	+1	+1	9.72	17.05	59.5	4.38	5.65

Sl. No.	Controlled factors			Noise factors		Yarn properties				
	X_1 (Shade depth, %)	X_2 (Spindle speed , rpm)	X_3 (Twist multiplier, TM)	Machine end	Bobin position	U %	Tenacity (cN/tex)	Imperfection (IPI)	Elongation at break (%)	Hairiness index
25	0	+1	-1	-1	-1	9.34	18.66	56.3	4.45	5.39
26	0	+1	-1	-1	+1	9.32	19.02	43.6	4.66	5.55
27	0	+1	-1	+1	-1	9.30	19.50	51.3	4.51	5.36
28	0	+1	-1	+1	+1	9.28	19.36	51.5	4.77	5.66
29	0	-1	0	-1	-1	9.36	18.23	46.3	4.13	5.73
30	0	-1	0	-1	+1	9.39	18.56	54.5	4.97	5.74
31	0	-1	0	+1	-1	9.40	18.11	50.4	4.03	5.56
32	0	-1	0	+1	+1	9.41	18.46	53.1	4.67	5.78
33	0	0	+1	-1	-1	9.43	17.42	55.5	3.87	5.61
34	0	0	+1	-1	+1	9.47	17.75	58.6	4.15	5.89
35	0	0	+1	+1	-1	9.46	17.75	47.9	3.85	5.63
36	0	0	+1	+1	+1	9.49	17.68	55.2	4.28	5.74

	U %	Tenacity (cN/tex)	Imperfection (IPI)	Elongation at break (%)	Hairiness index
Mean	9.24	18.66	42.71	4.41	5.26
Minimum	8.67	16.70	25.20	3.82	4.47
Maximum	9.72	20.75	59.50	4.97	5.89
Range	1.05	4.05	34.30	1.15	1.42

Table 3.6 Average values of yarn strength, breaking elongation (%) and S/N ratios

Experiment Number	Factors and their levels			Yarn properties			
	X_1	X_2	X_3	Strength (cN/tex)	S/N ratio	Breaking elongation (%)	S/N ratio
1	-1	-1	-1	18.93	25.54	4.42	12.9
2	-1	0	0	19.98	26.01	4.46	12.93
3	-1	+1	+1	20.52	26.24	4.37	12.8
4	0	-1	0	17.86	25.03	4.57	13.11
5	0	0	+1	18.52	25.35	4.59	13.23
6	0	+1	-1	16.98	24.60	4.17	12.36
7	+1	-1	+1	19.13	25.63	4.60	13.24
8	+1	0	-1	18.34	25.27	4.45	12.87
9	+1	+1	0	17.65	24.93	4.04	12.1

Table 3.7 Response for S/N ratios of yarn strength (cN/tex) and breaking elongation (%)

Factors	Yarn strength (cN/tex)					Yarn breaking elongation (%)				
	Average S/N			Range	Rank	Average S/N			Range	Rank
	Level -1	Level 0	Level +1			Level -1	Level 0	Level +1		
X_1	25.93	25.28	24.99	0.94	1	12.88	12.74	12.90	0.16	3
X_2	25.40	25.54	25.26	0.28	3	13.08	13.01	12.42	0.66	1
X_3	25.14	25.33	25.74	0.60	2	12.71	12.71	13.09	0.38	2

The response for S/N ratios of yarn strength and breaking elongation are shown in Table 3.7. The summary of ANOVA conducted on S/N ratios of yarn strength and breaking elongation along with the percentage contributions of different parameters are shown in Table

3.8. It shows that the shade depth (%) has maximum impact on yarn strength followed by yarn twist (TM) and spindle speed (rpm). However, spindle speed (rpm) has maximum impact on yarn elongation at break (%) followed by yarn twist (TM) and shade depth (%).

The effect of various parameters on S/N ratios of yarn strength is depicted in Figure 3.9. It is evident that yarn strength reduces with the increase of shade depth (%) which may be ascribed to the higher proportion of weak dyed fibre content in the yarn cross section. During dyeing the fibre strength reduces which in turn reduces the yarn strength. It is also evident from Figure 3.9 that yarn strength increases with TM in the present experimental set up. An increase in twist increases the fibre-to-fibre cohesion resulting in higher yarn strength. The spindle speed doesn't show any significant effect on the yarn strength within the given experimental range.

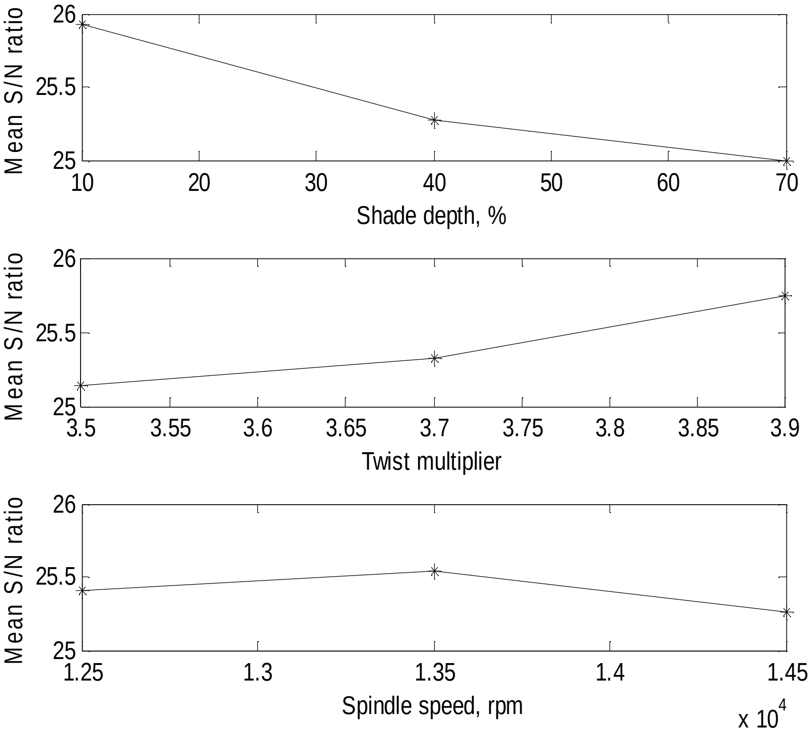


Figure 3.9 S/N ratio plot of yarn strength (cN/tex) for 20’s Ne cotton mélange yarn

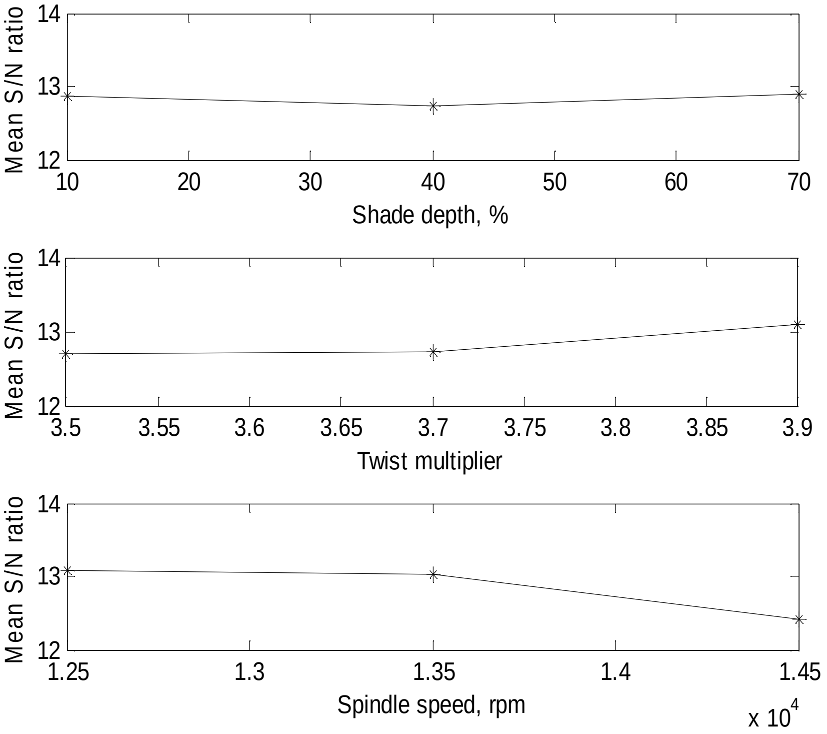


Figure 3.10 S/N ratio plot of yarn breaking elongation (%) for 20’s Ne cotton mélange yarn

Figure 3.10 depicts the effect of various parameters on S/N ratios of yarn breaking elongation. It is apparent from Figure 3.10 that there is hardly any impact of shade depth (%) on yarn breaking elongation (%) within the experimental range. Figure 3.10 also shows that yarn breaking elongation is marginally increased with the increase of TM but it is significantly reduced at higher spindle speed. Incraese of TM increases the fibre helix angle in the yarn. While a yarn is subjeced to tensile testing, initially the helical fibres become straight to some extent before their straining. This phenomenon could be the reason for marginal increase of yarn breaking elongation with higher TM. Whereas at higher spindle speed twisting occurs under higher spinning tension which causes more straightaining of fibres while they are emerging out from the front roller nip and thereby reducing yarn breaking elongation.

Table 3.8 ANOVA summary conducted on S/N ratios of yarn strength and breaking elongation (%)

Factors	Yarn strength (cN/tex)				Yarn breaking elongation (%)			
	SS	DF	MS	PC	SS	DF	MS	PC
X_1	1.3899	2	0.69497	63.96	0.048319	2	0.024159	4.03
X_2	0.12178	2	0.060891	5.60	0.80344	2	0.40172	67.43
X_3	0.57628	2	0.28814	26.52	0.28978	2	0.14489	24.33
Residual	0.085046	2	0.042523	3.92	0.050038	2	0.025019	4.21
Total	2.173	8			1.1916	8		

SS-Sum of squares; DF-Degree of freedom; MS- Mean square; PC- Percentage contribution

Table 3.8 shows the summary of ANOVA conducted on S/N ratios on yarn strength and yarn elongation at break along with the percentage contribution of different factors on the responses of yarn strength and yarn elongation at break. It is obvious from Table 3.8 that, the shade depth (%) is the most dominating factor affecting yarn strength with 63.96% contribution. The next dominating factor affecting yarn strength is TM which has 26.52% contribution. The spindle speed has only a little contribution i.e. 5.6% on yarn strength. In case of yarn breaking elongation the most dominating parameter is spindle speed followed by TM and shade depth with percentage contribution of 67.43%, 24.32% and 4.06% respectively.

3.3.2 Yarn unevenness (U %) and imperfection (IPI)

The experimental results of average U%, IPI and their corresponding S/N ratios (smaller –the better) are shown in Table 3.9. Table 3.10 shows the response of S/N ratios of yarn unevenness (U %) and yarn imperfection (IPI).

Table 3.9 Average values of yarn U%, IPI and their S/N ratios

Experiment number	Factors and their levels			Yarn properties			
	X_1	X_2	X_3	U%	S/N ratio	IPI	S/N ratio
1	-1	-1	-1	8.71	-18.8	26.63	-28.52
2	-1	0	0	8.73	-18.82	28.25	-29.04
3	-1	+1	+1	8.88	-18.97	34.58	-30.79
4	0	-1	0	9.5	-19.56	41.22	-32.31
5	0	0	+1	9.5	-19.56	45.27	-33.14
6	0	1	-1	9.64	-19.68	52.35	-34.44
7	+1	-1	+1	9.31	-19.38	50.67	-34.13
8	+1	0	-1	9.39	-19.45	51.07	-34.18
9	+1	+1	0	9.46	-19.52	54.3	-34.72

Table 3.10 Response for S/N ratios of yarn U% and IPI

Factors	U%					IPI				
	Average S/N			Range	Rank	Average S/N			Range	Rank
	Level -1	Level 0	Level +1			Level -1	Level 0	Level +1		
X_1	-18.86	-19.45	-19.59	0.73	1	-29.44	-34.34	-33.29	4.90	1
X_2	-19.25	-19.27	-19.39	0.14	2	-31.65	-32.12	-33.31	1.66	2
X_3	-19.31	-19.29	-19.30	0.02	3	-32.37	-32.02	-32.68	0.66	3

It is observed from Table 3.9 that the highest S/N ratios of yarn U% and IPI are -18.8 and -28.52 respectively. The optimum combination of parameters that lead to the maximum S/N ratio of U% and IPI is 10%, 3.5 and 12500 rpm respectively, for shade depth, TM and spindle speed.

The response for S/N ratios as shown in Table 3.10 suggests that the shade depth (%) has the maximum impact on yarn evenness (U %) and yarn imperfection (IPI) followed by spindle speed (rpm) and yarn twist (TM).

Figure 3.11 and 3.12 show the effect of various parameters on U% and IPI respectively. It is observed from the Figures 3.11 and 3.12 that both U% and IPI increase at higher shade depth (%). As the shade becomes more darker, there is an increase in the fibre entanglement as well as fibre-to-fibre friction. Hence, the opening and drafting of fibres turn out to be more difficult which eventually leads to higher yarn unevenness and imperfections at darker shade. It is also observed that the TM has a marginal influence on both U% and IPI. The spindle speed has no significance influence on U% but yarn imperfection increases at higher spindle speed. At higher spindle speed the balloon size increases, which increases the frictional contact area at balloon control ring and traveller. Thus the rubbing action between yarn surface and thread guide, balloon control ring and ring traveller is more. As a result of the enhanced rubbing action, the longer protruding fibres of the yarn body get rolled up and generates neps and thick places. This leads to an increase in the yarn imperfection at higher spindle speed.

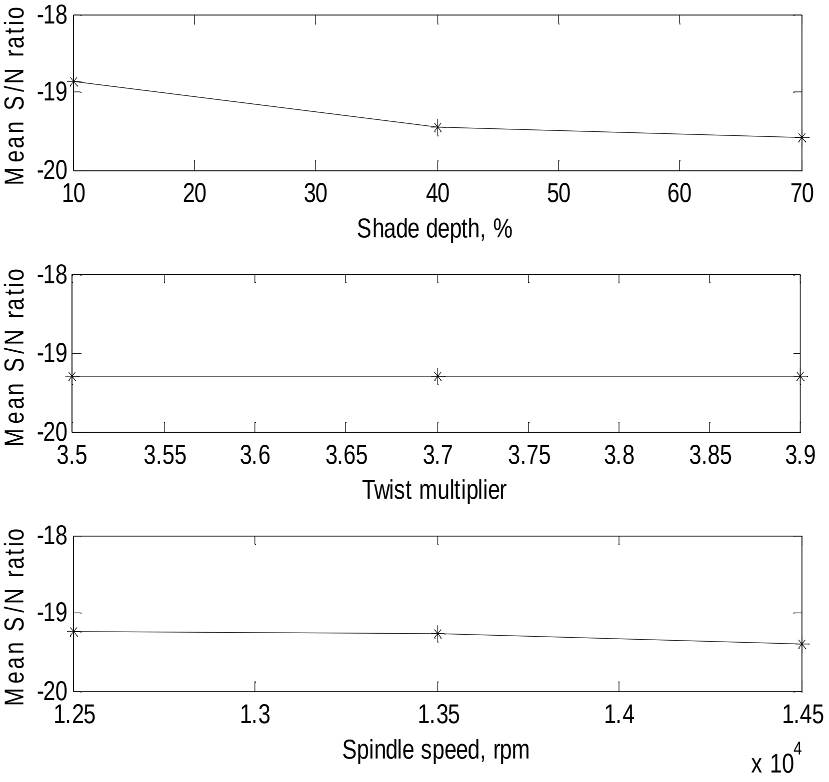


Figure 3.11 S/N ratio plot of yarn unevenness (U%) for 20's Ne cotton mélange yarn

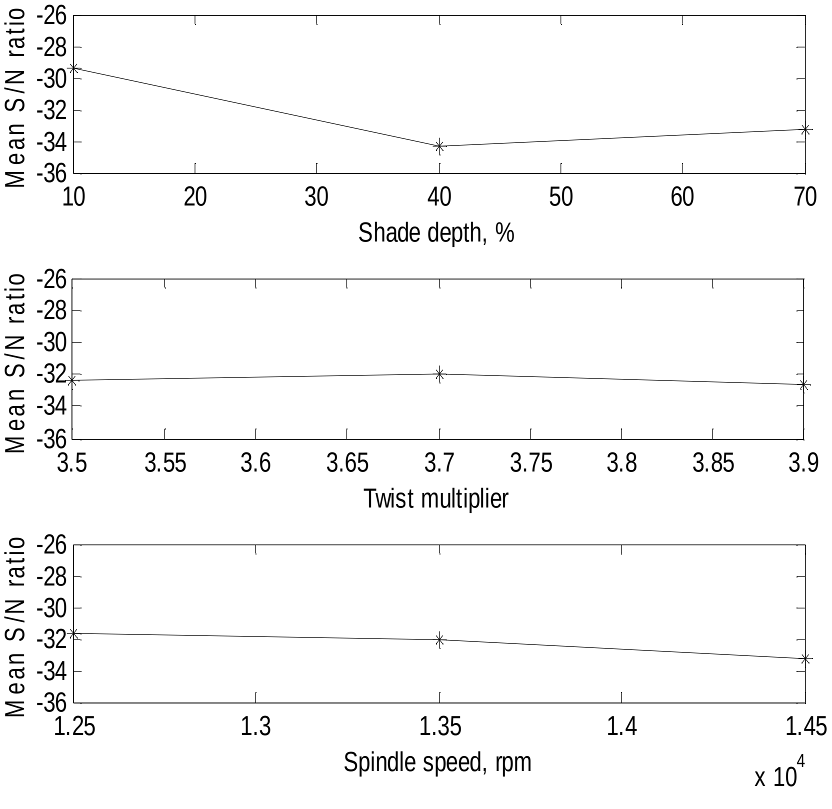


Figure 3.12 S/N ratio plot of yarn imperfection (IPI) for 20's Ne cotton mélange yarn

The ANOVA of S/N ratios of U% and IPI is depicted in Table 3.11 along with the percentage contribution of different parameters on these responses. It is evident from Table 3.11 that the shade depth (%) is the most dominating paramter influencing the U% and IPI with percentage contributions of 95.88% and 88.16% respectively. The second dominating factor is the spindle speed with a percentage contribution of 3.83% and 9.77% respectively for U% and IPI, nevertheless TM has a little influence on these responses in the present experimental set up.

Table 3.11 ANOVA summary conducted on S/N ratios of yarn U% and IPI

Factors	U%				IPI			
	SS	DF	MS	PC	SS	DF	MS	PC
X_1	0.90731	2	0.45366	95.88	39.887	2	19.944	88.16
X_2	0.036268	2	0.018134	3.83	4.4192	2	2.2096	9.77
X_3	0.0002511	2	0.00012554	0.03	0.66472	2	0.33236	1.47
Residual	0.002426	2	0.001213	0.26	0.27131	2	0.13565	0.60
Total	0.94626	8			45.243	8		

SS-Sum of squares; DF-Degree of freedom; MS- Mean square; PC- Percentage contribution

3.3.3 Yarn hairiness (HI)

The experimental results of average yarn hairiness and their corresponding calculated S/N ratios (smaller the better) for 20’s Ne cotton mélange yarn are shown in Table 3.11. The response of S/N ratios of hairiness index are shown in Table 3.12, whereas, the ANOVA conducted on hairiness are presented in Table 3.13.

Table 3.12 shows that the highest S/N ratio of yarn hairiness index (HI) is -13.19. The optimum parameters corresponding to the highest S/N ratio of HI is 10%, 3.7 and 13500 rpm respectively, for shade depth, TM and spindle speed.

The response for S/N ratios which are presented in Table 3.13 clearly show that the shade depth (%) has the maximum impact on yarn hairiness similar to other yarn properties yarn U% and imperfection, followed by spindle speed (rpm) and yarn twist (TM).

Table 3.12 Average values of yarn HI and their S/N ratios

Experiment number	Factors and their levels			Yarn properties	
	X_1	X_2	X_3	HI	S/N ratio
1	-1	-1	-1	4.70	-13.44
2	-1	0	0	4.57	-13.19
3	-1	+1	+1	4.74	-13.51
4	0	-1	0	5.48	-14.77
5	0	0	+1	5.54	-14.88
6	0	1	-1	5.80	-15.27
7	+1	-1	+1	5.49	-14.79
8	+1	0	-1	5.70	-15.12
9	+1	+1	0	5.72	-15.15

Table 3.13 Response for S/N ratios of yarn HI

Factors	HI				
	Average S/N			Range	Rank
	Level-1	Level0	Level+1		
X_1	-13.38	-15.02	-14.97	1.65	1
X_2	-14.33	-14.40	-14.64	0.31	2
X_3	-14.61	-14.37	-14.39	0.24	3

Table 3.14 ANOVA summary conducted on S/N ratios of yarn HI

Factors	HI			
	SS	DF	MS	PC
X_1	5.231	2	2.6155	95.05
X_2	0.1601	2	0.08008	2.9105
X_3	0.1046	2	0.0523	1.901
Residual	0.0075	2	0.00375	0.13633
Total	5.503	8		

SS-Sum of squares; DF-Degree of freedom;

MS- Mean square; PC- Percentage contribution

The ANOVA of S/N ratios of HI is shown in Table 3.14 along with the percentage contribution of different parameters on these responses. It is evident from Table 3.14 that the shade depth (%) is the most dominating paramter influencing the HI with percentage contributions of 95.05%. The second dominating factor is the spindle speed with a percentage contribution of 2.91%. and TM has a little influence on these responses in the present experimental setup.

From Figure 3.13, it is evident that HI increases with the increase of shade depth (%). The difficulty in opening of fibres during the mechanical processing at darker shade causes more chance of fibre breakage and thereby it increases the short fibre generation. The presence of more number of short fibres increases the number of protruding fibres in the yarn surface which in turn increases the hairiness of the yarn. Moreover, the fibre becomes coarser after dyeing and the coarser fibres have a tendency to migrate in the the outer surface of the yarn body during spinning. This phenomenon may also cause higher hairiness at darker shade. It is also observed from Figure 3.13 that spindle speed and TM have only a little influence on yarn hairiness index.

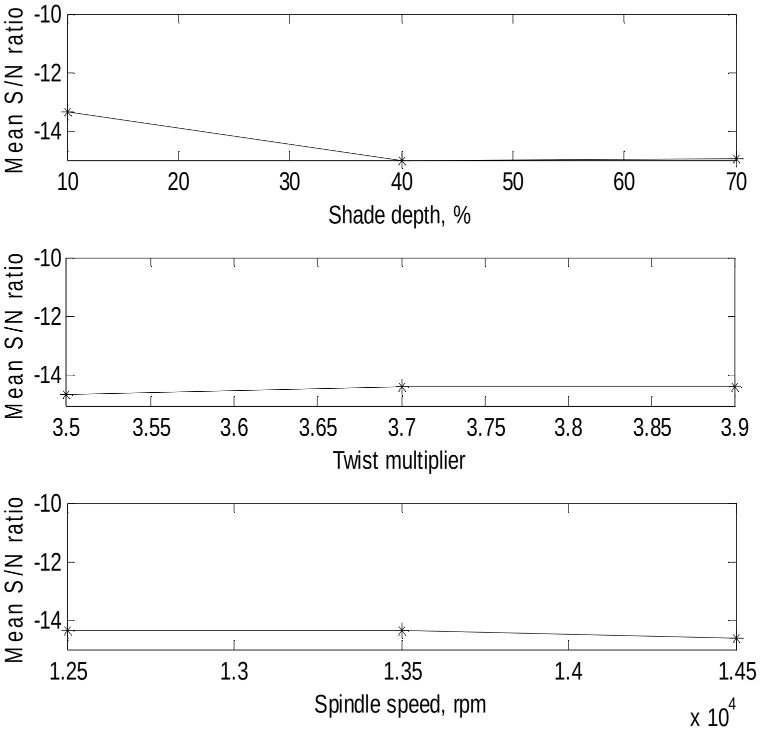


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Figure 3.13 S/N ratio plot of yarn hairiness (HI) for 20’s Ne cotton mélange yarn

3.4 Conclusions

This part of the research work determines the significant factors influencing the quality parameters of 20's Ne cotton mélange yarn considering the two noise factors using Taguchi method. The main advantage of the Taguchi experimental design lies in the introduction of uncontrolled noise factors in the experimentation. Taguchi design also provides a simple, systematic and efficient methodology for the optimization of controlled factors with few well defined experimental runs. Based on the S/N ratio and ANOVA results, it has been observed that the shade depth (%) and spindle speed (rpm) are the most significant parameters affecting mélange yarn quality. Higher shade depth and higher spindle speed causes deterioration in yarn quality parameters. In addition to that, the optimum levels of these controlled factors for each response were also obtained. The change in surface characteristics of cotton fibres during dyeing makes the mélange manufacturing process more difficult. Problems arising in drafting of dyed cotton at higher production speed also make the productivity level a limiting factor in achieving better mélange yarn quality. It can be concluded that shade depth (%) is the most dominating factor followed by spindle speed affecting yarn evenness, imperfection, tenacity, breaking elongation and hairiness. TM has significant impact on yarn strength and breaking elongation (%) only.

Chapter 4

Analysis of Influence of Spinning Process Variables and Shade Depth on Quality Parameters of Blow Room Blended Cotton Mélange Yarn using Box and Behnken Experimental Design

CHAPTER 4

ANALYSIS OF INFLUENCE OF SPINNING PROCESS VARIABLES AND SHADE DEPTH ON QUALITY PARAMETERS OF BLOW ROOM BLENDED COTTON MÉLANGE YARN USING BOX AND BEHNKEN EXPERIMENTAL DESIGN

4.1 Introduction

Any textile manufacturing process whether it is spinning, weaving, chemical processing or garment making involves an interaction of a large number of variables related to that process. The variables are input materials, process factors, ambient condition, etc. Spinning is the backbone of the textile manufacturing chain and the fabric quality is largely determined by the quality of spinning out put i.e. yarn. Although, technological advancement has enabled the textile industry to produce various kinds of fancy yarns, the quality and characteristics of that yarn decides its application further. Cotton mélange yarn is a latest fancy yarn product which has been well accepted by the textile value chain for its special effect. Ever changing fashion demands have made the fibre dyed cotton mélange yarn more popular in the fashion clothing sector. Cotton spun mélange yarn is produced mainly by traditional ring spinner with lower production efficiency and the dyeing process of cotton fibres lead to greater entanglement and cohesion among them and further mechanical processes lead to fibre damage which makes the cotton mélange yarn manufacturing process more difficult (Zou, 2014; Naik *et al.*, 2008). Increase in dyed fibre content in the mixture further increases the difficulties in cotton mélange yarn manufacturing. Customers demand for quality mélange yarn can be fulfilled by the selected raw material and optimized machinery set up.

As already mentioned before, an optimization problem requires objective functions and constraint functions. Since for optimization, selection of important controllable parameters affecting the objective functions and constraint functions are necessary so that mathematical relationships between the objectives, constraints and controllable parameters can be developed, an attempt was made to trace out the decisive factors controlling yarn unevenness (U %), tenacity, elongation at break, imperfection and hairiness of 20’s Ne blow room blended cotton mélange yarn. Therefore, experiments were conducted in the preceding Chapter 3 using Taguchi experimental design including noise parameters. It has been observed that shade depth (%) is the most decisive factor, followed by spindle speed, influencing yarn unevenness, imperfection, strength, elongation at break and hairiness for 20’s Ne blow room blended cotton mélange yarn. Yarn twist (TM) has significant impact on yarn strength and breaking elongation (%) only.

There is hardly any reported literature on the process parameters optimization of cotton mélange yarn manufacturing. Even no study has been reported on the effect of individual and interactive effect of raw material, spinning process parameters and productivity on cotton mélange yarn qualities. One of the main disadvantages of the Taguchi method is that the results obtained are only relative and do not able to draw exact relationship between the response and factors. Further, Taguchi method has some difficulty in accounting for interactions between factors. Thus in this work, an attempt has been made to investigate the individual and interactive effects of decisive factors such as raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) on the properties of blow room blended cotton mélange yarn using a Box and Behnken design of experiment. Attempt has also been made to derive the response surface equations of yarn quality parameters as functions of decisive factors for the purpose of optimization.

4.2 Materials and method

4.2.1 Preparation of yarn samples

Same grey and black dyed cotton fibres and production methods as described in Chapter 3 were followed to produce 20's Ne cotton mélange yarns.

Three controlled factors, viz., shade depth (%), ring frame spindle speed (rpm) and yarn twist multiplier (TM) were chosen and for each factor three levels were considered as mentioned in previous chapter (Table 3.2). The actual values of the controlled factors corresponding to their coded levels are shown in Table 4.1. The actual levels of controlled factors were taken within the range of industrially acceptable limits for mélange yarn production. The controlled factors X_1, X_2 and X_3 correspond to shade depth (%), spindle speed (rpm) and TM respectively. It is essential to plan the experiments so that the analysis of data yielded helps us to draw a valid conclusion. Therefore, an experimental design was chosen to prepare the mélange yarn samples to analyze the effect of controllable factors on the responses with minimum number of experimental runs. Yarn samples were prepared in a conventional ring spinning system according to the experimental plan of Box and Behnken (Adinarayana *et al.*, 2003) design as depicted in Table 4.2. The prepared yarn samples are shown in Figure 4.1.

Table 4.1 Actual values corresponding to coded levels

Coded level	Actual value		
	Shade depth (%) (X_1)	Spindle speed (rpm) (X_2)	Yarn TM (X_3)
-1	10	12500	3.5
0	40	13500	3.7
+1	70	14500	3.9

Table 4.2 Experimental plan for preparation of mélange yarn samples

Combination No.	Shade Depth (%)	Spindle speed (rpm)	Yarn TM
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

Figure 4.1 Prepared yarn samples of 20’s Ne blow room blend cotton mélange yarn

4.2.2 Testing of samples

All the fifteen yarn samples were placed for 24 hours in standard temperature of 27±2°C and 65±4% relative humidity. Subsequently, the samples were evaluated for yarn unevenness (U %), imperfections (IPI), hairiness index (HI), tenacity (cN/tex) and breaking elongation (%). All the testing was done as per the standards mentioned in Chapter 3. Yarn IPI is estimated as a sum total of number of +50% thick place, -50% thin place and +200% neps per Km length of yarn. For each of 15 yarn types, 10 readings were taken for measuring the average U%, IPI and HI. Average yarn tenacity and breaking elongation were estimated for each type of yarn based on 1000 readings.

4.2.3 Response surface equations

In this chapter, quadratic regression equation models (Dean and Voss, 1999) were used to relate various independent factors, namely shade depth (%), spindle speed and yarn twist multiplier (TM) with response variables, namely yarn unevenness (U %), imperfection, hairiness index, yarn tenacity and elongation at break. Equation (4.1) shows the general form of the models:

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_1 X_2 + \alpha_5 X_1 X_3 + \alpha_6 X_2 X_3 + \alpha_7 X_1^2 + \alpha_8 X_2^2 + \alpha_9 X_3^2 \quad (4.1)$$

where Y is the dependent variable or measured response, X_1, X_2 and X_3 are the different input factors to the model as indicated in Table 4.2 and $\alpha_{0,}$ α_1, α_2, α_3,…. α_9 are the coefficients of regression equation.

The regression coefficients of the fitted quadratic equation models were determined along with adjusted coefficient of determination(R^2_{adj}), mean absolute error (%) of the fitted models, beta coefficient (β) and percentage contribution of significant factors. The model explained the coefficient of determination as a measure of the proportion of variability in the response variable. The significance test of regression coefficients in the fitted regression equation models was conducted and those regression coefficients, which are significant at 95% confidence limits, were considered.

The beta (β) coefficients are the estimates resulting from an analysis carried out on the variables that have been standardized by subtracting their respective means and dividing by their standard deviations as shown in Equation (4.2).

$$Z_i = \frac{x_i - \bar{x}}{\sigma_x} \quad (4.2)$$

where Z_i is the i^{th} value of standardized variable, x_i is the i^{th} value of actual variable and σ_x stands for the standard deviation of the variable.

Standardization of independent variables, having different units, makes them comparable as all of them possess a mean =0 and standard deviation = 1 after standardization.

So, the regression coefficients, when standardized variables are used, can be used to appraise the strength of independent variable in determining the response variable in the fitted models, when the variables are measured in different units of measurement.

The percentage contribution of the i^{th} significant controlled factors (C_i) can be estimated by using following equation:

$$C_i\,(\%) = \frac{|\beta_i|}{\sum_{i=1}^{k}|\beta_i|} \times 100 \qquad (4.3)$$

where β_i is the beta coefficient of the i^{th} significant controlled factor and k is the total number of significant controlled factors.

4.3 Results and discussion

4.3.1 Yarn quality parameters

The experimental results of yarn quality parameters like U%, tenacity, elongation at break, imperfections (IPI) and hairiness index of blow room blended 20's Ne cotton mélange yarns for 15 experimental runs have been shown in Table 4.3. The yarn samples have U% ranging from 9.21% to 10.08%, tenacity ranging from 16.24 cN/tex to 19.51 cN/tex, imperfection ranging from 34.6 to 71.3, elongation at break ranging from 4.02% to 4.91% and hairiness index ranging from 4.09 to 5.43.

4.3.2 Response surface models

The response surface equations of the yarn quality parameters were derived from the experimental data using MATLAB coding. The estimated regression coefficients and *p*-values of model terms for different response variables are tabulated in Table 4.4. A minus sign of regression coefficient indicates that the value of response variable decreases with the corresponding increase of factor value and vice versa. If the *p*-value of the model term is less than 0.05 then that model term is significant, indicating statistical significance at 95% confidence level. Table 4.5 illustrates the fitted quadratic regression models with the significant regression coefficients along with the coefficient of determination (R^2_{adj}), mean accuracy of the fitted model and β-coefficient for different yarn quality parameters. It is evident from Table 4.5 that except yarn breaking elongation all other response variables show reasonably good R^2_{adj} values as well as mean accuracy (%), which substantiates a good fit of response surface equation to the experimental data. It is also observed from the values of percentage contribution of significant terms shown in Table 4.5 that the shade depth has more dominant influence on the yarn quality parameters (except breaking elongation) over other factors. This may be ascribed to the fact that the percentage change in shade depth from the lower to the upper level is 600 % (from 10% to 70%), whereas that for spindle speed and TM are 16 % (from 12500 rpm to 14500 rpm) and 11.43 % (from 3.5 to 3.9) respectively.

Table 4.3.Parameters and properties of 20's Ne blow room blend cotton mélange yarn

Experimental Run No.	X_1 (Shade depth, %)	X_2 (Spindle speed, rpm)	X_3 (Twist multiplier, TM)	Yarn properties				
				Evenness (U %)	Tenacity (cN/Tex)	Elongation at break (%)	Imperfection (per km)	Hairiness index (-)
1	-1	0	-1	9.24	18.34	4.19	41.8	4.43
2	1	0	-1	9.67	16.24	4.09	66.5	5.43
3	-1	0	1	9.26	19.51	4.34	34.6	4.09
4	1	0	1	9.65	17.35	4.37	61.5	5.09
5	-1	-1	0	9.21	19.44	4.91	44.1	4.31
6	1	-1	0	9.63	17.06	4.74	62.3	5.31
7	-1	1	0	9.42	18.65	4.03	52.8	4.23
8	1	1	0	9.87	17.53	4.35	71.3	5.23
9	0	-1	-1	9.73	17.94	4.25	43.0	4.86
10	0	-1	1	10.00	19.16	4.25	41.6	4.56

Experimental Run No.	X_1 (Shade depth, %)	X_2 (Spindle speed, rpm)	X_3 (Twist multiplier, TM	Yarn properties				
				Evenness (U %)	Tenacity (cN/Tex)	Elongation at break (%)	Imperfection (per km)	Hairiness index (-)
11	0	1	-1	10.08	17.79	4.11	53.8	4.75
12	0	1	1	9.92	18.74	4.02	53.3	4.88
13	0	0	0	9.54	17.97	4.12	47.1	4.69
14	0	0	0	9.66	18.85	4.35	48.3	4.72
15	0	0	0	9.88	18.72	4.25	53	4.69
Mean				9.65	18.22	4.29	51.67	4.75
Minimum				9.21	16.24	4.02	34.6	4.09
Maximum				10.08	19.51	4.91	71.3	5.43
Range				0.87	3.27	0.89	36.7	1.34

Table 4.4 Estimated coefficients (Coeff.) and p-values of model terms for different response variables

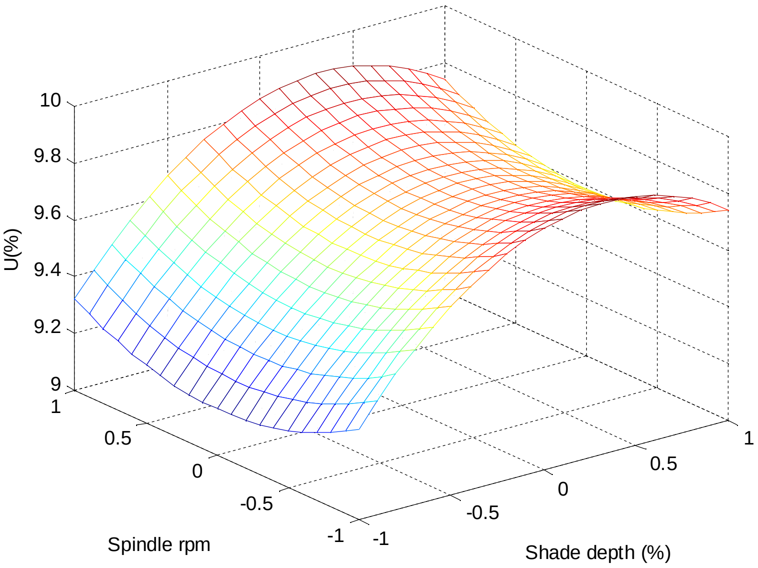
Model term	U (%)		Yarn tenacity		Elongation at break		Imperfection		Hairiness index	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	9.693	0.000	18.513	0	4.24	0	49.467	0	4.7	0
X_1	0.211	0.003	-0.97	0.000	0.01	0.883	11.037	0.0003	0.5	0.00003
X_2	0.090	0.076	-0.111	0.379	-0.205	0.025	5.025	0.010	-0.006	0.866
X_3	0.013	0.747	0.556	0.004	0.042	0.540	-1.762	0.220	-0.106	0.030
X_1^2	-0.319	0.003	-0.445	0.046	0.178	0.119	5.667	0.028	0.033	0.546
X_2^2	0.158	0.044	0.102	0.574	0.088	0.394	2.491	0.236	0.036	0.518
X_3^2	0.080	0.232	-0.207	0.275	-0.171	0.132	-4.033	0.081	0.026	0.636
X_1X_2	0.007	0.900	0.315	0.111	0.122	0.238	0.075	0.968	0	1
X_1X_3	0.010	0.867	-0.015	0.930	0.032	0.737	0.55	0.769	0	1
X_2X_3	-0.107	0.118	-0.067	0.696	-0.022	0.815	0.225	0.904	0.107	0.084

Table 4.5 Response surface equations of various mélange yarn quality parameters

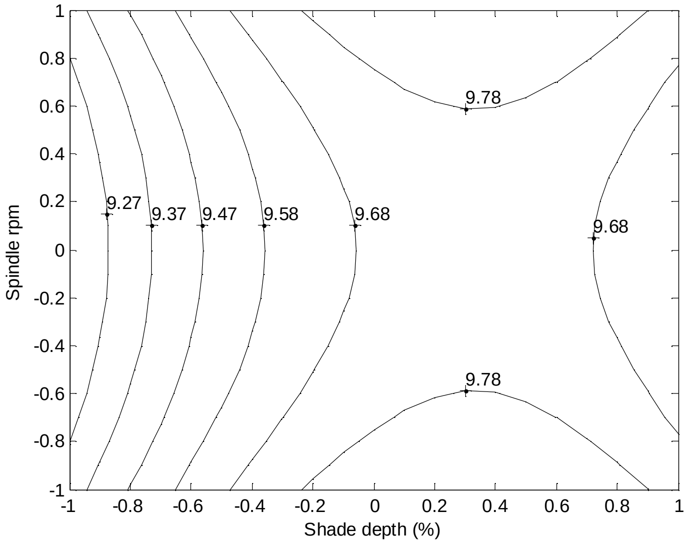
Yarn quality parameters	Response surface equation	R_{adj}^2	Mean accuracy (%)	β- coefficient of significant terms	Percentage contribution of significant terms (%)
Unevenness (U %)	$9.69+0.21X_1-0.32X_1^2+0.16X_2^2$	0.81	98.82	$\beta(X_1)= 0.58$ $\beta(X_1^2)= - 0.61$ $\beta(X_2^2)= 0.28$	$C(X_1)= 31.84$ $C(X_1^2)= 33.50$ $C(X_2^2)= 15.66$
Tenacity (cN/tex)	$18.51-0.97X_1+0.56X_3-0.44X_1^2$	0.89	98.61	$\beta(X_1)= - 0.79$ $\beta(X_3)= 0.45$ $\beta(X_1^2)= - 0.24$	$C(X_1)= 47.55$ $C(X_3)= 27.27$ $C(X_1^2)= 14.66$
Elongation at break (%)	$4.24 - 0.21X_2$	0.39	96.65	$\beta(X_2)= - 0.63$	$C(X_2)= 39.11$
Imperfection (IPI)	$49.47+11.04X_1+5.02X_2+5.67X_1^2$	0.88	94.05	$\beta(X_1)= 0.81$ $\beta(X_2)= 0.37$ $\beta(X_1^2)= 0.29$	$C(X_1)= 48.49$ $C(X_2)= 22.08$ $C(x_1^2)= 17.34$
Hairiness index (HI)	$4.7+0.5X_1-0.11X_3$	0.95	98.61	$\beta(X_1)= 0.95$ $\beta(X_3)= - 0.20$	$C(X_1)= 78.46$ $C(X_3)= 16.67$

4.3.2.1 Yarn unevenness (U %)

The response surface equation of mélange yarn unevenness (U %) is given in Table 4.5 and Figure 4.2 depicts the corresponding response surface plot and contour diagram. The response-surface equation indicates that the TM has no significant influence on yarn unevenness. It can be observed from the Figure 4.2 that shade depth and spindle speed has nonlinear effect on yarn evenness. The yarn unevenness increases with the increase of shade depth. Increase in dyed fibre in the mixture causes processing difficulties as the surface characteristics of dyed fibre changes after dyeing and there is an increase in the fibre entanglement as well as fibre to fibre friction. Opening and drafting difficulties while processing more dyed fibre in the mixture leads to uneven movement of fibres in the drafting zone. Increased erratic movement of floating fibres causes variation in cross sectional mass and results into more yarn unevenness. Also it is noted from Table 4.5 that percentage contribution value for quadratic term of spindle speed is 15.66, which is significantly lower than that of linear and quadratic terms of shade depth. Hence, the spindle speed has relatively much lower influence on yarn irregularity than the shade depth.



(a) Response surface plot

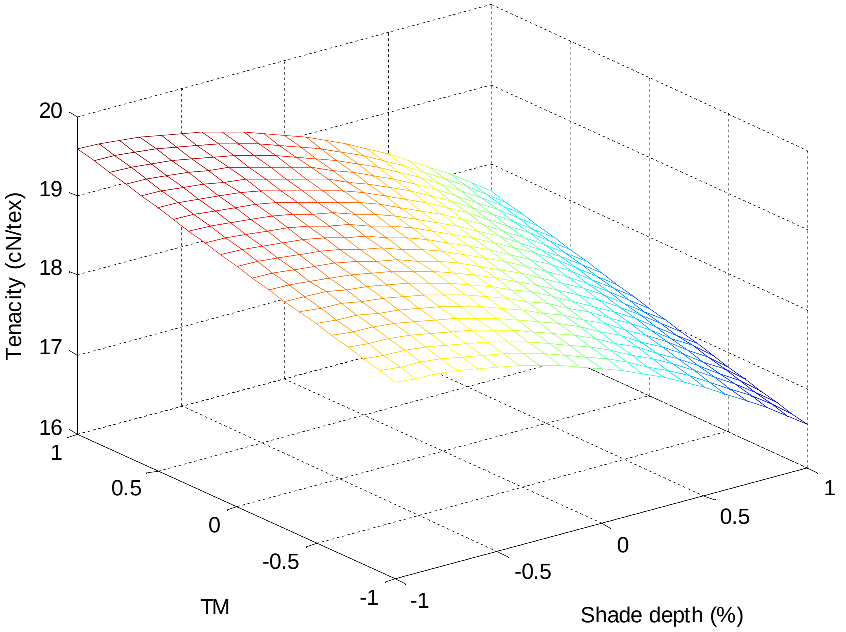


(b) Contour plot

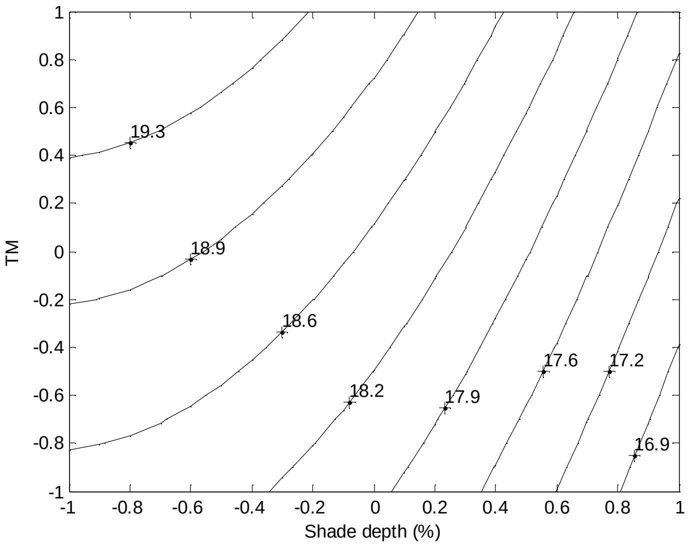
Figure 4.2 Response surface and contour plot of yarn unevenness as a function of shade depth and spindle rpm for blow room blended cotton mélange yarn

4.3.2.2 Yarn strength

Table 4.5 shows the response surface equation of mélange yarn tenacity and the corresponding response surface plot and contour diagram are illustrated in Figure 4.3. It is evident from the Figure 4.3 that yarn tenacity is significantly affected by the shade depth and yarn twist. As the shade depth increases the yarn tenacity reduces which may be ascribed to the higher proportion of weak dyed fibre content in the yarn cross section. The fibre strength reduces during the dyeing process and that drop in dyed fibre strength is reflected into yarn tenacity. Further, during mechanical processing of fibre more damage to weak dyed cotton fibre takes place. The damage of dyed fibres also results for the drop of yarn strength. It is also evident from the Figure 4.3 that yarn strength increases with the TM in the present experimental set up. Higher yarn twist causes more fibre-to-fibre cohesion by increased fibre surface contact and thereby augmenting the yarn strength. The spindle speed does not show any significant impact on the yarn tenacity within the present experimental set up.



(a) Response surface plot



(b) Contour plot

Figure 4.3 Response surface and contour plot of yarn tenacity as a function of shade depth and TM for blow room blended cotton mélange yarn

4.3.2.3 Yarn elongation at break

It is apparent from the response surface equation of Table 4.5 that mélange yarn elongation at break decreases with the increase of spindle speed. The effect of spindle speed on yarn breaking elongation is shown in Figure 4.4. At higher spindle speed twisting phenomenon occurs at higher spinning tension which causes more straightening of fibres while they are emerging out from the front roller nip and eventually yarn breaking elongation is reduced. Shade depth and yarn TM have no significant impact on the yarn breaking elongation.

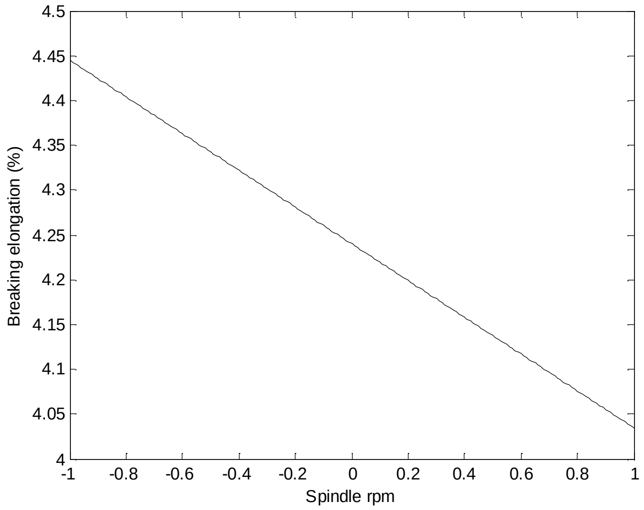
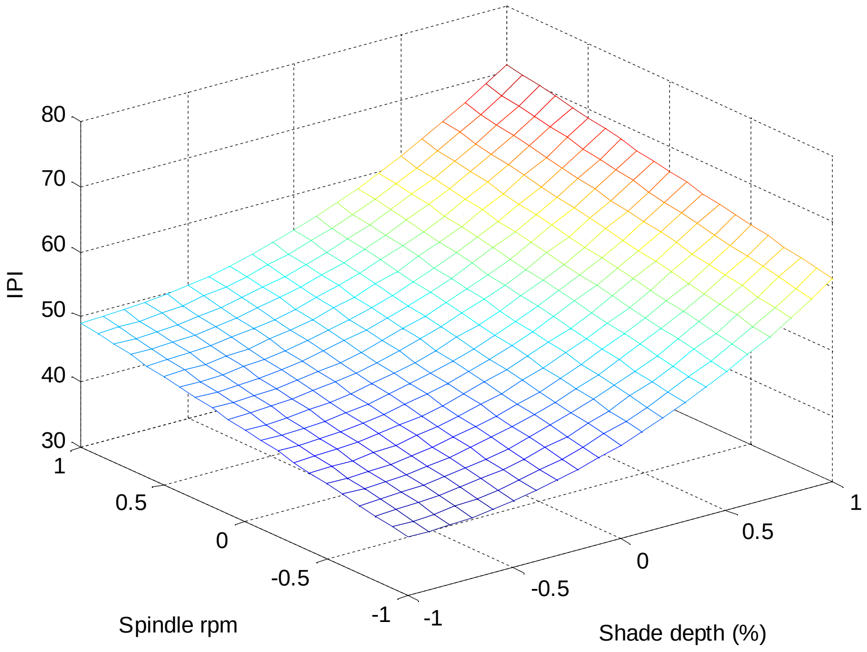


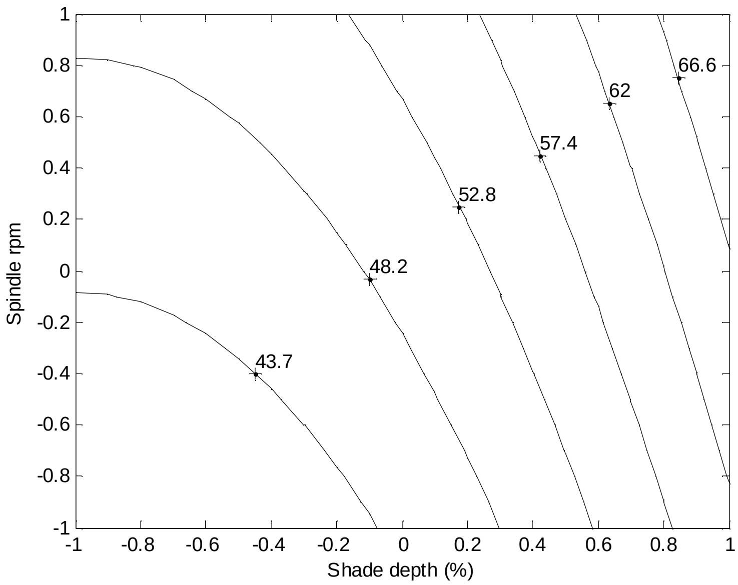
Figure 4.4 Effect of spindle rpm on yarn elongation at break for blow room blended cotton mélange yarn

4.3.2.4 Yarn imperfection

Response surface equation of mélange yarn imperfection (IPI) is given in Table 4.5. Figure 4.5 displays the response surface and contour plot of yarn IPI as a function of shade depth and spindle speed. It is clear from Figure 4.5 that the yarn imperfection incresaes with increase of shade depth and spindle speed. As the shade depth increases, opening and drafting difficulties increases and hence more fibre damage occurs which causes reduction in effective length of fibres. More short fibre content due to fibre damage may result in higher drafting wave which is responsible for more thick and thin places in the yarn. In addition, with the increase of shade depth, opening of fibres at blow room and card becomes difficult and causes more fibre entanglement, which in turn generates higher number of fibrous neps in the yarn. At higher spindle speed the rubbing action between yarn surface and thread guide, balloon control ring and ring traveller is more. Due to increased rubbing action, longer protruding fibres of the yarn body get rolled up and generates neps and thick places. Therefore imperfection level increases at higher spindle speed. Yarn TM has no significant impact on yarn imperfection.



(a) Response surface plot

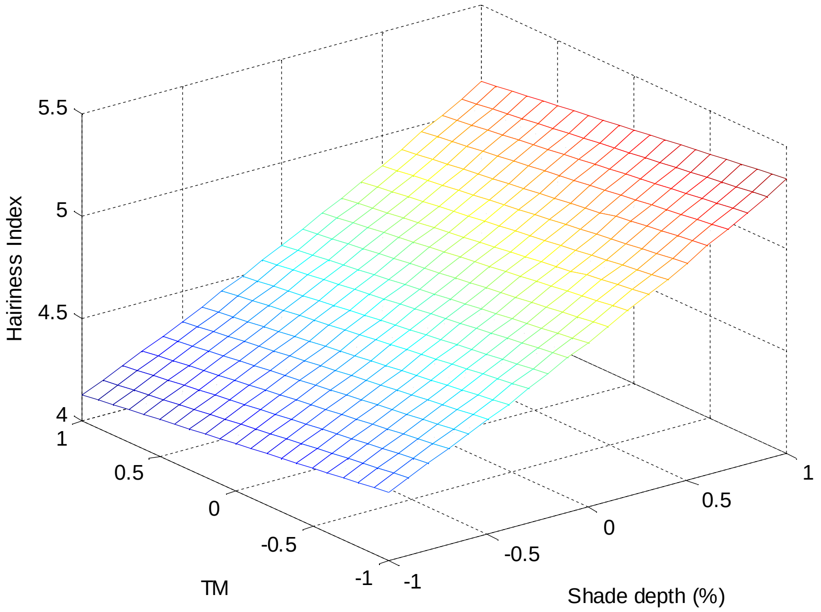


(b) Contour plot

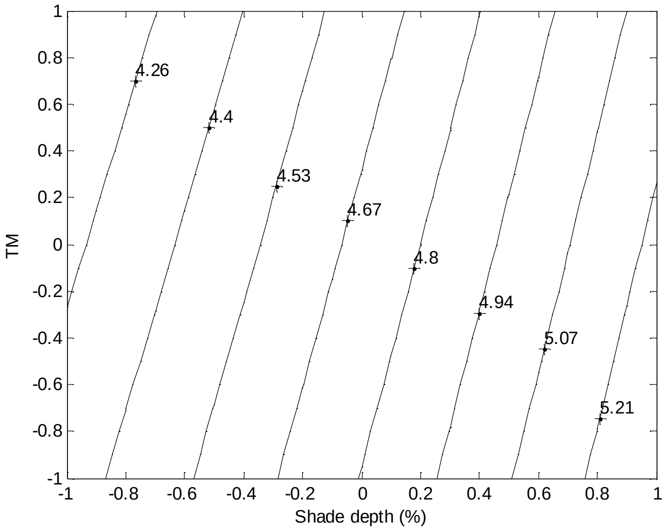
Figure 4.5 Response surface and contour plot of yarn imperfection (IPI) as a function of shade depth and spindle rpm for blow room blended cotton mélange yarn

4.3.2.5 Yarn hairiness

The response surface equation of mélange yarn hairiness is found to be a linear function of shade depth and TM (Table 4.5). Response surface and contour plot of yarn hairiness index (HI) is shown in Figure 4.6. It is obvious from Figure 4.6 that yarn HI increases with the increase of shade depth. In case of darker shade the difficulty in opening of fibres during the mechanical processing causes more chance of fibre breakage and thereby it increases the short fibre generation. The presence of more number of short fibres increases the number of protruding fibres in the yarn surface which in turn increases yarn HI. Moreover, after dyeing the fibre becomes coarser and the coarser fibres have a tendency to migrate towards outer surface of the yarn body during spinning. This phenomenon may be a cause of higher hairiness at darker shade. It is also observed from Figure 4.6 that yarn HI reduces with the increase of yarn TM. Higher level of twist improves the binding of fibres in the yarn body and reduces the protruding fibre in the yarn surface, therefore yarn HI reduces. The spindle speed has no significant effect on yarn HI in the present experimental set up.



(a) Response surface plot



(b) Contour plot

Figure 4.6 Response surface and contour plot of yarn hairiness index as a function of shade depth and TM for blow room blended cotton mélange yarn

4.4 Conclusions

The influence of shade depth (%), spindle speed and TM on the blow room blended cotton mélange yarn quality has been studied using Box and Behnken design of experiment. The following conclusions are made from the study:

- Shade depth and spindle speed have significant effect on the mélange yarn unevenness and imperfections. Darker shade is responsible for higher yarn unevenness and imperfection. Higher spindle speed is also liable for deterioration of yarn evenness and imperfection.
- Mélange yarn strength is significantly affected by shade depth and TM. The yarn strength decreases with the increase of shade depth (%) whereas the yarn strength increases with the TM.
- Yarn elongation at break is only influenced by the spindle speed. The elongation at break of cotton mélange yarn decreases with the increase of spindle speed.

- The mélange yarn hairiness also increases with the increase of shade depth (%). Increase in yarn TM reduces the mélange yarn hairiness.
- Although higher TM makes the productivity level a limiting factor, but it helps to achieve better mélange yarn quality in terms of its strength and hairiness.

Chapter 5

Analysis of Influence of Spinning Process Variables and Shade Depth on Quality Parameters of Draw Frame Blended Cotton Mélange Yarn using Box and Behnken Experimental Design

CHAPTER 5

ANALYSIS OFINFLUENCE OF SPINNING PROCESS VARIABLES AND SHADE DEPTH ON QUALITY PARAMETERS OF DRAW FRAME BLENDED COTTON MÉLANGE YARN USING BOX AND BEHNKEN EXPERIMENTAL DESIGN

5.1 Introduction

Off late various types of fancy yarns are being manufactured by textile industry using different techniques. For fibre dyed cotton mélange yarn also, mixing of fibres with different colours could be done either in blow room at the beginning of the spinning preparation or by feeding coloured and grey slivers to the draw frame. Both methods have their own advantages and disadvantages. The fibre blending or blow room blending provides the most intimate mixing of fibres in terms of fibre distribution while the draw frame blending provides an alternative way to manipulate the fibre distribution, which in turn affects the quality of final yarn (Cyniak et al., 2006; Moghassem and Fakhrali, 2013; Pan et al., 2000; Subramanian et al., 2015; Chollakup et al., 2008; Anandjiwala and Goswami, 1999). The blending method of fibre components (fibre or sliver blending) directly influences the yarn tenacity and specifically, fibre blending offers more even distribution of fibres in the spinning process as opposed to the sliver blending method (Lam et al., 2017). On the other hand, draw frame blending gives very good blending evenness in the longitudinal direction (Vasconcelos et al., 2008; Svetnickiene and Ciukas, 2009). Therefore, both the blending techniques can be used to produce cotton mélange yarn with varying degree of shade ratios. Depending upon the stage of mixing, mélange yarn is classified as either blow room blended or draw frame blended mélange yarns. The cotton mélange yarn properties are significantly influenced by blending methods and blending stages (Behera et al., 1997).

In the previous Chapter - 4, an attempt has been made to investigate the individual and interactive effects of decisive factors as identified in Chapter - 3 e.g. raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) on the properties of blow room blended cotton mélange yarn using Box and Behnken design of experiment. As cotton mélange yarn can be manufactured by using both the bending methods and spinners need to decide the best suitable method of blending for achieving optimum quality mélange yarn at highest possible productivity level, it was felt to conduct similar study, conducted for blow room blended cotton mélange yarn in Chapter - 4, for draw frame blended cotton mélange yarn also. A comparison between two blending methodologies is made to investigate the effect of blending methodologies and blending stages at different shade depth (%) on the properties of cotton mélange yarn. This investigation will be helpful for a spinner to choose the most suitable blending method in achieving desired yarn quality parameters and productivity level.

5.2 Materials and methods

5.2.1 Preparation of yarn samples

Same grey and black dyed cotton fibres as described in Chapter - 3 have been used to produce 20’s Ne mélange yarns. The dyed fibre and grey fibre properties at different stages of manufacturing are shown in Table 5.1. Figure 5.1 illustrates the process flow chart for dyed fibre preparation. At first, Mixing Bale Opener (MBO) was used for opening of 100% dyed cotton fibres and then dyed fibre layering was made in mixing bin to even out the bale to bale variation. In order to improve the processing in subsequent operations 6% water and 0.15% lubricant (LV-40) were sprayed over the layering. The layering was then conditioned for 24 hours before processing through blow room and carding. Subsequently, the carded sliver was processed at draw frame to produce levelled (uniform linear density) 100 % dyed sliver.

Table 5.1Fibre properties

Material	HVI test results			Bare sorter analysis	
	Length (mm)	Bundle strength (g/tex)	Short fibre index (SFI)	Effective length (mm)	Short fibre content (%)
Grey combed fibre	27.59	32.6	6.6	33	10.32
Dyed combed fibre	27.47	20.43	6.7	33	10.73
Carded dyed fibre	26.71	16.37	8.5	32	14.62
Mixing fibre of 40% shade	26.70	26.5	6.7	33	11.06
Card sliver of 40% shade	26.06	22.2	6.2	32	16.12

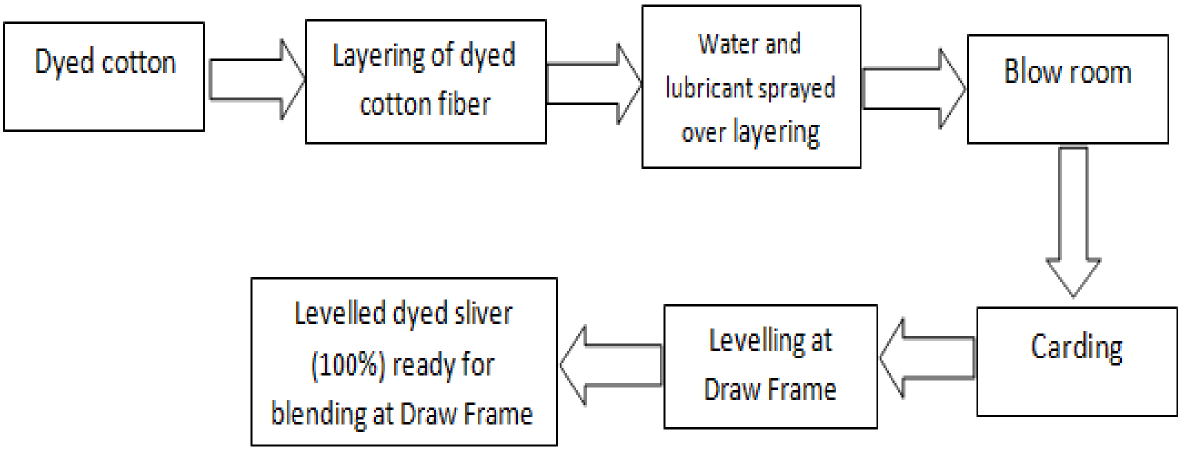


Figure 5.1 Process flow chart for dyed fibre preparation

The process flow chart for grey fibre preparation is shown in Figure 5.2. The grey cotton bales were layered under bale plucker and processed through blow room, card and comber. The combed grey sliver was then drawn through the draw frame to produce levelled grey sliver.

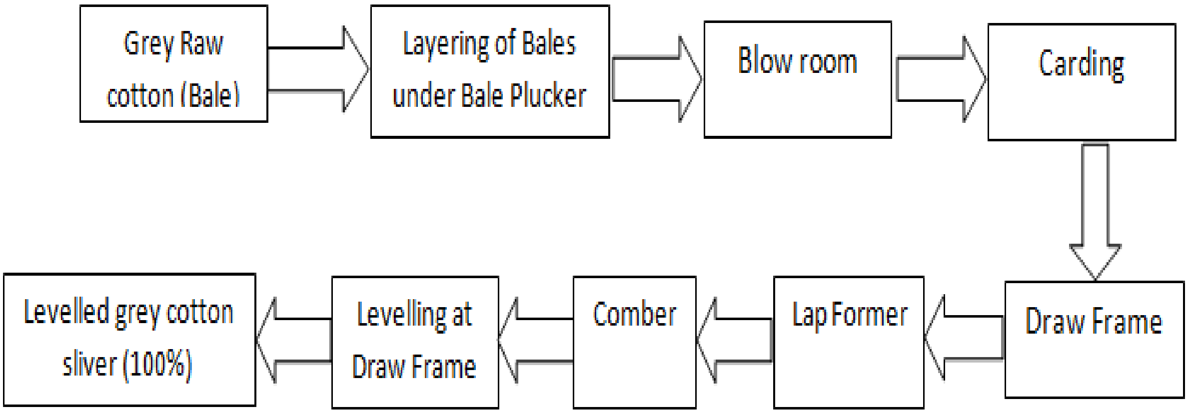


Figure 5.2 Process flow chart for grey fibre preparation

The blending of dyed and grey slivers was done at blending draw frame. The blended slivers were then processed through the breaker draw frame, finisher draw frame, speed frame and ring frame to produce 'draw frame blended mélange yarn'. Figure 5.3 schematically represents the blending of dyed and grey slivers at blending draw frame and flow chart of the subsequent processes for producing mélange yarn of 40% shade depth. The dyed sliver count and grey sliver count were determined as per required shade %. The sliver count and number of slivers blended for both types of grey and dyed fibre used to produce three different shade % in this study are shown in Table 5.2. In case of mélange yarn production the percentage of dyed fibre in the mixture is commonly termed as shade percentage or shade depth (%). As an example, if a yarn is to be produced with 60% grey cotton fibre and 40% dyed cotton fibre then the shade depth for that yarn is 40%.

Table 5.2 Levelled sliver count and number of slivers

Parameters	Shade Depth (%)		
	10	40	70
Levelled grey sliver count	3.37 Ktex	4.43 Ktex	4.80 Ktex
Levelled dyed sliver count	2.36 Ktex	4.92 Ktex	3.74 Ktex
Number of grey sliver	07	05	02
Number of dyed sliver	01	03	06

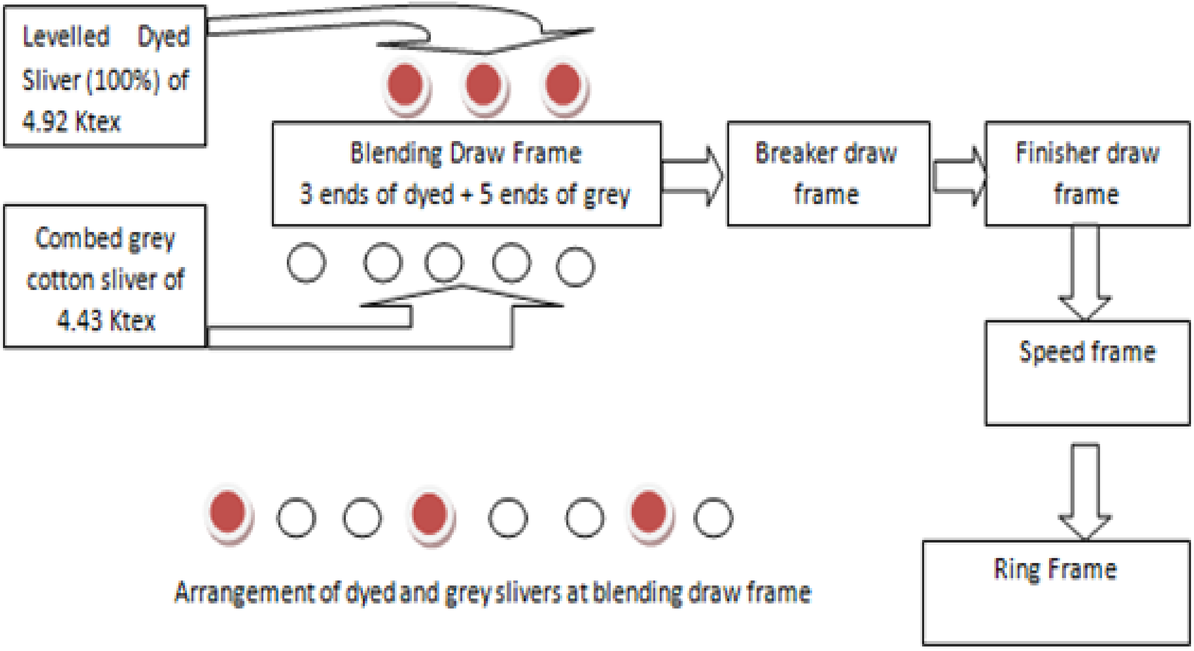


Figure 5.3 Blending of dyed and grey slivers at blending draw frame and flow chart of the subsequent processes for 40% shade depth.

Three controlled factors, viz., shade depth (%), ring frame spindle speed (rpm) and yarn twist multiplier (TM) were chosen and for each factor three levels were considered as mentioned in previous chapter (Table 3.1). The actual values of the controlled factors corresponding to their coded levels are shown in Table 5.3. The actual levels of controlled factors were taken within the range of industrially acceptable limits for mélange yarn production. The controlled factors X_1, X_2 and X_3 correspond to shade depth (%), spindle speed (rpm) and TM respectively. Conventional ring spinning system was used to prepare yarn samples according to the experimental plan of Box and Behnken (Adinarayan et al., 2003) design of experiment as shown in Table 5.4. The total number of yarn samples produced was 15. One image of prepared yarn samples is shown in Figure 5.4.

Table 5.3 Actual values corresponding to coded levels

Coded level	Actual value		
	Shade depth(%) (X_1)	Spindle speed (rpm) (X_2)	Yarn TM (TPI/Ne$^{0.5}$) (X_3)
-1	10	12500	3.5
0	40	13500	3.7
+1	70	14500	3.9

Table 5.4 Experimental plan for preparation of draw frame blended mélange yarn samples

Combination No.	Shade Depth (%)	Spindle speed (rpm)	Yarn TM
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

Figure 5.4 Prepared yarn samples of 20's Ne draw frame blend cotton mélange yarn

5.2.2 Testing of samples

All the fibre and yarn samples were kept in standard atmospheric condition for 24 h before testing. The grey combed fibre, dyed combed fibre and dyed fibres after processing through carding were subjected for their length and strength parameters in HVI 900 and Bare Sorter instruments. The yarn samples were evaluated for yarn unevenness (U %), imperfections (IPI), hairiness index (HI), strength (RKM) and breaking elongation (%). All the yarn quality parameters were tested as per standards and methodologies as described in Chapters 3 and 4.

5.2.3 Response surface equations

Similar to Chapter - 4, in this chapter also quadratic regression equation models (Dean and Voss, 1999) were used to relate various independent factors, namely shade depth (%), spindle speed and yarn twist multiplier (TM) with response variables, namely yarn unevenness (U %), imperfection, hairiness index, yarn tenacity and elongation at break. The details of the model used have already been described in Chapter - 4 (sections 4.2.3 and 4.3.2).

5.3 Results and discussion

5.3.1 Yarn quality parameters

The experimental values of yarn unevenness (U%), strength (RKM), elongation at break (%), imperfections (IPI) and hairiness index (HI) of draw frame blended mélange yarn are tabulated in Table 5.5. The yarn samples have a U% ranging from 8.21 % to 9.57%, tenacity ranging from 17.02 cN/tex to 21.20 cN/tex, imperfection ranging from 27.5 to 67, elongation at break (%) ranging from 4.08 to 5.10 and hairiness index ranging from 4.04 to 5.31.

The response surface equations of the yarn quality parameters were derived from the experimental data using MATLAB coding. The estimated regression coefficients and *p*-values of model terms for different response variables are shown in Table 5.6. A negative sign of regression coefficient indicates that the value of response variable decreases with the corresponding increase of factor value and vice versa. If the *p*-value of the model term is less than 0.05 then that model term is significant, indicating statistical significance at 95% confidence level.

Table 5.5 Parameters and properties of 20’s Ne draw frame blend cotton melange yarn

Experimental Run No.	X_1 (Shade depth, %)	X_2 (Spindle speed, rpm)	X_3 (Twist multiplier, TM)	20’s Ne Draw frame Blend Cotton Melange Yarn				
				Evenness (U %)	Tenacity (cN/Tex)	Elongation at break (%)	Imperfection (per km)	Hairiness index (-)
1	-1	0	-1	8.30	19.80	4.37	27.50	4.08
2	1	0	-1	9.47	17.02	4.35	60.30	5.31
3	-1	0	1	8.26	21.20	4.80	29.80	4.17
4	1	0	1	9.42	17.92	4.42	56.00	4.96
5	-1	-1	0	8.21	20.81	5.10	28.10	4.04
6	1	-1	0	9.26	17.86	5.01	52.80	5.16
7	-1	1	0	8.50	19.87	4.55	31.50	4.12
8	1	1	0	9.57	17.38	4.70	67.00	5.21
9	0	-1	-1	8.96	17.72	4.34	36.50	4.60
10	0	-1	1	9.16	19.37	4.44	37.00	4.24

Experimental Run No.	X_1 (Shade depth, %)	X_2 (Spindle speed, rpm)	X_3 (Twist multiplier, TM)	20's Ne Draw frame Blend Cotton Melange Yarn				
				Evenness (U %)	Tenacity (cN/Tex)	Elongation at break (%)	Imperfection (per km)	Hairiness index (-)
11	0	1	-1	9.57	18.68	4.25	47.60	4.39
12	0	1	1	9.49	19.13	4.13	49.80	4.23
13	0	0	0	9.35	18.08	4.08	44.00	4.31
14	0	0	0	9.21	18.82	4.35	43.00	4.35
15	0	0	0	9.36	18.60	4.34	52.30	4.36
Mean				9.07	18.82	4.48	44.21	4.50
Minimum				8.21	17.02	4.08	27.5	4.04
Maximum				9.57	21.20	5.10	67.0	5.31
Range				1.36	4.18	1.02	39.5	1.27

Table 5.6 Estimated regression coefficients (Coeff) and *p*-values of model term for different response variables

Model term	Unevenness (U%)		Yarn strength (g/tex)		Elongation at break (%)		Imperfection (IPI)		Hairiness index (HI)	
	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
Constant	9.306	0.000	18.500	0.000	4.256	0.000	46.433	0.000	4.340	0.000
X_1	0.556	0.00001	-1.437	0.0002	-0.042	0.495	14.900	0.00006	0.528	0.000
X_2	0.192	0.001	-0.087	0.587	-0.157	0.041	5.187	0.008	-0.011	0.696
X_3	0.003	0.909	0.550	0.015	0.060	0.346	0.087	0.945	-0.097	0.016
X_1^2	0.005	0.914	0.115	0.613	0.060	0.495	2.700	0.179	-0.007	0.853
X_2^2	-0.002	0.957	-0.125	0.584	-0.090	0.321	-1.650	0.384	-0.110	0.035
X_3^2	-0.070	0.176	-0.300	0.219	-0.055	0.531	0.425	0.816	0.050	0.251
X_1X_2	-0.427	0.0002	0.370	0.157	0.389	0.006	-0.454	0.811	0.278	0.001
X_1X_3	0.005	0.911	0.110	0.642	0.194	0.071	-1.129	0.558	0.014	0.745
X_2X_3	-0.017	0.727	0.115	0.627	-0.161	0.117	-2.579	0.212	0.011	0.790

Table 5.7.Response surface equations of various mélange yarn quality parameters

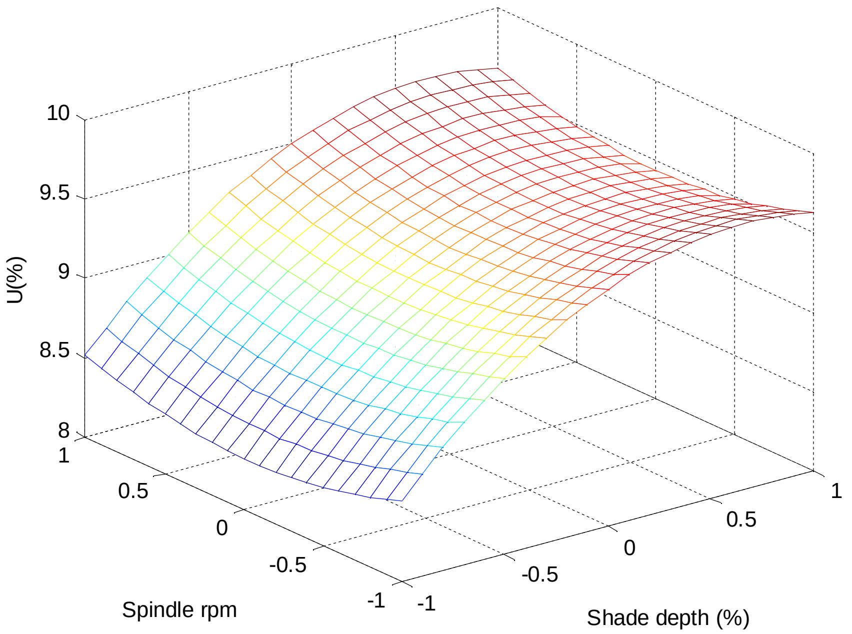
Yarn quality parameters	Response surface equation	R^2_{adj}	Mean accuracy (%)	Beta coefficient of significant terms	Percentage contribution of significant terms (%)
Unevenness (U %)	$9.31+0.55X_1+0.19X_2-0.43X_1^2$	0.98	99.42	$\beta(X_1) = 0.84$ $\beta(X_2)= 0.29$ $\beta(X_1^2) = -0.44$	$C(X_1) = 52.57$ $C(X_2)= 18.19$ $C(X_1^2) = 27.52$
Strength (cN/tex)	$18.5-1.43X_1+0.55X_3$	0.90	97.81	$\beta(X_1) = -0.89$ $\beta(X_3) = 0.34$	$C(X_1) = 65.41$ $C(X_3) = 25.02$
Elongation at break (%)	$4.25-0.15X_2+0.39X_1^2$	0.61	96.52	$\beta(X_2) = -0.40$ $\beta(X_1^2) = 0.67$	$C(X_2) = 22.68$ $C(X_1^2) = 38.04$
Imperfection (IPI)	$46.43+14.9X_1+5.18X_2$	0.94	91.81	$\beta(X_1) =0.92$ $\beta(X_2) = 0.32$	$C(X_1) = 69.67$ $C(X_2) = 24.26$
Hairiness index (HI)	$4.34+0.52X_1-0.09X_3-0.11X_1X_3+0.27X_1^2$	0.98	99.15	$\beta(X_1) = 0.91$ $\beta(X_3) = -0.17$ $\beta(X_1X_3) = -0.13$ $\beta(X_1^2) = 0.33$	$C(X_1) = 58.27$ $C(X_3) =10.74$ $C(X_1X_3) = 8.57$ $C(X_1^2) = 20.85$

Table 5.7 illustrates the fitted quadratic regression models along with the coefficient of determination (R^2_{adj}), mean accuracy of the fitted model, beta coefficient (β) and percentage contribution of the significant terms for different yarn quality parameters. In the fitted models, only the regression coefficients which are significant at the 95% confidence level are taken into account.

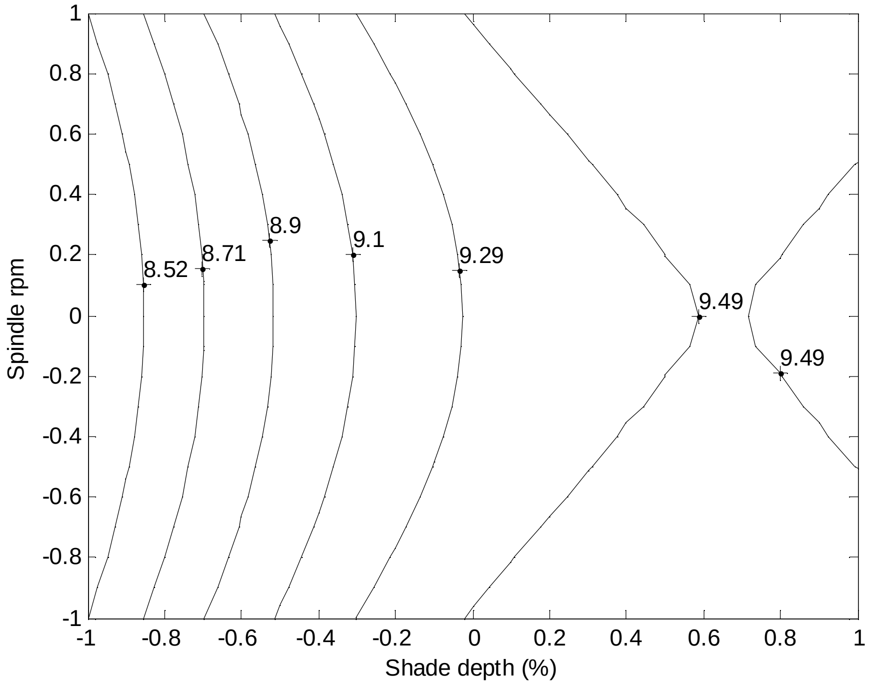
It is evident from the Table 5.7 that invariably for each case higher value of R^2_{adj} and higher mean accuracy substantiate a good fit of response surface equations to the experimental data. From the values of percentage contribution shown in Table 5.7 it is observed that shade depth is most influencing factor among all the three factors for mélange yarn quality parameters. This may be ascribed to the fact that the percentage change in shade depth from the lower to the upper level is 600 % (from 10% to 70%), whereas that for spindle speed and TM are 16 % (from 12500 rpm to 14500 rpm) and 11.43 % (from 3.5 to 3.9) respectively.

5.3.1.1 Yarn unevenness (U %)

The response surface equation of draw frame blended mélange yarn unevenness is given in Table 5.7 and Figure 5.5 depicts the corresponding response surface plot and contour diagram. It is apparent from the response surface equation that the TM in the range from 3.5 to 3.9 has no significant influence on yarn unevenness. Basically yarn unevenness is strongly dependent upon the drafting rather than twisting. As twist is applied after the final drafting process in ring frame, it has no significant influence on the yarn unevenness. It can be observed from Figure 5.5 that yarn unevenness increases with the increase of shade depth. The change in surface characteristics of dyed cotton fibre leads to processing difficulties of dyed cotton in spinning. The problem is more intensified while the amount of dyed fibre in the mixture increases. Opening difficulties while processing more dyed fibre in the mixture lead to uneven movement of fibre cluster in the drafting area. Cross sectional mass variation occurs due to increased erratic movement of fibres during drafting and eventually it results into more yarn unevenness. It is also observed from Figure 5.5 that there is only a slight increase of yarn unevenness with the increase of spindle speed. More rubbing action of yarn with the metallic part in the ring frame due to higher spindle speed may cause a slight increase in yarn unevenness. From Table 5.7, it is noted that the contribution of spindle speed for the range from 12500 to 14500 on yarn unevenness is only 18.19 %, which is significantly lower than that of shade depth. Hence, the influence of spindle speed on yarn irregularity is much lower than the shade depth.



(a) Response surface plot

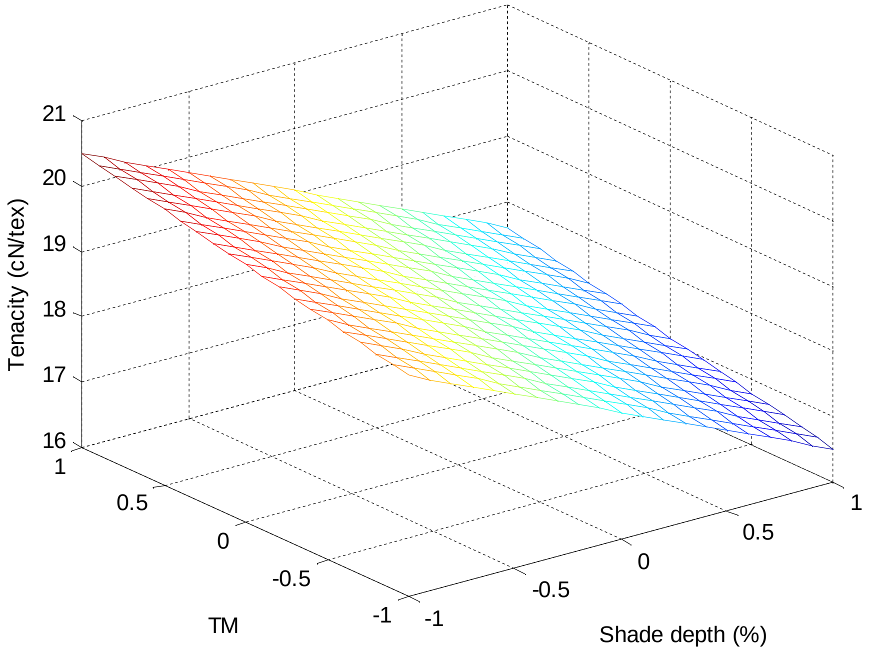


(b) Contour plot

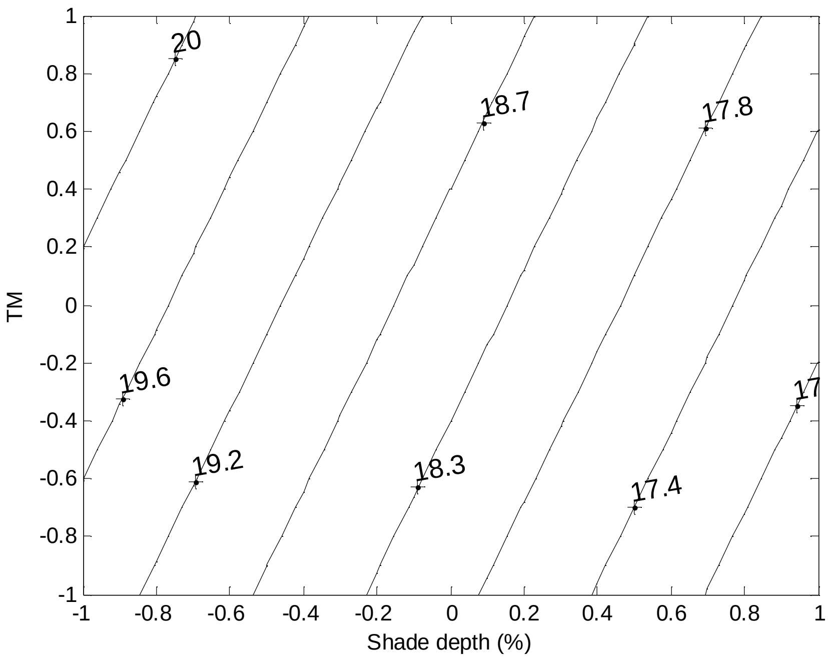
Figure 5.5 Response surface and contour plot of yarn unevenness as a function of shade depth and spindle rpm for draw frame blended cotton mélange yarn

5.3.1.2 Yarn strength

Table 5.7 shows the response surface equation of draw frame blended cotton mélange yarn strength and the corresponding response surface plot and contour diagram are illustrated in Figure 5.6. It is clearly evident from Figure 5.6 that yarn strength reduces with the increase of shade depth (%) which may be ascribed to the higher proportion of weak dyed cotton fibre content in the yarn cross section. Chemical processing causes strength loss of cellulosic cotton fibre and the drop in dyed fibre strength is reflected into yarn strength. In addition to that, mechanical processing causes more damage to dyed cotton fibre resulting in more short fibre generation. Shorter length fibre contributes less towards the yarn strength. Table 5.1 depicts the HVI and Bare Sorter results of fibre strength and length parameters of combed grey fibre, combed dyed fibre and dyed fibre after processing through blow room and carding. It is clearly evident from Table 5.1 that dyeing of cotton fibre causes 37.3 % loss of fibre bundle strength. Furthermore, the processing of dyed fibre in the blow room and card causes around 20 % reduction in fibre bundle strength. It is also observed from the Bare Sorter analysis of Table 5.1 that there is an increase of 36.2% short fibre content (by number) after processing of dyed fibre in the blow room and card. It is also apparent from Figure 5.6 that yarn strength increases with TM in the present experimental set up. Fibre-to-fibre cohesion increases with increased surface contact due to increase of twist and thereby augmenting the yarn strength. Table 5.7 shows that the contributions of shade depth and TM on yarn strength are 65.41% and 25.02% respectively. No significant impact of spindle speed on yarn strength is observed within the present experimental set up.



(a) Response surface plot

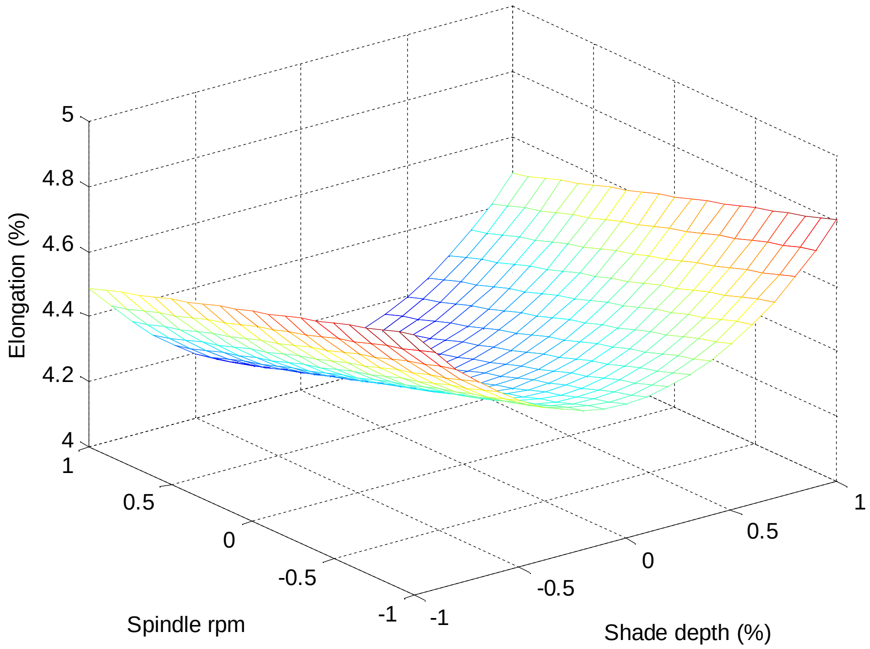


(b) Contour plot

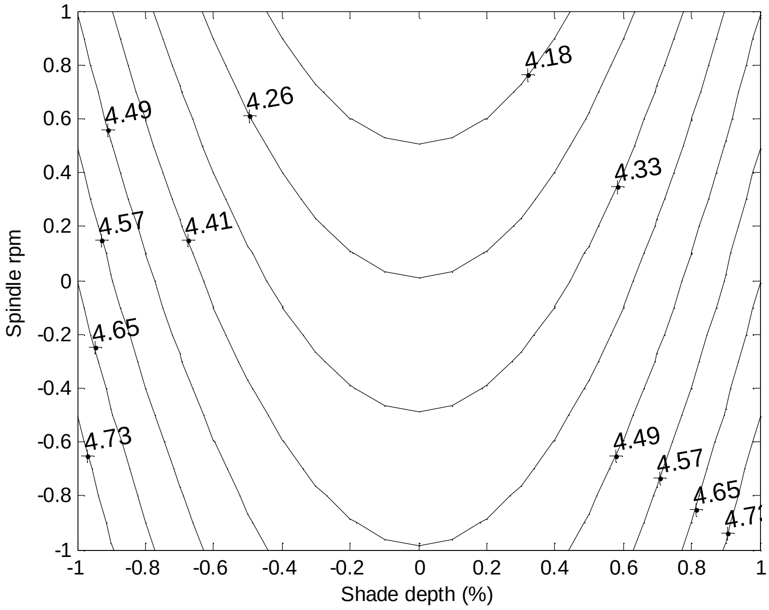
Figure 5.6 Response surface and contour plot of yarn strength as a function of shade depth and TM for draw frame blended cotton mélange yarn

5.3.1.3 Yarn elongation at break (%)

The response surface equation for yarn elongation at break is given in Table 5.7. Figure 5.7 illustrates the effect of shade depth and spindle speed on yarn elongation at break for draw frame blended mélange yarn. From Table 5.7 and Figure 5.7 it is observed that yarn elongation at break decreases with increase of spindle speed. It is obvious that at higher spindle speed twisting phenomenon occurs at higher spinning tension which causes more straightening of fibres while they are emerging out from the front roller nip and resulting in a reduction in yarn breaking elongation. It is also observed from the Figure 5.7 that the yarn elongation at break varies within a narrow range with the change of shade depth. In this study the yarn elongation has not been affected by TM within the experimental set up. This may be ascribed to more number of draw frame passages used to produce the draw frame blended mélange yarn. More number of draw frame passages enables better fibre straightening which leads to lower yarn elongation. Thus the reduction in yarn elongation due to fibre straightening is balanced by the possible improvement in yarn elongation due to increase of yarn twist.



(a) Response surface plot

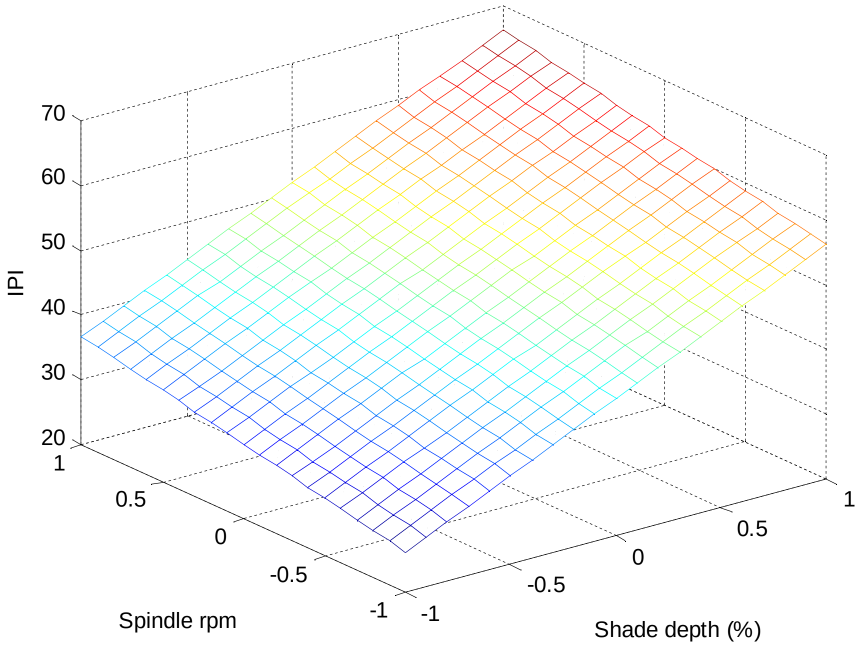


(b) Contour plot

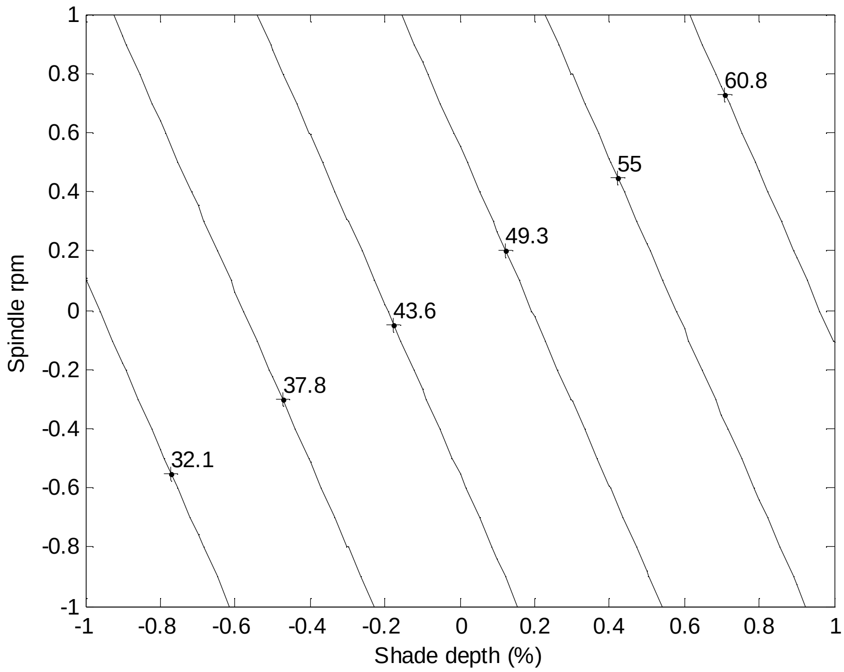
Figure 5.7 Response surface and contour plot of yarn elongation at break as a function of shade depth and spindle rpm for draw frame blended cotton mélange yarn

5.3.1.4 Yarn imperfection (IPI)

Response surface equation of mélange yarn IPI is shown in Table 5.7. Figure 5.8 illustrates the effect of shade depth and spindle speed on yarn IPI. It is manifested from the Figure 5.8 that the yarn IPI increases with increase of shade depth and spindle speed. Opening and processing difficulties associated with mélange yarn manufacturing causes more dyed fibre damage and resulting reduction in effective length of fibres. When the dyed sliver contains more short fibre due to fibre damage blended with grey combed sliver at draw frame, it may cause higher drafting wave resulting in more thick and thin places in the yarn. In addition to that the opening difficulties of dyed cotton fibre at blow room and carding causes more fibre entanglement, which in turn generates higher number of fibrous neps in the yarn. As the spindle speed increases the rubbing action between yarn surface and thread guide, balloon control ring and ring traveller also increases. Due to increased rubbing longer protruding fibres of the yarn surface get rolled up and generates neps and thick places. This leads to more yarn IPI at higher spindle speed. From Table 5.7, it is evident that the contributions of shade depth and spindle speed on yarn imperfection are 69.67 % and 24.26% respectively. Yarn TM was found to have no significant influence on the yarn IPI.



(a) Response surface plot

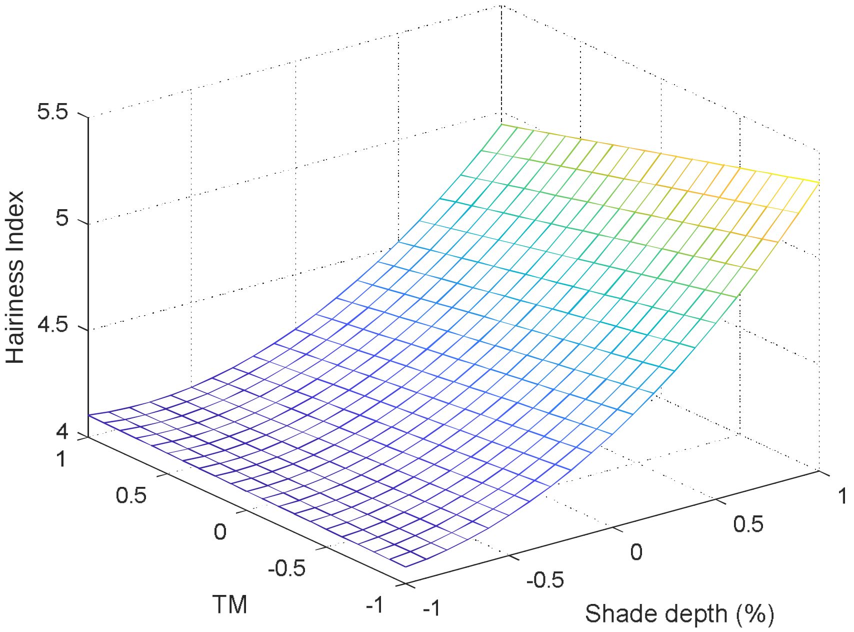


(b) Contour plot

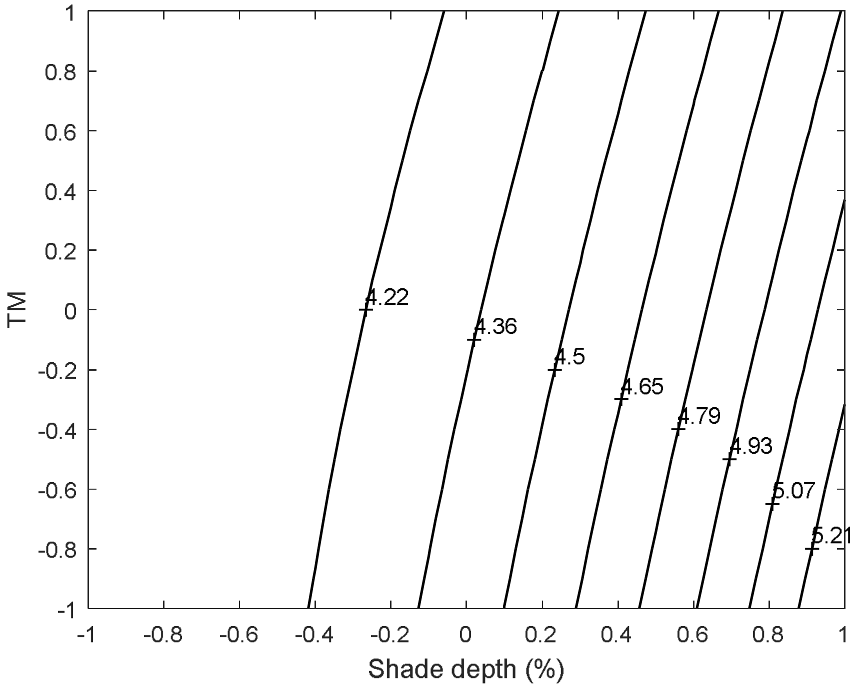
Figure 5.8 Response surface and contour plot of yarn imperfection (IPI) as a function of shade depth and spindle rpm for draw frame blended cotton mélange yarn

5.3.1.5 Yarn hairiness index (HI)

Table 5.7 shows the response surface equation of mélange yarn hairiness. Figure 5.9 depicts the influence of shade depth and yarn TM on yarn HI. It is observed that yarn HI increases significantly with the increase of shade depth. It is obvious from Table 5.1 that the opening difficulty of dyed fibre during mechanical processing at blow room and card causes more fibre damage and high short fibre generation. The higher short fibres content increases the number of protruding fibres in the yarn surface. Hence yarn HI increases as the shade becomes darker. From Figure 5.9 it is also observed that the yarn HI reduces with the increase of yarn TM. Higher level of twist improves the binding of fibres in the yarn body which curbs the presence of protruding fibre in the yarn surface and thereby yarn HI reduces. In the present experimental set up the spindle speed has no significant effect on yarn HI, which may be explained in the following lines. At higher spindle speed due to intense rubbing action, the longer hairs of weak dyed fibre either get entangled and become fibrous neps or get broken and cause higher fluff generation in ring frame section. Therefore, an increase in small hairs due to rubbing action is compensated by reduction in long hairs. Also this phenomenon may be a reason for higher fluff generation in ring frame section while manufacturing cotton mélange yarn compared to conventional grey yarn.



(a) Response surface plot



(b) Contour plot

Figure 5.9 Response surface and contour plot of yarn hairiness index as a function of shade depth and TM for draw frame blended cotton mélange yarn

5.4 Comparison between blow room and draw frame blending

5.4.1 Results and discussions

The experimental values of yarn evenness, tenacity, elongation at break, imperfections (IPI) and hairiness index of 20’s Ne cotton mélange yarns prepared with blow room blending (Chapter 4) and draw frame blending (Chapter 5) techniques are tabulated in Table 5.8 and 5.9.

Table 5.8 Yarn properties of 20’s Ne cotton mélange yarn produced with different blending techniques

Yarn properties	Type of mélange yarn	Shade depth (%)		
		10%	40%	70%
U (%)	Blowroom blended	9.28	9.70	9.71
	Drawframe blended	8.32	9.22	9.43
Strength (cN/tex)	Blowroom blended	18.98	18.11	17.04
	Drawframe blended	20.42	19.00	17.55
Elongation at break (%)	Blowroom blended	4.48	4.25	4.09
	Drawframe blended	4.76	4.44	4.35
Imperfections per Km (IPI)	Blowroom blended	43.32	47.92	65.40
	Drawframe blended	29.23	42.73	59.02
Hairiness index (HI)	Blowroom blended	4.27	4.76	5.26
	Drawframe blended	4.10	4.36	5.16

Table 5.9 Experimental results of 20’s Ne cotton mélange yarn

X_1(Shade depth, %)	X_2 (Spindle speed, rpm)	X_3 (Twist multiplier, TM)	Evenness (U %)		Tenacity (cN/Tex)		Elongation at break (%)		Imperfection (per km)		Hairiness index	
			Blow Room Blend	Draw Frame Blend	Blow Room Blend	Draw Frame Blend	Blow Room Blend	Draw Frame Blend	Blow Room Blend	Draw Frame Blend	Blow Room Blend	Draw Frame Blend
10	12500	3.7	9.24	8.30	18.34	19.80	4.19	4.37	41.80	27.50	4.43	4.08
	14500	3.7	9.26	8.26	19.51	21.20	4.34	4.80	34.60	29.80	4.09	4.17
	13500	3.5	9.21	8.21	19.44	20.81	4.91	5.10	44.10	28.10	4.31	4.04
	13500	3.9	9.42	8.50	18.65	19.87	4.48	4.77	52.80	31.50	4.23	4.12
40	12500	3.9	9.73	8.96	17.79	19.13	4.25	4.44	43.0	36.5	4.86	4.6
	13500	3.7	9.54	9.35	17.97	19.37	4.25	4.44	41.6	37.0	4.56	4.24
	12500	3.5	9.66	9.21	17.94	18.82	4.21	4.40	53.8	47.6	4.75	4.39
	13500	3.7	9.88	9.36	18.72	18.68	4.29	4.48	53.3	49.8	4.88	4.23
70	12500	3.7	9.67	9.47	16.24	17.02	4.09	4.35	66.5	60.3	5.43	5.31
	14500	3.7	9.65	9.42	17.35	17.92	4.09	4.35	61.5	56.0	5.09	4.96
	13500	3.5	9.63	9.26	17.06	17.86	4.03	4.29	62.3	52.8	5.31	5.16
	13500	3.9	9.87	9.57	17.53	17.38	4.15	4.41	71.3	67.0	5.23	5.21

5.4.1.1 Yarn unevenness (U %) and imperfections (IPI)

The effect of shade depth on yarn unevenness (U %) and imperfections (per km) for blow room blended and draw frame blended cotton mélange yarns are shown in Figure 5.10 and 5.11 respectively. It is observed from Figure 5.10 and Figure 5.11 that yarn unevenness and imperfections increase as the shade becomes darker for both the types of blending methodology. The average yarn U% and imperfections for blow room blended mélange yarns are significantly higher than that of draw frame blended mélange yarns for all shade depth %.

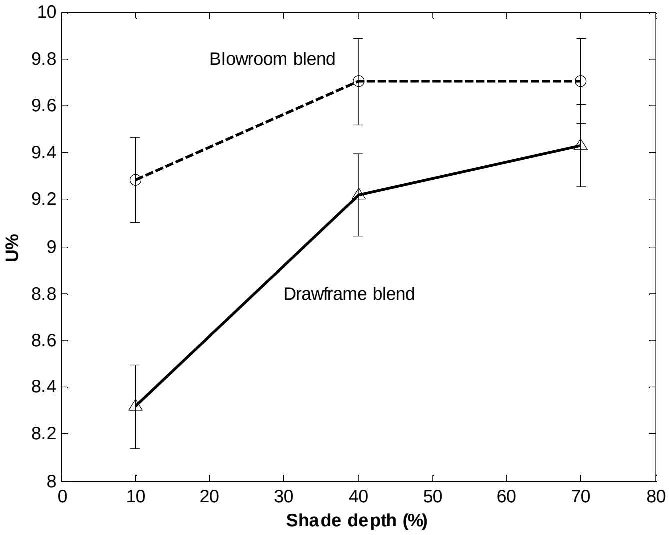


Figure 5.10 Effect of shade depth (%) on yarn unevenness (U %) for blow room and draw frame blended mélange yarns.

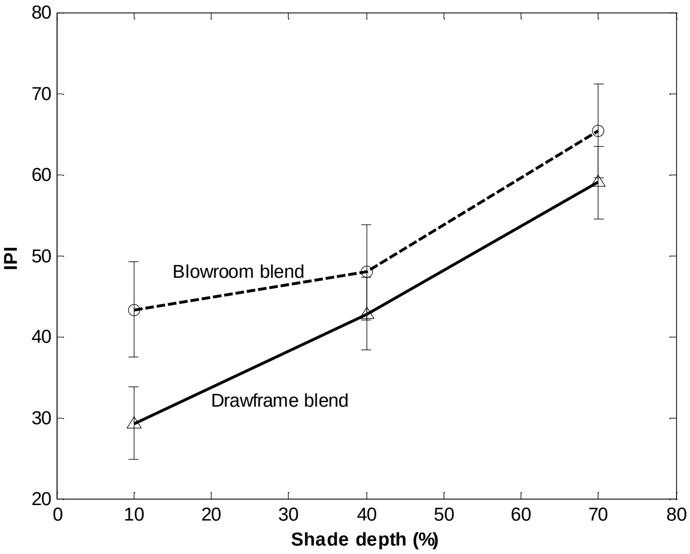


Figure 5.11 Effect of shade depth (%) on imperfections (IPI) for blow room and draw frame blended mélange yarns.

The process flow charts of mélange yarn production for both the types of blending techniques as shown in Figure 3.2 (Chapter 3) and Figure 5.1,Figure 5.2 and Figure 5.3 clearly indicate that the entire grey cotton fibre used in the mélange mixture is actually processed twice through the blow room and carding machines in case of blow room blend. In order to produce blow room blended mélange yarn, firstly the grey fibre is opened and cleaned by processing from blow room to comber separately and then they are mixed with the dyed fibre (amount depending upon the shade depth %) at the tuft blender which is subsequently processed though blow room and card. Hence, for blow room blending, the chances of short fibre generation due to fibre breakage and formation of fibrous neps and entanglements increase with excessive mechanical action and fibre transportation through the pipelines. Once the fibre mix (dyed and grey) is processed through the card, there is no further scope available for removing the short fibre and entanglement in next processes of yarn manufacturing. Thus the reduction in effective fibre length and higher proportion of fibrous neps and entanglement are eventually reflected in terms of yarn unevenness, thick places, thin places and neps. On the other hand, in case of draw frame blending method the grey fibre is treated separately up to combing stage for only once before mixing with the dyed cotton at draw frame stage. Therefore, the amount of short fibre and fibrous neps present in grey cotton part is much lesser. Moreover, the dyed fibre sliver passes through draw frame stage for four times in case of draw frame blending method as compared to only two times in case of blow room blending method. More number of drawing passages improves the alignment of fibre. Therefore draw frame blended mélange yarn shows better yarn evenness and imperfections than that of blow room blended mélange yarn.

5.4.1.2. Yarn strength and elongation at break

Figure 5.12 and Figure 5.13 depict the effect of shade depth (%) on cotton mélange yarn strength and elongation at break respectively for both type of blending method. The strength and breaking elongation of draw frame blended yarns are observed to be higher than that of blow room blended yarn for all levels of shade depth (%).

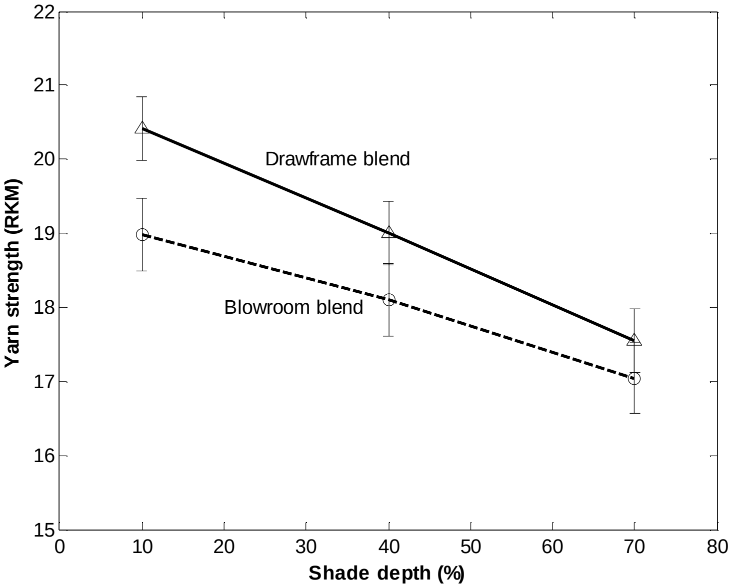


Figure 5.12 Effect of shade depth (%) on strength (RKM) for blow room and draw frame blended mélange yarns.

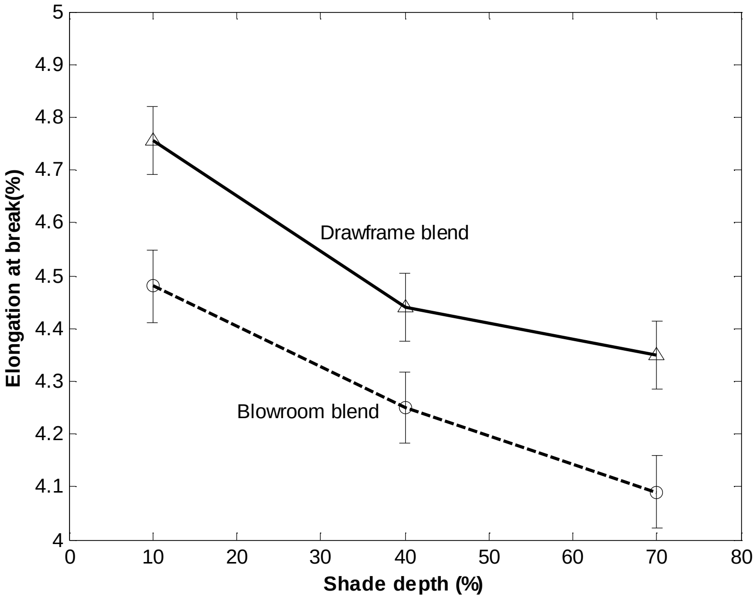


Figure 5.13 Effect of shade depth (%) on elongation at break (%) for blow room and draw frame blended mélange yarns.

It has been discussed in the earlier section that the chance of fibre breakage is more evident for blow room blending method as compared to the draw frame blending method.

The generation of short fibres increases proportionately with the fibre breakage. While a yarn is subjected to tensile testing, short fibres in the yarn share the load only partially, resulting in lower yarn strength and breaking elongation. In addition, higher number of drawing passages imparted in draw frame blending technique improves the effective fibre length because of more parallelisation and that factor also contributes towards the improvement in yarn strength and elongation at break.

5.4.1.3 Yarn hairiness index (HI)

The effect of shade depth on yarn hairiness index for blow room blended and draw frame blended cotton mélange yarn are shown in Figure 5.14. It is noted from Figure 5.14 that the yarn hairiness index increases with the increase in shade depth (%) for both methods of blending. The blow room blended mélange yarns shows higher hairiness index than that of draw frame blended mélange yarns for all shade depth %. Higher hairiness index for blow room blended cotton mélange yarn is ascribed to the presence of more number of short fibres which in turn increases the protruding fibres in the yarn surface.

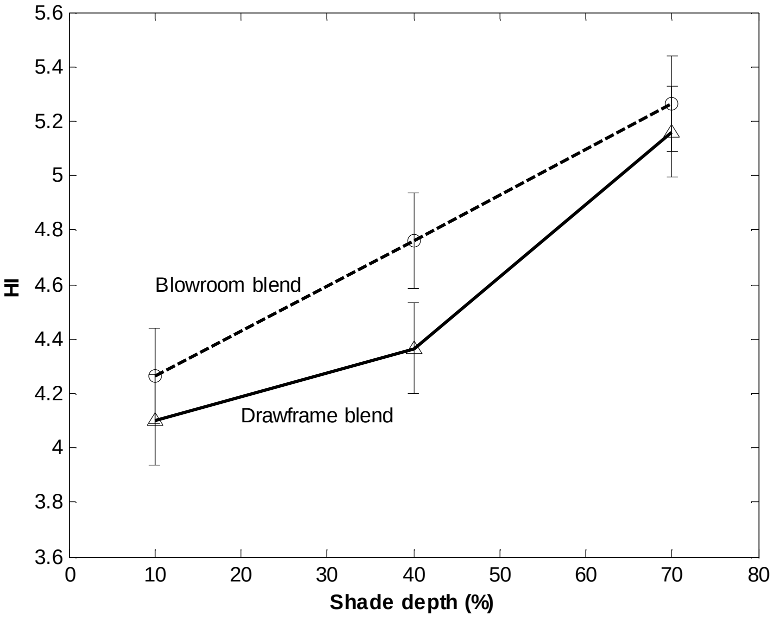


Figure 5.14 Effect of shade depth (%) on hairiness index (HI) for blow room and draw frame blended mélange yarns.

5.5 Conclusions

The simultaneous effects of raw material (dyed fibre %), spinning process parameter (yarn TM) and productivity (spindle rpm of ring frame) on the properties of draw frame blended mélange yarn have been analysed in this work. The shade depth is the most influential parameter over the others, affecting mélange yarn quality. Yarn unevenness, imperfection and elongation at break are significantly affected by shade depth and spindle speed, whereas yarn strength and hairiness index are significantly affected by shade depth and TM. Higher shade depth is responsible for higher yarn unevenness, imperfection, hairiness and lower yarn strength. Higher spindle speed is also responsible for deterioration of mélange yarn quality. The change in surface characteristics and drop in strength of cotton fibres after dyeing make the productivity level a limiting factor in achieving better mélange yarn quality, especially for darker shades. Although higher yarn TM makes the productivity level a limiting factor, but it leads to achievement of better mélange yarn quality in terms of its strength and hairiness index.

Cotton Mélange yarn quality is significantly affected by the method of blending. Better mélange yarn quality is achieved with draw frame blending techniques compared to blow room blending technique. Repetitive blow room and carding action imparted in blow room blending method causes more fibre damage and higher short fibre generation which results in lower yarn strength and breaking elongation, higher yarn unevenness, imperfections and hairiness. Furthermore, higher number of draw frame passages improves the fibre parallelisation which results in better yarn quality in case of draw frame blending methodology. Mélange yarn quality significantly deteriorates with the increase of shade depth (%) for both type of blending techniques.

Chapter 6

Engineering of Cotton Mélange Yarn with Optimal Yarn Evenness, Tenacity, Imperfection and Hairiness Index using Desirability Function

CHAPTER 6

ENGINEERING OF COTTON MÉLANGE YARN WITH OPTIMAL YARN EVENNESS, TENACITY, IMPERFECTION AND HAIRINESS INDEX USING DESIRABILITY FUNCTION

6.1 Introduction

One of the important objectives of this work is to design cotton mélange yarns that possess optimum quality characteristics at highest productivity level. Optimization problem requires mathematical relationship between controllable factors and objective functions. Therefore an attempt was made in Chapters 3, 4 and 5 to study the individual and interactive effects of controllable factors, namely shade depth (%), yarn twist (TM) and spindle speed (rpm) on yarn evenness, tenacity, elongation at break, imperfection and hairiness for both blow room blend and draw frame blended cotton mélange yarns. Taguchi and Box and Behnken experimental designs were used for the aforesaid purpose. It was inferred from Chapters 3, 4 and 5 that shade depth (%), spindle speed and yarn twist (TM) are the decisive factors affecting yarn properties (yarn evenness, tenacity, imperfection and hairiness) of 20's Ne blow room blend and draw frame blended cotton mélange yarns. Quadratic regression equations for yarn evenness, tenacity, imperfection and hairiness were derived in Chapter - 4 and Chapter - 5 which can be utilized to engineer cotton mélange yarns. Consequently, optimization of important cotton mélange yarn qualities such as tenacity, evenness, imperfection level and hairiness index basically requires adjustment of several process parameters. The mélange yarn quality demands for higher yarn tenacity as well as lower yarn unevenness, imperfection level and hairiness index. Higher spindle speed results in higher yarn unevenness and hairiness whereas lower yarn twist (TM) results in lower strength for cotton yarn. Simultaneously, spindle speed and yarn twist both affects the productivity level.

Higher yarn twists (TM) and lower spindle speed (rpm) cause reduction in productivity. Hence, to achieve a cotton mélange yarn with desired qualities as well as optimum production, it is necessary to optimize multiple parameters simultaneously. There is hardly any reported investigation available on the process parameters optimization of cotton mélange yarn manufacturing. Therefore, an attempt has been made in this work for multi-objective optimization of yarn evenness, tenacity, imperfection and hairiness index for both blow room and draw frame blended 20’s Ne cotton mélange yarns. The multi-objective optimization has been tackled by desirability function approach which determines the values of the controlled factors that yield maximum desirable values of yarn tenacity, evenness, imperfections and hairiness index for both blow room and draw frame blended mélange yarns.

6.2. Materials and method

Any kind of optimization problem requires mathematical relationships between the objective functions and controllable factors affecting them. Therefore, mathematical relationships between the objective functions, namely yarn evenness, tenacity, imperfection, hairiness and controllable factors as derived in Chapters 4 and 5 have been used here for multi-objective optimization. Final quadratic regression models along with the adjusted coefficient of determination $\left(R_{adj}^2\right)$ of the blow room blended 20’s Ne cotton mélange yarns and 20’s Ne draw frame blended cotton mélange yarns, which are considered for optimization problem, are shown in Table 6.1 and Table 6.2 respectively. The symbols X_1, X_2 and X_3 correspond to shade depth (%), spindle speed and twist multiplier (TM) respectively.

Table 6.1 Response surface equations for blow room blend cotton mélange yarn

Response variables	Response surface equations	Adjusted coefficient of determination $\left(R^2_{adj}\right)$
Tenacity (cN/tex)	$18.51-0.97X_1+0.56X_3-0.44X_1^2$	0.89
Unevenness (U %)	$9.69+0.21X_1-0.32X_1^2+0.16X_2^2$	0.81
Imperfections (per km)	$49.47+11.04X_1+5.02X_2+5.67X_1^2$	0.88
Hairiness index	$4.7+0.5X_1-0.11X_3$	0.95

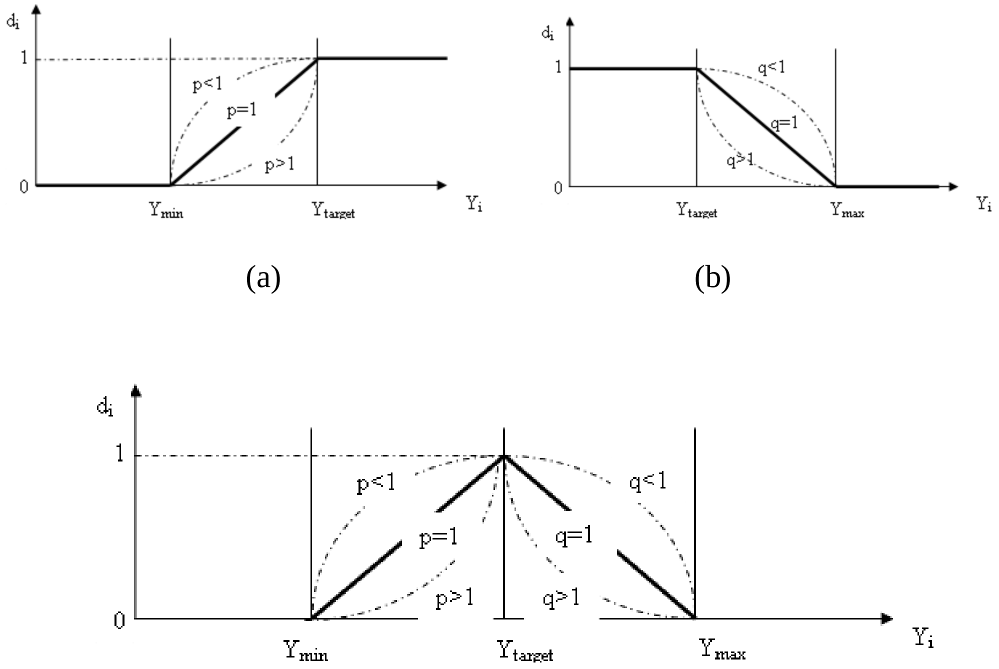
Table 6.2 Response surface equations for draw frame blend cotton mélange yarn

Response variables	Response surface equations	Adjusted coefficient of determination $\left(R^2_{adj}\right)$
Tenacity (cN/tex)	$18.5-1.43X_1+0.55X_3$	0.90
Unevenness (U %)	$9.31+0.55X_1+0.19X_2-0.43X_1^2$	0.98
Imperfections (per km)	$46.43+14.9X_1+5.18X_2$	0.94
Hairiness index	$4.34+0.52X_1-0.09X_3-0.11X_1X_3+0.27X_1^2$	0.98

6.3 Multi-objective optimization using desirability function

6.3.1 Desirability function

Harrington (1965) developed the concept of desirability function in 1965 and it was further developed by Derringer and Suinch (1980). Ghosh *et al.* (2016) used desirability function approach for optimization of knitted fabric comfort and UV protection. A desirability function (d_i) is defined individually for each response variables or objectives with goals and boundaries. The desirability functions with different goals and boundaries are shown in Figure 6.1. There are three types of goals, namely maximize the response, minimize the response and target the response. Equations defining each type of response are expressed in Table 6.3.



(a) (b)

(c)

Figure 6.1 Desirability functions to (a) maximize; (b) minimize; (c) reach a target value

The exponents *p* and *q* in Table 6.2 determine the degree of importance to hit the target value. The desirability function approaches linearly for $p = q = 1$. The desirability function is convex for $p < 1$, $q < 1$ and is concave for $p > 1$, $q > 1$.

Individual desirability function (d_i) values are combined to calculate the overall desirability function for optimization. The equation of ‘overall desirability function’ is manifested in the following equation:

$$D = \sqrt[w]{\left(d_1^{w_1} \times d_2^{w_2} \times \ldots . \times d_n^{w_n}\right)} \qquad \ldots \qquad (6.1)$$

where $w = \sum w_i$, w_i is the weight of i^{th} response, n is the number of responses. Both the individual desirability function and overall desirability function have a range from zero to one. A desirability of zero corresponds to complete lack of fulfilment of objectives whereas a value of one implies complete fulfilment.

Table 6.3 Expressions of desirability functions for different goals

Maximize the response	Minimize the response	Target the response
$d_i = \left(\frac{Y_i - Y_{\text{min}}}{Y_{\text{target}} - Y_{\text{min}}}\right)^p$ where $Y_{\text{min}} \leq Y_i \leq Y_{\text{target}}$ $d_i = 0$, if $Y_i \leq Y_{\text{min}}$ $d_i = 1$, if $Y_i \geq Y_{\text{target}}$	$d_i = \left(\frac{Y_i - Y_{\text{max}}}{Y_{\text{target}} - Y_{\text{max}}}\right)^q$ where $Y_{\text{target}} \leq Y_i \leq Y_{\text{max}}$ $d_i = 0$, if $Y_i \geq Y_{\text{max}}$ $d_i = 1$, if $Y_i \leq Y_{\text{target}}$	$d_i = \left(\frac{Y_i - Y_{\text{min}}}{Y_{\text{target}} - Y_{\text{min}}}\right)^p$ where $Y_{\text{min}} \leq Y_{\text{i}} \leq Y_{\text{target}}$ $d_i = 0$, if $Y_i \leq Y_{\text{min}}$ $d_i = 1$, if $Y_i = Y_{\text{target}}$ and $d_i = \left(\frac{Y_i - Y_{max}}{Y_{target} - Y_{max}}\right)^q$ where $Y_{\text{target}} \leq Y_i \leq Y_{\text{max}}$ $d_i = 0$, if $Y_i \geq Y_{\text{max}}$ $d_i = 1$, if $Y_i = Y_{\text{target}}$

6.4 Results and discussion

The objective of this present work is to achieve the target values for yarn evenness, tenacity, imperfection level and hairiness index for both blow room blend and draw frame blended cotton mélange yarns by maximizing the ‘overall-desirability’. The maximum value of yarn tenacity and minimum values of yarn U%, imperfection and hairiness index were set as target values for blow room blended yarn. The minimum and maximum values for yarn U%, imperfection, tenacity and hairiness index were estimated from their corresponding response surface equations. Hence, in case of blow room blend, maximize the response equation as shown in the first column of Table 6.3 was used for yarn tenacity and minimize the response equation as shown in second column of Table 6.3 was used for yarn unevenness, imperfection and hairiness index. However, in case of draw frame blended yarn, the same target values of yarn quality parameters are set that were used for the blow room blended yarn. This may be argued to the fact that cotton mélange yarn is sold in the market based on the final yarn quality characteristics, but not by the blending method used in manufacturing. The customer of mélange yarn is not influenced by the production method followed by the yarn manufacturer but by the quality characteristics of the yarn for their further applications.

Table 6.4 shows the target, minimum and maximum values for yarn quality parameters for both type of blending methods with all the three shade depths. In the present study, the values of p and q were chosen as 1. The optimum value of 'overall desirability' as expressed in Equation 6.1 was determined for each type of blending method with three different shade depths (%) using MATLAB optimization toolbox. The weight value (w_i) was chosen as 1 which implies equal importance among responses.

Table 6.5 depicts the solutions resulting from the optimization problem. In case of blow room blended cotton mélange yarn of 10% shade depth, the maximum 'overall desirability' value is estimated as 0.88 which corresponds the optimum values of 19.6, 9.18, 42.43 and 4.09 for yarn tenacity (cN/tex), U%, imperfections (per Km) and hairiness index respectively at 13167 rpm spindle speed and 3.90 yarn TM. Similarly for 40% shade depth, the maximum 'overall desirability' value is also estimated as 0.88 which corresponds the optimum values of 19.07, 9.71, 47.8 and 4.59 for yarn tenacity (cN/tex), U%, imperfections (per Km) and hairiness index respectively at 13167 rpm spindle speed and 3.90 yarn TM, whereas for 70% shade depth, the maximum 'overall desirability' value is again estimated as 0.88 which corresponds the optimum values of 17.66, 9.59, 64.59 and 5.09 for yarn tenacity (cN/tex), U%, imperfections (per Km) and hairiness index respectively at 13183 rpm spindle speed and 3.90 yarn TM. The overall-desirability curves for blow room blended mélange yarns at three different shade depths are shown in Figures 6.2-6.4.

Table 6.4 The boundaries and target values of different responses

Type of Yarns	Responses	Shade depth: 10%			Shade depth: 40%			Shade depth: 70%		
		Lower Limit	Target	Upper Limit	Lower Limit	Target	Upper Limit	Lower Limit	Target	Upper Limit
Blow room blend	Tenacity	18.48	19.60	19.60	17.95	19.07	19.07	16.54	17.66	17.66
	U%	9.16	9.16	9.32	9.69	9.69	9.85	9.58	9.58	9.74
	Imperfections	39.08	39.08	49.12	44.45	44.45	54.41	61.16	61.16	71.72
	Hairiness index	4.09	4.09	4.31	4.59	4.59	4.81	5.09	5.09	5.31
Draw frame blend	Tenacity	19.38	19.60	20.48	17.95	19.07	19.05	16.52	17.66	17.62
	U%	8.14	9.16	8.52	9.12	9.69	9.5	9.24	9.58	9.62
	Imperfections	26.35	39.08	36.71	41.25	44.45	51.61	56.15	61.16	66.51
	Hairiness index	4.07	4.09	4.11	4.25	4.59	4.43	4.93	5.09	5.33

Table 6.5 Solutions of optimization problems for cotton mélange yarn

Type of yarns	Responses	Shade depth: 10%			Shade depth: 40%			Shade depth : 70%		
		Predicted value of the response	DV	Solutions	Predicted value of the response	DV	Solutions	Predicted value of the response	DV	Solutions
Blow room blend	Tenacity	19.60	0.88	X_1= 13167 X_2= 3.90	19.07	0.88	X_1= 13167 X_2= 3.90	17.66	0.88	X_1= 13183 X_2= 3.90
	U%	9.18			9.71			9.60		
	Imperfections	42.43			47.8			64.59		
	Hairiness index	4.09			4.59			5.09		
Draw frame blend	Tenacity	19.87	1	X_1= 13400 X_2= 3.68	19.05	1	X_1= 13111 X_2= 3.90	17.62	1	X_1= 13449 X_2= 3.90
	U%	8.31			9.23			9.42		
	Imperfections	31.01			44.41			61.06		
	Hairiness index	4.09			4,25			4.93		

DV-Overall desirability value

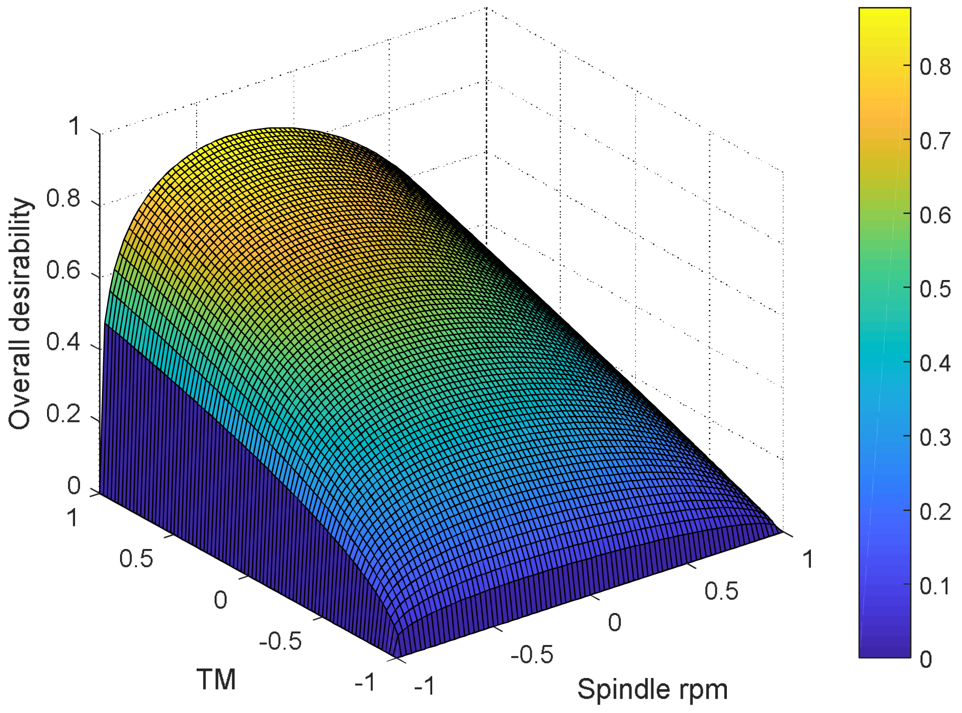


Figure 6.2 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 10% shade depth blow room blended cotton mélange yarn

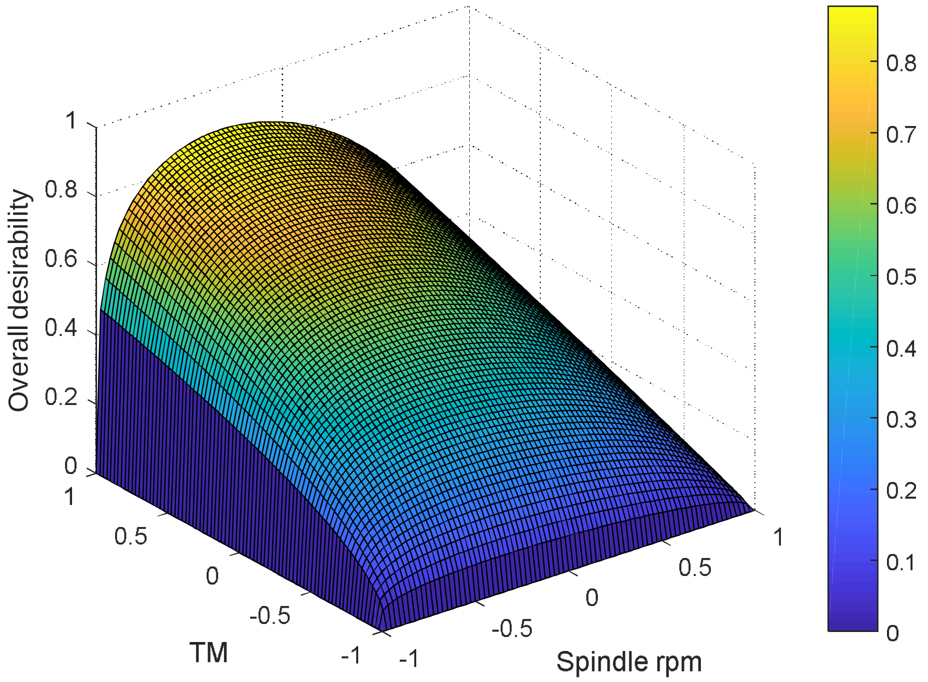


Figure 6.3 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 40% shade depth blow room blended cotton mélange yarn

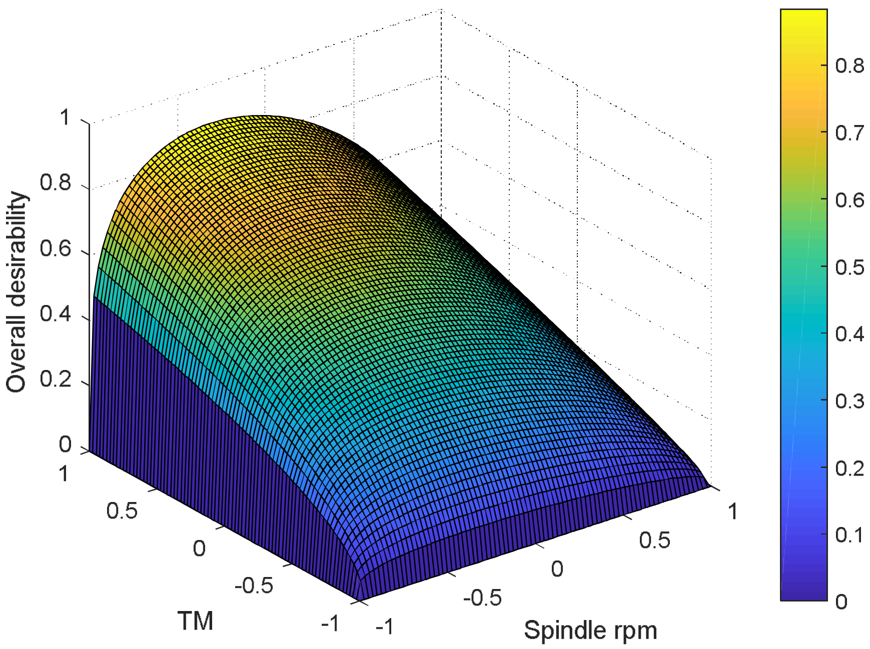


Figure 6.4 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 70% shade depth blow room blended cotton mélange yarn

In case of draw frame blended cotton mélange yarn of 10% shade depth, the maximum ‘overall desirability’ value is estimated as 1.0 which corresponds the optimum values of 19.87, 8.31,31 and 4.09 for yarn tenacity (cN/tex), U%, imperfections and hairiness index respectively at 13400 rpm spindle speed and 3.68 yarn TM. Similarly for 40% shade depth, the maximum ‘overall desirability’ value is also estimated as 1 which corresponds the optimum values of 19.05, 9.23, 44.41 and 4.25 for yarn tenacity (cN/tex), U%, imperfections and hairiness index respectively at 13111 rpm spindle speed and 3.90 yarn TM whereas for 70% shade depth, the maximum ‘overall desirability’ value is yet again obtained as 1.0 which corresponds the optimum values of 17.62, 9.42, 61.06 and 4.93 for yarn tenacity (cN/tex), U%, imperfections and hairiness index respectively at 13449 rpm spindle speed and 3.90 yarn TM. The overall-desirability curves for draw frame blended mélange yarns at three different shade depths are shown in Figures 6.5-6.7.

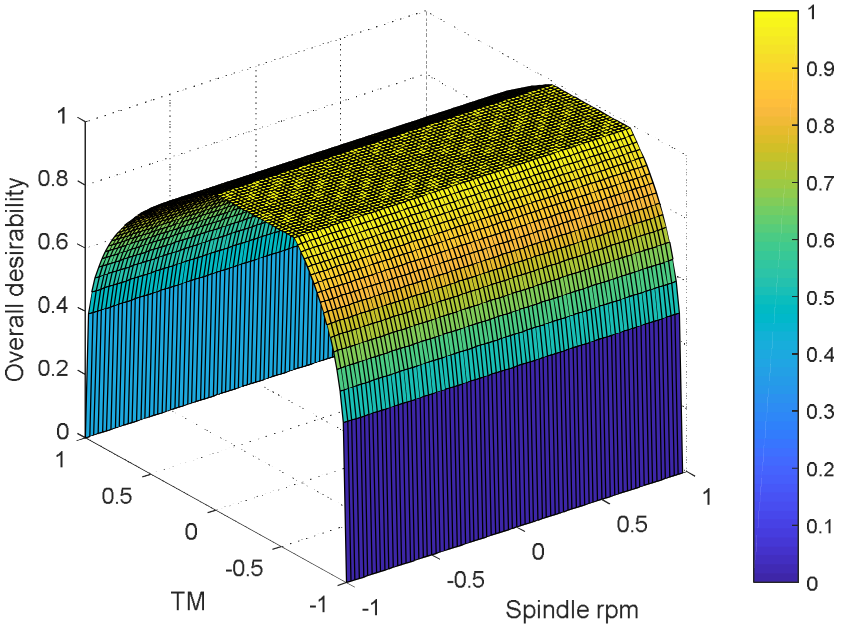


Figure 6.5 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 10% shade depth draw frame blended cotton mélange yarn

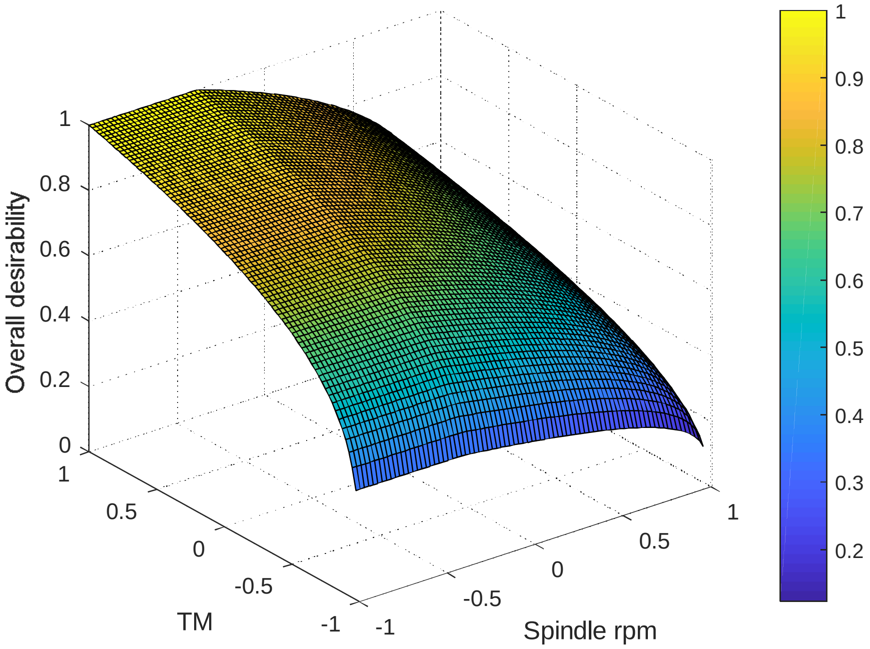


Figure 6.6 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 40% shade depth draw frame blended cotton mélange yarn

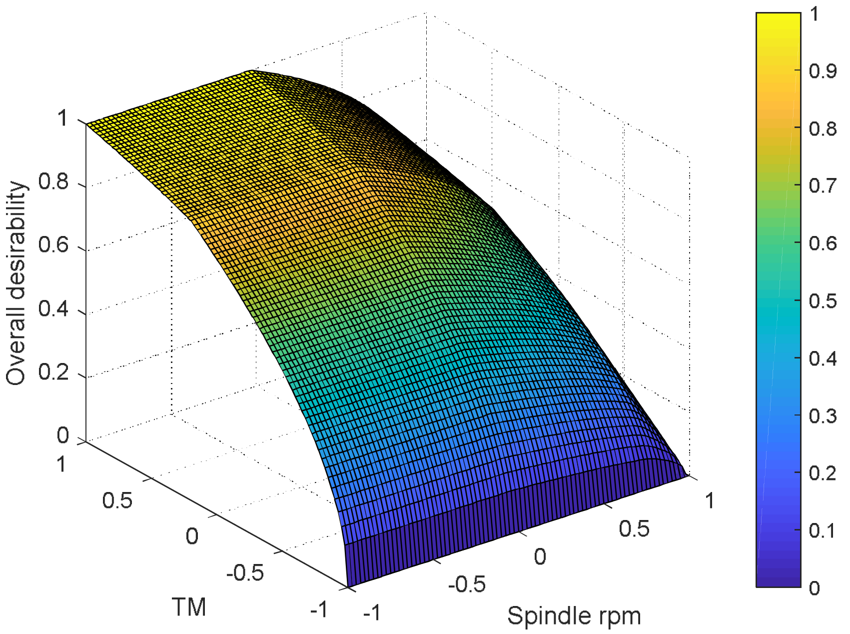


Figure 6.7 Overall-desirability as a function of spindle speed (rpm) and yarn twist (TM) for 70% shade depth draw frame blended cotton mélange yarn

It is also evident from the Table 6.5 that the better 'overall desirability' is achieved for draw frame blended cotton mélange yarn over the blow room blended mélange yarn. The productivity is related to the spindle speed and twist per unit length by the following relationship:

$$\text{Productivity} \propto \frac{\text{Spindle rpm}}{\text{Twist per unit length}}$$

Again, TM is related to twist per inch (TPI) and yarn count in English system (Ne) as:

$$\text{TM} = \frac{\text{TPI}}{\sqrt{\text{Ne}}}$$

Therefore, for given yarn count it can be written that

$$\text{Productivity} \propto \frac{\text{Spindle rpm}}{\text{TM}}$$

The percentage gain in productivity for draw frame blending technique than that of blow room blending for three shade depths is shown in Table 6.6. From Table 6.6 it is evident that except 40% shade depth, draw frame blending method has an edge in productivity over blow room blending while achieving same target yarn quality. For lighter shade depth the gain in productivity is highest for draw frame blending method. But at medium shade depth category, the productivity gain for draw frame blending method is found to be negative, although the difference is marginal. This may be attributed to that fact that when the percentage of dyed fibre and grey fibre in the sliver is more or less same, the control of fibre movement in the drafting zone becomes difficult due to difference in length characteristics of dyed fibre and grey fibre. The drafting roller setting is better suited for either grey fibre or dyed fibre. The more number of drawing passage is associated with the draw frame blending method as compared to blow room blending method. Thus, draw frame blending method has slightly less productivity over blow room blending method for achieving same target yarn quality while processing medium shade depth.

Table 6.6 Comparison between blow-room and draw frame blend for productivity

Shade depth	10%		40%		70%	
Optimized parameters	Spindle speed (rpm)	TM	Spindle speed (rpm)	TM	Spindle speed (rpm)	TM
Blow room blend	13167	3.90	13167	3.90	13183	3.90
Draw frame blend	13400	3.68	13111	3.90	13449	3.90
Gain in productivity by draw frame blending method	+7.85 %		-0.425%		+ 2.02 %	

Table 6.7 Optimized and achieved mélange yarn properties

Type of yarns	Responses	Shade depth: 10%			Shade depth: 40%			Shade depth: 70%		
		O	A	Error (%)	O	A	Error (%)	O	A	Error (%)
Blow room blend	Tenacity, cN/tex	19.60	19.40	1.02	19.07	18.63	2.33	17.66	17.12	3.06
	U%	9.18	9.25	1.55	9.71	10.01	3.12	9.60	9.92	3.34
	Imperfections	42.43	44	3.71	47.8	50	4.15	64.59	67.3	4.20
	Hairiness index	4.09	4.15	1.96	4.59	4.71	2.67	5.09	5.20	2.12
Draw frame blend	Tenacity, cN/tex	19.87	19.8	0.38	19.05	18.84	1.12	17.62	17.52	0.62
	U%	8.31	8.55	2.88	9.23	9.51	3.62	9.42	9.68	2.76
	Imperfections	31.01	30	3.26	44.41	46	4.12	61.06	59	3.37
	Hairiness index	4.09	4.13	1.03	4,25	4.34	2.04	4.93	5.06	2.64

O– Optimized value, A–Achieved value

6.5 Experimental Validation

The optimization model was validated by comparing actual results and optimum values. For this, blow room blended and draw frame blended 20’s Ne cotton mélange yarn samples were produced for all the three shade depths with the respective solutions of spindle rpm and yarn TM. All the yarn samples were again tested for yarn tenacity, evenness, imperfections and hairiness index as per standard testing procedure described in the preceding section. Actual values and calculated optimum values of yarn qualities are shown in Table 6.7. It is evident from the Table 6.7 that the actual values of yarn tenacity, evenness, imperfection and hairiness index are very close to the calculated optimum values with an error of less than 5% in all cases for both the blow room blended and draw frame blended cotton mélange yarns.

6.6 Conclusion

The overall desirability index was maximized by optimizing multiple yarn properties such as tenacity, evenness, imperfection and hairiness index against target values. Optimum values are obtained for spindle speed and TM in order to engineer a cotton mélange yarn with desired combinations of yarn tenacity, evenness, imperfection and hairiness index. The experimental results have shown significant agreement between the calculated and actual values of the yarn properties. Except medium shade depth, the desired yarn properties can be achieved with better productivity level with draw frame blending method compared to blow room blending method. This study may be used by a yarn manufacturer to produce cotton mélange yarn for target yarn qualities.

Chapter 7

Overall Conclusions

CHAPTER 7

OVERALL CONCLUSIONS

Designing and manufacturing of cotton mélange yarn with optimal properties and productivity is an important aspect in spinning industry. This thesis is the outcome of some systematic investigations on controllable material, structural and process parameters, manufacturing methods and techniques (multi-objective optimization) to achieve desired level of quality parameters and productivity level for fibre dyed cotton mélange yarn. The overall conclusion of the research work is summarized below.

- Taguchi experimental design was used to determine the significant factors affecting important yarn quality parameters (evenness, imperfection, tensile properties and hairiness) for 20's Ne cotton mélange yarn. Shade depth (%) and spindle speed (rpm) were found to be the major determinant of evenness, imperfection, tenacity, breaking elongation and hairiness for cotton mélange yarn. However, TM is found to be determinant only for yarn tensile properties. The optimum levels of the controlled factors for each response are obtained.
- Response surface methodology was used to study the individual and interactive effects of raw material (dyed fibre % in the mixing), spinning process parameter (yarn twist multiplier) and productivity (spindle rpm of ring frame) and thus determining the significant factors affecting properties of both blow room and draw frame blended cotton mélange yarns. Shade depth (%) and spindle speed (rpm) were found to be the major determinants affecting the cotton mélange yarn quality for both the blow room blend and draw frame blend. Quadratic regression equations

were developed for the response variables which paves a way to cotton mélange yarn engineering.

- Using both the experimental designs, shade depth (%) was found to be the most dominating parameter followed by spindle rpm and TM.
- Correct selection of spindle speed (rpm) and yarn TM is crucial in designing cotton mélange yarn for desired level of quality and productivity for a particular shade depth (%).
- Two blending methodologies, viz., blow room and draw frame blending were compared to determine the best suited technique for better melange yarn quality. It was observed that cotton mélange yarn quality is significantly affected by the method of blending. Better mélange yarn quality was achieved with draw frame blending techniques compared to blow room blending technique.
- Multi-objective optimization of cotton mélange yarn properties for both the blow room and draw frame blend were attempted using desirability function approach that combined the multiple properties of cotton mélange yarn into a single index representing the overall desirability varying from 0 to 1. The optimization problem was formulated to maximize the overall desirability by satisfying the multiple properties of mélange yarn such as evenness, tenacity, imperfection and hairiness to their respective target values for three different shade depths (%). The optimum values of the controlled factors i.e. spindle speed and yarns TM for the maximum overall desirability were obtained. In case of blow room blended mélange yarn, the overall desirability was found to be 0.88 for all the three shade depths of 10%, 40% and 70%. In case of draw frame blended cotton

mélange yarn, the overall desirability was found to be 1 for all the three shade depths. A better value of overall desirability was achieved for draw frame blend compared to blow room blend even at higher productivity level.

- Multi-objective optimization using desirability function approach was validated by spinning mélange yarns with optimum solutions of spindle speed and yarn TM for all three shade depth 10%, 40% and 70% for both the blow room and draw frame blending methods. Subsequently optimized and achieved values of mélange yarn properties were compared. The optimized and achieved values were found to be in good agreement. The deviation of achieved value of yarn evenness, tenacity, imperfection and hairiness index was always less than 5% as compared to the respective optimized value.

Chapter 8

Suggestions for Future Research

CHAPTER 8

SUGGESTIONS FOR FURTHER WORK

The following suggestions may be made for conducting further research work in the area of manufacturing mélange yarn for optimal productivity with desired yarn qualities.

1. In the present research work the yarn qualities of 100% ring spun cotton mélange yarn (20’s Ne) for different blending methodologies were studied. The studies were carried out to optimize productivity with desired level of mélange yarn quality parameters. Though the cotton mélange yarn is widely used for its unique characteristics, the value added synthetic fibres are slowly replacing them in knitwear sector. Moreover, difficulties in achieving desired qualities and productivity level for 100% cotton mélange yarn may be reduced by adding certain percentage of strong synthetic fibres in the mixture. Therefore, mélange yarns from blends of cotton and synthetic fibres (for example: cotton–viscose blend, cotton-polyester blend, cotton-acrylic blend) may be used to conduct similar studies to optimize the mélange yarn qualities and productivity.The cotton-synthetic blend will help the spinner to reduce the cost of the product which in turn will help to increase the market share. Besides, the present study has not covered the production of mélange yarns for finer counts. Therefore, similar studies may be conducted for manufacturing of relatively finer yarn counts.

2. In this research, widely used conventional ring spinning system was considered for quality optimization. The technological advancement like innovation of compact spinning technology has helped the yarn manufacturer to achieve better yarn quality with higher productivity. This compact spinning may be used for production of cotton

compact mélange yarn to achieve better yarn qualities and productivity. Therefore, it will be worthy to conduct similar kind of research for compact spinning system.

3. Application of mélange yarn is rapidly increasing in different textile sectors for its huge advantages. Along with the popularity in knitwear sector, prospect of the mélange yarn in woven sector is also very bright. Therefore, future endeavour can be made to optimize the mélange yarn qualities for high end woven clothing.

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APPENDIX

1. MATLAB codes for calculation of S/N ratio of yarn tenacity for blow room blended mélange yarn

```
%Calculation of S/N ratio for B/R USTER (Taguchi method)
clc
clearall
closeall

formatshortg

x=[ 19.11   18.73   19.11   18.77
    20.10   19.97   20.05   19.8
    20.37   20.27   20.68   20.75
    18.23   18.56   18.11   18.46
    17.42   17.75   17.75   17.68
    18.66   19.02   19.5    19.36
    16.70   16.97   17.21   17.05
    17.35   18.39   17.69   17.99
    18.45   18.58   18.53   18.5];
[m,n]=size(x);
x1=x.^2;
x2=1./x1;
for i=1:m
y_avg(i)=mean(x(i,:));
    sumsq_x1(i)=sum(x1(i,:));
    sumsq_x2(i)=sum(x2(i,:));
SN_smaller_better(i)=-10*log10(sumsq_x1(i)/n);
SN_larger_better(i)=-10*log10(sumsq_x2(i)/n);
end
mean_y=y_avg'
SN_smaller_better=SN_smaller_better'
SN_larger_better=SN_larger_better'

z=[1    1   1
   1   2   2
   1   3   3
   2   1   2
   2   2   3
   2   3   1
   3   1   3
   3   2   1
   3   3   2];
%for z: Col 1=shade depth%, Col 2=TM, Col 3=spindle rpm
z1=[z SN_larger_better];
[m1,n1]=size(z1);
Sum=0;
for j=1:n1-1
for i=1:m1
if z1(i,j)==1
SN1(i,j)=z1(i,end);
```

```
elseif z1(i,j)==2
SN2(i,j)=z1(i,end);
elseif z1(i,j)==3
SN3(i,j)=z1(i,end);
end
end
end
v1=SN1;
v2=SN2;
v3=SN3;
[m3,n3]=size(v1);
for i=1:n3
v11(:,i)=nonzeros(v1(:,i));
v22(:,i)=nonzeros(v2(:,i));
v33(:,i)=nonzeros(v3(:,i));
end
SN_avg=[mean(v11);mean(v22); mean(v33)];
R=range(SN_avg);
[s1,I]=sort(R,'descend');
[a,rank]=sort(I,'ascend');
Table_SN=[SN_avg; R;rank]
M_SN=mean(SN_avg);
[m,n]=size(SN_avg);
for i=1:n
   S_SN(:,i)=(SN_avg(:,i)-M_SN(i)).^2;
end
SS_SN=sum(m*S_SN)';
T_SN=sum(SS_SN);
100*SS_SN./T_SN;
df_SN=(m-1)*ones(n,1);
df_Res=(9-1)-sum(df_SN);
Model_SS=T_SN;
df_Model=sum(df_SN);
Total_SS=sum((z1(:,end)-mean(z1(:,end))).^2);
Residual=Total_SS-Model_SS;
Model_MS=Model_SS/df_Model;
Model_F_cal=Model_SS/Residual;
df=[df_Model;df_SN;df_Res];
I=[Model_SS;SS_SN;Residual];
MS_SN=I./df;
Table_ANOVA_SN=[I df MS_SN]
Total_SS
Total_df=9-1
F_cal=MS_SN(1:end-1)/MS_SN(end)
x=F_cal;
nu1=df(1:end-1);
nu2=ones(length(nu1),1)*df(end);
pval = 1-(fcdf(x,nu1,nu2)); % Probability value
Significance=[x,pval]
%F_table=[finv(0.95,6,2);finv(0.95,2,2)]
```

```
Percentage_contribution=(100*([SS_SN; Residual]/Total_SS))
R_sq=Model_SS/Total_SS
figure(1)
subplot(3,1,1)
plot([10 40 70], SN_avg(:,1), '*-k')
ylim([25 26])
xlabel('Shade depth, %')
ylabel('Mean S/N ratio')
subplot(3,1,2)
plot([3.5 3.7 3.9], SN_avg(:,2),'*-k')
ylim([25 26])
xlabel('Twist multiplier')
ylabel('Mean S/N ratio')
subplot(3,1,3)
plot([12500 13500 14500], SN_avg(:,3),'*-k')
ylim([25 26])
xlabel('Spindle speed, rpm')
ylabel('Mean S/N ratio')
set(gcf,'color','w')
```

2. MATLAB codes for significance test of controlled factors on strength of blow room blended mélange yarn

```
clc
clearall
closeall
formatshortg
%Loading the data (Columns 1 to 3 = Inputs, Column 4 (RKM=Output)
data=[10  13500   3.5     18.34
70  13500   3.5     16.24
10  13500   3.9     19.51
70  13500   3.9     17.35
10  12500   3.7     19.44
70  12500   3.7     17.06
10  14500   3.7     18.65
70  14500   3.7     17.53
40  12500   3.5     17.94
40  12500   3.9     19.16
40  14500   3.5     17.79
40  14500   3.9     18.74
40  13500   3.7     17.97
40  13500   3.7     18.85
40  13500   3.7     18.72];
%Normalization of independent variables(between -1 to 1)
for j=1:3;
 X(:,j)=2*((data(:,j)-min(data(:,j)))/(max(data(:,j))-min(data(:,j))))-1;
end
% Conversion of input matrix to design matrix for regression analysis
x=x2fx(X,'quadratic');
```

```
%x=[1 X1 X2 X3 X1.*X2 X1.*X3 X2.*X3 X1.^2 X2.^2 X3.^2]
y=data(:,4); %output of 4th column
b=pinv(x)*y; %pinv(x)=(inv(x'*x))x'; pinv is the pseudo inverse of x
% b=Regression coefficient
y_est=x*b; %y_est=Estimated value of output
%y_est=b1*1+b2*X1+b3*X2+b4*X3+b5*X1.*X2 +b6*X1.*X3 +b7*X2.*X3+b8*X1.^2
+b9*X2.^2 +b10*X3.^2
res=y-y_est; %res=Residual
R_sq=(corr(y,y_est))^2 %R_sq=Coeffient of determination
mean_accuracy=mean(100-((abs(res)./y)*100)) %Average accuracy of prediction
%Statistical Analysis of quadratic regression
[Q,R]=qr(x,0);%Orthogonal-triangular decomposition
nobs=length(y);%Number of observation
p=length(b);%Number of regression coefficients
dfe = nobs-p;%Degree of freedom
sse = norm(res)^2; % Sum of squared errors
mse = sse./dfe; %Mean square error
ri = R\eye(p);%R from the QR Decomposition of the design matrix
xtxi = ri*ri';
covb = xtxi*mse;%covb=Covariance of regression coefficients
se = sqrt(diag(covb));%Standard errors of regressioncoefficients
t=b./se;% t-stats for regression coefficients
pval = 2*(tcdf(-abs(t), dfe)); % Probability value
Table=[b se t pval]
% Finding the regression coefficients which are significant at 95% confidence level
j=0;
for i=1:length(pval)
ifpval(i)<=0.05
        j=j+1;
row_pval(j)=i;
end
end
Significant_b=row_pval'%Significant coefficients
xe=x(:,row_pval);
be=b(row_pval');
y_e=xe*be;
resi=y-y_e;
[yy_eresi];
R_sq_e=(corr(y,y_e))^2
mean_accuracy_e=mean(100-((abs(resi)./y)*100))
%Percentage contribution from beta-coefficient
x=x(:,Significant_b');
%x=[1 X1 X2 X3 X1.*X2 X1.*X3 X2.*X3 X1.^2 X2.^2 X3.^2]
input_data=zscore(x);
target_data=zscore(y);
[beta_coef,Var_beta,residual,sR2]=regress(target_data,input_data);
%Percentage contribution
bc=abs(beta_coef);
cd=R_sq_e;
for i=1:length(bc)
```

```
c(i)=100*((bc(i))/sum(bc))*cd;
end
Beta_Contribution=[beta_coef c']%[beta_coefficientpercentage_contribution]
Total_explained_variation=sum(c)
predicted_value1=input_data*beta_coef;
cod=(corr(target_data,predicted_value1))^2
```

3. MATLAB codes for multi-objective optimization of the quality of blow room blended mélange yarn with 40% shade depth using desirability function approach

```
function Y=dfn_br(X)
s=0;
U=9.69 + 0.21*s - 0.32*s^2 + 0.16*X(1).^2;
Str=18.51- 0.97*s+ 0.56*X(2)- 0.44*s^2;
IPI=49.47+11.04*s+5.02*X(1)+5.67*s^2;
H=4.7+0.5*s-0.11*X(2);
Str_min=17.95;
Str_max=19.07;
Str_target=Str_max;
U_min=9.69;
U_max=9.85;
U_target=U_min;
IPI_min=44.45;
IPI_max=54.49;
IPI_target=IPI_min;
H_min=4.59;
H_max=4.81;
H_target=H_min;
if (Str<=Str_target) && (Str>=Str_min)
  d1=(Str-Str_min)/(Str_target-Str_min);
elseifStr_target<Str
  d1=1;
else d1=0;
end

if (U>=U_target) &&  (U<=U_max)
  d2=(U_max-U)/(U_max-U_target);
elseifU_target>U
  d2=1;
else d2=0;
end

if (IPI>=IPI_target) &&  (IPI<=IPI_max)
  d3=(IPI_max-IPI)/(IPI_max-IPI_target);
elseifIPI_target>IPI
  d3=1;
else d3=0;
end
```

```
if (H>=H_target) &&  (H<=H_max)
   d4=(H_max-H)/(H_max-H_target);
elseifH_target>H
   d4=1;
else d4=0;
end
Y=-((d1*d2*d3*d4)^(1/4));
```

```
clc
closeall
clearall
formatshortg
%
s=0;
x0=[-1 -1];
A=[];
B=[];
Aeq=[];
Beq=[];
vlb=[-1 -1];
vub=[1 1];
nonlincon=[];
options=optimset('LargeScale','on');
x1=[12500 14500];
x2=[3.5 3.9];
[x,fval]=fmincon(@dfn_br,x0,A,B,Aeq,Beq,vlb,vub,nonlincon,options);
x_max=x
max_dfnc=-fval%Maximum value of desireability function
Optimum_val_x1=((x(1)+1)*(max(x1)-min(x1)))/2+min(x1)%Optimum value of spindle
speed
Optimum_val_x2=((x(2)+1)*(max(x2)-min(x2)))/2+min(x2)%Optimum value of yarn TM
Str_val=18.51- 0.97*s+ 0.56*x(2)- 0.44*s^2
U_val=9.69 + 0.21*s - 0.32*s^2 + 0.16*x(1).^2
IPI_val=49.47+11.04*s+5.02*x(1)+5.67*s^2
H_val=4.7+0.5*s-0.11*x(2)
Str_min=17.95;
Str_max=19.07;
Str_target=Str_max;
U_min=9.69;
U_max=9.85;
U_target=U_min;
IPI_min=44.45;
IPI_max=54.49;
IPI_target=IPI_min;
H_min=4.59;
H_max=4.81;
H_target=H_min;
```

```
Str=Str_min:0.01:Str_target;
d1=(Str-Str_min)/(Str_target-Str_min);
figure,plot(Str,d1,'k')
xlabel('Yarn strength (RKM)')
ylabel('Desirability')
set(gcf,'color','w')
U=U_target:0.01:U_max;
d2=(U_max-U)/(U_max-U_target);
figure,plot(U,d2,'k')
xlabel('U(%)')
ylabel('Desirability')
set(gcf,'color','w')
IPI=IPI_target:0.01:IPI_max;
d3=(IPI_max-IPI)/(IPI_max-IPI_target);
figure,plot(IPI,d3,'k')
xlabel('IPI')
ylabel('Desirability')
set(gcf,'color','w')
H=H_target:0.01:H_max;
d4=(H_max-H)/(H_max-H_target);
figure,plot(H,d4,'k')
xlabel('HI')
ylabel('Desirability')
set(gcf,'color','w')
%
xx1=-1:0.025:1;
xx2=-1:0.025:1;
[X1,X2]=meshgrid(xx1,xx2);
[m,n]=size(X1);
p=0;
for i=1:m
for j=1:n
Z(i,j)=-(dfn_br([X1(i,j) X2(i,j)]));
end
end
%
figure,surf(X1,X2,abs(Z))
xlabel('Spindle rpm')
ylabel('TM')
zlabel('Overall desirability')
set(gcf,'color','w')
colorbar
%
figure,contour(X1,X2,abs(Z),10)
```