Optimization of Dyeing Process Parameters on Cotton Knit Fabric Using Taguchi Method

(Case Study: MAA Garment and Textiles Factory)

Ethiopian Institute of Technology-Mekelle

School of Mechanical and Industrial Engineering

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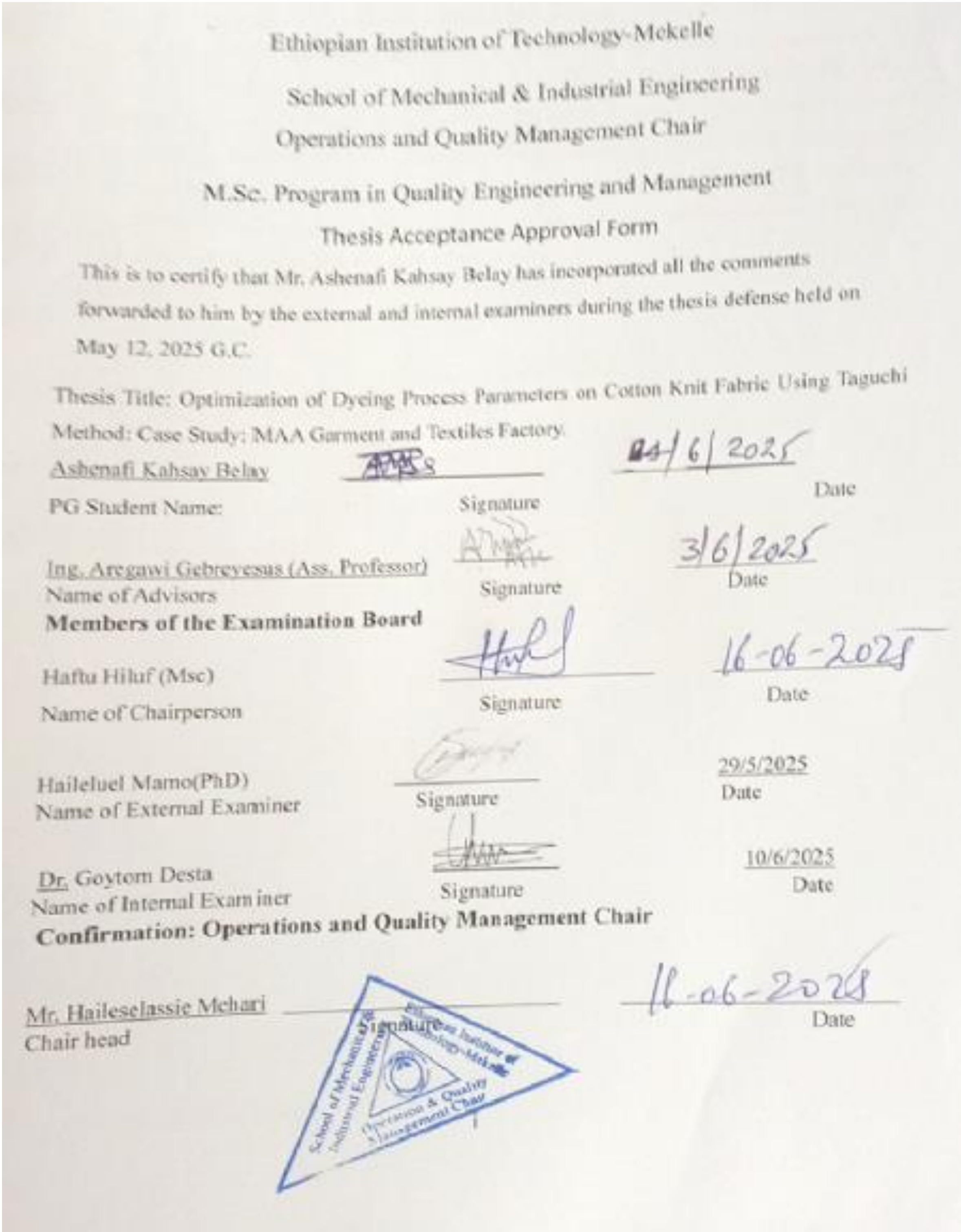

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DECLARATION

This is to certify that this title entitled "Optimization of Dyeing Process Parameters on Cotton Knit Fabric Using Taguchi Method" the case of MAA Garment and Textiles Factory submitted for partial fulfillment of the requirement for the award of degree of MSc in Industrial Engineering (Quality Engineering and Management) Mekelle University through the School of Mechanical and Industrial Engineering done by Mr. Ashenafi Kahsay under my full guidance. The work contained in this thesis has not been previously submitted for a degree at any other higher education institutions to the best of my knowledge and all the sources that I have used or quoted have been indicated and acknowledged by means of referencing.

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Ashenafi Kahsay Belay

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Table of Contents

Table of Contents

List of Abbreviations and Acronyms

ANOVA - Analysis of variance

RSM - Response Surface Methodology

DOE - Design of Experiment

QE - Quality Engineering

OA - Orthogonal Arrays

D – Degree of freedom

S/N - Signal to Noise Ratio

S.D – (Undesirable effect) signal disturbance

GRA - Grey relation analysis

PH - Percentage of Hydrogen

MLR - Material Liquor Ratio

PC blend - Polyester/Cotton blend

ECL - Electrical Communication Laboratories of Nippon Telephone and Telegraph company

CS – Color Strength

g/l – gram per liter

GSV - Grey Scale Values

owf – percent weight of fabric

conc. – concentration

coef – coefficient

List of tables

List of figures

Abstract

The research focus on optimizing the dyeing process parameters on knit fabric by applying the Taguchi method in the selecting case is in MAA Garment and Textiles Factory. Taguchi method is used to find the overall optimum dyeing condition and to investigate which machining parameters significantly affect the performance characteristic. Dyeing in the textile industry is all about giving color to fabrics. It's a process that uses dyes to permanently color finished fabrics. The goal is to achieve a specific shade with good colorfastness, meaning the color should resist fading or bleeding during washing and use.

The study has identified the optimal conditions for dye concentration, temperature, time, PH, Material Liquor Ratio, salt, alkali, and fixing agent and L27(3^8) orthogonal array by using Minitab and Response factor is washing fastness.

Accordingly, the product dye concentration, temperature, MLR, salt concentration, alkali concentration, PH, fixing agent, and time (A3, B2, C2, D3, E2, F2, G3 and H2) can be replaced. The main effect plot and the ANOVA has jointly showed that, dye concentration for the experiment is found to be highly influential of the performance for it attains an F value 25.56, higher than each dyeing parameter. From the ANOVA table has also displayed the minimal role of some of the process parameters such as temperature, MLR, and salt concentration under the selected alpha value of 0.05.

Keywords: Optimization, Dyeing, Taguchi Method, Main effects plots, Colorfastness, PH

CHAPTER ONE: INTRODUCTION

1.1. Background and Justification of the study

Quality has become one of the most important considerations influencing consumer decisions when deciding between competing products and services. This trend is evident across various sectors, including individual consumers, company organizations, retail stores, banks, financial institutions, and military defense programs. Therefore, applying and improving quality are crucial for business success, growth, and competitiveness (Hoque and Maalouf, 2022). Investing in quality yields substantial returns, especially when quality is integrated into the whole business strategy. Quality has been highlighted as a strategic component that adds value (Komal and Saad, 2022). Quality is defined as a product or service's ability to meet or exceed customer expectations regarding efficiency, performance, durability, comfort, and ease of use. However, maintaining high quality requires consistency and adequate resources to support and manage all related activities (Mkwanazi Michael Sizwe, 2017).

Today is the world’s most scientific and advanced level of dyeing. There are huge numbers of processes to do coloration. Natural and man-made colors are also used (Rahul Sharma, 2014). Proper dyeing of fabric, dyeing parameters need to be optimized to achieve the best fastness results. Optimization is needed for optimization of dyeing process variables for achieving uniform and reproducible shades which is not done earlier (H. D. Sinnur, 2018). Process optimization is important in controlling the process to obtain the targeted results. In general, textile dyeing is a complex process equipped with a manufacturing plant function oriented and requires various steps to maintain the operation performance. According to the Taguchi design in Minitab software, an experiment was conducted to ensure the repetitiveness of the dyeing process (Nahid Pervez, 2023).

Process optimization is the practice of modifying a process to enhance the certain characteristics while adhering to established constraints. The primary objectives often include minimizing costs, maximizing throughput, and enhancing efficiency. This discipline serves as a significant tool in industrial decision-making. Therefore, developing and applying techniques that optimize the fabric dyeing process are necessary to minimize the chemicals and water used, process costs, and environmental impacts, while maintaining the quality of textile products (Rosa et al., 2021). The optimization of the conditions for obtaining coloristic intensities in the cotton dyeing process with

Reactive dyes (Boukouvalas et al., 2021). When optimizing a process, it is essential to focus on the particular specification while ensuring that all other parameters remain within their constraints. Many people associate process optimization exclusively with the use of statistical techniques to find the best solution. While statistical methods are indeed valuable, a comprehensive understanding of the process is essential before investing time in optimization. Over the years, various methodologies for process optimization have been developed, including the Taguchi method, Six Sigma, lean manufacturing, and others (Makwana and Patange, 2021).

Design of Experiments (DOE) mathematical technique used for planning and conducting experiments as well as analyzing and interpreting data obtained from the experiments. It is a branch of applied statistics that is used for conducting scientific studies of a system, process or product in which input variables (Xs) were manipulated to investigate its effects on measured response variable (Y). Over past 20 years, DOE was a very useful tool traditionally used for improvement of product quality and reliability (Durakovic, 2017). The usage of DOE has been expanded across many industries as part of decision-making process either along a new product development, manufacturing process and improvement. It is not used only in engineering areas it has been used in administration, marketing, hospitals, pharmaceutical, food industry, energy and architecture, and chromatography. DOE is applicable to physical processes as well as computer simulation models. In order for the product designed and produced in engineering studies to have the best performance, the features and factors affecting the performance should be determined, and experiments should be carried out to obtain the optimum values (Beg et al., 2019).

The Taguchi experimental design method is widely used in the various engineering field. Experiments are conducted in order to obtain the optimum values of the product designed or produced in the field of engineering (Hisam et al., 2024). It is difficult to make the experiments because of the large number of parameters in the studies made. Therefore, with the Taguchi experimental design method, less experimentation can be done in shorter time and an accurate test strategy is being developed. Thus, saving is provided from time and cost, high quality and low-cost production is achieved (Oğuz, 2022).

Conversely, pigments are colorants made up of particles that are insoluble in the media which they are applied. They do not possess substantivity for the material, meaning they cannot penetrate the substrate. Rather, pigments remain on the surface of the substrate and can be easily removed unless they are fixed with an adhesive. The majority of textile dyeing processes begin with the transfer of the colored chemical, or its precursor, from the aqueous solution to the fiber surface in a process called adsorption. The dye may slowly diffuse into the fiber. This diffusion occurs through holes or between the polymer molecules of the fiber that is depending on the fiber's internal structure (Repon et al., 2024). The combined processes of adsorption and penetration of the dye into the fiber are referred to as absorption. Because, absorption is a reversible process. Thus, the dye can return to the aqueous medium from the dyed material during washing, a process known as desorption. In addition to direct absorption, the coloration of a fiber may also involve the precipitation of a dye within the fiber or undergo a chemical reaction between the dye and the fiber. Since these two types of processes typically offer better fastness to washing since they are essentially irreversible (Broadbent, 2001).

The objective of dyeing is to produce uniform coloration of a substrate obviously to match a pre-selected color. The color should be uniform throughout the substrate and be of a solid shade with level or no change in shade over the whole substrate. There are a lot of factors that will influence the appearance of the final shade, including: texture of the substrate, construction of the substrate (both chemical and physical), pre-treatments applied to the substrate prior to dyeing and post-treatments conducted after the dyeing process. The application of color can be performed by a number of methods, but the most common three popular methods are exhaust dyeing or batch, continuous or padding and printing (Clark, 2011).

Cotton is the most important natural fiber. It is the purest form of cellulose found in nature. And also, it is a single biological cell with a multilayer structure (Teli and Adere, 2016). The content of cellulose in cotton is around 91% and increases to 95% after removing the natural impurities. The remaining 5% consists of other impurities materials such as protein, pectin, ash and minerals (Shore, 1995, Jhatial et al., 2020). Cellulosic fibers particularly cotton is the most widely used types of fiber due to several merits such as the ability to withstand harsh washing solutions, specifically under alkaline conditions, good perspiration absorption characteristics, comfortable wear properties, and the capacity to take up a large variety of dyestuffs (Pervez, 2018). Knit fabrics have excellent comfort properties because of their typical design porous structure. The different comfort properties of knitted fabrics like air permeability, thermal absorptivity, and thermal conductivity depend on the properties of raw material and knitting factors or parameters (Anindya Ghosh, 2017).

A detailed study was conducted for small scale textile industry in depth for the various processes involved, chemicals needed, raw material and equipment information, operating parameters, energy requirements during operations including different losses etc. Moreover, to optimize thermal energy requirements in order to produce acceptable good quality of cotton-colored products (Kuldip A Rade, 2014). To optimize the dyeing condition using of wool/cotton blended fabric in union shade with a direct dye at neutral pH and to investigate the effects of dye bath additives, dyeing temperature, and dyeing time. A Box-Behnken design was used to fit a second order model that would be necessary for optimal dyeing condition (L. Ammayappan, 2011). To optimize the conditions of the extracted operations using nettle plant leaf as raw material for natural dye and antibacterial activity by using Central composite design. Nettle leaf plant extracts as color agent in dyeing as well as impart antibacterial properties to the cotton fabric (Ketema, 2023). Other research studies concentrate on the characterization of Gunda Gundo orange peels are cultivated in abundance in the northern region of Ethiopia and followed by the optimization of variables affecting the extraction process (Ebuy Werede, 2021).

In modern manufacturing processes, selecting of optimal parametric settings is becoming a essential issue for obtaining improved process/product performance. Every optimization method serves specific purposes and is chosen based on the complexity of the system, the importance of interactions, and resource availability. The Taguchi method offers a practical and efficient approach to optimization, specifically when resources are limited and focuses on robustness against variability is a priority. Its designing of simplicity and effectiveness makes it a valuable tool in various optimization scenarios. So, my study is to the context of quality and Taguchi method is helpful rather than the others optimization tools. In this study, although the Taguchi method is widely used in many research fields, there have been few applications in textile manufacturing process specially in dyeing process. And in MAA garment and textiles factory none had been done in the dyeing section to minimize the variations. The study was identified the optimal conditions for dye concentration, temperature, time, PH, MLR, salt, alkali, and fixing agent with their three factor levels. The washing fastness has taken as measured quality characteristics. Finally, the significant factors influencing the dyeing process were determined.

1.2. Description of the case study factory

The company Kebire Enterprises, is a privately owned company established and registered in April 2001 in accordance with the commercial laws of the Federal Democratic of Ethiopia. MAA Garment & Textile Factory started its operation in June 2004 in the northern part of Ethiopia, Tigray, Mekelle wholly owned by Kebire Enterprises PLC. It is spearheaded by dynamic local staffs combined with expatriate from Turkey, Pakistan & Philippines, with production set-up fully equipped with state-of-the-art machineries & equipment's from renowned manufacturers in the world like Juki, Brothers, Myers & Cie, THIES, MONFORTS. MAA Garments is emerging to be one of the leading apparel manufacturers not only in Ethiopia but also in the rest of the world.

The MAA garment and textile factory dyeing section is capable to create dyed and bleached knit product. Its product blend is 100% cotton and PC in different quality properties, different chemical treated products, Enzyme washed, milking treated and anti-microbial treated products are the main output of the process. Daily production capacity is about 8.1 tons. The company is producing its products on different machines amongst which the dyeing machine is known to be sensitive to changes in each of input parameters.

Figure 1 Dyeing section products

1.3. Statement of the problem

Dyeing in the textile industry is all about giving color to fabrics. It's a process that uses dyes to permanently color finished fabrics. The goal is to achieve a specific shade with good colorfastness, meaning the color should resist fading or bleeding during washing and use. The product's color may play a significant role in the consumer's purchasing decisions for certain products. We are usually dissatisfied when washing our T- shirts, trousers, skirts, jackets specially with dark shade of black color. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing.

Currently, in MAA Garment and textile factory product for knit fabric are encountering poor wash fastness which show the result of grey scale value average is around two to three values. Yearly production capacity is around 2916 tons. But this factory was focused for producing these products with better quality characteristics greater than four values for the aim of acceptable range, minimizing customer complaints and more customer satisfaction. Shifts in and shifts out; the quest to determine the optimal processing parameters is performed routinely in the MAA garment and textiles factory as it has a direct and dramatic influence on the quality of the product to be produced. This tuning exercise is repeated until the quality of the product is found satisfactory, thus incurring long setup time moreover.

Parameters are critical for evaluating the performance and effectiveness of the dyeing process. These parameters collectively provide a robust framework for assessing the dyeing process's performance, guiding optimization efforts to achieve high-quality dyed fabrics (Nahid Pervez, 2023). Study on dyeing process variables includes variation in dyeing time, temperature, MLR, pH, mordant conc., dye conc., and salt conc. (Sinnur et al., 2018). Other factors are known to affect the wash fastness of dyeing conditions such as the pretreatment conditions of the fabric, dye recipe, dyeing temperature, and dyeing time significantly affect the bonding and reaction rate between the dye and the fiber (Kim et al., 2024). Additionally, these parameters are such as fixing agent, pressure, acetic acid, humidity, fabric structure, fiber type and GSM (Verma et al., 2022). These affects the fabric's color fastness and overall quality.

The study aims to address this issue by utilizing the Taguchi method to optimize the dyeing process parameters and reduce the variation in textile manufacturing. By identifying the optimal process conditions and parameters, the research seeks to contribute to the development of more sustainable and efficient dyeing process in the textile industry. As result, this project is intended to fill this gap.

1.4. Research Question

The major research question to be raised in the process of the research preparation could be generalized in the following areas:

- ✓ What are the optimum levels for the control factors parameters in production of dyed knit fabric?
- ✓ What are the optimum process parameters setting that yield for a good quality characteristic of the fabric?
- ✓ What are the problems associated with dyeing process parameters?

1.5. Objectives

1.5.1. General objectives

- ❖ The general objective of the study is investigating the color fastness in dyeing process of knit fabric by Taguchi method.

1.5.2. Specific objectives

- ❖ Examining the optimal process conditions for achieving the best dyeing process.
- ❖ Examining the contribution of each parameter.
- ❖ Investigating the wash fastness of fabric to the acceptance range.
- ❖ Analyzing the desired color on cotton knit fabric.

1.6. Scope of the study

- ✓ The scope of this study is focused on improving color fastness of dark shade dyed fabric through application of quality engineering tools specially Taguchi of DoE. By the experimental design methods of the Taguchi is used to reduce poor colorfastness of products.

- ✓ It is limited to the application of Taguchi parameter design for the selected 100% cotton knit fabric and selected quality characteristics of the product in MAA Garment and textiles factory.

1.7. Significance of the study

Quality is becoming a big concern in today's highly competitive market and the definition of quality ranges from meeting requirements to ultimate customer satisfaction. The effort to ensure quality of a product is limited to inspection activity in the vast majorities of industries in Ethiopia. Yet it is a settled fact that it is difficult to achieve customer satisfaction by a sole inspection-based quality on to a product.

This thesis work is significant based on theoretically, academically, and practically. Theoretically, the study contributes to the body of knowledge in process parameter optimization and product testing literature. And also, to enhance the quality of the dyeing process in textile manufacturing, particularly for cotton knit fabrics. Academically, by applying the Taguchi method, the study aims to determine optimal process parameters that improve color fastness specifically wash fastness. Practically, the study provides tangible benefits for textile manufacturing process industries. By examining the optimal dyeing conditions it helps reduce dye wastage, leading to improved product quality, and cost savings.

1.8. Limitation of the research

Like many other research, this one had some limitations. Current Base as there is difficulty in obtaining clear data of the baseline performance. Documents that are important for the researcher but confidential to the organization are not allowed for providing detail resource.

The limitations of the study include the restricted range of factors examined, as only specific dye concentrations, electrolyte concentrations, temperatures, dyeing times, PH, MLR, fixing agent and alkali concentration were considered. This may not fully capture the complexity of the dyeing process in real-world applications. Additionally, the study focused solely on eight parameters, which may limit the generalizability of the findings to other dyes or fabric types. The use of only three levels for each factor in the Taguchi design may also overlook potential interactions and effects that could be revealed with a more comprehensive experimental design. Lastly, the study did not account for the influence of uncontrollable factors, such as water hardness, on the dyeing process, which could affect the reproducibility of the results.

1.9. Organization of the Study

This thesis comprises of five different chapters, the first of which is the introduction chapter including the background information of the study, its introduction and problem statement along with its corresponding objective. The second chapter is the literature review which looks into the science of quality engineering and examines academic papers in the thematic areas of process parameter optimization for single and multiple performance characteristics. The third chapter is about the methodology, materials and measurements being used to achieve the objectives set. The fourth chapter of thesis is the result and discussion body of the study which encompasses all tasks from the data collection through validation tests that has been put in practice during the study. The last chapter draws a conclusion and recommendation from the findings obtained in the study.

CHAPTER TWO: LITERATURE REVIEW

2.1. Definition of Quality

The field of quality has undergone significant changes as reflected by changes in its definition, paradigms, methodologies, approaches, techniques, and scope of application. Changes in customer expectation have driven the changes in the technology of design and manufacturing, which is becoming more important in satisfying individual customer expectations (Alzoubi, 2022). This also calls for special attention to the engineering aspects of quality. There are brief reviews on recent advances in the prominent quality tools such as statistical process control, quality function deployment, and design of experiment are known. General trends in quality engineering research show the tools are being enhanced, integrated, computerized and expanded their application bases, where possible opportunities for further investigation are indicated (Ghane et al., 2022).

The importance of quality in today's business environment is crucial at multiple levels. Organizations aim to manage quality effectively, adopt suitable marketing strategies, and develop new products that meet customer quality requirements. Companies compete on the basis of quality, customers actively seek for quality, and business are significantly influenced by it. Quality is a key driver of customer happiness, company profitability, and the economic growth of nations. Additionally, product quality is a vital factor in establishing a competitive advantage in the marketplace. For businesses to survive and succeed, maintaining high quality has been an integral part of any competitive marketing strategy for the past two decades (Rafi Ahmad Lone, 2022).

Recently, the most widely used definition of quality is that of (ISO, 2015). It says a quality product or service possesses essential characteristics that make it added value to customers. For example, products should be reliable, usable, and repairable. Similarly, a good quality service should be efficient and effective. In essence, quality refers to desirable traits that a product or service should have. However, not all qualities carry the same weight; some are more significant than others. The most important qualities are those that customers specifically desire. Therefore, providing quality products and services centers on meeting these customer requirements and expectations. Ultimately, a quality product or service is one that successfully fulfills the needs and expectations of its customers (Birhanu Beshah, 2013).

According to Phadke in his book of “Quality Engineering Using Robust Design”; defines quality engineering as product life cycle divided in to two primary components: products before sale to the customer and after sale to the customer. All costs incurred prior to the sale of the product are included to the unit manufacturing cost and while all the costs incurred after the product sale to the customer is added together as quality losses. Quality engineering is concerned with reducing both of this cost, and that is an interdisciplinary field of science involving engineering design, manufacturing (industrial) operation and economics (Phadke, 1989).

Quality engineering as the collection of operational, managerial, and engineering activities that a company uses to ensure that the quality characteristics of a product are at the nominal or required levels. It focuses on the functionality of a system generic functions and then makes an evaluation of a system component according to three function categories signal factor, control factor, and error factor in a view to system optimization. Quality engineering is aimed at as far as possible, to streamline development by assessing the positive and negative points of view technologies in the upstream process stages of commercialization of products (Subramaniam, 2021).

2.2. Taguchi Method

The Taguchi method was created by Dr. Taguchi. Unlike traditional experimental design methods, which can be complicated and difficult to use, the Taguchi method simplifies the process (Moffett et al., 2024). As the number of process parameters increases, traditional methods often require a large number of experiments. To address this issue, the Taguchi method apply a unique special design known as orthogonal arrays, allowing researchers to explore the entire parameter space with a significantly reduced number of experiments. This simplification of the experimental plan, along with the ability to study interactions between different parameters, makes the Taguchi method a popular technique for process optimization (Lestari et al., 2024). It is widely utilized around the world for both process optimization and product design. One of the key advantages of the Taguchi method is that it requires fewer experiments, which leads to substantial reductions in both time and cost saving (Dar et al., 2024). In the Taguchi method, an experimental plan is laid out using orthogonal arrays that provide various combinations of parameters and their levels for each experiment. This techniques allows for comprehensive exploration of the parameter space with a minimal number of required experiments (Roy, 2010).

The Taguchi method focuses on reducing variation in a process through a robust design of experiments. The main objectives of this method are to produce high-quality products at a low cost for manufacturers. By utilizing the orthogonal array experimental design created by Taguchi, one can examine the effects of various parameters on performance characteristics in a condensed set of experiments. Taguchi realized that the best opportunity to reduce variation in final product quality occurs during the design of the product and its manufacturing process. This technique is a statistical approach aimed at optimizing processes and enhancing the quality of manufactured components. The Taguchi approach emphasizes building quality into the design of a product and its manufacturing process, rather than relying on inspection and quality control charts to identify and remove defective products. To achieve this, product designers must select parameter levels that define the product and reducing variability in its performance. This is referred to as obtaining "on-target performance" (Shyam Kumar Karna, 2012b).

2.3. Process parameter

Process parameters play prominent role for successful manufacturing of any product. But their lots of process parameters involved in any process. Taguchi method involves identification of proper control factors to obtain the optimum results of the process (Bhardwaj et al., 2021).

2.4. Process Optimization

Process optimization involves adjusting a process to improve specific parameters without violating any constraints (Mohammed et al., 2024). The most common goals of optimization include minimizing costs and maximizing throughput and efficiency. This discipline is a crucial tool in industrial decision-making. When optimizing a process, it is important to ensure that all other factors remain within their established constraints (Shyam Kumar Karna, 2012a).

2.5. Design of Experiment (DoE)

Design of Experiments (DOE) is a powerful statistical technique created by R. A. Fisher in England during the 1920s (Silva et al., 2023). It is used to investigate the effects of multiple variables simultaneously. In his early applications, Fisher aimed to determine the optimal amounts of rain, water, fertilizer, sunshine, and other factors needed to produce the best crop yields. Since then, the technique has evolved significantly within academic settings, leading to various applications in production environments. DOE is a valuable tool for improving product and process designs as well as solving production problems (Lamidi et al., 2024). A standardized version of DOE, developed by Dr. Genichi Taguchi, simplifies the application of this technique for product design optimization and investigation of production challenges. Since its introduction in the United States in the early 1980s, Taguchi's approach to DOE has become a popular tool among engineering and scientific professionals for product and process improvement. DOE is an experimental strategy that examines the effects of multiple factors by conducting tests at various levels of those factors (Lin et al., 2022). Important considerations in DOE include which levels to select, how to combine them, and how many experiments to run. The factors are the variables (often referred to as ingredients or parameters) that directly influence the performance of the product or process being studied (Jankovic et al., 2021).

Summarize common areas of application of the methods that include:

- Optimize Designs using analytical simulation studies.
- Select alternative in Development and Testing.
- Optimize manufacturing Process Designs.
- Identify the best Assembly Method.
- Solve manufacturing and production problems.

2.6. Taguchi Approach to Design of Experiment

Dr. Taguchi as given the task of creating a methodology for continuous quality improvement to achieve the challenges that Japan faced after world war-II, who was at the time the manager at the Electrical Communication Laboratories (ECL) of Nippon Telephone and Telegraph company (NTT) in charge of improving the Research and Development productivity and increasing product quality of certain telecommunication products. He saw that little emphasis was given to the process of creative brainstorming to reduce the expenditure of resources (Sanjeevannavar et al., 2022). He observed that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can restore quality back into the product. Thus, he thought that quality concepts should be based upon, and developed around, the philosophy of prevention. Taguchi began to develop new methods to optimize the process of engineering experimentation (Hisam et al., 2024). He believed that the best way to improve quality was to design, incorporating and build it into the product. His primary contribution lies not in the mathematical formulation of the design of experiments, but rather in the accompanying philosophy. His ideas produced a unique and powerful quality improvement technique that differs from traditional methods. He created manufacturing systems that were “robust” or insensitive to daily and seasonal variations of environment, machine wear and other external influences. His philosophy had far reached consequences, yet it is founded on three basic simple concepts. His techniques arise entirely out of these three ideas (Oğuz, 2022).

The concepts are:

1. Quality should be designed into the product and not inspected into it.
2. Quality is better achieved by reducing the deviation from a target. The product should be so designed that it is immune to uncontrollable environmental factors.
3. The cost quality should be calculated as a function of deviation from the standard and the losses should be measured system wide.

The Taguchi method is applied in four steps.

1. Brainstorm the quality characteristics and design parameters essential to the product or process.
2. Design and conduct the trial experiments.
3. Analyze the results to determine the optimum conditions.
4. Run a confirmatory test using the optimum conditions.

2.7. Orthogonal Arrays (OA)

The method of outlining the conditions (designs) of experiments involving multiple factors was first proposed by Sir R. A. Fisher, in the 1920s. The technique is popularly known as factorial design of experiments. A full factorial design identifies all possible combinations for a given set of factors. Since most industrial experiments involve a significant number of factors, a full factorial design results may involve a large number of experiments.

According to Taguchi, quality improvement is a continuous process. He continually strived to reduce the variation around the target value not to eliminate (Yazar, 2021). The first step towards improving quality is to achieve the population distribution as close to the target value as possible. To accomplish this, Taguchi designed experiments using specially constructed tables known as

"Orthogonal Arrays" (OA). The use of these tables makes the design of experiments very easy and consistent (Hisam et al., 2024).

Major Premises of Taguchi Techniques: -

- ✓ Focusing on the robustness of the product.
- ✓ To make the product correctly in spite of variation in materials and processes.
- ✓ To design the product to be insensitive to the common cause variation that exists in the process.
- ✓ Quantifying the effects of deviation using Quality Loss Function

2.8. Quality Loss Function

Loss is usually thought of as additional manufacturing expenses incurred up to the point that a product is shipped. After that, it is society, the consumer, who bears the cost for loss of quality. Initially, the manufacturer pays in warranty expenses. After the warranty period expires, the customer may pay for repair on a product. But indirectly, the manufacturer will ultimately ''foot the bill'' due to negative customer reaction and costs that are difficult to capture and account for, such as customer inconvenience and dissatisfaction, and time and money spent by customers. As a result, the company's reputation will suffer and eventually the market share will be lost. Real growth comes from the market, cost, and customer satisfaction. The money the customer spends for a product and the perceived loss due to poor quality ultimately come back as long-term loss to the manufacturer. According to Taguchi, quality is ''the loss imparted by the product to the society from the time the product is shipped.'' The goal of the quality loss function is quantitative evaluation of loss resulting by functional variation of a product.

2.9. Signal to Noise Ratio (S/N)

The signal to noise ratio (S/N ratio) is a measurement scale that has been employed in the communication industry for almost a century. A radio measures the signal or the wave of voice transmitted from a broadcasting station and converts the wave into sound. The larger the voice sent, the larger the voice received. In this case, the magnitude of the voice is the input signal, and the voice received is the output. Actually, the input is combined with the audible noise in the space. Good measuring equipment catches the signal and is not affected by the influence of noise (Ahmad et al., 2021). The signal to noise ratio (S/N ratio) was used to measure the sensitivity of the quality characteristic being investigated in a controlled manner. In Taguchi method, the term 'signal' represents the desirable effect or mean for the output characteristic and the term 'noise' represents the undesirable effect or signal disturbance (S.D) for the output characteristic which influence the outcome due to external factors namely noise factors. Taguchi Method is a multi-stage process, namely systems design, parameter design, and tolerance design. The following sections delineate the three-stage process suggested by Dr. Taguchi to obtain desirable product quality.

There are three Signal-to-Noise ratios of common interest for optimization;

1. Smaller-the-better: n = -10 Log10 [mean of sum of squares of measured data]. This is usually the chosen S/N ratio for all undesirable characteristics like " defects " etc. for which the ideal value is zero.
2. Larger-the-better: n = -10 log10 [mean of sum squares of reciprocal of measured data]. This case has been converted to smaller-the-better by taking the reciprocals of measured data and then taking the s/n ratio as in the smaller-the-better case.
3. Nominal-the-best: n = 10 Log10 (Ybar^2/s^2). This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable.

2.10. Robust design

Robust design is the design of the product that will be least impacted by user conditions. Noise levels must be considered in the development. Since the development is conducted in a small-scale research laboratory, the conclusions obtained must be repeatable downstream that is, in large-scale production and under a customer's conditions. To verify reproducibility, the concepts SN ratio and orthogonal array are used (Mahapatra and Kumar, 2022).

2.11. Analysis of Variance

The purpose of ANOVA is to determine which machining parameters significantly affect the performance characteristic. The ANOVA is a statistical approach to study the influence of chosen variables on the output response and distributed the variability of the response variables among the available factors. In many types of analyses, it is necessary to identify the parameters that are responsible for a wide variation in the output responses and to quantify the variation. This technique is applied for evaluating the differences between the available factors and is also employed to quantify the chosen parameters contribution towards the output. The percent of the significance of the process parameters to the total sum of the squared deviations was utilized to evaluate the importance of the parameter changes on the performance characteristics. In addition, an F test was also used to examine which process parameters had a significant impact on the performance characteristics. The change in the process parameter has a significant effect on the performance characteristic when the F-value is large. The inferences derived from the ANOVA table are used to determine which input parameters are responsible for changes in the process performance by controlling these parameters, the process can be improved. In this technique, more importance is placed on data variance than data analysis.

2.12. Literature Survey

Many studies have been focused on optimizing manufacturing process parameters using the Taguchi method. One typical application of this method is in the optimization of the dyeing process. In a study by Shekh Md. Mamun Kabir on salt-free reactive dyeing of cotton, the Taguchi method was employed to improve the dyeing process conditions. The research considered four factors, including cationization temperature, dyeing pH, material-to-liquor ratio (MLR), and concentration of ALBAFIX-WFF. The optimal conditions found for the dyeing process were a cationization temperature of 80°C, a dyeing pH of 12, an MLR of 1:5, and a concentration of ALBAFIX-WFF at 30 g/l. The goal of study was to improve both color strength and wash fastness of the dyed cotton fabric. By using orthogonal arrays and calculating signal-to-noise ratios, the research identified the best dyeing conditions, which resulted in increased dye exhaustion and fixation. Additionally, a comparison was made between the single characteristic value conversion method and the process maximization method. This comparison revealed differences in dyeing quality and properties, with the process maximization method obtaining higher exhaustion and fixation rates. Overall, the study offers valuable insightful into enhancing dyeing techniques for cotton fabrics, contributing to advancements in the textile industry (Kabir, 2023).

In the other related work of Wahyudin and his colleagues have focused on enhancing the efficiency of dyeing processes in the textile industry. By applying the Taguchi method and ANOVA, their research goals to examine the optimal conditions for dye concentration, Na2SO4 concentration, Na2CO3 concentration, and temperature to obtain the desired color on cotton knit fabric while reducing the need for re-dyeing. The optimum conditions identified for the dyeing process are as follows: dye concentration of 3.5%, Na2SO4 concentration of 80 g/L, Na2CO3 concentration of 5.8 g/L, and a temperature of 80 °C. The study also emphasizes the environmental impact and cost implications of inefficient dyeing practices, underscoring the importance of reducing waste and improving process efficiency. Through experimental design and statistical analysis, the research aims to provide practical insights that can be applied in textile manufacturing to optimize the dyeing process and minimize the necessity for re-dyeing. Ultimately, this contributes to sustainable and environmentally friendly practices within the industry (Wahyudin, 2017).

The research examines a new method for enhancing the whiteness of polyester fabric by using nanoparticles of OB-1 (OB-1-G) combined with dispersing agents in an aqueous exhaust dyeing process. By employing the Taguchi methodology, the study optimized important parameters such as whitening temperature, OB-1-G mass, and treatment time to achieve a notable improvement in whiteness, with temperature emerging as the most influential factor. The results imply a high whiteness index of 94.12 under the optimized conditions, and the fabric also exhibited good color fastness against washing and rubbing. These findings suggest that the use of OB-1-G nanoparticles for optical brightening presents a sustainable alternative to traditional optical brightening agents in the textile industry (Yingjie Cai, 2023).

The study investigates another methodology of the dyeing properties of Euclea divinorum extract on cotton fabric, using response surface methodology (RSM) to optimize the dyeing conditions. It determines the optimal parameters as dyeing for 68 minutes at a pH of 3.3 and a temperature of 82°C, achieving a color strength of 0.609. The research emphasizes the environmental advantages of using natural dyes like E. divinorum, which are non-toxic and biodegradable, in contrast to synthetic dyes. Additionally, the study explores the effects of mordanting to enhance color strength and fastness properties, concluding that Euclea divinorum serves as a sustainable and effective source of natural dye for textiles (Manyim et al., 2022).

This work explores the optimization of dyeing process parameters for cotton and silk fabrics using Racinus communis leaf extract, focusing on antimicrobial activity and fastness properties. Various factors such as extract concentration, dyeing temperature, material-to-liquor ratio, alum concentration, and treatment time were optimized by utilizing Central Composite Design and single-factor design methodologies. The results showed that optimized conditions achieved a significantly reducing in bacterial counts against Staphylococcus aureus and Pseudomonas aeruginosa, with reductions of 99.84% and 99.78% for cotton, and 99.88% and 99.83% for silk, respectively. Further indicating, the dyed fabrics maintained notable antimicrobial activity even after numerous washing, exhibited moderate to excellent fastness properties, and demonstrating the potential for eco-friendly textile applications (Musinguzi et al., 2022).

Faezeh Fazeli and his friends have examined the color yield of 100% cotton fabric treated with six selected direct dyes using Taguchi approach and full factorial experimental design techniques. By varying parameters such as dye concentration, electrolyte concentration, temperature, and dyeing time, the researchers were able to determine the significant factors impacting color yield through ANOVA analysis. They created a response surface regression model to forecast color yield based on these factors. The study emphasizes the importance of experimental design in optimizing dyeing processes and achieving desired color results in textile applications (Faezeh Fazeli, 2012).

The study conducted by Jung and his colleagues focuses on optimizing the digital textile printing process using the Taguchi method to increase color strength and fastness, which are crucial for the mass customization of clothing items. The researchers employed two multiple characteristic parameter design methods: the single characteristic value conversion method and the minimum-maximum selection method. Through this approach, they were identified optimal conditions that surpassed current industry practices regarding color strength and wash fastness. In this work, the researchers chosen four easily controllable factors: pre-process pick-up ratio, post-process steaming temperature, steam pressure, and steaming time. Each of these factors was analyzed at three distinct levels, as determined by preparatory experiments. They were found that steam pressure and time significantly influenced both color strength and wash fastness, with optimal conditions identified as a steam pressure of 0.18 MPa and a steaming time of 10 minutes. Using an L9 (3^4) orthogonal array table design, the study analyzed nine experiments. The aim was to maximize wash fastness while contributing to advancements in digital textile printing processes, ultimately improving product quality and customization capabilities (Jin Joo Jung, 2016).

In this work, the researchers explored the application of biodegradable surfactants in cotton fabric dyeing to mitigate environmental damage caused by dyeing wastewater. By utilizing the Taguchi method, they analyzed important parameters such as the hydrophobic group chain length of the surfactant, surfactant concentration, and processing time to determine the optimal conditions for dyeing process. The finding indicated that processing time was the most significant factor affecting the dyeing process, followed by surfactant concentration. The addition of surfactant was found to enhance the dyeing effect during processing. Through signal-to-noise ratio analysis, analysis of variance, and confirmation tests, the research demonstrated that using the optimal parameters identified through the Taguchi method could improve the dyeing efficiency and reduce environmental impact in cotton fabric dyeing processes (Chung-Feng Jeffery Kuo, 2012).

The study concentrated on optimizing the dyeing parameters for standardized samples of cotton to evaluate dye transfer inhibition in washing machines, particularly using reactive red dye. To determine the optimal dyeing conditions the single factor analysis and central composite design were employed. The important parameters examined included dye dosage, temperature, sodium sulfate, and sodium carbonate. Results from the response surface analysis showed the optimal dyeing parameters: a dye dosage of 5.63% (on the weight of fabric - owf), a dyeing temperature of 60 °C, a sodium sulfate dosage of 93.60 g/L, and a sodium carbonate dosage of 15 g/L. Accordingly, the study demonstrated that this specific dye dosage was ideal for obtaining maximum target values in the dyeing process. The standardized samples effectively highlighted the dye transfer inhibition capabilities of the washing machines, proving to have good operability and feasibility. Cotton fabric and reactive dyes were utilized to prepare these standardized samples, with the study providing detailed experimental methods (Mingqi Guo, 2020).

The research investigated to optimize dyeing parameters in functional textiles in order to reduce overall dyeing expenses while ensuring robust dyeing performance. Several critical parameters influence dyeing performance such as temperature, time, and bath ratio. The research utilizes experimental design methods to forecast outcomes and optimize these parameters. It concentrates on minimizing dyeing expenses and errors while enhancing the reliability of the dyeing process. By employing Central Composite Design and analyzing the relationships between manufacturing parameters and dyeing performance, the research seeks to enhance efficiency and cost-effectiveness in functional textile dyeing processes (I-Hsuan Hong, 2017).

In this study, he concentrates on optimizing the printing parameters for sublimation printing on polyester fabrics. Specifically, he examined the following parameters such as the number of strokes (2), the weight of the sublimation paper (74 grams per square meter), the fusing temperature (205 degrees Celsius), and the fusing time (50 seconds). He utilized the Taguchi experimental design technique to achieve this optimization. To evaluate the results, he utilized the signal-to-noise ratio.

A total of sixteen experiments were conducted based on the L16 orthogonal array design of the Taguchi method. The results show a significant improvement in the signal-to-noise ratio compared to the initial conditions. This paper not only identifies the optimal printing conditions for sublimation printed polyester fabrics but also highlights the crucial factors that influence water vapor resistance(Jeyaraman Anandha Kumar, 2021).

The research article focuses on optimizing the coating process parameters to address color differences that occur after the abrasion of denim fabrics, utilizing the Taguchi method. Researchers conducted experiments to determine the optimal levels of input parameters, including a fabric passing speed of 10 m/min, a drying temperature of 120 °C, a squeeze pressure of 5 bar, a viscosity of 30 dPas, and a weft density of 17 picks/cm. By studying the signal-to-noise ratios and color difference values, the study aimed to determine the most effective combination of factors to minimize color differences after abrasion. The results showed that the Taguchi method successfully identified the important parameters that significantly impact color variation, offering valuable insights for improving the quality of coated denim fabrics (Hüseyin Gazi TÜRKSOY, 2019).

In this work, they optimized the natural dyeing process of cotton fabric using an antibacterial dye extracted from nettle leaves. The optimization was conducted using a central composite design. The ideal dyeing conditions identified are as follows: a dye concentration of 16.943 g, a temperature of 50 °C, and a dyeing time of 40 minutes. Under these optimal conditions, the color strength attained was 1.53. The nettle natural dye is treated to cotton fabrics using the Pad-Dry-Cure method, which imparts antibacterial properties suitable for apparel applications. Bio mordants were used on scoured cotton fabric during the pre-mordanting process of dyeing. They conducted quantitative assessments of antibacterial effectiveness against Gram-positive (S. aureus) and Gram-negative (E. coli) bacteria using the AATCC-100 test method. The finding demonstrated that the treated fabric exhibited a significant antibacterial efficiency, achieving a reduction of 96.5% to 98% in bacterial presence compared to the control samples. Additionally, the fabric with the highest antibacterial activity was subjected to washing 15 times under the same conditions, with samples taken after 1, 5, 10, and 15 washes for further detail analysis (worku, 2023).

This paper article aims to enhance the tear strength and reduce the stiffness of denim fabrics by optimizing the parameters of the coating process. It employs the Taguchi method for studying single performance characteristics and Grey Relational Analysis for assessing multiple performance characteristics. The study identifies the optimal levels of several factors such as weft density, drying temperature, viscosity, squeeze pressure, and fabric passing speed, to improve both tear strength and stiffness. The optimal conditions determined for enhancing tear strength while minimizing stiffness in coated denim fabrics are as follows: weft density of 14 picks/cm, drying temperature of 160°C, viscosity of 50 DPa, squeeze pressure of 3 bar, and fabric passing speed of 30 m/min. These optimal parameter levels were established through ANOVA analysis and confirmation tests, which identified the statistically significant factors influencing the fabric properties and verified the effectiveness of the optimized process parameters. The combination of the Taguchi method and Grey Relational Analysis provides a comprehensive technique to maximizing tear strength and minimizing stiffness in denim fabrics, offering valuable insights for the textile industry in its pursuit of efficient and sustainable manufacturing practices (Sümeyye Üstüntağ, 2020).

This work focuses on optimizing and forecasting the cotton fabric dyeing process using a Taguchi design integrated machine learning approach. By combining design of experiments with machine learning techniques, the researchers developed a least square support vector regression (LSSVR) model based on Taguchi's statistical orthogonal design to predict important parameters such as exhaustion percentage, fixation rate, total fixation efficiency, and color strength in reactive cotton dyeing. The experimental results from the dyeing process were used to inform the development of this integrated model, which takes the dye dosage, dye-fixing temperature, dye-fixing time, dyebath pH, material-to-liquor ratio, and salt concentration as input. The finding demonstrated the effectiveness of the LSSVR model in accurately forecasting these parameters, showcasing its potential to enhance the efficiency and sustainability of cotton fabric dyeing practices in the textile sector (Nahid Pervez, 2023).

A comprehensive study was thoroughly examined on the small-scale textile industry, focusing on the various processes involved, the chemicals required, operating parameters, mass-to-liquor ratio (MLR), and energy requirements. This paper aimed to investigate the effect of process parameters on the dyeing process and to optimize thermal energy consumption in order to achieve high-quality cotton-colored products. The main parameters identified as affecting energy consumption rates were process temperature, process time, and liquor ratio. Additionally, the study includes some technical information along with schematic diagrams of the production processes used (Kuldip Arun Rade, 2017).

The study conducted by Iusuf Khan, Jahid Khan, Habibullah Mohammad Jayed, and Abdullah Al Ibrahim focuses on the application of the L9 Taguchi experimental design analysis to the dip-pad-dry dyeing of cotton fabric using reactive dyes. The study aimed to optimize various dyeing parameters, including dyeing time, dye concentration, drying temperature, and pH, in order to improve the color performance of cotton fabric. Through systematic experimentation and analysis, the study identified the optimal conditions for dyeing with C.I. Reactive Red 195 as follows: pH 12, dye concentration of 20 g/L, drying time of 5 minutes, and drying temperature of 120 °C. The findings showed that pH is the most significant factor influencing the dyeing process with Reactive Red 195. Overall, this research provides valuable insights for enhancing color performance and efficiency in cotton fabric dyeing processes, which have important implications for the textile sector (Md. Iusuf Khan, 2021).

The primary aim of this research was to identify the optimal dyeing conditions and forecasting the color strength (CS) of viscose/Lycra blended knit fabrics using the Taguchi method. The controllable elements considered as input variables included dye concentration, temperature, time, alkali concentration, salt concentration, and liquor ratio, while the CS of the fabric served as the response variable for constructing the Taguchi model. An L25 orthogonal array design was selected, leading to the execution of 25 experiments, each with three repetitions. The optimal parameters for the dyeing process were determined to be a dye concentration of 9%, a dyeing time of 60 minutes, a temperature of 75 °C, a salt concentration of 50 g/L, an alkali concentration of 14 g/L, and a liquor ratio of 1:8. The Taguchi mathematical model developed in this study was verified through confirmation experiments trial and additional unseen experimental data. The mean absolute error and the coefficient of determination (R^2) between the actual and forecasted CS were found to be 3.48% and 0.88, respectively. Finally, the Taguchi method proved to be effective for optimizing and forecasting fabric color strength in the complex and non-linear process of dyeing (Hossain, 2016).

2.13. Literature gap

The typical textile dyeing process calls for a wide range of operational parameters, and it has always been difficult to pinpoint which of these qualities is the most important in dyeing performance. Consequently, this research used a design of experiments method to offer a sustainable and beneficial reactive cotton fabric dyeing process.

Reviewed literature gaps summarized as below:

- ✓ Most of the reviewed literatures not considered the crucial role parameters process in combined manner for the dyeing processes. They were conducted less trial. However, no better decision making with less trial.
- ✓ Most of the reviewed literatures not considered the Taguchi method in dyeing process to the context of quality.

As we know Each optimization method serves specific purposes and is chosen based on the complexity of the system, the importance of interactions, and resource availability. As a result, most the literatures what I have reviewed that regarding to the minimization of process costs, chemicals usage, water wastage, and others rather than quality and wash fastness. In this research, although the Taguchi method is widely used in many research fields, there have been few applications in textile manufacturing process specially in dyeing process. And in MAA garment and textiles factory none had been done in the dyeing section to minimize the variations. The study identified the optimal conditions for dye concentration, temperature, time, PH, MLR, salt, alkali and fixing agent with their three factor levels. The washing fastness has taken as measured quality characteristics. Finally, the significant factors influencing the dyeing process were determined.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. The Research Design

The primary goal of the research is in general to improve the quality of colorfastness of cotton knit fabric in the dyeing process. Thus, the research is designed in terms of the research's approach, type, primary focus, potential hypotheses, environment under which the research is conducted, and methods or tools used for data collection and data analysis.

3.2. Type of Data Collection

Data collection is a process of obtaining information that are relevant to complete the research or the study. There are two data collection methods such as primary and secondary data collection and this study used both of the methods. The sources of data utilized in the study namely primary and secondary data sources. Under this two-methods literature review, oral interview, referring machine operator, technical data, experimental trials and observation have been used.

3.2.1. Primary Data

Primary data collection is one of the methods used in this research. Under primary data collection observation and experimental data have been used.

I. Observation: is one way of primary data sources. It is a technique of watching and listening to an interaction or phenomenon where it occurs. In order to understand the facts about the case industry what they do in the dyeing process that is how exactly the existing system is working, the situations that the industry company doing things, how operators perform their potential in quality product occurs activities have been observed.

II. Experimental data: are considered as primary sources. This is because they are the original and firsthand data collected directly by researcher conducting experiments.

3.2.2. Secondary Data

Secondary data collection is one of the methods used in this research. Under secondary data collection the two mostly used methods which are literature review and case industry documents have been used.

I. Literature Review: As secondary data to gain understanding about the process parameter optimization of manufacturing process by different researchers and create solid foundation, the research work begins with an extensive literature study. Considering the research title, the literature review method take look on journals and articles related researches this is due to the reason that to find out how far researchers had done in those areas.

II. Documents from the Case Industry: I have collected the data from industry record documents. To analysis the existing industry situation and examine in detail, industry recorded data is necessary.

3.2.3. Materials And Equipment

3.2.3.1. Materials

Raw material used in this experiment is 100% cotton knit fabric construction (Article) is single jersey that had undergo pretreatment process. Fabric preparation was by cutting the cotton knitted fabric to a square shape and a weight of 10 grams. Chemicals used such as dyestuffs, soda ash, salt, detergent, acetic acid and other auxiliaries.

Table 1 Chemicals and their functions

SR	Chemicals	Functions
1	Reactive dye	Dye stuff (coloring matter)
2	Soda ash or sodium carbonate (Na_2CO_3)	For fixation
3	Glauber salt (Na_2SO_4)	For diffusion or migration dyes to fabric
4	Sequestering agent	Prevent from interfering with other reactions
5	Sodium Perborate Tetrahydrate	As bleaching agent during wash fastness testing
6	Acetic acid (CH_3COOH)	For neutralization
7	Soap or detergents	Used for washing, remove excessive dye, and for removing added impurities
8	Fixing agent (Hydrocol sun)	For improving resistance of fading

3.2.3.2. Equipment (instruments)

I was used AHIBA NUANCE infrared dyeing machine, Scissor, Weight Balance, Measuring Cylinders, PH meter, Auto Lab data color dyeing Machine, washing tester machine, Squeezer, Dryer, Small Pipe, pipet, Spool, Stirrer, Beaker, Washing Machine, Steel Balls, Grey Scale Values (GSV) and other accessories (apparatuses).

3.4. Experimental design

The experimental design is based on the Taguchi method. Design/methodology/approach of Taguchi method experimental design for optimization of manufacturing processes has been widely published in the existing literature (Antony et al., 2006). The Taguchi method is one of a design of experiment variant developed by G. Taguchi, with a special set design of orthogonal arrays that provide the optimum parameters settings. The merits of Taguchi design include minimizing the number of experiments and simplifying the test plan. According to this method, the minimum number of experiments should be equal to or greater than the sum of the degree of freedom (Rasheed et al., 2023). The degree of freedom is very essential for the selection of the appropriate array in Taguchi design. In this study, data analysis based on the Taguchi method is performed by applying the Minitab statistical software (Ahmed et al., 2022). The Taguchi method is a systematic mechanism to optimize design parameters by using a procedure of well-defined steps, including defining the problem and quality characteristic, identifying control and noise factors, choosing a proper orthogonal array, conducting experiments, analyzing data using the signal-to-noise (S/N) ratio, and validating the results.

3.4.1. Selection of Process Parameter

Once the problems are identified now here where to apply the quality engineering tool to mitigate these problems. But, before commencing on that need to identify the influential parameters and their respective working ranges, assigning levels and determining key response variables. Since several parameters were discussed in literature survey. So, parameters screening is used to narrow the number of variables quickly and to select the crucial role parameters. I have selected the process parameters through scoring matrix mechanisms. Scoring was assigning weights to each selection parameters. Several different schemes can be used to weight the parameters such as allocating 100%-point net.

Table 2 Parameters scoring

No	Parameters selection	Weight (%)	Rate	Weight score	Rank
1	Dye concentration	10	8	0.8	1
2	Temperature	10	6	0.6	2
3	MLR	8	5	0.4	3
4	Salt	5	4	0.2	7
5	Soda ash	7	4	0.28	5
6	PH	6	4	0.24	6
7	Fiber type	5	2	0.1	9
8	Wetting agent	4	1	0.04	13
9	Fixing agent	8	4	0.32	4
10	Dyeing method	3	1	0.03	14
11	Fabric construction	5	1	0.05	12
12	Time	7	4	0.28	5
13	GSM	6	2	0.12	8
14	Pressure	5	2	0.1	9
15	Speed	7	1	0.07	11
16	Dye type	4	1	0.04	13

These parameters are critical in influencing the washing fastness of the cotton knit fabrics in dyeing process section. I have selected the above process parameters through scoring matrix mechanisms. The selection of eight parameters in the study is based on their significant impact on the dyeing process and the quality of the final product which their result weight score was greater than 0.2 result. According to the researcher, these parameters are selected: dye concentration, temperature, liquor ratio, salt concentration, alkali concentration, PH, fixing agent, and time. And also, I have been discussing so far with quality head section and brainstorming on the above factors.

3.4.2. Selection of orthogonal array

Once the control factors, noise factors, different levels of the control factors are clearly known the task subsequent to this is to select the right orthogonal array for the design of experiment.

Sample size

In Taguchi experimental design the number of orthogonal arrays was the amount of sample size itself. For the above selected eight parameters with their three assigned levels L27 is the appropriate OA from the Minitab software. Then 27 number of experimental runs were needed. And, for each experimental runs replicated three times for better making decision. Finally, the total numbers of sample size are 81 trials performed.

3.4.3. Procedures of conducting the Experiment

The research will conduct on the following methods sequentially:

Fabric preparation

Firstly, prepared a scour bleached knit fabric which was get after the pretreatment process and conditioned in the conditioner machine about 48 hours. Then the fabric cut in to small weight by using scissor and weighing the weight of the 10-gram fabric with the help of weighing balance for each single experimental trial. After that according the fabric weight prepared water with the use of MLR (material liquor ratio) into the dye bath beakers. And, it was calculated how much liter of required for the given fabric weight.

Dyeing cycle

I was used the exhaust dyeing which is one of the most common methods used for cotton reactive dyeing. In this technique, fabric was immersed in a dye bath beaker. So, the chemicals were prepared and measured with the help of pipit. After that added the prepared dyes and the sample into water then heating gradually, side wise the other necessary chemicals such as salt and reactive dyes also added for 15-minute run time at 30 ºC. The dye gradually migrated and diffused into the fiber. After that added the alkali at 60 ºC, continued dyeing for about 25-minute run time to ensure proper dye fixation and checked the PH value of the solution. Then hold to the required amount of time and gradually increased to the given set temperature by 1 ºC per minute speed for additional around 15 minutes.

Washing fabric

After the dyeing is complete; the fabric washed by hot water three times to remove some impurities from the fabric and then wash it the sample used a detergent or soaping agent at 60 °C to remove any unfixed dye. Finally, washed the fabric by cold water and added acetic acid respectively to make it neutral Ph of dyed fabric.

Drying fabric

After completed the process of washing fabric sample; then the fabrics were squeezed by squeezer machine to remove the excess water from the dyed fabric and dry by a dryer machine. After dry the fabrics were evaluated their quality parameters i.e. washing fastness by washing tester machine. Finally, it measured by grey scale method to check staining in the multifiber.

3.4.4. Fabric Testing

Following tests were carried out for all knitted fabric samples. The testing of knitted fabrics was carried out in the standard atmosphere conditions of 65% relative humidity and 27ºC. Color fastness to washing: this means the resistance of color against the washing action. It is the longest step of testing method as shown in the below table requirements rather than display easy on computer. This is great importance to the consumer and there are several washing tests which are applied according to the purpose for which the material is intended. ISO 105 C06 washing machine tester used to test color fastness to washing. Washing recipe for this method is given below:

Table 3 Washing fastness tester recipe

SR	Materials	Units
1	Detergent	4 g/l
2	Sodium Perborate	1 g/l
3	Temperature	60 º C
4	Time	30 min
5	Steel balls	5 pieces
6	Multi fiber and fabric samples	10 by 4 cm

The procedure of color fastness to washing is firstly cut the white multi fiber fabric and dyed fabric samples cut similar size through scissor into 10 cm by 4 cm rectangular shape form and attached or sewing together. Then immersed both in 1:6 material liquor ratio. After that entered the samples into washing fastness tester machine for about 30 minutes run time at 60 °C. Then rinse thoroughly and dry the samples. Finally, compare the staining on white multi fiber and how much was faded of the dyed fabric. And, scored fastness on a 1–5 scale (1 = heavy staining/fading, 5 = no change).

3.4.5. Data Analysis tools

To get the desired outcome from the study the collected data has to be analyzed. Different tools and methods have been used in different researches in analyzing data. Tools and method have to be selected as necessary in which to get a meaningful result. Accordingly, the selected tools and methods in this study to analyze the effect of dyeing parameters on the colorfastness behavior of the knitted fabric the data collected using Taguchi approach. This is used with Minitab statistical software 20 for selecting appropriate Orthogonal Array (OA), Taguchi Design of experiments (DoE), Main- Effect plots, ANOVA (analysis of variance), and Signal to noise ratio(S/N) plot were employed.

Confidence levels (p-value thresholds)

The p-value is the probability of observing results at least as extreme as the ones you got and its values to proceed with the decision-making process.

Table 4 Confidence Levels and P-value Thresholds

SR	P-value threshold	Confidence Level	Significance Level (α)
1	0.10	90%	10%
2	0.05	95%	5%
3	0.01	99%	1%

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Introduction

In this chapter, key input variables (parameters) are identified along with their respective operating ranges. Once the operating ranges of these input parameters are established, appropriate levels are assigned based on their sensitivity to the response variable of interest. This is followed by selecting an orthogonal array for the experiments conducted using Taguchi's experimental design for optimization.

4.2. Process parameters study

These parameters collectively provide a robust framework for assessing the dyeing process's performance, guiding optimization efforts to achieve high-quality dyed fabrics (Nahid Pervez, 2023). The selection of eight parameters in the study is based on their significant impact on the dyeing process and the quality of the final product. According to the researcher, these parameters are selected: dye concentration, time, temperature, salt concentration, alkali concentration, PH, fixing agent, and liquor ratio. I have selected the above process parameters through scoring matrix mechanisms from table 1 which their result weight score was greater than 0.2 result. And also, I have been discussing so far with quality head section and brainstorming on the above factors. These are critical in influencing the washing fastness of the cotton knitted fabrics.

The Taguchi method is designed to optimize parameters to achieve the best possible quality while minimizing variability. By concentrating on eight key parameters, researchers can effectively analyze their interactions and contributions to the dyeing process. This ensures a systematic approach to optimization without introducing overwhelming complexity. Selecting these parameters allows for a more manageable experimental design while still addressing the essential factors that influence dyeing outcomes. Here's how each of the eight parameters affects the dyeing process and the washing fastness of cotton knitted fabrics:

1. Dye Concentration (A):

Higher dye concentrations generally result in increased dye uptake by the fabric, leading to better washing fastness. This occurs because a more concentrated dye bath offers a greater number of dye molecules available for absorption by the fibers.

2. Dyeing Temperature (B):

Higher dyeing temperatures can enhance the kinetic energy of the dye molecules, which promotes better penetration and fixation of the dye onto the cotton fibers. This can improve wash fastness, as the dye becomes more securely attached to the fabric. Additionally, higher dyeing temperatures typically increase the solubility of the dye, facilitating faster diffusion into the fabric fibers and resulting in improved washing fastness. However, if the temperature exceeds an optimal level, it can lead to dye hydrolysis, which negatively affects washing fastness.

3. Liquor Ratio (C):

The liquor ratio refers to the volume of dye solution compared to the weight of the fabric. This ratio influences the concentration of dye in the bath. An optimal liquor ratio ensures that there is enough dye concentration for effective uptake by the fabric. However, if the liquor ratio is too high, it can dilute the dye bath, resulting in lower dye uptake and reduced washing fastness.

4. Salt Concentration (D):

Salt is added to enhance dye exhaustion by neutralizing the negative charges on the fabric's surface, which allows for better dye fixation. Maintaining an optimal salt concentration can improve washing fastness. However, excessive salt can cause dye aggregation and interfere with dye migration, ultimately decreasing washing fastness.

5. Alkali Concentration (E):

Alkali is used to adjust the pH of the dye bath, affecting the ionization of the dye and its interaction with the fabric. While a certain level of alkali can enhance dye uptake, too much can lead to negative effects, such as fabric damage or reduced dye fixation, which may ultimately lower washing fastness.

6. pH (F):

The pH level plays a crucial role in the ionization of both the dye and the fiber. An optimal pH can enhance the reactivity of the dye with cotton, leading to better fixation and, ultimately, improved wash fastness. The pH of the dye bath significantly impacts how dye molecules ionize. Many dyes, particularly reactive dyes, require a specific pH range for optimal fixation on the fabric. In acidic conditions, certain dyes may not ionize properly, resulting in poor dye uptake and lower color strength. Moreover, highly acidic environments can damage some fibers. On the other hand, alkaline conditions can enhance the ionization of reactive dyes, which promotes better bonding with the fabric. However, excessive alkalinity can lead to the hydrolysis of the dye, which may reduce washing fastness and potentially harm the fabric. Each type of dye has an optimal pH range that maximizes dye uptake and fixation. Therefore, maintaining the correct pH is essential for achieving the desired wash fastness and ensuring fabric quality.

7. Fixing Agent (G):

Fixing agents are substances used to enhance the adherence of dyes to fabric. They can improve the washing fastness properties of dyed materials by forming a chemical bond between the dye and the fabric. This bond significantly increases dye retention and color vibrancy, which is particularly important for dyes that might otherwise wash out or fade over time. The use of an appropriate fixing agent can result in deeper and more vibrant colors, as well as improved wash and light fastness. However, it is crucial to carefully control the concentration and type of fixing agent, as excessive amounts may lead to adverse effects, such as fabric stiffness or discoloration.

8. Dyeing Time (H):

The relationship between dyeing time and washing fastness is not linear. Initially, increasing the dyeing time allows more dye to adhere to the fabric, thereby enhancing color strength. However, if the dyeing time is extended too long, it can result in hydrolysis of the dye, which may reduce washing fastness. In summary, each parameter plays a vital role in the dyeing process, and their interactions can significantly affect the final washing fastness of the fabric. This study highlights the importance of optimizing these parameters to achieve the desired dyeing results. Together, they contribute to the overall quality and durability of the dyed fabric.

4.3. Selection of levels and orthogonal array for process parameters

Constructing an orthogonal array with 2 levels is simple to figure out by hand using Trial and Error. Large arrays can be derived using deterministic algorithms. An effective orthogonal array is the one that assign to each variable a state based on a uniform sample. (e.g., if there are 3 states, then each is chosen with 0.33 probabilities). Random design tends to work poorly for small experiments but work well for large systems.

Design of experiments can be a Factorial design, or Taguchi Method. Factorial design is important to use when there is small number of variables with a few states (1 to 3), Interactions between variables are strong and important, and each variable contributes significantly to the desired response output characteristics. Taguchi method is important to use when intermediate number of variables from 3 to 50 exists, interactions between variables is comparatively few, in a situation when a few variables contribute significantly.

An orthogonal array designated as La (b c) where a, b, and c represent number of experimental runs, number of levels for each factor, and minimum number of columns in the array (factors) respectively. The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi (DoE). Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. The process parameters considered in DoE of the case industry production process were dye concentration, temperature, MLR, salt, alkali, PH, fixing agent, and time.

4.3.1. Process parameter selection

In any Taguchi based optimization of process parameters, the leading task is to identify the key process parameters and their permissible operating ranges. Once these parameters of study are obtained the researcher then tend to decide the respective levels of key input parameters based on the sensitivity of the change in process factor on the response value of interest. Doing this will help the researcher undertake an experiment by use of Taguchi's orthogonal array which produces an input to the upcoming data preprocessing phase of the research for the optimization.

Table 5 Process parameters and their corresponding operating range

SR	Controlled factor	Operating range	Unit
1	Dye concentration	6 – 8	%
2	Temperature	50 – 60	^{o}C
3	MLR	1:4 – 1:8	g/l
4	Salt	40 – 50	g/l
5	Soda ash	16 – 20	g/l
6	PH	10.5 – 11.5	PH

7	Fixing agent	1 – 3	%
8	Time	50 – 60	Min

Table 6 Process parameters and their assigned levels

Controlled factor		**Operating range**	**Level**	**Level 1**	**Level 2**	**Level 3**
A	Dye concentration	6 – 8	3	6	7	8
B	Temperature	50 – 60	3	50	55	60
C	MLR	1:4 – 1:8	3	1:4	1:6	1:8
D	Salt	40 -50	3	40	45	50
E	Soda ash	16 – 20	3	16	18	20
F	PH	10.5 – 11.5	3	10.5	11	11.5
G	Fixing agent	1 – 3	3	1	2	3
H	Time	50 – 60	3	50	55	60
Response Factor: Wash Fastness						

4.3.2. Identification of Control Parameters and Levels

The level should be chosen sufficiently far apart to cover a wide experimental region because sensitivity to noise factors doesn’t usually change with small changes in control factor sittings. Although by choosing a wide experimental region, we can identify good regions as well as bad regions, for control factors.

Selecting of an appropriate OA to fit a specific task involve either of the two conditions:

Conditions 1: By determining the degree of freedom. The total degree of freedom tells the minimum number of experiments that must be performed to study all chosen factors. The number of degrees of freedom is a very important value because it determines the minimum number of treatment conditions. The selection of OA depends on the following conditions:

1. The number of factors and interactions of interest
2. The number of levels for each factor of interest

These two items determine the total degrees of freedom required for the entire experiment. The degrees of freedom for each factor are the number of levels minus one. The degrees of freedom for the factors under investigation, D, assuming no interactions is given as;

$D = F\ (L-1)$

Where, D is degree of freedom, F number of factors and L is number of levels for each factor. Therefor the number of factors and levels under investigation is 8 and 3 respectively for all the three products of the study consequently the degree of freedom is computed as;

$D=8(3-1)=16$

Thus, an OA is required that will accommodate D the total number of degrees of freedom. The total degree of freedom available in an OA, Do, is equal to the number of trial N minus one; $Do=N-1$

In order to select the particular orthogonal array for an experiment the following inequality must be satisfied.

$D\ o \geq D$

Hence, the appropriate orthogonal array which can accommodate this degree of freedom is chosen to be L27, because the degree of freedom D of L27 OA is 26 satisfying the above conditions. The corresponding values for the selected orthogonal array are depicted in the following tables for the products this study will address.

Condition 2: By using standard orthogonal array, or table. The number of rows of an orthogonal array represented by the number of experiments. In order for the array to be a viable choice, the number of rows must be at least equal to the degree of freedom needed for the study. The number of columns of an array represents the maximum number of factors that can be studied using that array. To use a standard orthogonal array directly, must be able to match the number of levels of the factors with the numbers of levels of the columns in the array. Usually, it is expensive to conduct experiments. Therefore, to use the smallest possible orthogonal array that meets the requirements of the case study.

1. When: 2-level arrays: L4, L8, L12, L16, L32, L64
2. When: 3-level arrays: L9, L27, L81

3. When: Mixed 2-level and 3-level arrays: L18, L36, L54

When to come, on mine case there are eight factors each with three levels are selected. From standard table of orthogonal array, the preferable OA selected would be L27(3^8). Minitab software helps to generate Taguchi orthogonal array.

Subsequently, 27 groups combination of coded parameters performed. The experiments were conducted by following the settings of parameters using to measure the wash fastness in the dyeing process. Settings of parameters will determine by the orthogonal array L27(3^8).

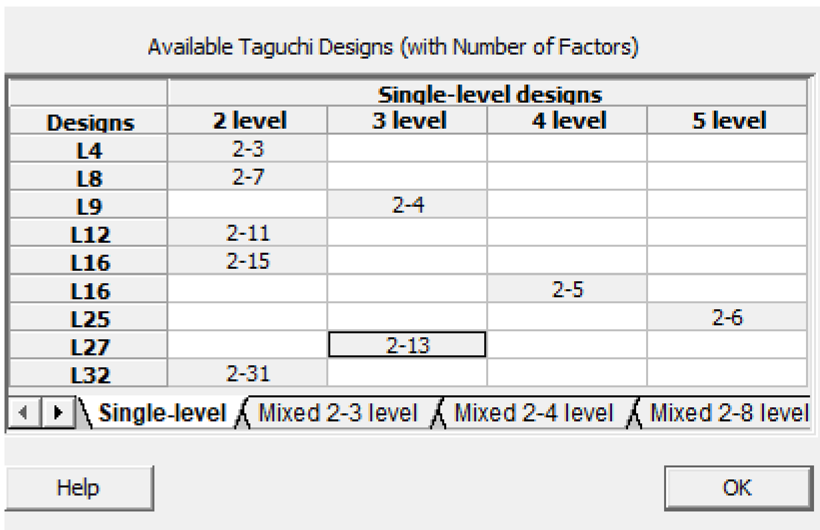

Figure 2 OA selected would be L27(3^8) for eight factors

Minitab 20 software provides easily access for Taguchi Design of different levels and factors that to want for constructing an appropriate OA selected for study.

Table 7 Taguchi design summary L27 (3^8) orthogonal array by using Minitab 20 software

Run Order	Factors and levels							
	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2
3	1	1	1	1	3	3	3	3
4	1	2	2	2	1	1	1	2
5	1	2	2	2	2	2	2	3

6	1	2	2	2	3	3	3	1
7	1	3	3	3	1	1	1	3
8	1	3	3	3	2	2	2	1
9	1	3	3	3	3	3	3	2
10	2	1	2	3	1	2	3	1
11	2	1	2	3	2	3	1	2
12	2	1	2	3	3	1	2	3
13	2	2	3	1	1	2	3	2
14	2	2	3	1	2	3	1	3
15	2	2	3	1	3	1	2	1
16	2	3	1	2	1	2	3	3
17	2	3	1	2	2	3	1	1
18	2	3	1	2	3	1	2	2
19	3	1	3	2	1	3	2	1
20	3	1	3	2	2	1	3	2
21	3	1	3	2	3	2	1	3
22	3	2	1	3	1	3	2	2
23	3	2	1	3	2	1	3	3
24	3	2	1	3	3	2	1	1
25	3	3	2	1	1	3	2	3
26	3	3	2	1	2	1	3	1
27	3	3	2	1	3	2	1	2

The letters A, B, C, D, E, F, G, and H describe the control factors under the thesis work. The number 1, 2, and 3 represent associated levels for each control factor for OA L27 (3^8). And, 27 experimental run is needed.

Table 8 Taguchi design experiment L27 (3^8) orthogonal array by using Minitab 20 software

Run order	Controlled parameters							
	Dye concentration	Temperature	MLR	Salt	Soda ash	PH	Fixing agent	Time

1	6	50	1:4	40	16	10.5	1	50
2	6	50	1:4	40	18	11	2	55
3	6	50	1:4	40	20	11.5	3	60
4	6	55	1:6	45	16	10.5	1	55
5	6	55	1:6	45	18	11	2	60
6	6	55	1:6	45	20	11.5	3	50
7	6	60	1:8	50	16	10.5	1	60
8	6	60	1:8	50	18	11	2	50
9	6	60	1:8	50	20	11.5	3	55
10	7	50	1:6	50	16	11	3	50
11	7	50	1:6	50	18	11.5	1	55
12	7	50	1:6	50	20	10.5	2	60
13	7	55	1:8	40	16	11	3	55
14	7	55	1:8	40	18	11.5	1	60
15	7	55	1:8	40	20	10.5	2	50
16	7	60	1:4	45	16	11	3	60
17	7	60	1:4	45	18	11.5	1	50
18	7	60	1:4	45	20	10.5	2	55
19	8	50	1:8	45	16	11.5	2	50
20	8	50	1:8	45	18	10.5	3	55
21	8	50	1:8	45	20	11	1	60
22	8	55	1:4	50	16	11.5	2	55
23	8	55	1:4	50	18	10.5	3	60
24	8	55	1:4	50	20	11	1	50
25	8	60	1:6	40	16	11.5	2	60
26	8	60	1:6	40	18	10.5	3	50
27	8	60	1:6	40	20	11	1	55

4.4. Experimental results

Table 9 Experimental results of wash fastness

Exp. No	Result 1	Result 2	Result 3	Mean
1	1	1.25	1	1.083333
2	1.5	1	1.25	1.25
3	1	1	1.5	1.166667
4	2.5	3	2.5	2.666667
5	3.5	3	3.25	3.25
6	3	3.25	3.5	3.25
7	2.5	2.5	2.75	2.583333
8	3.5	3	3.25	3.25
9	3	2.5	2.75	2.75
10	4	3.5	4	3.833333
11	3.5	3	3.25	3.25
12	3	3	3	3
13	3.5	3.5	3.75	3.583333
14	3	2.5	2.75	2.75
15	3.75	4	3.75	3.833333
16	3	2.5	3	2.833333
17	2.5	2	2.5	2.333333
18	3.5	3	3.25	3.25
19	3	2	3	2.666667
20	4.25	3.5	3.75	3.833333
21	3	2.75	3	2.916667
22	4	3.5	3.5	3.666667
23	3.5	3.75	3.75	3.666667
24	3.5	3.25	4	3.583333
25	3.25	3	3.5	3.25
26	3.5	3.75	3.5	3.583333
27	3	2.75	3	2.916667

A total of twenty-seven runs must be conducted while using Taguchi design, using the combination of levels for each control factor. Each experiment was repeated three times.

Table 10 Experimental layout using L27 orthogonal array with results

Run order	Controlled parameters								Response value
	Dye concentration	Temperature	MLR	Salt	Soda ash	PH	Fixing agent	Time	Washing fastness
1	6	50	1:4	40	16	10.5	1	50	1.083333
2	6	50	1:4	40	18	11	2	55	1.25
3	6	50	1:4	40	20	11.5	3	60	1.166667
4	6	55	1:6	45	16	10.5	1	55	2.666667
5	6	55	1:6	45	18	11	2	60	3.25
6	6	55	1:6	45	20	11.5	3	50	3.25
7	6	60	1:8	50	16	10.5	1	60	2.583333
8	6	60	1:8	50	18	11	2	50	3.25
9	6	60	1:8	50	20	11.5	3	55	2.75
10	7	50	1:6	50	16	11	3	50	3.833333
11	7	50	1:6	50	18	11.5	1	55	3.25
12	7	50	1:6	50	20	10.5	2	60	3
13	7	55	1:8	40	16	11	3	55	3.583333
14	7	55	1:8	40	18	11.5	1	60	2.75
15	7	55	1:8	40	20	10.5	2	50	3.833333
16	7	60	1:4	45	16	11	3	60	2.833333
17	7	60	1:4	45	18	11.5	1	50	2.333333
18	7	60	1:4	45	20	10.5	2	55	3.25
19	8	50	1:8	45	16	11.5	2	50	2.666667
20	8	50	1:8	45	18	10.5	3	55	3.833333
21	8	50	1:8	45	20	11	1	60	2.916667
22	8	55	1:4	50	16	11.5	2	55	3.666667

23	8	55	1:4	50	18	10.5	3	60	3.666667
24	8	55	1:4	50	20	11	1	50	3.583333
25	8	60	1:6	40	16	11.5	2	60	3.25
26	8	60	1:6	40	18	10.5	3	50	3.583333
27	8	60	1:6	40	20	11	1	55	2.916667

Response factor values for the corresponding selected layout of the design are shown in the table above. In order to increase the precision of the conducting experiment and to maximize the sample size; the data to be collected the representative of the ongoing process the experiment is replicated three times. Then three responses value for a single combination of each of the orthogonal array is recorded from the trial of data of the machine. And, the mean of these three responses is taken as a response of the respective combination were considered for further processing in the thesis work. Each recorded results with their means are shown here in Table 8.

Figure 3 Tested samples and grey scale method

4.5. Main effect plot

The S/N ratio for each level of the parameters is summarized and called the S/N response table for washing fastness. The delta statistics, S/N ratios, were used in designing these response values, which were calculated by subtracting the maximum and minimum S/N ratios from the average values for each component. In order to adjust the mean on target and try to identify which factors has the highest impact on mean, use and interprets response table for mean. By using Minitab software 20, each value of the response output is inserted in the worksheet and evaluated using a special Module to obtain response table for signal to noise ratio and response table for means. Session window showing Response Tables for S/N ratio and Response Tables for Means is seen as follows:

Table 11 Response Table for Signal to Noise Ratios

Level	A (Dye concentration)	B (Temperature)	C (MLR)	D (Salt)	E (Soda ash)	F (PH)	G (Fixing agent)	H (Time)
1	6.693	7.213	7.141	7.349	8.812	9.217	8.169	9.174
2	9.960	10.466	10.119	9.459	9.204	9.322	9.323	9.229
3	10.418	9.392	9.811	10.264	9.055	8.532	9.579	8.668
Delta	3.726	3.254	2.977	2.915	0.393	0.790	1.410	0.560
Rank	1	2	3	4	8	6	5	7
Optimum	A3	B2	C2	D3	E2	F2	G3	H2

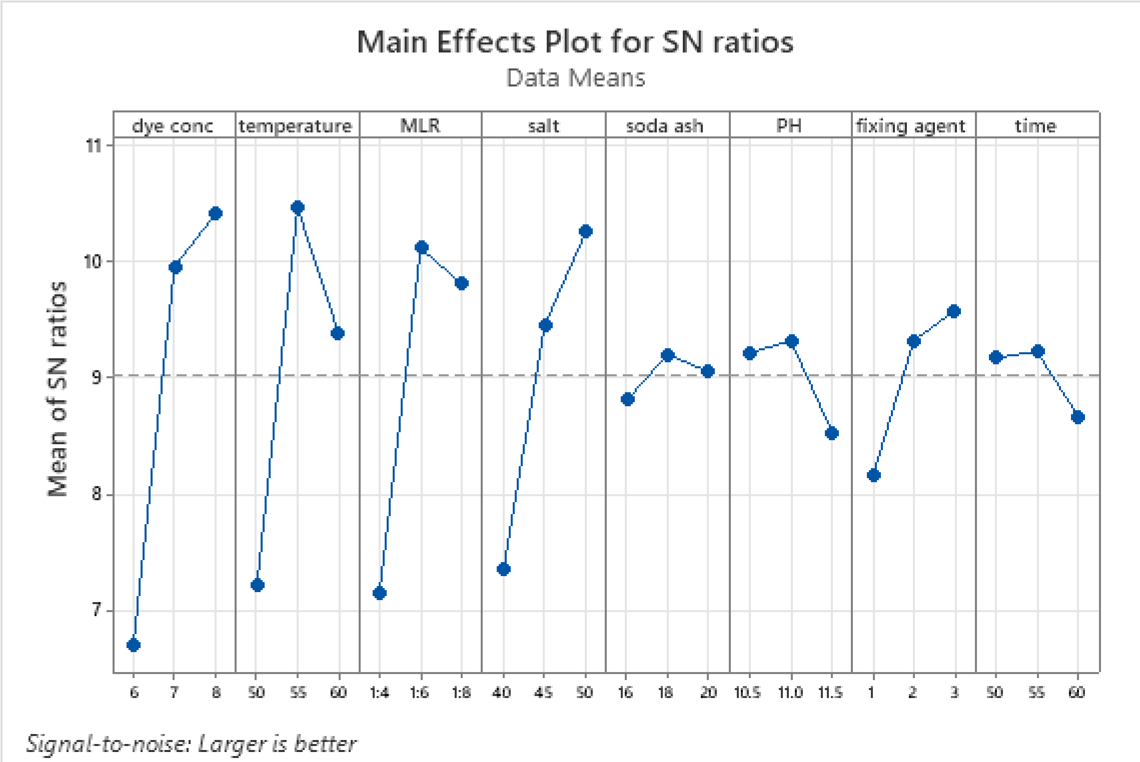

Figure 4 Main effect plot for Signal to Noise Ratios

Table 12 Response Table for Means

Level	A (Dye concentration)	B (Temperature)	C (MLR)	D (Salt)	E (Soda ash)	F (PH)	G (Fixing agent)	H (Time)
1	2.361	2.556	2.537	2.602	2.907	3.056	2.676	3.046
2	3.185	3.361	3.222	3.000	3.019	3.046	3.046	3.019
3	3.343	2.972	3.130	3.287	2.963	2.787	3.167	2.824
Delta	0.981	0.806	0.685	0.685	0.111	0.269	0.491	0.222
Rank	1	2	3	4	8	6	5	7

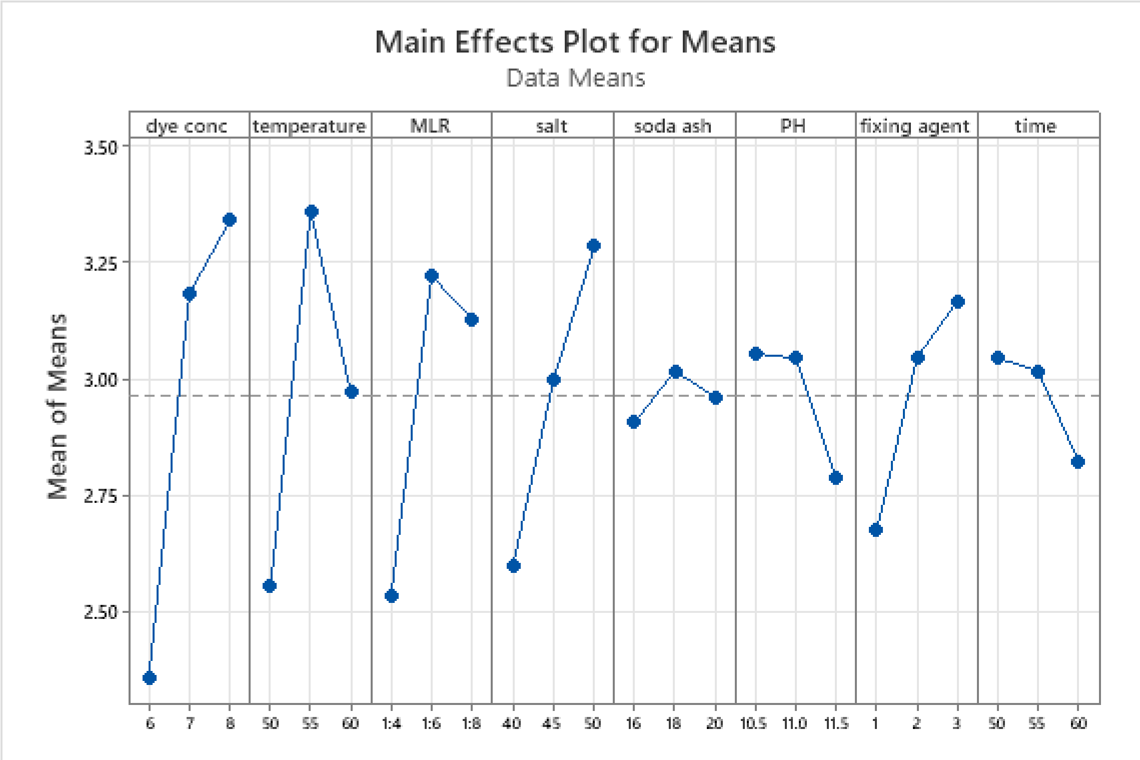

Figure 5 Main effect plot for means

Using main effects plots to help us visualize the relative value of the effects of different factors. Figure 4 shows the S/N response graph for washing fastness. As shown in the figure, the greater the S/N ratio, the smaller is the variance of washing fastness around the desired (the-Larger-The-Better) value. However, the relative importance amongst the parameters for washing fastness still needs to be known so that optimal combinations of the parameter levels can be determined more accurately.

4.5.1. Interpreting the results signal to noise and means:

The response tables show the average of the selected characteristic for each level of the factors. The response tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The response tables and main effects plots for the signal to noise (S/N) ratios to see which factors have the greatest effect on S/N ratio, which in this case study is Larger-is-better is used.

$$\text{S/N ratio for the larger the better} = -10\ \log_{10}\frac{1}{n}\sum 1/y_i{}^2$$

n: is the number of experiments of the orthogonal design, which for this case is $n = 27$, y_i: is the response at each experiment.

Therefore, the greater the delta value of a parameter is the better. The optimum conditions on this approach obtained by sorting the delta in an order of significantly affecting the process (Yingjie Cai, 2023). The highest plots of each parameter were chosen as could be seen in Figure 4, with the reason that the ratio set was the larger the better. The higher the delta value signifies the more effect its parameter contributes. In this case, the factor with the biggest impact on the S/N ratio is dye concentration (Delta = 3.726, Rank = 1). And the factor with the least effect on S/N ratio soda ash (Delta = 0.393, Rank = 8). In order to reduce the impact of noise on response (i.e., reducing the poor wash fastness of the knitted fabric), possible parameter combination settings are the one with higher S/N ratio in each factor. The S/N ratio optimum parameter level for minimum value of poor wash fastness of the knitted fabric is dye concentration, temperature, MLR, salt, alkali, PH, fixing agent, and time (A3, B2, C2, D3, E2, F2, G3 and H2). And for response table and main effects plots for mean both show that the factor with the greatest effect on the mean is dye concentration (Delta = 0.981, Rank = 1). And the factor with the least effect on the mean is soda ash (Delta = 0.111, Rank = 8). The main effect plots for means are helpful for adjusting the mean on target value, those parameter levels with near or close to the desired target wash fastness of knitted fabric that means optimum parameter level for minimum value of poor wash fastness of the product is dye concentration, temperature, MLR, salt, alkali, PH, fixing agent, and time (A3, B2, C2, D3, E2, F2, G3 and H2) can be replaced.

Table 13 The recommended possible parameter combinations

Control parameters		Unit	Optimum parameter level for S/N ratio
A	Dye concentration	%	8
B	Temperature	°C	55
C	MLR	g/l	1:6
D	Salt	g/l	50

E	Soda ash	g/l	18
F	PH	PH	11
G	Fixing agent	%	3
H	Time	Min	55

The response variable selected in this study is washing fastness. Parameters dye concentration, temperature, time, PH, MLR, salt, alkali, and fixing agent. Those has a significant contribution towards the products to get quality problems. In this case study, the above factors associated impacts on production of defected products were investigated. This study, after identifying above factors by the Taguchi method, optimization process parameter applied in dyeing process.

4.6. Validation test

The Taguchi methodology necessitates the execution of a validation examination to provide further insight into the obtained results. For statistical methodologies, it is highly advised to conduct such a test. The principal objective of this inquiry is to ascertain the reliability of the responses. Provides a comprehensive account of the outcomes obtained from the validation experiments. Once the parameters for achieving optimal performance have been identified, the subsequent step involves verifying the effectiveness of the enhanced process.

The predicted values were calculated and determined using the Minitab 20 software. Consequently, the experiment was conducted utilizing optimal parameters that significantly enhance the signal-to-noise ratio. The primary aim of the present investigation was successfully achieved, as evidenced by the observed augmentation in wash fastness are 4, 4.25, and 4 the average grey scale value is 4.0833. Based on the findings, it is suggested that optimal outcomes could be achieved through the implementation of an experimental design that consistently adheres to statistical standards.

4.7. ANOVA (Analysis of Variance)

ANOVA was used to investigate which design parameter significantly affected the quality characteristic. ANOVA was performed by separating the total variability of the S/N ratio into contributions from each of the design parameters and the errors (Durakovic, 2017, Yasmin et al., 2024). It is a statistical test for estimating how a quantitative dependent variable changes according to the levels of one or more categorical independent variables. It tests whether there is a difference in means of the groups at each level of the independent variable (Bevans, 2023). The total variability of the S/N ratio was measured by the sum of the squared deviations from the total mean S/N ratio. First, the total sum of the squared deviations SS_T from the total mean of the results can be calculated by equation one below:

$$SST = \sum_{j=0}^{p} (\mathrm{Yj} - \mathrm{Ym})2$$

Where p is the number of experiments in the OA, Ym is the mean of results and Yj is the observed of the results for the jth Experiment.

P test values to proceed with the decision-making process. The P value was calculated for each design parameter. Usually, when the P value is ≤ 0.05, the related design parameter appears to have a significant effect on the quality characteristic; when the P value for a factor is > 0.05, that factor is not significant and can be neglected (Sedgwick, 2015). Whereas, P values were > 0.05, then we go for validation of the result in either of three cases. I.e., Normality, Constant Variance, and Independence Test (Ayele, 2019). Normality - ANOVA requires the population in each treatment from which you draw your sample be normally distributed. The population normality can be checked with a normal probability plot of residuals. If the distribution of residuals is normal, the plot will resemble a straight line.

Constant Variance - The variance of the observations in each treatment should be equal. The constant variance assumption can be checked with Residuals versus Fits plot. This plot should show a random pattern of residuals on both sides of 0, and should not show any recognizable patterns.

Independence test - ANOVA requires that the observations should be randomly selected from the treatment population. The independence, especially of time related effects, can be checked with the Residuals versus Order (time order of data collection) plot. If the plot does not reveal any pattern, the independence assumption is satisfied. After this go for validation of the result of P value to put values in ANOVA for wash fastness versus with control parameters.

In addition, the Fisher's F test can also be used to determine which dyeing parameters have a significant effect on the product characteristic. Usually, the change of the dyeing parameter has a significant effect on the product characteristic when F is large (Das et al., 2022).

General Linear Model: Wash fastness versus control parameters (A, B, C, D, E, F, G, H) Method

Factor coding (-1, 0, +1)

Table 14 Factor Information

Factor	Type	Level	Values
A	Fixed	3	6, 7, 8
B	Fixed	3	50, 55, 60
C	Fixed	3	1:4, 1:6, 1:8
D	Fixed	3	40, 45, 50
E	Fixed	3	16, 18, 20
F	Fixed	3	10.5, 11, 11.5
G	Fixed	3	1, 2, 3
H	Fixed	3	50, 55, 60

Table 15 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Remarks
A	2	5.0015	2.50077	25.56	0.000	Significant
B	2	2.9213	1.46065	14.93	0.001	Significant
C	2	2.4877	1.24383	12.71	0.002	Significant
D	2	2.1312	1.06559	10.89	0.003	Significant
E	2	0.0556	0.02778	0.28	0.759	Insignificant

F	2	0.4182	0.20910	2.14	0.169	Insignificant
G	2	1.1775	0.58873	6.02	0.019	Significant
H	2	0.2639	0.13194	1.35	0.303	Insignificant
Error	10	0.9784	0.09784			
Total	26	15.4352				

Table 15 it displays the use of ANOVA to determine the process characteristics that had a statistically significant effect on washing fastness, along with their confidence levels. It was concluded that a dye concentration considerably affected wash fastness performance, as evident by a high F-value of 25.56 and a p-value of 0.000 statistically significant and followed by temperature, MLR, salt concentration (Na_2SO_4 or Globular salt), and fixing agent with p-values below 0.05. However, other factors such as alkali Concentration (Na_2CO_3), PH, and time, have F-values of 0.28, 2.14 and 1.35 respectively, and they are considered statistically insignificant with p-values above 0.05 respectively.

Table 16 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.312793	93.66%	83.52%	53.79%

R-squared (R^2), also called the coefficient of determination. It is a statistical measure which used in regression analysis to examine how well a model explains the variability of a response variable based on one or more independent factors. R^2 quantifies the proportion of variance in the response variable that is predictable from the independent factors. Its value ranges from the interval 0 to 1. So, the model was obtained by the least-squares method and validated through the analysis of variance (ANOVA). From table 16 the determination coefficient achieved R^2 is 0.9366 and indicates its good accuracy for making predictions (Boukouvalas et al., 2021). While the remaining 0.0634 is due to other variables or inherent randomness.

Table 17 Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.9630	0.0602	49.22	0.000	
A					
6	-0.6019	0.0851	-7.07	0.000	1.33
7	0.2222	0.0851	2.61	0.026	1.33
B					
50	-0.4074	0.0851	-4.79	0.001	1.33
55	0.3981	0.0851	4.68	0.001	1.33
C					1.33
1:4	-0.4259	0.0851	-5.00	0.001	1.33
1:6	0.2593	0.0851	3.05	0.012	1.33
D					
40	-0.3611	0.0851	-4.24	0.002	1.33
45	0.0370	0.0851	0.44	0.673	1.33
E					
16	-0.0556	0.0851	-0.65	0.529	1.33
18	0.0556	0.0851	0.65	0.529	1.33
F					
10.5	0.0926	0.0851	1.09	0.302	1.33
11	0.0833	0.0851	0.98	0.351	1.33
G					
1	-0.2870	0.0851	-3.37	0.007	1.33
2	0.0833	0.0851	0.98	0.351	1.33
H					
50	0.0833	0.0851	0.98	0.351	1.33
55	0.0556	0.0851	0.65	0.529	1.33

In regression analysis coefficients are numerical values that quantify the relationship between independent factors predictors and a response variable. They indicate both the direction and magnitude of this relationship as shown below.

Regression Equation

After applying the least squares method on the experimental data set, several models were obtained and the one that fitted better is showed in Equation below. It fitted the experimental with that corresponds to an R^2 value of **0.9366**.

Washing Fastness = 2.9630 - 0.6019 Dye concentration_6 + 0.2222 Dye concentration_7

+ 0.3796 Dye concentration_8 - 0.4074 Temperature_50

+ 0.3981 Temperature_55 + 0.0093 Temperature_60 - 0.4259 MLR_1:4

+ 0.2593 MLR_1:6 + 0.1667 MLR_1:8 - 0.3611 Salt_40 + 0.0370 Salt_45

+ 0.3241 Salt_50 - 0.0556 Soda ash_16 + 0.0556 Soda ash_18

+ 0.0 Soda ash_20 + 0.0926 PH_10.5 + 0.0833 PH_11.0 - 0.1759 PH_11.5

- 0.2870 Fixing agent_1 + 0.0833 Fixing agent_2 + 0.2037 Fixing agent_3

+ 0.0833 Time_50 + 0.0556 Time_55 - 0.1389 Time_60

Table 18 Fits and Diagnostics for Unusual Observations

Obs	Washing fastness	Fit	Resid	Std Resid	
12	3.000	3.398	-0.398	-2.09	R
19	2.667	3.074	-0.407	-2.14	R

Note: R for Large residual

In the experiment dye concentration is observed to play a significant role in producing the greater value of washing fastness. From the ANOVA table 15 displayed above the highly significant factors can easily be identified, dye concentration for the experiment is found to be highly influential of the product for it attains an F value 25.56, higher than each dyeing process parameters. This conveys that the change of dye concentration from one level to another will bring about a visible effect on the response variables or quality characteristics of interest under investigation. Followed by temperature the other significantly affecting dyeing process parameters are MLR, and salt in descending order.

Summary of results

In this study, a dyeing process that is used for production of knitted fabric at MAA garment was studied process parameter optimization of dyeing process that have significant effect on reducing poor washing fastness problems to bringing them to the desired targeted. Finally, Taguchi design of experiment is systematically approached from the existing dyeing machine parameters set points to identify the possible response output values that is approaching or nearest to the L27 orthogonal array. From the above discussion of the highlight of the study, a general output of this study was one method of reducing such poor wash fastness problem is by applying and using the Taguchi method. And the optimum combination of parameters was found with an intension of bringing the product to its desired value, that is “Larger-The-Better” approach is selected for both S/N Ratio in the study. This study to reduce the impact of noise on response is for reducing variation around the selected product, possible parameter combination settings are the one with higher S/N ratio in each factor. The S/N ratio optimum parameter level for better value of washing fastness of the knitted fabric is dye concentration, temperature, MLR, salt, alkali, PH, fixing agent, and time (A3, B2, C2, D3, E2, F2, G3 and H2) from response table 10 for Signal to Noise Ratios are the possible parameter combinations for reducing such poor wash fastness of the knitted fabric.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The pillars of quality engineering are known to be system design, parameter design and tolerance design. The primary aim of design of experiment-based parameter design is to have a robust product capable of consistently functioning withstanding all the noise factor.

In this study, a dyeing process that is used for production of knitted fabric at MAA garment was studied process parameter optimization of dyeing process that have significant effect on reducing poor washing fastness problems to bringing them to the desired targeted. And the study immense endeavors are made to reduce the variability in response characteristics wash fastness for the selected products of interests. Variation is inevitable for every process system or products; no two processes can yield alike products and or no two products of the same process are exactly alike in every process. The very reason that the process in this regard is controlled, the need for the application of Taguchi based parameter design has emanated.

Finally, Taguchi design of experiment is systematically approached from the existing dyeing machine parameters set points to identify the possible response output values that is approaching or nearest to the L27 orthogonal array.

The study identifies 8 process parameters amongst which eight of them are considered as key input parameters dye concentration, temperature, MLR, salt, alkali, PH, fixing agent, and time based on the variability they induce on the preferred response variables. These process parameters are also assigned to a level based on their operating range and sensitivity on the response characteristics.

Accordingly, the process dye concentration, temperature, MLR, salt concentration, alkali concentration, PH, fixing agent, and time (A3, B2, C2, D3, E2, F2, G3 and H2) can be replaced. The main effect plot and the ANOVA has jointly showed that, dye concentration for the experiment is found to be highly influential of the performance for it attains an F value 25.56, higher than each dyeing parameter. From the ANOVA table has also displayed the minimal role of some of the process parameters such as temperature, MLR, salt concentration, and fixing agent under the selected alpha value of 0.05.

5.2. Recommendation

In today's intense, volatile and tight competitive market, the issue of ensuring quality isn't a matter to be negotiated round table; rather it is a matter of survival. A firm who understands how much quality matters its market ought to know how to build quality into its product i.e. how to make quality an integral part of the product. Firms need to of a maximum information of their process to achieve the intended quality level, one of which is the stability level of the process. Processes under statistical control do experience variation due to common causes which still needs to be minimized to reduce variations in the quality characteristics of a product.

Design of 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. So, firms are advised to optimize their process by making use of design of experiment.

Based on the design of experiment test, it is recommended to have a more detail analysis in other color fastness tests such as color strength and in both washing fastness and rubbing fastness. It also recommended conducting experiments with a broader range of dye concentration and temperatures to fully understand their effects on wash fastness.

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Appendix

Table 19 Taguchi Standard Orthogonal Array

Orthogonal Array	Number of rows	Maximum number of factors	Maximum number of columns at this level			
			2	3	4	5
L4	4	3	3	-	-	-
L8	8	7	7	-	-	-
L9	9	4	-	4	-	-
L12	12	11	11	-	-	-
L16	16	15	15	-	-	-
L′16	16	5	-	-	5	-
L18	18	8	1	7	-	-
L25	25	6	-	-	-	6
L27	27	13	-	13	-	-
L32	32	31	31	-	-	-
L′32	32	10	1	-	9	-
L36	36	23	11	12	-	-
L′36	36	16	3	13	-	-
L50	50	12	1	-	-	11
L54	54	26	1	25	-	-
L64	64	63	63	-	-	-
L′64	64	21	-	-	21	-
L81	81	40	-	40	-	-

Table 20 Company specification

No.	Chemicals	Amount description
1	Acetic acid	0.5 g/l
2	Reactive Red color	0.1 g/l
3	Reactive Yellow color	0.1 g/l
4	Relative humidity	63 % - 67 %
5	Temperature	23 ºC – 27 ºC