ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

‘Integrating Taguchi and Response Surface Methodology for Process Parameter Optimization of Extrusion Process

(Case in Ethiopia Plastic Industry)’

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SCHOOL OF GRADUATE STUDIES

POSTGRADUATE PROGRAM IN INDUSTRIAL ENGINEERING

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DECLARATION

I declare that *'Integrating Taguchi and Response Surface Methodology for Process Parameter Optimization of Extrusion Process (Case in Ethiopia Plastic Industry)'* is original work of my own, has not been presented for a degree of any other university, and all the sources that I have used or quoted have been indicated and acknowledged by means of referencing. It is submitted in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering (Industrial Engineering) at Addis Ababa University.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The research focus on identifying possible product quality problems that adversely affect rate of rework or recyclability by selecting case in EPI. By performing cause and effect analysis to strengthen and diagnose causes corresponding to the identified, prioritized quality problems. Taguchi and Response Surface Methodology design of experiment is systematically approached from the existing EPI extrusion machine set- points to identify the possible response output values approaching.

Taguchi is used to screen the variables that have significant effects (were: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature) and $L_{27}(3^7)$ orthogonal array by using Minitab and know Response factor: Thickness and Width variation. RSM design experiment for process parameter optimization the selected response factor from Taguchi design experiment selected independent experimental factors: Feed drum, vacuum chamber, rotational screw speed and barrel temperature. The dependent response parameters: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature. After this, Analysis of Variance(ANOVA) used to integrate Taguchi and Response Surface Methodology design experiments.

Accordingly, in this research, to set possible parameter combinations and to reduce variation around thickness and width pipe and control the factor with the biggest impact on the Signal to noise ratio is Screw speed. And for mean both show that the factor with the greatest effect on the mean is Feed speed. Finally, the desired target thickness and width of pipe that means optimum parameter level for minimum value of thickness and width variation of the pipe is Feed speed-1, vacuum pressure-1, Take-off speed-1, screw speed-1, temperature one-2, temperature two-3 and temperature three-3 (A1, B1, C1, D1, E2, F3, G3). The S/N ratio optimum parameter level for minimum value of thickness and width variation of the pipe is Feed speed-1, vacuum pressure-2, Take-off speed-1, screw speed-1, temperature one-3, temperature two-1 and temperature three-2 (A1, B2, C1, D1, E3, F1, G2).

Keywords: Taguchi Method, Response Surface Methodology, Process Parameter Optimization, ANOVA

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LIST OF ACRONYMS AND ABBREVIATION

CSA - Central statistics authority

GTP - Growth and Transformation Plan

PVC - Plasticized Poly Vinyl Chloride

HDPE - High-density polyethylene

CCD - Central Composite Design

RSM - Response Surface Methodology

EPI - Ethiopian Plastic Industry

DoE - Design of Experiment

PN - Pressure Range

UMC - Unit Manufacturing Cost

QE - Quality Engineering

OAs - Orthogonal Arrays

ANOVA - Analysis of variance

S/N - Signal to Noise Ratio

S.D - Undesirable effect (signal disturbance)

NPS - Noise Performance Statistics

FEA - Finite Element Analysis

MRR - Material removal rate

LDPE - Low Density Polyethylene

WEDM - Wire Electrical Discharge Machining

D/t - Diameter to thickness

EPSC - Ethiopia Plastic Share Company

RPMI - Rubber and Plastic Manufacturing Industries

CIF - Cost-in-Freight

ISIC - International Standard Industrial Classification

RPRP - Rubber and plastic raw materials

ERTA - Ethiopian Radio and Television Agency

PET - Polyethylene terephthalate

VCM - Vinyl chloride monomer

SOPs - Standard Operating Procedures

SAWM - Simple Average Weighted Method

ISO - International Organization for Standardization

CHAPTER ONE

THE PROBLEM AND ITS APPROACHES

1.1. Introduction

Extrusion is any process in which a material is forced through a shaped orifice, with the material solidifying to produce a continuous length of constant cross section. Squeezing toothpaste from a tube is a familiar example. In plastic extrusion, thermoplastic was softened by heating prior to extrusion and, for the shape to be held; the thermoplastics must be quickly chilled and, usually, supported while cooling. Some large extruders in polymerization plants are fed hot melts, so their main duty is generating enough pressure to force the melt through spider die. In most extrusion operations, however, the plastics arrive as powders or pellets at room temperature, and the extrusion process must melt the plastic and homogenize it before it enters the die. Therefore, heating and melting the feedstock, converting it from a cold solid to a hot viscous liquid, accounts for about 93% of the energy required. The work done in pumping the melt through the die is only 5-10% of the total (Sidney and Carley, 1989).

Plastic pipe extrusion process is the most widely pipe manufacturing process in the plastic manufacturing industries (Gadekar et al.., 2015). The complexity of extrusion process and the enormous amount of process parameters involved make difficult keep the process under control. One of the main goals of extrusion is the improvement of quality of extruded parts besides the reduction of cycle time and lower the production cost (Raju et al.., 2014). Common plastic extrusion failure or defects are normally occurred due to part and mold design, material selection and processing. In many cases, the failures occur during the processing and these failures causes some defects that can be found in extruded parts such as: warpage, sink mark, residual stress, air trap, weld line, sink marks, low gloss, uneven surface gloss, spotted surface, rough surface, extruder surging, uneven wall thickness, diameter variation, centering problem (Narasimha et al.., 2014). In the extrusion process as discuss above the various defects are frequently occurs and hampers the productivity. If we need to enhance the production rate, it is very essential to optimize the process parameters and improve the productivity (Gadekar et al.., 2015).

1.2. Background of the study

Ethiopia's manufacturing sector is among the key productive sectors of the economy identified under GTP (2013-2015) which can spur economic growth and development because of its immense potential for wealth creation, employment generation and poverty alleviation. The manufacturing sector makes an important contribution to the Ethiopian economy and employs about 173 thousand people in 2014/2015. The sector comprises about 2,610 manufacturing establishments and for this study purpose divided into eight broad subsectors namely food and beverage products, textile and apparel products, leather and leather products, wood and pulp products, chemical and chemical products, rubber and plastic products, other non-metallic minerals products and metal and engineering products industries (CSA, 2105).

The rubber and plastic product industries were among the major targeted manufacturing industries for first round GTP. The government of Ethiopia planned to enhance the capacity of the subsector to substitute imported goods of plastics and rubber products. In the production of plastic, the GTP put to increase total production of plastic produced domestically to reach 37000 tons per year to meet about 30% of the domestic demand. And for the rubber industries, through expansion of cultivated land available for commercial rubber tree, GTP envisaged to produce 6,700 tons of rubber annually (GTP policy matrix, 2010, Volume II).

The number of establishment under this subcategory according to the data obtained from CSA (2014) indicated that there are 154 establishments under this subcategory and only 7 of them are under the management of the public. Tires, inner tubes, plastic dishes, plastic crates etc. are the major products produced in the manufacturing of rubber and plastic subsector (CSA, 2105).

The material used in the plastic industry includes polyvinylchloride granules nylon, polytetra, flonoroethylen granules, polyurethane granules, dyes, antioxidants, fillers, polypropylene granules while rubber tree plantation is the main raw material source for rubber industries. The rubber and plastic products manufacturing establishments largely depend on imported raw materials. According to the survey, about 74% of the material inputs for this subsector was obtained from foreign market through importation. Skilled manpower availability for this subsector was rated as "satisfactory" and "not satisfactory" by 44.1% and 31.2% of the interviewed industries (CSA 2015).

Process optimization is the discipline of adjusting a process to optimize some specified set of a parameters without violating some constraints. The most common goals are minimizing cost, maximizing throughout, and or efficiency. This is one of major tool in industrial decision making. When optimizing a process specification, while keeping all others within their constraints. Many relate process optimization directly to use of statistical techniques to identify the optimum solution. This is not true. Statistical techniques are definitely needed. However, a thorough understanding of the process is required prior to committing time to optimize it. Over the years, many methodologies have been developed for process optimization including Taguchi method, six-sigma, lean manufacturing and others. (Rajeshwar Sahai et al.., 2012).

The research focuses on the optimization of process parameters in extrusion process of Ethiopian plastic manufacturing industry. It deeply discuses by identifying the possible product quality problems that adversely affect rate of rework or recyclability. After identifying the problem performing the cause and effect analysis to strengthen and diagnose causes then, by integrating the experimental design methods of the Taguchi and RSM.

1.3. Problem Statement

In general, the common failures or defects of plastic extrusion process are normally occurred due to three main causes, i.e., part and mold design, material selection, and processing. In general, problems that have been seen in plastic shaping industries are unable to confirm customer specification in a way to alleviate quality problems after the item was shipped due usually following a cure-inspection oriented program rather than concerning on prevention by incorporating ideas either at the product development or process stage: thickness variation after a product lunched to end user (Gadekar et al.., 2015).

The reason of this study, at Ethiopia plastic Industry in this time, Quality and Inspection work holder announced that the factory Product for PVC pipes are encountering defect problems which constitute around 23% of their total production.

In Ethiopia plastic Industry, plastic extrusion process is one of the current emerging technologies used for production of Plasticized Poly Vinyl Chloride (PVC) pipes. This factory was focuses for producing these pipes with better quality characteristics for the aim of minimizing customer complaints and more customer satisfaction. But the factory has a various quality problem which have been difficult to address customer satisfaction.

The origin of defect arises due to several working conditions such as:

- Variation in the thickness of pipe which is aroused due to loosen screw knob located on the die longitudinal surface.
- Temperature set-point for heating Plasticized Poly Vinyl Chloride (PVC) powder due to malfunctioning of heater pads at die section they will not compressed.
- Breaking down of gearbox.
- Disordering of machine components.
- Variation in temperature profile at the heater around die section.

Then, the defect arises occur in the operation problem variation in thickness and width of pipe. This cause can extra loss of the company about 23% of their total production can be for rework or recycle.

Some Written Literature on Extrusion Process and due to the above listed problems, customers will be dissatisfied and the company will lose them. This study is attempting to optimize extrusion process parameters that contribute towards least thickness and width variation effect with target of ensuring good Quality characteristics on Plasticized Poly Vinyl Chloride (PVC) pipes and product so that the company can minimize complaints of its customers.

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 PVC pipe?
- What are the optimum process parameters setting that yield for a good quality characteristic pipe?
- What are the problems associated with plastic extrusion process?

1.5. Research objectives

1.5.1. General objective

The main objective of this study is to optimize the various process control parameters of extrusion machine so as to provide a quality pipe with least thickness and width variation effect using Integrating Taguchi and Response Surface Methodology.

1.5.2. Specific objectives

The specific objectives of this study:

- To determine the optimum levels for the control factors, and predicting performance under these levels.
- To prioritize the optimal parameter setting for controllable factors that contribute to minimum plastic defects, and uncontrollable noise factors.
  - To determine loss associated with recyclability of scrap, or defects.
  - To identify those process parameters which have most significant effect on the rate of re-work, or recyclability.
- To propose system through selection of appropriate orthogonal array determine optimize the number of experiments required for study.
- To determine the optimal parameter setting for controllable factors that contribute to minimum plastic defects, and uncontrollable noise factors.

1.6. Significance of the study

This study is devoted to investigate quality related problems of PVC pipes that Ethiopian Pipe Factory an extra invisible expense for rework, or recyclability of those defective pipes. By integrating the experimental design methods of the Taguchi and RSM is used to reduce performance variation of products. The study provides importance to those plastic Industries involved in manufacturing of PVC Pipes for:

- ✓ Determining Optimum process parameters setting that yield good quality characteristic pipes.
- ✓ Improving production rate through reducing rate of rework, or recyclability.
- ✓ Reducing frequent parameter set-up trials to get a better dimensionally stable product.

- ✓ Reducing part Inspection time intermittently.

1.7. Scope of the study

The scope of this study is focused on reduction of quality problems which arise due to deviation of performance from its desired target value through application of quality engineering tools specially Taguchi and RSM of DoE. Taguchi loss function analysis is also employed to calculate the loss associated with recyclability of nonconforming PVC pipe products due to variation of performance from its specified target value set by the company Quality and Inspection work holder.

This study is devoted to investigate quality related problems of PVC pipes that incurs Ethiopia plastic industry an extra invisible expense for rework, or recyclability of those defective pipes. By integrating the experimental design methods of the Taguchi and RSM is used to reduce performance variation of products. Also, other plastic industries can take the same procedure for better process parameter in extrusion process.

1.8. Limitation of the study

The study is limited only to thus extrusion machine located at production factories line, producing Pressure range (PN) of PVC pipe type because of the line contributes higher percentage of recyclability of pipes, and loss. And the factories line is also subjected to repeated sudden machine breakdown due to un optimized process variation.

- ➢ Quality related problems of PVC pipes that incurs Ethiopia plastic industry an extra invisible expense for rework, or recyclability of those defective pipes.
- ➢ The line is also subjected to repeated sudden machine breakdown due to un-optimized process variation.
- ➢ Machine down time is higher as compared to other production factories lines.

1.9. Organization of the document

This research is organized into seven chapters. The first chapter will cover the introduction, problem statement, research question’s, objectives of the study followed and the scope of the study. This will be the guiding outline followed by the study. Chapter two will cover the related literature review about Taguchi and RSM, see two methods as quality perspective, optimization of process parameters, design of experiment, orthogonal array, quality loss function and gaps of this study can be identified from lot of literatures. Chapter three discusses the research methodology, the data analysis tools and methods the research will be conducted on the following methodology sequentially and then chapter four discusses the overview of the Ethiopian plastic industry and the case company of Ethiopia plastic industry and the next chapter five deals data analysis, organization, interpretation, analysis of the Ethiopia plastic industry and design of experiment producers Ethiopia plastic industry and next chapter, the results and discussion. Finally, conclusion and recommendation will be forwarded.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

The Taguchi and RSM are often independently utilized to develop new products and to improve quality. Nevertheless, these two experimental design methods appear to have significant differences in terms of efficiency and additivity.

The field of quality has undergone significant changes as reflected by changes in its definition, paradigms, 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. This also calls for special attention to the engineering aspects of quality. 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 broaden their application bases, where possible opportunities for further investigation are indicated (Adnan et al.., 2000).

2.2. Definition of quality

It obvious that nowadays more emphasis is placed on quality issues than ever before (Yamalik, 2007). Many researchers when starting their descriptions about quality note it is a difficult concept to define since it may be tied up to individual perceptions of value for money as well as expectations of performance and appearance. Sometimes, people visualize quality in absolute terms by comparing it with certain absolute characteristics and the products and service must achieve a pre-set standard in order to obtain a quality rating. Quality implies different meaning to different people. Its concepts may be easy to grasp but formulating a universal definition is difficult (Dale et al., 2006). Thus, there is no single universally agreed definition of quality. Some people view quality as conformance standards; others view it as meeting customers' requirements (Diana Green et al..,1993).

Recently, the most widely used definition of quality is that of ISO 9001 (2000). It says that a quality is a characteristic that a product or service must have. For instance, products must be reliable, useable, and repairable. These are some of the characteristics that a good quality product must have. Similarly, service should be efficient, and effective. These are some of the characteristics that a good quality service must have. In short, a quality is a desirable characteristic. However, not all qualities are equal. Some are more important than others. The most important qualities are the ones feature that customers want. These are the qualities that products and services must have. So, providing quality products and services is all about meeting customer requirements. It is all about meeting the needs and expectations of customers. So, a quality product or service is one that meets the needs and expectations of customers (Mekonnen et al.., 2012).

According to Phadke (1989) in his book of "Quality Engineering Using Robust Design"; defines quality engineering as product life cycle divided in to two main parts: 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 (UMC) and while all the costs incurred after the product sale to the customer is added together as 'quality loss'. Quality engineering(QE) is concerned with reducing both of this cost, and that is an interdisciplinary science involving engineering design, manufacturing operation and economics.

Quality engineering as the set 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 (Montgomery et al.., 2002).

QE 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 evaluating the good and bad points of view technologies in the upstream process stages of commercialization of products (Takeshita et al.., 2006).

2.3. Taguchi Method

Taguchi method was invented by Dr. Taguchi and Konishi (Taguchi and Konishi, 1987). Traditional method of experimental design is very complicated and not easy to use. The number of process parameters increases when large numbers of experiments are carried out. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Due to simplification of experimental plan and feasibility of study of interaction between different parameters, the Taguchi method is well known technique that provides a systematic and efficient methodology for process optimization. It is widely used for process optimization and product design in worldwide (Wang. et al.., 1989). In Taguchi method, lesser number of experiments is required. As a consequence, time as well as cost is reduced considerably. Taguchi proposes experimental plan in terms of orthogonal array that gives different combinations of parameters and their levels for each experiment. According to the Taguchi technique, entire parameter space is studied with minimum number of experiments is necessary (Phadke, 1989 and Roy, 1990). The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. 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 (Fraley, 2012). Taguchi realized that the best opportunity to eliminate variation of the final product quality is during the design of a product and its manufacturing process. Consequently, he developed a strategy for quality engineering that can be used in both contexts (https://en.wikipedia.org/wiki/ Taguchi methods). The process has three stages (source: https:// en.wikipedia.org/wiki/ Taguchi_ methods): -

A. System design: This stage involves the application of engineering knowledge and analysis to develop a prototype design that will meet customer needs. In the product design stage, system design refers to the final product configuration and features, including starting materials, components and subassemblies. Actually, product and process design stages overlap, because product determines the manufacturing process to a great degree. Also, the quality of the product is impacted significantly by decisions made during the product design (Mekonnen et al.., 2012).

B. Parameter design: Once the concept is established, the nominal values of the various dimensions and design parameters need to be set, the detail design phase of conventional engineering. Taguchi's radical insight was that the exact choice of values required is under-specified by the performance requirements of the system. In many circumstances, this allows the parameters to be chosen so as to minimize the effects on performance arising from variation in manufacture, environment and cumulative damage (https://en.wikipedia.org/wiki/ Taguchi methods, May/03/2019). As per G. Taguchi, a robust design is one in which the parameter values have to be selected so that the product or process performs consistently, even in the face of influencing factors that are difficult to control (Mekonnen et al.., 2012).

C. Tolerance design: In tolerance design the objective is to specify appropriate tolerances about the nominal values established in parameter design. A reality that must be addressed in manufacturing is the nominal value of the product or process parameter that cannot be achieved without some inherent variation. A tolerance is the allowable variation that is permitted about the nominal value. The tolerance design phase attempts to achieve a balance between setting wide tolerances to manufacture and minimizing tolerances to optimize product performance. Tolerance design is strongly influenced by the Taguchi's loss function (Mekonnen et al.., 2012).

The objective of problem statement is to obtain maximum value or minimum value of desired response. Taguchi method chooses to calculate the signal-to-noise ratio for finding effective parameter for desire response value. To calculate the S/N ratio, experiments are conducted in a systematic manner. Taguchi's idea is to recognize controllable and noise factors and to treat them separately as a design parameter matrix and a noise factor matrix, respectively. Experiments are organized according to orthogonal arrays (OAs). Noise factors are changed in a balanced fashion during experiments. The characteristics of S/N ratio can be divided into three categories smaller is better, Higher is better and nominal is best when the characteristic is continuous (Patel Rajendra et al., 2016).

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. 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. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less values can be tested or the values tested can be closer together (Fraley, 2012).

According to Taguchi when a poor-quality product is shipped, there is a loss imparted to a society. The effect of a loss is found to be a value in his loss function model. According to his model, relates the quality loss in dollars to the deviation away from the target value of the measured response. The resulting graphs of loss function vs. quality characteristics is parabola, with zero loss when the quality characteristics is equal to the target value. The focus of Taguchi approach was to strive towards defect free product with zero loss. From the previous manufacturing adopted practice of so-called "goalpost mentality" approach in which the most important goal that the factory to stay within customer specification limit (the lower and the upper specification limit is analogous to the two uprights of the goalpost). The goalpost approach doesn't encourage manufacturers to produce products on target because products close to the upper and lower specification limits are equal in status to the desired target value. In the other way, Taguchi approach emphasize manufacturers by encouraging them to produce goods with least possible variation from the target value, with the goal of being on target 100% of the time -which ultimately leads to delighted, satisfied customers (Sarin, 1997).

In the competitive market, the company that holds customer confidence with on-time delivery of defect free, reliable products and services is the one that will succeed. Quality is then a gateway to success in the global free-for-all for customer satisfaction and loyalty. Quality in products and product related processes is now, more than ever, a critical requirement for success in manufacturing (Tarcolea et al.., 2011).

Taguchi approach emphasizes building quality in to the design of a product and their process instead of screening out those defective products by inspection and/or by using quality control charts. To accomplish this, a product designer needs to select those parameter levels that define the product and reduce variability in the performance of those parameters. This is referred to as "on target performance" (Sarin, 1997).

2.4. Response Surface Methodology (RSM)

Different from the Taguchi Method, Response Surface Methodology basically combines statistical and experimental methods with data-fitting techniques. Based on the responses acquired in the experiments, Regression Analysis is utilized to identify the relationships between the responses and the variables to establish a mathematical model that satisfies the relationship between a group of test factors and objective functions. This model is then used to explore the optimal solution in the experimental area because of its practicability, favorable efficiency, and ease of implementation, RSM has been widely applied to various industries, such as chemical engineering, semiconductors, electronics manufacturing, machining, and metal cutting (Deng et al.., 2010).

Applied RSM to rapidly identify the optimal welding set for laser transmission welding (Bappa et al.., 2012). Utilized Response Surface Methodology to design their experiments and established a Regression Model to identify the optimal welding parameters and efficiently determine the effects of various factors on the quality (Paventhan et al.., 2011). Applied RSM to the modeling and analysis of thrust force in the drilling of GFRP Composites to identify the optimal setting for reducing the processing time and significantly enhancing the production rate. Another important issue for Response Surface Methodology is explaining the shape of the Response Surface based on the relationships between the responses and independent variables. When the independent variables change values in certain directions, the responses should also change (Rajamurugan et al.., 2012).

In other words, RSM tends to focus on the relationships between multiple factors (x_1, x_2, x_3..., x_k) and the response (quality) y. Consequently, the functional relationship between the responses and the independent variables should first be determined to produce a proper approximating function, and then the factor setting levels (x_i) needed to obtain the optimal response should be identified. The relationship between the response variables and the independent variables (factors) can be presented in the form of equation:

$$y = f\ (x_1, x_2, x_3..., x_k)$$

where *f* is a multivariate function, the items represent the factors (independent variables), and the relationship describes a curved surface $y = f\ (x_1, x_2, x_3..., x_k)$ that is known as a Response Surface. Equation are First-Order and Second-Order Response Surfaces, respectively:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + +\beta_k x_k + \varepsilon$$

A Response Surface is analyzed through the fitting surface, and the analysis of the fitting surface is regarded as an analysis of the real system when the fitting surface thoroughly describes the response function. Generally, Response Surface Methodology utilizes First-Order and Second-Order models; the Second-Order model would be used in cases in which the First-Order model is not suitable (Montgomery et al.., 2009).

When selecting fitting experiments requiring Second-Order RSM, Central Composite Design (CCD) experiments are normally performed. CCD was developed by Box and Wilson (Wilson, 1951) and improved by successive researchers. Because Second-Order fitting with CCD provides favorable predictions, the fitting model shows consistent and stable variance for the prediction of any input point. CCD combines the original fractional factorial or full factorial design with axial runs and center points to produce Central Composite Design experiments. Including axial runs in the design is done to introduce quadratic terms in the model, while the inclusion of center points tends to test the curvature of the response surface. In the beginning of the solving procedure, a starting point is selected as the experimental center for the CCD factorial fitting experiments. Regression Analysis is applied to the experimental results to find a suitable model. A Desirability Function is further applied to acquire the optimal processing parameter composition and operating window (Taipei et al.., 2009).

2.5. Process parameter

The most important process parameters are melting pressure and temperature. They are the best indicators of how well or how poorly an extruder function. Process problems, in most cases, first become obvious from melt pressure and/or temperature readings. Just think about what a doctor does when a patient comes into the office with a problem. Usually, the first check of the patient’s condition is made by taking blood pressure and body temperature. These are two good indicators of the functioning of the human body. In the same fashion, melt pressure and temperature are good indicators of how the extruder is functioning. Other important process parameters are: screw speed, motor load, barrel temperature, die temperatures, power draw of various heaters, cooling rates of various cooling unit, vacuum level in vented extrusion, and these parameters relate just to the extruder. However, there are many more process parameters for the entire extrusion line and this, of course, depends on its specific components. Important parameters for any extrusion line are: line speed, dimensions of extruded product, cooling rate, line tension. Many other factors can influence the extrusion process, such as ambient temperature, relative humidity, air currents around the extruder, and plant voltage variations, among others (Rauwendaal et al.., 2010).

The process of polyethylene extrusion and various types of extruders is necessary to have an exact control on process to producing high quality products with safe operation and optimum energy consumption. The granule size is depending on granulator motor speed. Results show at constant feed rate a decrease in granule size was found with Increase in motor speed. Relationships between HDPE feed rate and speed of granulator motor, main motor and gear pump were calculated (Alavi et al.., 2018).

2.6. Process Optimization

Process optimization is the discipline of adjusting a process to optimize some specified set of a parameters without violating some constraint. The most common goals are minimizing cost, maximizing throughout, and or efficiency, this is one of major tool in industrial decision making. When optimizing a process specification, while keeping all others within their constraints (Karna et al.., 2012).

2.7. Optimization of process parameters

Plastic pipe extrusion process is most widely pipe manufacturing process in the industry (Gadekar et al.., 2015). The complexity of extrusion process and the enormous amount of process parameters involved make difficult keep the process under control. One of the main goals of extrusion is the improvement of quality of extruded parts besides the reduction of cycle time and lower the production cost (Geo raju et al.., 2014). The common failure or defects which are normally occurring in plastic extrusion process are due to the three main causes part and mold design, material selection and processing. In many cases, the failures occur during the processing and these failures causes some defects that can be found in extruded parts such as: warpage, sink mark, residual stress, air trap, weld line, sink marks, low gloss, uneven surface gloss, spotted surface, rough surface, extruder surging, uneven wall thickness, diameter variation, centering problem (Narasimha et al.., 2013). In the extrusion process as discuss above the various defects are frequently occurs and hampers the productivity. If we need to enhance the production rate, it is very essential to optimize the process parameters and improve the productivity (S. Gadekar et al.., 2015).

2.8. Design of Experiment (DoE)

Design of Experiments (DOE) is a powerful statistical technique introduced by R. A. Fisher in England in the 1920's to study the effect of multiple variables simultaneously. In his early applications, Fisher wanted to find out how much rain, water, fertilizer, sunshine, etc. are needed to produce the best crop. Since that time, much development of the technique has taken place in the academic environment, but did help generate many applications in the production floor. Design of Experiment (DoE) is a powerful statistical technique for improving product/process designs and solving production problems. A standardized version of the DoE, as forwarded by Dr. Genichi Taguchi, allows one to easily learn and apply the technique product design optimization and production problem investigation. Since its introduction in the U.S.A. in early 1980's, the Taguchi approach of DoE has been the popular product and process improvement tool in the hands of the engineering and scientific professionals. DoE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of the factors. What levels should we take, how to combine them, and how many experiments should we run, are subjects of discussions in DoE. Factors are variables (also think of as ingredients or parameters) that have direct influence on the performance of the product or process under investigation. (source: From the complimentary copy of Nutek, Inc. summarize Common areas of application of the technique that include):

- ✓ Optimize Designs using analytical simulation studies.
- ✓ Select better alternative in Development and Testing.
- ✓ Optimize manufacturing Process Designs.
- ✓ Determine the best Assembly Method.
- ✓ Solve manufacturing and production Problems. (Source: http://www.nutek-us.com; DOE-I Basic Design of Experiments (The Taguchi Approach), Nutek, Inc)

Consider an example. An experimenter has identified three controllable factors for a plastic molding process. Each factor can be applied at two levels (Table below). The experimenter wants to determine the optimum combination of the levels of these factors and to know the contribution of each to product quality.

Table 1: Factors and levels for molding process (Source: http://www.nutek-us.com; DOE-I Basic Design of Experiments (The Taguchi Approach), Nutek, Inc)

Factors/ Levels	A. Injection Pressure	B. Mould Temperature	C. Set Time
Level 1	A_1= 250psi	B_1=150 F	C_1= 6 sec
Level 2	A_2=350psi	B_2= 200 F	C_2= 9 sec

There are 3 factors, each at 2 levels, thus an OA of L4 is suitable which is shown in Table below:

Table 2: An experiment layout using L4 OA (Source: http://www.nutek-us.com; DOE-I Basic Design of Experiments (The Taguchi Approach), Nutek, Inc)

Experiments	Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

This configuration is a convenient way to layout a design. Since an L4 has 3 columns, 3 factors can be assigned to these columns in any order. Having assigned the factors, their levels can also be indicated in the corresponding column. There are four independent experimental conditions in an L4. These conditions are described by the numbers in the rows. A full set of experiments for this process would require eight different experiments (full factorial design = 2^3) as opposed to the four which are needed for the Taguchi version of the experiment using L4 OA. As previously noted, the saving involved in using the Taguchi method becomes more significant as the number of levels or factor increases (Source: http://www.nutek-us.com; DOE-I Basic Design of Experiments (The Taguchi Approach), Nutek, Inc).

The following Standard Orthogonal Arrays are commonly used to design experiments:

2-Level Arrays: L4, L8, L12, L16, L32

3-Level Arrays: L9, L18, L27

4-Level Arrays: L16, L32

Some standard arrays also accommodate factors with mixed levels. In some situations, a standard OA is modified to suit a particular experiment requiring factors of mixed levels (https://www.openair.rgu.ac.uk/bitstream).

2.9. Taguchi Approach to Design of Experiment

Dr. Taguchi as given the task of developing a methodology for continuous quality improvement to meet 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 enhancing product quality of certain telecommunication products. He saw that little emphasis was given to the process of creative brainstorming to minimize the expenditure of resources. He noticed that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Therefore, he believed that quality concepts should be based upon, and developed around, the philosophy of prevention. Taguchi started to develop new methods to optimize the process of engineering experimentation. He believed that the best way to improve quality was to design and build it into the product. His main contribution lies not in the mathematical formulation of the design of experiments, but rather in the accompanying philosophy (Sanjiu Sarin, 1997). His concepts produced a unique and powerful quality improvement technique that differs from traditional practices. He developed manufacturing systems that were "robust" or insensitive to daily and seasonal variations of environment, machine wear and other external factors. His philosophy had far reaching consequences, yet it is founded on three very simple concepts. His techniques arise entirely out of these three ideas (C. Tarcolea et al., 2011). The concepts are:

1. Quality should be designed into the product and not inspected into it.
2. Quality is better achieved by minimizing 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 measured as a function of deviation from the standard and the losses should be measured system-wide (Kumar, 2015).

Taguchi viewed quality improvement as an ongoing effort. He continually strived to reduce the variation around the target value not to eliminate. 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 especially constructed tables known as “Orthogonal Arrays” (OA). The use of these tables makes the design of experiments very easy and consistent.

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 the Taguchi Method is applied in four steps.

1) Brainstorm the quality characteristics and design parameters important to the product/process.
2) Design and conduct the experiments.
3) Analyze the results to determine the optimum conditions.
4) Run a confirmatory test using the optimum conditions (Kumar, 2015).

Taguchi Method treats optimization problems in two categories (Rejikumar et al.., 2013),

I. Static problem (batch process optimization):

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "Static Problem". This is best explained using a P-Diagram which is shown below ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output. This is the primary aim of the Taguchi experiments to minimize variations in output even though noise is present in the process. The process is then said to have become Robust (Rejikumar et al.., 2013).

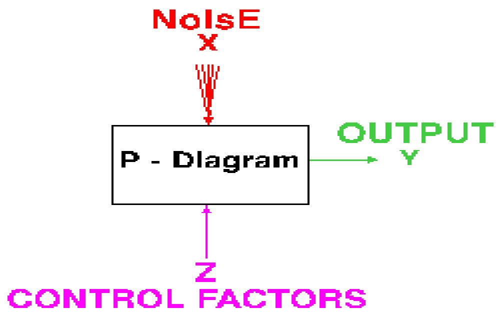


Figure 1: P-Diagram for static problems (Source: http://www.ce.ijtb.ac.in)

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

1. Smaller-the-better: n = -10 Log_{10} [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. Also, when an ideal value is finite and its maximum or minimum value is defined (like maximum purity is 100% or maximum Tc is 92K or minimum time for making a telephone connection is 1 sec) then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes (Rejikumar et al.., 2013),

n = -10 Log_{10} [mean of sum of squares of {measured - ideal}]

2. Larger-the-better: n = -10 log_{10} [mean of sum squares of reciprocal of measured data] (Rejikumar et al.., 2013).

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 (Rejikumar et al.., 2013).

3. Nominal-the-best: $n = 10 \, Log_{10} \frac{\text{square of mean}}{\text{variance}}$

This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable (Rejikumar et al.., 2013).

II. Dynamic problem (technology development):

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "dynamic problem". This is best explained by a P-Diagram which is shown below. Again, the primary aim of the Taguchi experiments to minimize variations in output even though noise is present in the process is achieved by getting improved linearity in the input/output relationship (Rejikumar et al.., 2013).

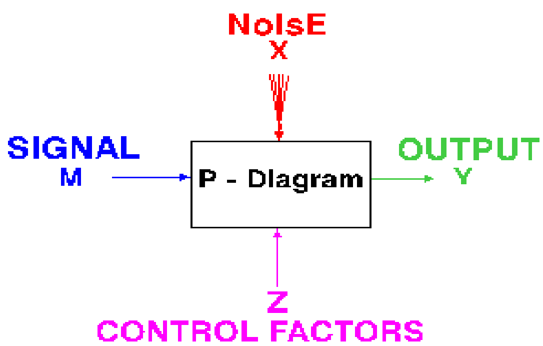


Figure 2: P-Diagram for dynamic problems (Source: http://www.ce.ijtb.ac.in)

There are 2 characteristics of common interest in "follow-the-leader" or "Transformations" type of applications (Sunil Kumar et al..,2015),

i. Slope of the I/O characteristics, and
ii. Linearity of the I/O characteristics (minimum deviation from the best-fit straight line)

The Signal-to-Noise ratio for these 2 characteristics have been defined as (Sunil Kumar et al..,2015);

1. Sensitivity {slope}: The slope of I/O characteristics should be at the specified value (usually 1). It is often treated as Larger-The-Better when the output is a desirable characteristic (as in the case of Sensors, where the slope indicates the sensitivity).

   $n = 10 \ Log_{10}$ [square of slope or beta of the I/O characteristics]

   On the other hand, when the output is an undesired characteristic, it can be treated as Smaller-the-Better.

   n = -10 Log10 [square of slope or beta of the I/O characteristics]

2. Linearity (larger-the-better): Most dynamic characteristics are required to have direct proportionality between the input and output. These applications are therefore called as "transformations". The straight-line relationship between I/O must be truly linear i.e. with as little deviations from the straight line as possible.

   $$n = 10 \text{ Log10 } \frac{\text{Square of slope or beta}}{\text{variance}}$$

   Note: Variance in this case is the mean of the sum of squares of deviations of measured data points from the best-fit straight line (linear regression) (Sunil Kumar et al..,2015).

2.10. Orthogonal Arrays (OA)

The technique of laying out the conditions (designs) of experiments involving multiple factors was first proposed by Sir R. A. Fisher, in the 1920s. The method 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.

Factors are the different variables which determine the functionality or performance of a product or system. Factors are (Yadav et al.., 2017):

- Design parameters that influence the performance.
- Input that can be controlled.
- Included in the study for the purpose of determining their influence upon the most desirable performance.

In a particular heat treatment experiment, for example, a factor can be “cooling rate” or “temperature” etc. Each factor may be set to different levels. Hence for another experiment the levels can be “slow cooling” and “fast cooling” or “low temperature” and “high temperature” etc. depending on the type of application (Yadav et al.., 2017).

For example, consider an experiment with three variables (factors A, B and C), each of which can be set at two different level values. For convenience, these values are denoted as levels, 1 and 2. According to Fisher, a full factorial experiment requires $2^3 = 8$ experiments, as shown in Table 1.

On the other hand, you can get as much useful data using four experiments as indicated in Table 2, which is an L4 OA according to Taguchi design of experiment (Tarng et al.., 2000).

Table 3: Full factorial table (https://www.openair.rgu.ac.uk/bitstream)

Experiment	A	B	C
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table 4: Orthogonal Array L4 (https://www.openair.rgu.ac.uk/bitstream)

Experiments	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

For example, in an experiment involving seven factors, each with two levels, the total number of combinations will be 2^7=128. To reduce the number of experiments to a practical level, only a small set of experiments from all possibilities is selected. The method of selecting a limited number of experiments which produces the most valuable information is known as a partial factorial experiment. Although this shortcut method is well known, there are no general guidelines for its application or the analysis of the results obtained by performing the experiments. Taguchi's approach comprises two important areas. First, Taguchi constructed a special set of tables, called Orthogonal Arrays (OA) to lay out his experiments in a tabulated format. And, by combining existing orthogonal Latin squares in a unique manner, Taguchi prepared a new set of standard OAs which could be used for a number of experimental situations. Second, He also devised a standard method for analysis of the results using analysis of variance (ANOVA). A single OA may accommodate several experimental situations. Commonly used OA is available for 2, 3 and 4 levels. Hence, due Taguchi's contribution by combining of the standard experimental design techniques and result analysis methods in his approach produces consistency and reproducibility (https://www.openair.rgu.ac.uk/bitstream).

2.11. Quality Loss Function

Loss is usually thought of as additional manufacturing costs incurred up to the point that a product is shipped. After that, it is society, the customer, who bears the cost for loss of quality. Initially, the manufacturer pays in warranty costs. After the warranty period expires, the customer may pay for repair on a product. But indirectly, the manufacturer will ultimately ''foot the bill'' as a result of 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 be damaged, 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. Taguchi defines quality as ''the loss imparted by the product to the society from the time the product is shipped.'' The objective of the quality loss function is quantitative evaluation of loss caused by functional variation of a product (Taguchi, 2005).

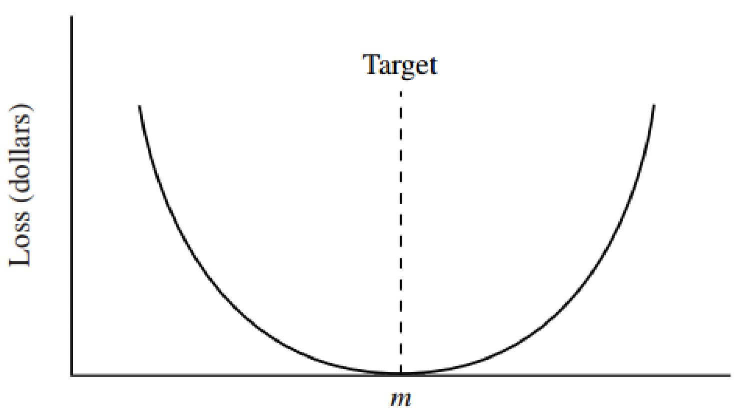


Figure 3: Quality loss function (Source: Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu, 2005).

Quality loss function is used for the nominal-the-best, smaller-the-better, larger-the better characteristics (Taguchi, 2005). The nominal-the-best characteristic is the type where there is a finite target point to achieve. There are typically upper and lower specification limits on both sides of the target. For example, the plating thickness of a component, the length of a part, and the output current of a resistor at a given input voltage are nominal-the-best characteristics (Taguchi, 2005).

As Quality loss function relates quality loss in dollars L(y) to the deviation away from a targeted value (m) of a measured response value (y).

i.e., |y-m|; Such that

$$L(y) = k\,(y - m)^2$$

If m is achieved…….. loss is zero.

When the deviation of product's functional characteristic is an amount A_O from the target value m, then the loss equals A_O.

$K = A_0 / \Delta^2_0$

K - Quality loss coefficient

A_O- Deviation of product functional quality characteristic from the target value.

L = k(MSD); where, MSD = $\frac{1}{n}\sum_{i=1}^{n}(y1 - m)2$

$$= \sigma^2 + (y\text{-}m)^2$$

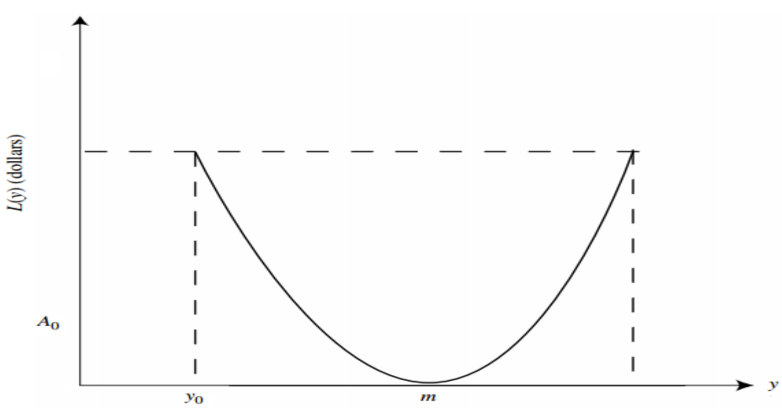


Figure 4: Nominal-the-best curve (Source: Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu, 2005).

A smaller-the-better output response is the type where it is desired to minimize the result, with the ideal target being zero. For example, the wear on a component, the amount of engine audible noise, the amount of air pollution, and the amount of heat loss are smaller-the-better output responses. Notice that all these examples represent things that we do not want, not the intended system functions. In the smaller-the-better characteristic, no negative data are included (Taguchi, 2005).

$L(y) = ky^2$; Where, $K = A_0/ y^2_0$

$L = k(MSD)$; Where, $MSD = \frac{[\Sigma(y)2]}{n}$

$L = k\ [(\sigma)^2 + (y)2]$

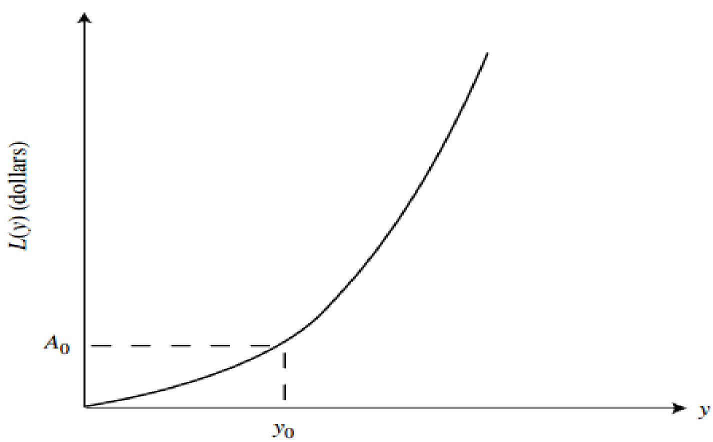


Figure 5: Smaller-the-best curve (Source: Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu, 2005).

The larger-the-better output response is the type where it is desired to maximize the result, the ideal target being infinity. For example, strength of material, and fuel efficiency are larger-the-better output responses. Percentage yield seems to be the larger the better, but it does not belong to the larger-the-better category in quality engineering, since the ideal value is 100%, not infinity. In the larger-the better characteristic, negative data are not included (Taguchi, 2005).

$L = k\ (\frac{1}{y2})$; Where $K= Ay^2$

$L = k(MSD)$; Where, $MSD = \frac{[\Sigma(^1/_{y2})]}{n}$

$$L = k\left[\frac{\Sigma(1/y^2)}{n}\right]$$

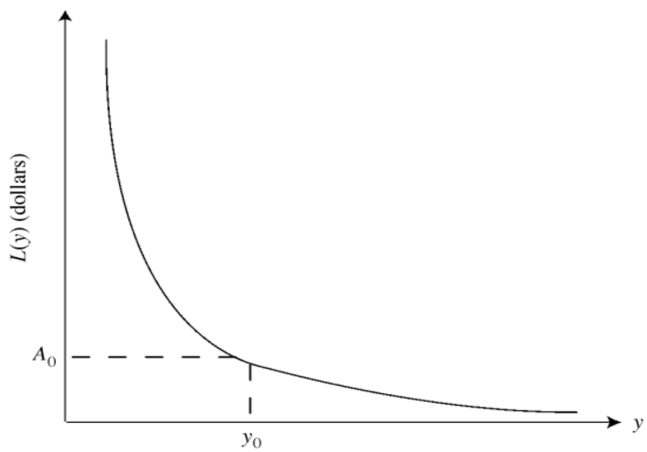


Figure 6: Larger-the-best curve (Source: Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu, 2005).

2.12. Signal to Noise Ratio (S/N)

The signal to noise ratio (S/N ratio) is a measurement scale that has been used in the communication industry for nearly 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 mixed with the audible noise in the space. Good measuring equipment catches the signal and is not affected by the influence of noise (Bikramjit et al.., 2015). 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 (mean) for the output characteristic and the term 'noise' represents the undesirable effect (signal disturbance, S.D) for the output characteristic which influence the outcome due to external factors namely noise factors (Kamaruddin et al.., 2017).

Taguchi Method is a multi-stage process, namely, (1) Systems design, (2) Parameter design, and (3) Tolerance design. The following sections delineate the three-stage process suggested by Dr. Taguchi to achieve desirable product quality (Kumar et al.., 2015).

Systems design: The focus of the systems design is on determining the suitable working levels of design factors. It includes designing and testing systems based on the researcher's judgment of selected materials, parts and technology. It also involves innovation and knowledge from applicable fields of sciences and technology (Kumar et al.., 2015).

Parameter design: Parameter design seeks to determine the factor levels that produce the best performance of the product/process under study. The optimal condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation of system performance. Noise Performance Statistics (NPS) are measures of process variability that are used to identify "Control factors" and the combined optimal levels which minimize that variability. Signal-to-Noise ratios (S/N ratios) are also used to measure the effect of "Noise" on the system. A robust (insensitive) system will have a high S/N ratio (Kumar et al.., 2015).

Noise factors: The noise factors can be classified on the basis of being either internal or external to the system, as follows; Inner noise: It is denoted by noise developed in the system or by the system itself. Example: vibration or disorientation. Outer noise: is the variation, which is, imposed by circumstances, which occur after the product leaves the producer, e.g., temperature, humidity, wear and tear effects (Kumar et al.., 2015).

Tolerance design: Tolerance design is a way to fine-tune the results of the parameter design by tightening the tolerance of factors with significant influence on the product. Such steps usually identify the need of innovation and identification of better materials, parts, machinery (Kumar et al.., 2015).

2.13. Robust design

Robust design is the design of the product that will be least affected by user conditions. Noise conditions must therefore be considered in the development. Since the development is conducted in a small-scale research laboratory, the conclusions obtained must be reproducible downstream, that is, in large-scale production and under a customer's conditions (Sachin Jadhav et al.., 2001). To check reproducibility, the concepts SN ratio and orthogonal array are used. There are two common paradigms among engineers: (1) Hit the target first at the design stage, then make it robust; and (2) to improve quality, higher-grade raw materials or component parts must be used.

Variations among parts manufactured to the same specifications are common even when all factors are properly controlled. Reduction of variation is our ultimate goal. It will favorably affect one aspect of quality by establishing consistency in performance. The most common variations are considered to be caused by factors that are not controllable or are too expensive to control. These are called noise factors. In robust design strategy, the approach is not to control the noise factors but to minimize their influence by adjusting the controllable factors that are included in the study (Genichi Taguch, 2005).

2.14. Steps for RSM application

Some stages in the application of RSM as an optimization technique are as follows (Chemometr, 1998):

(1) the selection of independent variables of major effects on the system through screening studies and the delimitation of the experimental region, according to the objective of the study and the experience of the researcher;

(2) the choice of the experimental design and carrying out the experiments according to the selected experimental matrix;

(3) the mathematic statistical treatment of the obtained experimental data through the fit of a polynomial function;

(4) the evaluation of the model's fitness;

(5) the verification of the necessity and possibility of performing a displacement in direction to the optimal region; and

(6) obtaining the optimum values for each studied variable (Chemometr, 1998).

2.15. Literature Survey

A lot of literatures written on optimizing manufacturing process parameters using Taguchi Method and RSM. From those, one of the usual method is optimization of extrusion process for aluminum 6061 alloy. They show that the extrusion temperature and load has significant on quality and cost of the extruded parts respectively. Hence, development of economical process conditions found as vital. Forward extrusion model developed to analyze the process responses temperature, extrusion load, extrusion ratio and blank velocity for deferent process designs. Some of the most significant design parameters ram velocity, coefficient of friction and die angle considered. Taguchi's L9 design employed to simulate the experiments for each set of chosen extrusion variables via Finite Element Analysis (FEA) solver. Analysis of variance (ANOVA) adopted to check the significance of the input variables on the output responses. Then, the optimal process parameters are determined using Taguchi's method (Krishna et al.., 2012).

Response surface methodology for their investigations. The surface roughness models were developed for turning leaded gun metal under dry conditions. The models were developed in terms of cutting speed, feed rate and depth of cut obtained experimentally. The effects of cutting variables (cutting speed, feed and depth of cut) on surface roughness had been investigated by Central Composite Design. The first order model was developed by an experimental design consisting of 12 experiments. Twelve experiments constitute Eight experiments (23 factorial designs) and Four experiments (an added center point repeated four times). This was done to predict the b 'parameters as used in the Equation. The blocks provide the confidence interval of the parameters and help in the analysis of variance. A second-order model was developed by adding six augment points to the factorial design (Kumar. H et al.., 2012).

Studied the defects in the plastic pipe, to optimize the plastic pipe manufacturing process. The optimization Taguchi techniques used in this paper. For the research work Shivraj HY-Tech Drip Irrigation pipe manufacturing, Company was selected. The experiment was analyzed using commercial Minitab16 software, interpretation has made, and optimized factor settings were chosen. After prediction of result the quality loss was calculated and it compared with before implementation of DOE. The research works has improved the production, quality and optimizes the process (Gadekar et al.., 2015).

Inconel 718, a nickel based super-alloy accounting for about 50% by weight of materials used in an aerospace engine, mainly in the gas turbine compartment. This is owing to their outstanding strength and oxidation resistance at elevated temperatures in excess of 5500 C. machining is a requisite operation in the aircraft industries for the manufacture of the components especially for gas turbines. This paper is concerned with optimization of the surface roughness when turning

Inconel 718 with cermet inserts. Optimization of turning operation is very useful to reduce cost and time for machining. The approach was based on Response Surface Method (RSM). In their work, second-order quadratic models were developed for surface roughness, considering the cutting speed, feed rate and depth of cut as the cutting parameters, using central composite design (Dhanalaksmi. V et al.., 2016).

Presented a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process. The cause and effect diagram were implemented to identify the root causes of these defects. The extrusion process parameters such as vacuum pressure, temperature, take-off speed, screw speed of the extrusion process and raw material properties were identified as the major root causes of the defects from the cause-and-effect diagram. The quality loss for the current performance variation was calculated using Taguchi's principle of loss function and requirement for improvement was verified. In this paper design of experiment (DOE) was applied to optimize the process parameters for the extrusion of high-density polyethylene (HDPE) pipe Ø 50mm and plain pipe Ø25mm. Four independent process parameters (Rejikumar et al.., 2013).

Used the Taguchi method to optimize the process parameters and improve the quality of components that manufactured. The objective of this study was to illustrate the procedure adopted in using Taguchi method to an extrusion blown film machinery. The orthogonal array, signal-to-noise ratio employed to study the performance characteristics on tensile strength; a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimum level of the process parameters was the level with the greatest S/N ratio. In this analysis; four factors namely melting temperature, extrusion speed, extrusion pressure and winding speed were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments, the tensile strength was measured and Signal to Noise ratio was calculated. With the help of graph and table, optimum parameter values were obtained (Kumar et al.., 2015).

Study present a systematic approach to find the root causes for the occurrence of defects and wastage in plastic extrusion process in the pipe manufacturing industries. It is very essential to learn the process parameter and the defect in the plastic pipe manufacturing process to optimize it. For the optimization Taguchi technique is used in this paper. Taguchi Method is a statistical approach to optimize the process and improve the quality of components that are manufactured. The experiment was analyzed using Minitab 17 software, interpretation has made, and optimized factor settings were chosen. In this analysis three factors namely take-off speed, melting temperature, extruder speed, were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments, the diameters were measured and Signal to Noise ratio was calculated. With the help of graph and table, optimum parameter values were obtained (Dubey et al.., 2015).

Optimize extrusion process parameters for maximizing the PVC pipe wall thickness using Taguchi's method are investigated. The material of pipe manufacturing was PVC plastic. The experimental investigation was done in Jain Irrigation Systems Ltd., pipe manufacturing, company. The experiments are analyzed using commercial Minitab17 software, interpretation has made, and optimized factor settings were chosen. The present study concludes that the feed drum temperature: 1300, the die temperature: 1700, the extrusion pressure 100 MPa, and extrusion speed: 50 rpm gives the maximum optimize the thickness of the PVC pipe for minimizing the pipe defects (Pawar et.al..,2017).

Optimization of turning process by the effects of machining parameters by applying Taguchi methods to improve the quality of manufactured goods. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The bars used are of diameter 44mm and length 60mm. they select three machining parameters i.e. Spindle speed, Feed rate, and Depth of cut. Different experiments are done on single point cutting tool made of high speed steel on Lathe by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. Taguchi orthogonal array is designed with three levels of turning parameters with the help of Minitab 15 software i.e., L9. In the first run nine experiments are performed and material removal rate (MRR) is calculated. When experiments are repeated in second run again MRR is calculated. By using Taguchi method, they stress the importance of studying the response variation using the signal to noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. Different graphs and plots are made to show significance of parameters under their study using Minitab 15 software. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better". So in their project the turning of EN24 steel is done in order to optimize the turning process parameters for maximizing the material removal rate. And they get the optimum spindle speed is 347 RPM, the optimum feed rate is 0.458 mm/rev and optimum depth of cut is 0.458 mm/rev (Krishankant et al.., 2012).

High-density polyethylene (HDPE) pipes find versatile applicability for transportation of water, sewage and slurry from one place to another. Hence, these pipes undergo tremendous pressure by the fluid carried. The present work entails the optimization of the withstanding pressure of the HDPE pipes using Taguchi technique in the proposed optimization strategy, the design of experiments (DOE) are conducted wherein different control parameter combinations are analyzed by considering multiple setting levels of each control parameter. The concept of signal-to-noise ratio (S/N ratio) is applied and ultimately optimum values of process control parameters are obtained as: pushing zone temperature of 166°C, Dimmer speed at 08rpm, and Die head temperature to be 192°C. Confirmation experimental run is also conducted to verify the analysis and research result and values proved to be in synchronization with the main experimental findings and the withstanding pressure showed a significant improvement from 0.60 to 1.004Mpa (Sharma et.al.., 2017).

Investigate the effect of injection molding parameter on the flow behavior of polyethylene plastic products. They took different observations for Low Density Polyethylene (LDPE) material used as a raw material for producing plastic products. Their research showed that the cooling time was the most effective prominent factor for LDPE material and refilling pressure and injection pressure accordingly was found to be the least effective factor by using Taguchi method (Lal et al.., 2013).

The effect and optimization of eight control factors on material removal rate (MRR), surface roughness and kerf in Wire Electrical Discharge Machining (WEDM) process for tool steel D2. The experimentation is performed under different cutting conditions of wire feed velocity, dielectric pressure, pulse on-time, pulse off-time, open voltage, wire tension and servo voltage by varying the material thickness. Taguchi's L18 orthogonal array is employed for experimental design. Analysis of variance (ANOVA) and signal-to- noise (S/N) ratio are used as statistical analyses to identify the significant control factors and to achieve optimum levels respectively. Additionally, linear regression and additive models are developed for surface roughness, kerf and material removal rate (MRR). Results of the confirmatory experiments are found to be in good agreement with those predicted. It has been found that pulse on-time is the most significant factor affecting the surface roughness, kerf and material removal rate (Ikram et al.., 2013).

Optimize the manufacturing process of the bread product using Taguchi method. Their study focused on the quality problems occurred as the outcomes of the process (quality of the bread produced) related to controllable factors of products design identified (machine temperature and length duration time) for the improvement required. By implementing the technique of analysis of variance (ANOVA), the composition of the controlled parameters, such as machine temperatures and duration times, is therefore determined and constructed into Orthogonal Array (OA) of L_9 (3^3) related to what the setting parameters produces the optimal output. To improve the quality of the manufactured product, bread the setting of parameter recommended on bakery machine in the study is 10 minutes' length duration time with 200 c^0 (Sihombing et al.., 2012).

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. The paper gives all the process parameters involved in the extrusion process and it also gives need of an optimization of process parameters. This paper considered various process parameters such as are takeoff speed, screw speed, temperature, vacuum pressure, die temperature, pushing zone temperature, melting temperature, feed drum temperature, extrusion speed, screw temperature, blowing time, exhaust/cooling time. After that accordingly they have selected suitable orthogonal array and experiment conducted (Sadaphale et al.., 2018).

It took two groups of aluminum blank sand casting processes for comparison:

1. Single aluminum blank sand casting and
2. Double aluminum blank sand casting aluminum blank green sand (green) casting process

To optimize the process parameter using Taguchi's robust design approach. By changing different sittings of the casting process, they attempt to obtain optimal settings of parameters that affect the various quality characteristics of the product made from aluminum. To optimize the process seven control factors were selected which include grain size, clay content, moisture content, ramming, sprue size, riser size, and diameter to thickness (D/t) ratio of the blank. Each factor was considered at three levels. For their study three uncontrollable (or noise) factors such as metal flow rate, pouring temperature and humidity were identified. To determine the effect of this noise factors on the casting yield, surface defects, and casting density for each group of aluminum were measured.

And finally through performing design of experiment, they reach on a conclusion that shows single aluminum blank sand casting process had better insensitivity to noise/ disturbance factors and proves the result using practical test (Nekere et al.., 2012).

Final assembly department at a manufacturing company which supplies fluid dynamic bearing (FDB) spindle motors for hard disk drives (HDDs). The work pieces used were the sleeves of FDB motors made of ferritic stainless steel, grade AISI 12L14. A 2k factorial experiment was used to characterize the effects of machining factors, depth of cut, spindle speed and feed rate on the surface roughness of the sleeve. The results show that the surface roughness was minimized when the spindle speed and feed rate were set to the highest levels while the depth of cut was set to the lowest level. Even though the results from this research were process specific, the methodology deployed can be readily applied to different turning processes. As a result, practitioners have guidelines for achieving the highest possible performance potential. The purpose of this research is to quantify the effect of depth of cut, spindle speed and feed rate on surface roughness of the FDB sleeve in HDD. The factorial design was utilized to obtain the best cutting condition which leads to the minimization of the surface roughness. The half normal plot and ANOVA indicate that the feed rate (C) is the most significant factor followed by spindle speed (B) and feed rate (A). Moreover, it was interesting to note that there are interactions among these three factors with the highest order term, ABC. Regarding the model validation, the regression model developed proves accuracy and has the capability to predict the value of response within the limits of factors investigated. After the optimal cutting condition is implemented, the surface roughness was significantly reduced about 8 percent. In addition to the factorial design experiment, the RSM and Taguchi design were proved to be potential methodologies to develop an empirical model and optimize the surface roughness of the metal work pieces (Kandananond et al.., 2014).

Where in order to find out a mathematical relation of polynomial second degree type which describe, in finish turning of hardened 205 Cr115 steel, the roughness parameter Ra dependence on cutting edge wear, depth of cut, feed rate and cutting speed, a factorial design methodology was used. The experimental tests were done according to a composed, central, four-factor five-level factorial program. The established second degree polynomial relationship for the Ra calculus as a function of the cutting conditions and the flank wear approximate in a satisfactory way the studied phenomena. The main influence on the surface roughness was exerted by the feed rate and flank wear. The interactions of some parameters as feed rate and flank wear had a great influence on the roughness values of the machined surface (Stanimir. A et al.., 2017).

Ethiopia Plastic Share Company (EPSC) was used as a case to show the application of Taguchi's methods (design of experiment (DOE)) together with loss function. Specifically, the paper is designed to develop Taguchi's method of DOE to alleviate process design problems of some of EPSC products. The quality loss for the current performance variation was estimated using Taguchi's loss function and requirement for improvement was proven. For the improvement purpose DOE was applied to optimize the process parameters of the products. Temperature zones were considered as process parameters for the products. Orthogonal arrays used in this optimization process were L8, L16, and L27 for the products. The experiment was analyzed using commercial Minitab 15 software and interpretation was made and optimized factor settings were chosen. Using the factors being chosen the performance value was predicted; based on the predicted values of the performances of the products loss function is calculated and compared with the quality loss before implementation of DOE. From this it was understood that, using Taguchi's method of DOE improves the quality loss because of performance deviation (scrap inclusive) by about 89.95% for the selected products of the company (Mekonnen, 2012).

Studied and find the root causes for nonconformity occurrences in plastic extrusion process. Data has been taken on the main causes for products defect and studied the relative contribution of plastic (HDPE Ø 50mm, Plain pipe Ø25mm), conduit (F/C Ø16mm) and poly products (F/B 8cm/220μm). Four independent process parameters were investigated, namely vacuum pressure, take-off speed, screw speed and temperature were considered for DOE. The defects identified are such as surface roughness and scratches, bulging, sink marks, uneven wall thickness, uneven film Width, dimensional variation, centering problem, tears and marks. On this particular case study, by using the principle of Taguchi's loss function, loss function was calculated and compared with the quality loss before applying of DOE. From this it was understood that, using Taguchi's method of design of experiment the quality loss because performance deviation improves by about 85.31% for the selected products (Woldearegay et.al.., 2013).

2.16. Literature gaps

To get enough information and best understanding about the subject matter and the field of study many literatures are reviewed from different sources, among these journal, articles, reports, and thesis are the main one. Summary of literatures are shown below table:

Table 5: summary of review papers

Journal No.	Author's Name	Journal year	Quality problem product	Optimizing process parameter	Design of experiment (DoE)
1	Thella Babu Rao and A.Gopala Krishna	2012	Aluminum 6061 alloy	Ram velocity, coefficient of friction and die angle considered	Taguchi method, orthogonal array L9, Element Analysis (FEA) and Analysis of variance (ANOVA)
2	Sandip S. Gadekar et al	2015	Shivraj HY-Tech Drip Irrigation pipe	Factor settings (production and quality)	Taguchi method, Minitab16 software
3	Narasimha and Rejikumar et al	2013	High-density polyethylene (HDPE) pipe Ø 50mm and plain pipe Ø25mm	vacuum pressure, temperature, take-off speed, screw speed	Taguchi method, Cause and effect diagram, Taguchi's principle of loss function
4	Dharmendra Kumar and Sunil Kumar et al	2015	Blown film machinery	Tensile strength, melting temperature, extrusion speed, extrusion pressure and winding speed	Taguchi method. Signal to Noise ratio and orthogonal array
5	Mukesh kumar verma and Mukesh dubey et al	2015	Plastic pipe manufacturing	Take-off speed, melting temperature, extruder speed	Taguchi method, Minitab 17 software, orthogonal array and Signal to Noise ratio
6	Krupal Pawar et.al	2017	PVC pipe	Factor settings (feed drum temperature: 1300, the die temperature: 1700, the extrusion pressure 100 Mpa, and extrusion speed: 50 rpm)	Taguchi method, Minitab17 software

7	Krishankant et al	2012	EN24 steel	Spindle speed, Feed rate, and Depth of cut	Taguchi method, Minitab 15 software, orthogonal array L9 and Signal to Noise ratio
8	G.V.S.S.Sharm a et.al	2017	HDPE pipes	Pushing zone temperature, Dimmer speed and Die head temperature	Taguchi method, Signal to Noise ratio
9	S. Kumar Lal et al	2013	Polyethylene plastic	Low Density Polyethylene (LDPE), refilling pressure and injection pressure	Taguchi method
10	Adeel Ikram et al	2013	Steel D2	Removal rate (MRR), surface roughness and kerf in Wire Electrical Discharge Machining (WEDM)	Taguchi method, L18 orthogonal array, Analysis of variance (ANOVA) and Signal to Noise ratio
11	Haeryip Sihombing et al	2012	Bread	setting parameters (outcomes of the process, machine temperature and length duration time)	Taguchi method, L9(33) orthogonal array, Analysis of variance (ANOVA)
12	Pankaj M. Patil and Prof. D.B. Sadaphale et al	2018	HDPE Pipes	takeoff speed, screw speed, temperature, vacuum pressure, die temperature, pushing zone temperature, melting temperature, feed drum temperature, extrusion speed, screw temperature, blowing time, exhaust/cooling time	Taguchi method
13	Kandananond et al	2014	stainless steel, grade AISI 12L14	machining factors, depth of cut, spindle speed and feed rate on the surface roughness	RSM and Taguchi design were proved to be potential methodologies to develop an empirical model and optimize the surface roughness

14	Stanimir. A et al	2017	205 Cr115 steel	depth of cut, feed rate and cutting speed	RSM for surface roughness was exerted by the feed rate and flank wear
15	Mekonnen L. Nekere et al	2012	Aluminum blank sand casting	Settings parameters (grain size, clay content, moisture content, ramming, sprue size, riser size, and diameter to thickness (D/t) ratio of the blank)	Taguchi method, Taguchi's robust design and Signal to Noise ratio
16	Asrat Mekonnen	2012	Some of Ethiopia Plastic Share Company (EPSC) products	Temperature zones	Taguchi method, loss function, Orthogonal array L8, L16, L27 and Minitab 15 software
17	Sisay G. Woldearegay et.al	2013	HDPE Ø 50mm, Plain pipe ∅25mm, conduit F/C ∅16mm and poly products F/B 8cm/220µm	vacuum pressure, take-off speed, screw speed and temperature	Taguchi method, Taguchi loss function

Reviewed literature gaps summarized as below:

- Most of the reviewed literatures not considered occurrences in plastic extrusion process.
- Most of the reviewed literatures not considered Integrating the Taguchi and Response Surface Methodology in plastic extrusion process.

In this research, even though so many researches are conducted on the sub sector they didn't provide the root causes for nonconformity occurrences in plastic extrusion process. Data has been taken on the main causes for products defect and studied the relative contribution of plastic specially PVC Pipes. So, this paper optimizes the parameter for defects of PVC pipes by Integrating the Taguchi and Response Surface Methodology.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. The research design

The main purpose of the research is, in general, to improve the quality of PVC pipe yield and other uncontrollable defect for Extrusion process. Thus, the research is designed in terms of the research's strategy, type, main focus, potential hypotheses, environment under which the research is conducted, and methods or instruments used for data collection and analysis.

3.2. Type of Data Collection

Data collection is a process of gathering information's that are relevant to accomplish the research or the study. There are two data collection methods such as primary and secondary data collection and the researchers 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, interview, referring machine operator, technical data 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 been used.

i. Observation: is one way of primary data sources. It's a method of watching and listening to an interaction or phenomenon where it takes place. In order to understand the facts about the case industry what they do in the extrusion process i.e. 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.

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 (Previous Research): As secondary data to gain understanding about the parameter optimization of manufacturing process by different researchers and create strong foundation, the research work begun with an extensive literature study. Considering the research title, the literature review method took 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. Case Industry Documents: The researchers have gone through collecting the industry record data. To analysis the existing industry situation and investigate in detail, industry recorded data is necessary. Accordingly, industry reports, during extrusion parameters on the thickness and width variation is behavior of the pipe.

3.3. Data Analysis tools and methods

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 has to be selected as necessary in which to get a meaningful result. Accordingly, the researcher selected tools and methods in this study to analyze the effect of extrusion parameters on the thickness and width variation behavior of the pipe the data collected using Taguchi and RSM approach is used together with Minitab statistical software for selecting appropriate Orthogonal Array (OA), building cause and effect diagram, Taguchi and RSM Design of experiments (DoE), Main- Effect plots, ANOVA (analysis of variance), and Signal to noise ratio(S/N) and contour surface plot would also be employed.

The research will be conducted on the following methodology sequentially:

1'st - Classify the main function of Extrusion process.

2'nd - Know the objective function to be optimized for the process parameter.

3'rd - Build cause and effect diagram schematically the effect of causes on the defect output of the pipe.

4'th - Select Ethiopia plastic industry production pipe line parameter.

5'th - Taguchi Orthogonal array selection.

6'th - Taguchi and RSM design of experiment from Ethiopia plastic industry production PVC pipe factories line.

7’th - From Taguchi and RSM design of experiment data inserting in ANOVA (Analysis of variance).

8’th - ANOVA (Analysis of variance) shows a surface plot and contour plot, and run experiment.

9’th - Using ANOVA, the significant factors impacting the quality characteristics of PVC Pipes are obtained from recorded data for predictions from the Taguchi and RSM Method.

For applying the above steps in the present study is to improve the quality in terms of PVC pipe yield and other uncontrollable defect for Extrusion process.

CHAPTER FOUR

INTRODUCTION TO ETHIOPIA PLASTIC INDUSTRY

4.1. Introduction

Extrusion process, which produces the largest volume of plastics, raw materials in the form of thermoplastic pellets, granules, or powder are poured into a hopper and fed into the barrel of a screw extruder. The barrel is made with an internal helical screw that blends the pellets with appropriate resins, or additives and conveys them down the barrel towards the die. Screws have three distinct sections: Feed section: Conveys the material from the hopper down into the central region of the barrel. Melt section (also called compression or transition section): the section where melting of plastic pellets begins by the heat generated due to the viscous shearing of the pellet and the external heaters. Metering or pumping section: Where additional shearing (at a high rate) and melting occur, with pressure building up at the die (Kalpakjian et al.., 2009).

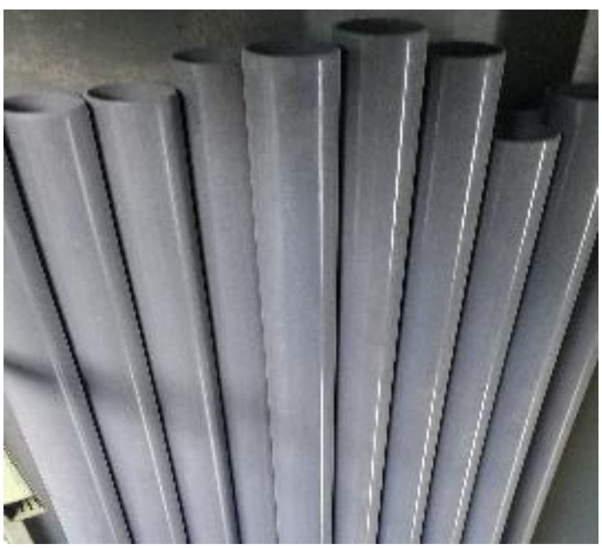


Figure 7: Some extrusion molding products (source: EPI)

4.2. The case Industry, Ethiopia Plastic Industry

4.2.1. History of EPI

Ethiopia Plastic Industry (EPI) is a government owned public enterprise which was established by five Italian private entrepreneurs in 1960 EC. Five years later, due to the change in the political situation of the country, the government has taken 55% of the share of the company. Since then the company passed through different organization setups and structures under different supervisory government bodies. In 1978 E.C the Government became full owner of the company. In 2000 E.C Ethiopia Plastic Industry was established as a new share company and works under the control of Privatization and State Owned Enterprises Authority with a capital of 29,670,000.00 Ethiopian Birr. And finally, since 2003 E.C the Company operates under the former name Metals and Engineering Corporation become National Metal Engineering Corporation.

Presently the industry is upgrading and expansion works are in progress to assure better customer satisfaction and business development. The management team and employees believe in the importance of system improvement efforts like Quality Management System, Business process re-engineering(BPR) and Performance Measurement for the company development.

The main objective of EPI is production and sales of plastic related construction materials, packaging, and household materials. Its Head office is located near its production center is in Bole Sub-city Kebele 12/13, Addis Ababa, Ethiopia. There are currently 394 workers, including highly professional plastic technologists, engineers, processors and management and marketing Professionals (Source: EPI Quality department).

4.2.2. Products of EPI

- Polyethylene products
- Electrical wires and cable
- PVC products
- House Hold utensils
- Boots
- Flexible Conduits
- Switch box
- Polyether high-density

4.3. Raw material of PVC pipe

There are so many materials to create PVC pipe to mix a compound ratio like: Poly Vinyl Chloride resin, Stabilizer, Calcium carbonate (filler), Titanium dioxide, Carbon black, Stearic acid (lubricant) and Pigment.

4.3.1. Poly Vinyl Chloride Resin

PVC is an acronym for polyvinyl chloride. A resin is a material often used in the production of plastics and rubbers. PVC resin is a white powder commonly used to produce thermoplastics. Other members of the vinyl family can be used for similar applications, but PVC tends to be the most popular member of that family. It is believed to be superior to other options because it can be produced in numerous forms and used to create a wide array of items for many industries. Products made with PVC resin include blood bags, windows, and pipes. Production of PVC resin generally relies heavily on the use of chlorine and crude oil. There are four manufacturing processes commonly used in its production. They are the suspension method, the mass method, the emulsion/dispersion method, and the solution method. PVC resin alone is a raw material. It can be made into products with a wide range of properties from soft and flexible to light and rigid. The outcome is often determined by additives. Other ingredients must typically be added to convert this resin into a finished product. These can include heat stabilizers, lubricants, and fillers. One of the most common types of additives to be blended with PVC is plasticizers, such as Butyl Glycolate, Epoxy Resins, and Dialkyl Azelates (Source: http://www.wisegeek.com).

PVC pipe compound consists mainly of bulk PVC thermoplastic resin. The resin is a basic polymer, which is produced as a fine, white powder. Between 70 and 90 percent of PVC pipe by weight is composed of PVC resin. The remaining percentage of the pipe compound is comprised of additives that chemically react and combine with PVC resin to optimize processing and generate desirable physical characteristics in the finished product. The bulk polymer associated with PVC pipe compound is known as PVC homo-polymer and is produced from vinyl chloride monomer (VCM), a colorless and odorless gas. VCM is produced from common salt and ethylene. Polyvinyl Chloride (PVC) Pipe compound is produced by adding a variety of ingredients to PVC resin. By adjusting the type and quantity of these ingredients, all of the different water, sewer, irrigation, plumbing, and electrical products can be produced (Source: http://www.ktron.com/industries).

4.3.2. Stabilizer

When PVC is heated to 170~180°C, chlorine and hydrogen in the molecules are eliminated and release of hydrogen chloride becomes evident. Once such decomposition starts, unstable structures are formed in the molecule, which further accelerate HCl elimination and decomposition. As PVC is heated to soften during the extrusion or molding process, prevention of hydrogen chloride elimination due to heat and subsequent decomposition is required. The stabilizer prevents such initial elimination of hydrogen chloride from PVC. Therefore, use of stabilizers (metal compounds) is essential to prevent the chain reaction of decomposition. They can also impart to the PVC enhanced resistance to daylight, weathering and heat ageing and have an important influence on the physical properties and the cost of a formulation (Source: http://www.pvc.org/en/p/stabilisers).

The stabilizer protects PVC pipe compound and compound polymer chains from thermally degrading during the extrusion process. Stabilizers also exhibit some external lubrication characteristics that promote a certain amount of slippage of the compound melt through the extruder and die metal surfaces (http://www.pweagleinc.com/literature/tb/tb-s3.pdf).

4.3.3. Filler (Calcium carbonate – $ca(co)_3$)

Calcium carbonate ($ca(co)_3$) is one of the most popular mineral fillers used in the plastics industry. It is widely available around the world, easy to grind or reduce to a specific particle size, compatible with a wide range of polymer resins and economical. As an additive in plastic compounds, $ca(co)_3$ helps decrease surface energy and provides opacity and surface gloss, which improves surface finish. In addition, when the particle size is carefully controlled, $ca(co)_3$ helps increase both impact strength and flexural modulus (stiffness). Calcium carbonate is also considered a non-reactive ingredient, although some grades improve the melt flow. It comes in different grades, which can be combined with other ingredients to optimize finished product characteristics. Some calcium carbonates can cost more than PVC resin on a cost-per-unit volume basis. Choice of grade and use level is made to design specific high modulus, high tensile and high impact compounds (Source: http://www.ktron.com/industries).

4.3.4. Titanium Di Oxide ($Ti(O)_2$)

When unprotected PVC is exposed to sunlight, the ultraviolet radiation causes a series of complex reactions to occur which results in the degradation of the polymer. The degradation is accompanied by the formation of highly colored compounds. In fact, the discoloration of unprotected PVC has been used as a quantitative measure of UV radiation. The most common protective agent used in PVC pipes is titanium dioxide which absorbs most of the incident UV and visible radiation, thereby protecting the PVC molecules. For pipes and fittings in Australia, a coated form of $Ti(O)_2$ is used as this optimizes the protection, minimizes chalking and achieves good dispersion. The protective agent for PVC can be incorporated into the material itself. In the case of PVC pipes protection is achieved by adding at least 1.5 parts of the white pigment titanium dioxide, $Ti(O)_2$ per 100 parts of PVC resin (Source: http://www.pipa.com.au).

4.3.5. Carbon Black

Carbon black is an important and versatile ingredient for plastics compounders. It can contribute color, opacity, electrical conductivity and protection from ultra-violet degradation. The choice of carbon black is dependent on the final product requirements. Particle size and structure (degree of permanent particle aggregation) are the two most important characteristics of a carbon black in determining its performance. The different end user requirements of carbon black in plastics applications, the larger volume of carbon black is used in rubber applications, the critical requirements of these products are much different than the needs in plastics applications such as molding and fiber. It is recommended to evaluate the end use product requirements and manufacturing process when choosing a carbon black. Carbon black suppliers have developed specialty grades of carbon black to meet the needs of the plastics market. Carbon black is typically used in thermoplastics to impart at least one the properties: Color, UV Protection, and Conductivity. Since most thermoplastics are rigid at the end use temperature, the reinforcing effects of the carbon black have to be balanced with desired end use mechanical properties. In addition, the carbon black contaminants such as grit, ash and sulfur have a more crucial impact on the thermoplastic's mechanical properties and the processing of these materials. For plastics applications involving color and UV protection, carbon black is typically dispersed into a plastic master batch at a high dosage, 25 to 40% by weight. High shear equipment such as an internal mixer, continuous mixer or twin screw extruder is commonly used to break the carbon black down to the aggregate size. These concentrates are then diluted down in a compounding stage or at the converter stage to the end use dosage which is typically 0.5% to 3.0% for mass tone and UV protective applications (Source: http://www.ramcharan.org).

4.3.6. Stearic acid (lubricant)

Capillary rheometer measurements show that stearic acid can be characterized as a normal lubricant. If the content of stearic acid is increased in rigid PVC formulations, the melt viscosity will decrease. This leads to a corresponding increase of shear rate and volumetric flow rate. The influence of calcium stearate is opposite to the normal characteristic of a lubricant. Increasing amounts of calcium stearate lead to an increased melt viscosity and a decreased shear rate and volumetric flow rate. In the extrusion of rigid PVC, the apparent “lubricating” effect of calcium stearate is probably due to the increased friction with resulting heat evolution and higher mass temperature, leading to a decreased viscosity of the plastic melt. This is in agreement with the results of the extrusion experiments. Both mass temperature and power consumption decrease when stearic acid is added and increase when calcium stearate is added to the formulation (Fredriksen et al.., 2003).

4.3.7. Pigment

Skillful selection and evaluation of pigments for use in PVC compositions demands careful recognition and interpretation of side effects. These include possible interfering effects due to additives such as lubricants, heat and light stabilizers, U.V. screeners, etc. In addition, it has been observed that pigments can chemically react with polymers (PVC included) initiating degradative processes or catalyzing oxidation of PVC or its additives. Other changes affecting pigment performance in PVC include its solvation by the polymer at high processing temperatures and particle size reduction by abrasion during high intensive premixing. Also, in applications where amount of heat build-up of dark vinyl’s due to light absorption is important, inorganic pigments are shown to be superior to their organic counterparts. However, care in controlling processing temperatures to preclude polymer-pigment reactions needs to be exercised when inorganic pigments such as iron oxide, cadmium yellow pigments, and any other mixed metal oxides are evaluated, for use in PVC compounds. Generally, what kind of industries whether it is manufacturing or service rendering in current market-driven, competitive environment, companies will survive if and only if they deliver product to client which is functionally desirable, adding features to aesthetically pleasing, giving versatility in service, easy for operating etc., by considering the purchasing capacity of a society in a way to provide items with least cost possible.

4.4. Process flow of PVC pipe in EPI

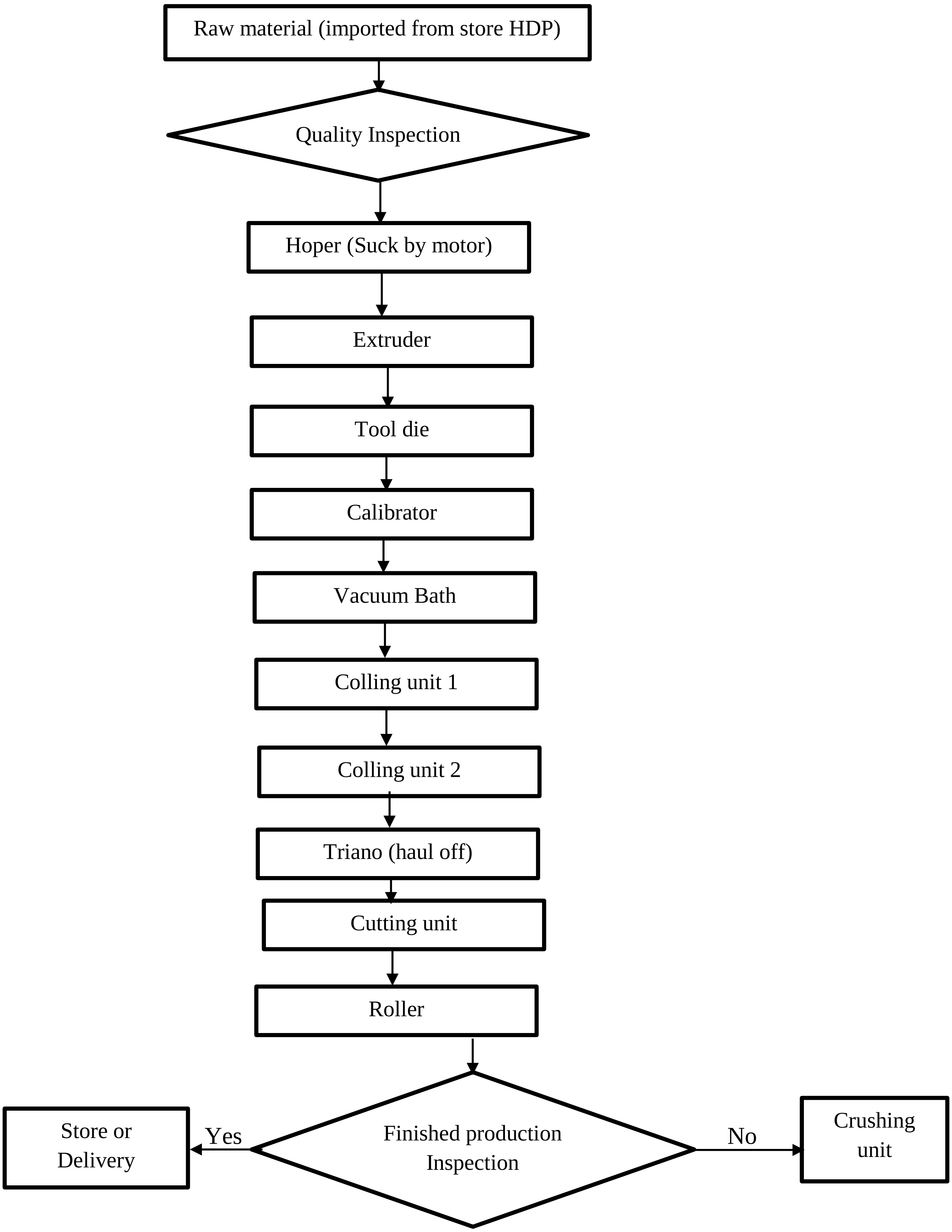


Figure 8: Process flow of PVC pipe in EPI (Source: EPI Quality department)

EPI produces products stating from raw material to different sized (HDPE, PVC) pipes. Although the machines assigned to perform different operations for production of different products, they commonly share same material flow.

Figure 9: Extrusion machine in EPI (Source: EPI)

4.5. Quality Policy of EPI

The management and workers of Ethiopia Plastic Industry is committed to:

⇒ Implement maintain and improve quality management system as per ISO 9001:2008 requirement.

⇒ Comply with the policies of the government and the metal and engineering corporation the plan in outstanding manner.

⇒ Assure and maintain the quality reputation of our polymers products; PVC pipes, HDPE pipes, PPR pipes, UPVC fittings, PPR fittings, HDPE fittings, plastic chairs, PVC profile and ceiling, polyethylene products, CSS cabinet and composite products, filament winding GRP pipe, rubber recycling products, military plastic products parts and other items.

⇒ Consistently meet and exceed the continuous needs and Expectation the customers and stake holders.

⇒ Define quality objectives and relevant process of industry revises at least once per year.

⇒ Develop a continuous capacity build programs and create persistent and hardworking industrious employees to meet the goal and objective of the metal and engineering corporation and the industry.

⇒ Promote the creativity, initiative, and team work sprits among employees in a problem solving and the continuous improvement of the quality management of the industry by providing all necessary resources.

⇒ Consider and respect contribution of suppliers and other related parties in the industry development.

⇒ Conduct internal audit and management review at planed interval and initiate corrective action.

⇒ Protect our worker's occupational safety and health through preventive and awareness creation training.

⇒ Assure communication, implementation and revision of this policy throughout the industry.

EPI made a quality policy as not only to check the quality level of the product, but also responsible for taking into account of customer satisfaction by delivering good quality characteristic products through sitting suggestion box for accepting customer complaints, conducting focus group, and undertaking customer related meetings. To this end, the company has guided and monitored their production process through quality management system which encourages employees to exploit their capabilities to do job by slogans and paradigm located every place of office, and that also helps to create high level customer appeal to product.

Implementing a quality management system is important for all manufacturing firms and service organization. But having such a policy doesn't mean they can produce fully quality product. According to the observations in the industry floor space and interview made with operators, the industry has producing some goods with desired specification; some made with some drawbacks. The drawbacks are:

- Electrical power interruption problem is:
  - ℵ Stopping rotation of screw which allows staying of plenty of hot powder mixture under beneath of the barrel well.
  - ℵ When turn off and on the machine mixture to exit at the die opening due to dryness.

- Exit of the mixture from the die due to dryness.
- Loss in maintenance operation.

Then, this electrical power interruption problem takes an extra machine start-up time that was reaching up to maximum of 4 hr.'s or it might be below depending on early coming of electric power and degree of machine hotness.

Figure 10: Defect occurrence in Electrical Power Interruption

- The problems that occur due to defects occur in the operation are:
  - Variation in the thickness of pipe which is aroused due to loosen screw knob located on the die longitudinal surface.
  - Temperature set-point for heating Plasticized Poly Vinyl Chloride (PVC) powder due to malfunctioning of heater pads at die section they will not compressed.
  - Breaking down of gearbox.
  - Disordering of machine components.
  - Temperature set-up for heating Plasticized Poly Vinyl Chloride (PVC) powder due to malfunctioning of Heater pads at die section.
  - Variation in temperature profile at the heater around die section.

Then, defects occur in the operation problem variation in thickness and width of pipe. So EPI announced due this defects can extra loss of the company and about 23% of their total production can be for rework or recycle.

Figure 11: Defects occurrence at tool die

In plastic production, controlling the quality of the product and making conforming product is not a simple matter of inspecting and testing the product as it comes off the machine. Many variables and unknown factors such as post mold shrinkage, the process parameters during production, cooling time after production play an important role in controlling the ultimate quality of the product.

Good method for set the optimum extruder temperature profile:

Several options are available to select the correct temperature profile, ranging from recommendations by the raw material supplier to trial and error methods in a production environment. With products made previously, experience or documented standard operating procedures (SOPs) dictate the best processing conditions. Possible temperature profiles include:

- ✓ Progressive or increasing temperature, with the set points increasing continually from the feed throat to the die.
- ✓ An inverted or decreasing temperature profile, with the set points decreasing from the first heated barrel to the die.
- ✓ A straight temperature profile, where all barrels are set at exactly the same temperature set point.
- ✓ A humped profile, where the temperature is lowest in the first heated barrel, gradually increases toward the middle of the extruder, and then decreases progressively toward the die (Harold F. Giles et al.., 2017).

CHAPTER FIVE

DATA ANALYSIS AND PRESENTATION

5.1. Defects in extrusion process

Defect is any form of deviation of the product's characteristic from the specification set up by the manufacturing process. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing. When EPI recorded data indicated that the measured product quality defect arise due to the specifications made before production by Quality assurance and Inspection department is varied to actual measured value. But not all products are produced according to the requirement of customers and specifications set by department. In extrusion products, defects occur when to see EPI like centering problem(off-center), Thickness variation, width variation, coloring, shrinkage, material handling and the figure below shows some of the defects.

Figure 12: Observed quality defect Pin Hole

Figure 13: Observed quality defect poor material handling

Figure 14: Observed quality defect thickness variation and width variation

- Quality defect due to coloring occurs color of the pipe shall be black, for the purpose of identification of the pipes covered in standard, each pipe shall contain minimum three equi-spaced longitudinal stripes of width 3 mm (Min) in blue color. These stripes shall be co-extruded during pipe manufacturing and shall not be more than 0.2 mm in depth. The material of the stripes shall be of the same type of resin, as used in the base compound for the pipe. From this master-batch (quality check) ratio of the chemicals $ca(co)_{3,}$ $Ti(O)_2$ and carbon black amount must be equal.
- Centering problem(off-center) defect occur the tool die change from current thickness to new thickens can set-up properly, temperature is over high and cooling set-up time must at 220^0c.
- Thickness variation and width variation occurs set-up time of the screw time, motor type of the extrusion machine ,flow of material is not equal and length of the pipe may vary due to inadequate supply of weight of raw material required during production process, and it is not taken as a defect characteristic since it's compensated by some other pipe that would be produced with a little longer than the required length, from such a length variation happen, the pipe would to be isolated not being rejected.
- Finally, after the finished goods from the overloading and no warehouse to store for final product causes material handling and pin holes occurs.

5.2. Application of Statistical Quality Control Tools

Application of statistical quality control tools can be used for quality defect product of PVC pipe. The quality of a product can be evaluated using either an attribute of the product or a variable measure. A variable measure is a product characteristic that is measured on a continuous scale such as dimension length, weight, volume, or time. However, attribute data are product characteristics that do not have numerical value (e.g. conforming or non-conforming).

5.2.1. Pareto chart (Attribute data)

The Pareto diagram is a graphic depiction showing both the relative distribution as well as the absolute distribution of types of errors, problems or causes of errors. It is generally known that in most cases a few types of errors (problems or causes) account for 80-90% of the total number of errors in the products and it is therefore important to identify these few major types of errors. This is what the Pareto diagram is used for (Dahlgaard et al.., 2007). Using Pareto chart to identify the most frequently occurring defect PVC product data about the total frequency of defects was taken and analyzed.

Table 6: Types of defects and their frequency (Note: the data recorded period from 15/02/2019 up to 15/05/2019 G.C. daily product quality control report)

S/N	Type of quality defect	Cause of quality defect and frequency			Total Frequency	Percentage (%)
		Operational	Machine	Raw material		
1	Centering problem(off-center)	23	2	0	25	7.74
2	Width variation	78	20	0	98	30.35
3	Thickness variation	111	41	0	151	46.74
4	Shrinkage	36	8	0	44	13.63
5	Others (Length, Crack, Pin hole, Color variation and so on)	3	2	0	5	1.54
Total		251	73	0	323	100

By using quality control tools i.e., Pareto chart were also used to analyze the data and to prioritize the order of frequently happening defects as shown below: -

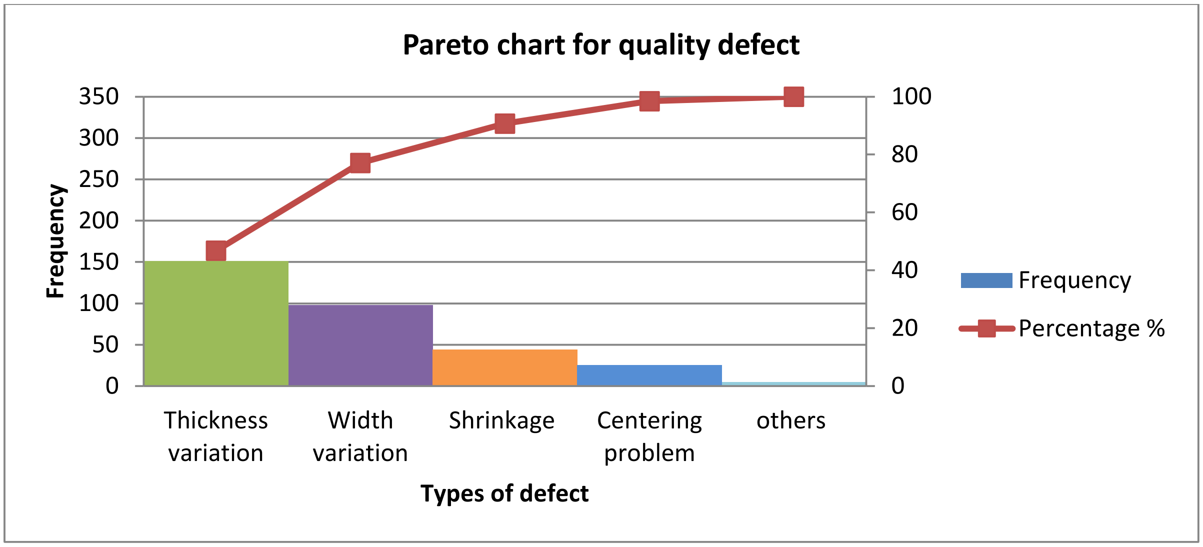


Figure 15: Pareto diagram

From the types of defects PVC pipe thickness variation and width variation defects are highly quality defect type. And Shrinkage, center problems(off-center) are the next highly quality defect type. After that others defects (Length, Crack, Pin hole, Color variation and so on) are type of defects on PVC pipe product type. Therefore, great emphasis was given to reduce those main frequently occurring defects for the production of the PVC products. EPI quality department measure the thickness and width from inner and outer diameter but not all length of PVC pipe. So, this can cause in the middle area of the PVC pipe have problem on thickness and width variation. Then the customer tries the product or use the product can't fit. Then return the product for reject or recycle. This can loss for rejection or recycle.

5.2.2. Fishbone diagram (Cause and Effect Diagram)

Returning to the underlying connection between quality tools, when the first cause and- effect diagram has been drawn, it is necessary to identify the most important causes, including the eventual testing of some of them. It is not always easy to identify the most important causes of a given quality problem. If it were, poor quality would be a rare occurrence and this is far from being the case. Most causes can be put down to men, materials, management, methods, machinery and milieu (the environment). Having been very careful in this process the cause and effect diagram may look like a fish where the causes resemble fish bones. The cause-and-effect diagram and the

Pareto diagram can and in many cases ought to be used simultaneously (Jens J. Dahlgaard et al.., 2007).

Fishbone diagram (Cause and Effect Diagram) for the main causes for thickness and width variation problem are identified and list down to environment, material, measurement, people, method, machine performance, equipment and management. Next see, the cause that have defect on PVC Pipe thickness and width variation problem.

1. Environment: the cause of environment is PVC is difficult to recycle because PVC product contain a unique mix of additives so, recycling PVC can't yield vinyl product from the original one. Production also the cause for environment.
2. Material: material composition, material mix, type of powder, size of powder and temperature set-up are the cause of material in PVC product.
3. Measurement: inspection and lack of measurement are the cause of measurement in PVC product.
4. People: Skill gap, lack of training and educational qualification gap are the cause of people in PVC product.
5. Method: Lack of documentation, lack of team work, no daily or weekly oriented program and lack of integration to do data analysis are the cause of method in PVC product.
6. Machine performance: loosen screw knob located on the die longitudinal surface, electrical power interruption prejudice, lack of maintenance, gearbox breaking down, disordering of machine components and temperature set-up for heating Plasticized Poly Vinyl Chloride (PVC) powder due to malfunctioning of Heater pads at die section are the cause of Machine performance in PVC product.
7. Equipment: design of tool and fixtures, protection equipment and emergency measurement are the cause of equipment in PVC product.
8. Management: leadership, commitment, quality policy, customer satisfaction and integration with other workers are the cause of management in PVC product.

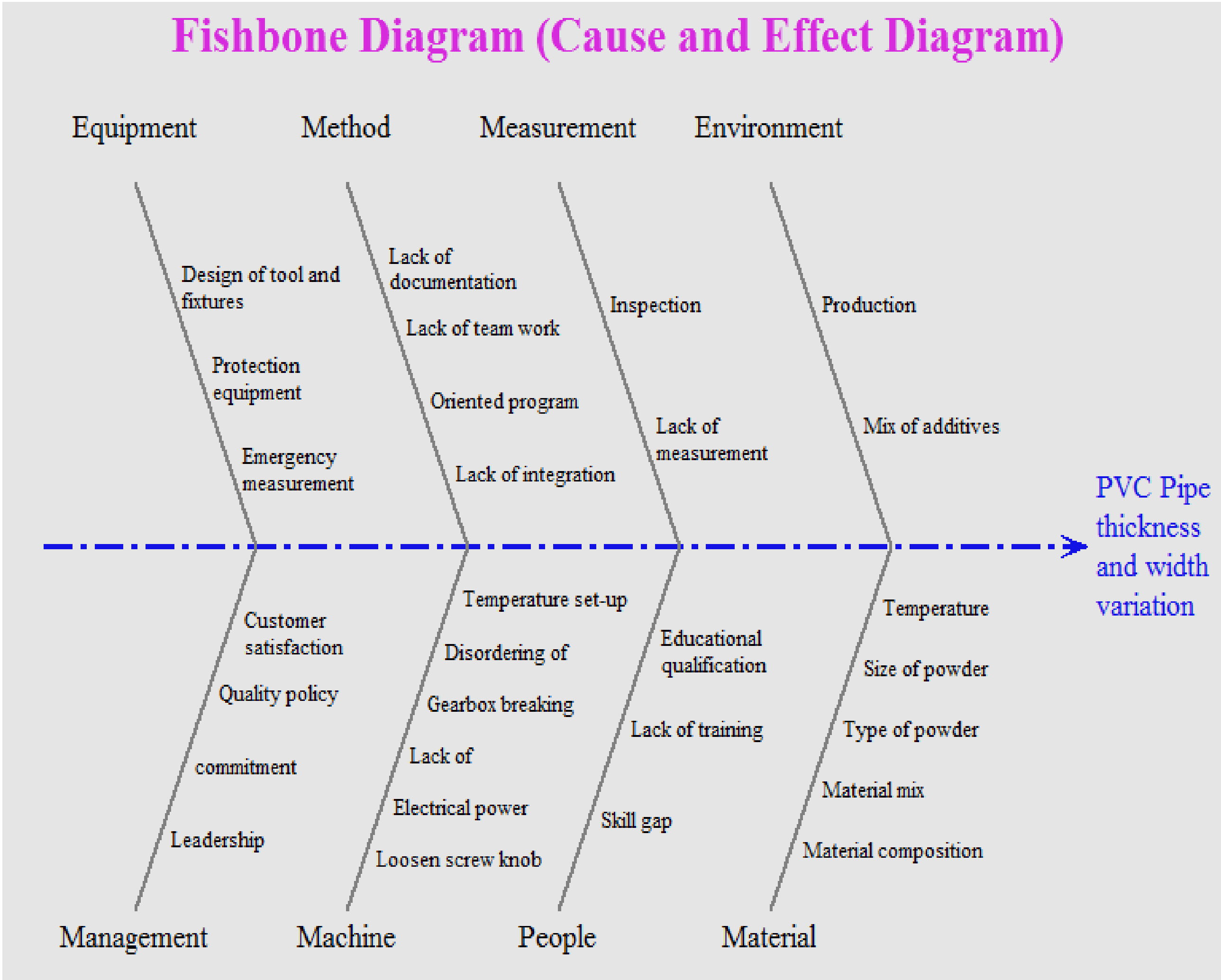


Figure 16: Fishbone diagram (Cause and Effect Diagram) on PVC Pipe thickness and width variation problem

From the above figure the main cause of thickness and width variation problem for PVC pipe was different machine performance due to frequent change in process parameters by operators to bring the product in to a desired specified dimension through experience. The company runs its production in three shifts. During each shift operators are changed so as possible existence of change in process parameters. Therefore, the effects of these process parameters would be investigated and an optimal setting would be proposed to minimize thickness and width variation problem and loss associated with desired performance characteristics would be determine by applying Taguchi DoE Approach.

5.3. Analysis of quality loss for determining the influence of process parameters

Taguchi loss function and design of experiment were applied to estimate quality loss incurred due to these defects and estimating optimum parameter settings for Extrusion process. Taguchi's loss function has been functional to calculate the quality loss of the chosen products. the loss function for the selected product using the theory of Taguchi's loss function the value of L (failure cost). As Quality loss function relates quality loss L(y) to the deviation away from a targeted value (m) of a measured response value (y).

i.e., |y-m|; Such that, $L(y) = k\,(y - m)^2$

L(y) - The loss, due to failure, repair, recycling, k - The proportionality constant, y - Actual performance value and m - The target value.

The average quality loss for a product is calculated using a formula;

$L_{arg} = k\,(s^2 + (\mu - m)^2)$;

Where: - s^2, variance or mean square deviation of y around its own mean and μ is the average value of y for the set of parts. A product is said to be loss for a company if they produce pipe above its targeted specification limit or below targeted value. Quality loss calculation for PVC pipe is done by using the principle of Taguchi's Loss Function. The value of L (Failure cost) is estimated with taking in to account of the following assumptions:

- Failure cost is production cost from cost saved by recycling scraps (this is because PVC product is failed to perform a required value it can be recycled and reworked).
- Maximum loss was occurring at the two tolerance.
- One performance parameter of a product was considered in the calculation at a time, this is because of (1) some part of loss due to other parameters can be included in the considered parameter, (2) the formula developed by Taguchi do not perform loss function calculation for many parameters simultaneously.

Failure cost = production cost (Birr/pc) – (mass of a product (kg/pc) *% of recyclable *cost of raw material (Birr/kg)) (Sisay et al.., 2013).

To determine production cost, Profit = Selling price – Production cost;

Production cost = Selling price – Profit. i.e., Negative in value since it's an Expense Not Receipt.

Input data used for analysis:

- From Marketing and sales department, the company has a cost policy of gaining profit not more than 15% of total production cost.
- Selling price per piece is about 650 Birr/pc before vat.
- Mass of product is 2.76 kg/m.
- Monthly customer order quantity for one month in September of 2010 = 8,000 pipe/ month. Different for different seasons which depend on customer order quantity.
- Raw material cost (Birr/kg) ≈ 49.79 Birr/ kg.

Raw material Specifications, how to estimate cost:

The raw material purchased products conform to specified purchase requirements by providing clear cut purchase information.

Table 7: Cost of the raw material for PVC pipe

No.	Raw material	Cost (Birr/kg)
1	Poly Vinyl Chloride Resin	48
2	Stabilizer	125
3	Filler (Calcium carbonate)	38
4	Titanium Di Oxide	102
5	Carbon Black	80
6	Stearic acid (lubricant)	78
7	Pigment	308

The information gained from mixer operator to produce PVC pipe involves preparation of the extrusion process for the above table raw material mixing at the hopper with some mix proportion. The mixer machine is horizontal mixing machine and it can mix one time up to 150kg, involves the following material composition.

Table 8: Raw material Compound Ratio to mix (Kg) for producing PVC pipe

No.	Raw material	Compound Ratio to mix (Kg)
1	Poly Vinyl Chloride Resin	150 kg
2	Stabilizer	4.5 kg
3	Filler (Calcium carbonate)	8 kg
4	Titanium Di Oxide	0.2 kg
5	Carbon Black	0.02 kg
6	Stearic acid (lubricant)	0.3 kg
7	Pigment	0.02 kg
	Total	163.4 kg

By using Simple Average Weighted Method (SAWM) for estimation purpose there is a difference in mixture content and their associated purchasing cost, the raw material cost (Birr/kg) would be determine by giving weight for the raw material compound ratio to mix.

Table 9:Total raw material estimation

No.	Raw material	Compound Ratio to mix (Kg)	Weight of mix material, W_i (g)	Cost of load, L_i (Birr/kg)	W_i (g)* L_i (Birr/kg)
1	Poly Vinyl Chloride Resin	150 kg	15 g	48	720
2	Stabilizer	4.5 kg	0.45 g	125	56.25
3	Filler (Calcium carbonate)	8 kg	0.8 g	38	30.4
4	Titanium Di Oxide	0.2 kg	0.02 g	102	2.04
5	Carbon Black	0.02 kg	0.002 g	80	0.16
6	Stearic acid (lubricant)	0.3 kg	0.03 g	78	2.34
7	Pigment	0.02 kg	0.002 g	308	0.616
		Total	W_i = 16.304		W_i * L_i = 811.806

Total raw material is ∑Wi * Li divide by ∑Wi

$$\frac{\sum Wi * Li}{\sum Wi} = \frac{811.806}{16.304} = 49.79 \text{ Birr/kg}$$

Table 10: Technical data for PVC pipes product according to ISO used in EPI

Nominal Outside Diameter	Outside Diameter	Pipe Series							
		S 20		S 16		S 12.5		S 10	
		Standard dimension ratio							
		SDR 41		SDR 33		SDR 26		SDR 21	
		Nominal Pressure(PN) Class							
		PN 5		PN 6		PN 6.3		PN 8	
		Wall Thickness	Apr. ox. Mass	Wall Thickness	Apr. ox. Mass	Wall Thickness	Apr. ox. Mass	Wall Thickness	Apr. ox. Mass
Mm	Mm	Mm	Kg/6 m	mm	Kg/6 m	mm	Kg/6 m	mm	Kg/6 m
Ø50	50+0.3	-	-	-	-	1.6+0.4	2.17	2.0+ 0.4	2.70
Ø63	63+0.3	1.6+0.4	2.76	1.9+ 0.4	3.26	2.0+ 0.4	3.43	2.5+ 0.5	4.25
Ø75	75+0.3	1.9+0.4	3.90	2.2+ 0.5	4.50	2.3+ 0.5	4.70	2.9+ 0.5	5.87
Ø90	90+0.3	2.2+0.5	5.43	2.7+ 0.5	6.62	2.8+ 0.5	6.86	3.5+ 0.6	8.51
Ø110	110+0.4	2.7+ 0.5	8.14	3.4+ 0.6	10.18	4.2+ 0.7	12.49	5.3+ 0.8	15.58
Ø125	125+0.4	3.1+ 0.6	10.62	3.9+ 0.6	13.27	4.8+ 0.7	16.21	6.0+ 0.8	20.04
Ø140	140+0.5	3.5+ 0.6	13.42	4.3+ 0.7	16.39	5.4+ 0.8	20.42	6.7+ 0.9	25.07
Ø160	160+0.5	4.0+ 0.6	17.53	4.9+ 0.7	21.35	6.2+ 0.9	26.79	7.7+ 1.0	32.92
Ø180	180+0.6	4.4+ 0.7	21.71	5.5+ 0.8	26.97	6.9+ 0.9	33.56	8.6+ 1.1	41.38
Ø200	200+0.6	4.9+ 0.7	26.86	6.2+ 0.9	33.76	7.7+ 1.0	41.60	9.6+ 1.2	51.31
Ø225	225+0.7	5.5+0.8	33.92	6.9+0.9	42.28	8.6+1.1	52.29	10.8+1.3	64.94
Ø250	250+0.8	6.2+0.9	42.47	7.7+1.0	52.42	9.6+1.2	64.84	11.9+1.4	79.54
Ø280	280+0.9	6.9+0.9	52.95	8.6+1.1	65.58	10.7+1.3	80.96	13.4+1.6	100.28
Ø315	315+1.0	7.7+1.0	66.48	9.7+1.2	83.21	12.1+1.5	102.98	15.0+1.7	126.32
Ø355	355+1.1	8.7+1.1	84.65	10.9+1.3	105.38	13.6+1.6	130.46	16.9+1.9	160.40
Ø400	400+1.2	9.8+1.2	107.44	12.3+1.5	133.99	15.3+1.8	165.38	19.1+2.2	204.23

From the above table let take the minimum Nominal Outside Diameter, Ø 63 and Nominal Pressure(PN) Class, PN 5 PVC pipe type has a weight of 2.76 kg/6m, then one PVC pipe raw material costs 2.76 kg/6m*49.79 Birr/ kg*6m = 137.4204 Birr.

Then, the production cost is estimated as follows.

- Profit = selling price – production cost
- 15% of production cost = 650 Birr/pc – production cost
- (0.15 + 1) production cost = 650 Birr/pc
- Therefore, Production cost is $\frac{650}{1.15}$ = 565.22 Birr/pc

The production cost is the amount of expense that a plant or industry incurred for producing a desired output at a given pre-assumed input values under control condition. Thus expense involves fixed, variable costs and overhead costs. Then, it is possible to calculate production cost that the company incurred per meter since the pipe length is 6m. By dividing 565.22 Birr/pc to 6, to get 94.3 Birr/m.

Mass of product found to be 2.76 kg/m * 6 m/pc = 16.56 kg/pc. And, the rate of defect for PVC pipe is reaching above 23% of the total amount of production. Since once defect on a product is obtained, it would be recycled and reworked that in turn add an extra production cost and even contribute to the final selling price of the product. This makes an assumption that 23% of pipe goes back to the production process to be recycled.

Failure cost = production cost (Birr/pc) - (mass of a product (kg/pc) *% of recyclable *cost of raw material (Birr/kg))

Failure cost = (565.5 Birr/pc - (16.56 kg/pc*23%*49.79 Birr/kg))

Failure cost = 375.86 Birr/pc

Now, calculate above, the failure cost that the company incurred for producing PVC pipe (PN 5) determined to be 375.86 Birr/pc.

According to Taguchi's Quality loss function equation, the loss was calculated by taking the performance value of measured characteristics i.e., the deviation of thickness of the product from its target value. Since the objective function is minimizing thickness variation and brings pipe to its nominal dimension, "The-Nominal-The Better" type of Loss function is selected.

Table 11:Tolernace limit Ø 63 mm

UPVC pipe type OD = Ø 63mm	Tolerance Limit	
	LSL	USL
(PN 5)	2.2	2.7
(PN 6)	2.4	2.9

Depending on the values of the failure costs calculated above, the proportionality constant K determined below by taking in to consideration of y, actual performance value of parameter taken as either minimum (LSL) or maximum of thickness and width variation (USL) that is 2.2 and 2.7 mm respectively for the selected product type. Therefore, we have two cases to find proportional constant, k and its associated average loss.

LSL: Actual performance value of parameter, y is taken as LSL. I.e., y = 2.2 mm

$$K = \frac{L(y)}{(y-m)2} = \frac{L(y)}{(y-m)2} = \frac{375.86}{(2.45-2.2)2} = 6{,}013.76$$

USL: Actual performance value of parameter, y is taken as USL. I.e., y = 2.7 mm

$$K = \frac{L(y)}{(y-m)2} = \frac{L(y)}{(y-m)2} = \frac{375.86}{(2.45-2.7)2} = 6{,}013.76$$

Therefore, the average quality loss for a product is calculated using a formula;

$L_{arg} = k\,(s^2 + (\mu - m)^2)$;

The company Quality control daily report of PVC pipe, data about thickness and variation were collected which is recorded at different points on the pipe at different time and interpreted in such a way that the table will be constructed as follows.

Table 12: Data from EPI Quality control daily report of PVC pipe

PVC pipe production

Total order quantity
(Pc) =8,000
Production line –
PVC factory
Outer Diameter = 63
mm Standard thickness
= (2.2 - 2.7 mm) Length
of pipe = 6m
Nominal pressure = 5 bar

Quality Personal’s Recorded Data (Diagonal measured thickness and width variation of pipe (mm))

Time (LT)	15/03/19 G.C		Shift	Time (LT)	23/03/19 G.C		Shift	Time (LT)	30/03/19 G.C		Shift
	LL	UL			LL	UL			LL	UL	
10:50	2.42	2.6	C- Morning	4:10	2.00	2.63	A- Night	1:10	2.0	2.75	A- Morning
	2.3	2.45			2.00	2.67			2.2	2.7	
	2.3	2.45			2.17	2.8			2.4	----	
12:30	2.3	2.45	A- Evening	9:10	1.86	2.34	B- Evening	7:50	2.06	2.4	A- Morning
	2.3	2.45			2.06	2.41			2.1	2.5	
	2.4	2.4			2.28	2.71			2.15	2.6	
2:00	2.24	2.39	B- Morning	12:30	2.20	2.44	C- Evening				
	2.24	2.37			2.35	2.48					
	2.5	2.30			2.43	2.58					
	----	2.30			----	----					
4:30	2.12	2.43	C- Morning	10:50	2.14	2.43	A- Evening				
	2.20	2.34			2.34	2.53					
	2.23	2.33			2.37	2.58					

Taguchi investigated in his quality loss function the loss in quality quantified in a parabolic relationship with the deviation of performance characteristics from the target value. From quality control daily report, 156 number of sample data was taken to estimate the mean and standard division.

Table 13: Descriptive statistics of thickness and width variation by Minitab

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Thickness Variation	156	0	2.4308	0.0219	0.2740	1.8300	2.2450	2.4250

Variable	Q3	Maximum
Thickness Variation	2.5975	3.6600

To find mean square deviation of thickness and width variation around its mean, session window on Minitab software shows descriptive statistics. The value of s = 0.2740 and average value of y, μ = 2.431. Then we use these values as an input for determining the average quality loss for a product under study. Since we get value of K previously, the desired target thickness of pipe needs to be 1.8 mm to maintain its symmetry. So, it is possible to calculate average quality loss.

The average quality loss for a product is calculated using a formula:

$L_{arg} = k\,(s^2 + (\mu - m)^2)$; since μ = 2.431and s = 0.2740

$L_{arg} = 6{,}013.76 * ((0.2740)^2 + (2.431 - 2.45)^2)$

$L_{arg} = 453.67$ Birr/pc

From the average quality loss function calculated above the average amount of money the company loss due to quality problem is estimated to be 453.67 Birr per each PVC Pipe of product (Note: estimation of each by taken least diameter and pressure range PN 5 of Ø 63). After the new optimal process parameter setting suggested together with improved production rate by reducing the average loss incurred by the company due to thickness and width variation problem using Taguchi and RSM approach of deign of experiment and loss functions analysis.

5.4. Design of experiment

5.4.1. Taguchi's Experimental Design

Taguchi and Konashi developed Taguchi techniques. These techniques have been utilized widely in engineering analysis to optimize the performance characteristics within the combination of design parameters. Taguchi technique is also optimization power tool for the design of quality system. It introduced an integrated that is simple and efficient to find the optimum range of design for quality performance, and computational cost (Asrat, et.al.., 2013).

The data was collected for PVC pipe products of the industry and by using Minitab 18 software, process factors mostly affecting the response output i.e., thickness and width variation in this case would be determined. Minitab provides a lot of statistical function for easily analyzing data and ease to use statistical tools.

5.4.2. 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, Taguchi Method, or Random design. 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 variable contributes significantly. Random designs used when there are many variables and very few variables contribute significantly. An orthogonal array designated as $L_a(b^c)$ 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. Thickness and width variation input process parameters involves in Temperature profile (^oC). The process parameters considered in DoE of the case industry production process were Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature. And die-temperature involves in melting (Temperature-1, Temperature-2 and Temperature-3). Because final output of PVC product into three stage extrusion machine process.

Table 14: parameters used for conducting the experiment (DoE)

Control parameters (were: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature)		Unit	Level 1 or Min (1)	Level 2 or Nom (2)	Level 3 or Max (3)
A	Feed speed	rpm	0.9	1.6	2.0
B	Vacuum pressure	Mpa	150	160	175
C	Take-off speed	m/min	1.2	1.8	2.6
D	Screw speed	rpm	65	75	90
E	Temperature-1	^{o}C	155	160	165
F	Temperature-2	^{o}C	170	175	180
G	Temperature-3	^{o}C	185	190	195
Response factor: Thickness and Width variation					

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 (Madhav S. Phadke, 1989).

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.

It is equal to the sum of:

- (Number of level-1) for each factor
- (Number of level-1) (Number of level-1) for each interaction
- One the average

Condition 2: By using standard orthogonal array, or Table.

The number of rows of an orthogonal array represents 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 required 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. Taguchi Standard Orthogonal Array was shown in Table in appendix:

When: 2-level arrays: L4, L8, L12, L16, L32, L64

When: 3-level arrays: L9, L27, L81

When: Mixed 2-level and 3-level arrays: L18, L36, L′36, L54

Prime ′ represents second array when there are two arrays with the same number of Rows.

When to come, on mine case there are seven factors each with three levels are selected. From standard table of orthogonal array, the preferable OA selected would be $L_{27}(3^7)$. Minitab software helps to generate Taguchi orthogonal array.

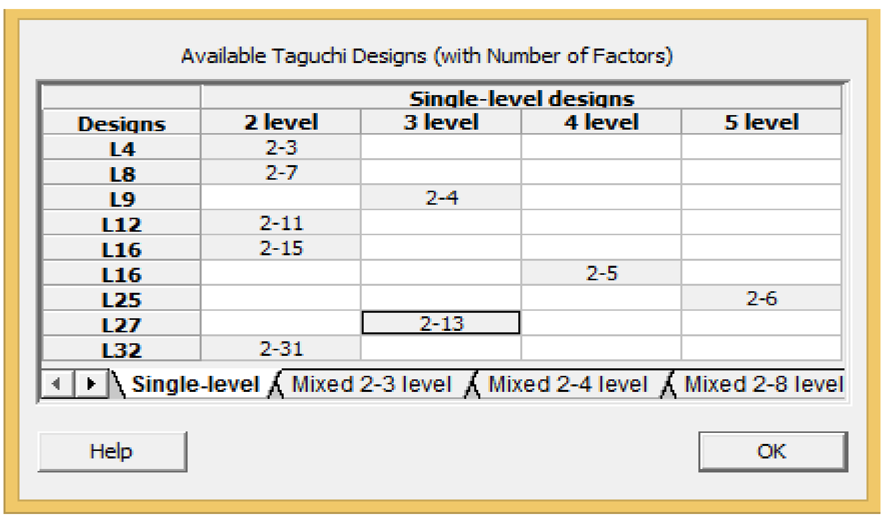


Figure 17: OA selected would be $L_{27}(3^7)$ for seven factors

Minitab 18 software provides easily access for Taguchi Design of different levels and factors that to want for constructing an appropriate OA selected for study.

Table 15: Taguchi design summary $L_{27}(3^7)$ orthogonal array by using Minitab 18 software

Run Order	Factors and levels						
	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2
3	1	1	1	1	3	3	3
4	1	2	2	2	1	1	1
5	1	2	2	2	2	2	2
6	1	2	2	2	3	3	3
7	1	3	3	3	1	1	1
8	1	3	3	3	2	2	2
9	1	3	3	3	3	3	3
10	2	1	2	3	1	2	3
11	2	1	2	3	2	3	1
12	2	1	2	3	3	1	2
13	2	2	3	1	1	2	3
14	2	2	3	1	2	3	1
15	2	2	3	1	3	1	2
16	2	3	1	2	1	2	3
17	2	3	1	2	2	3	1
18	2	3	1	2	3	1	2
19	3	1	3	2	1	3	2
20	3	1	3	2	2	1	3
21	3	1	3	2	3	2	1
22	3	2	1	3	1	3	2
23	3	2	1	3	2	1	3
24	3	2	1	3	3	2	1
25	3	3	2	1	1	3	2
26	3	3	2	1	2	1	3
27	3	3	2	1	3	2	1

The letters A, B, C, D, E, F, and G describe the control factors under study. The number 1, 2, and 3 represent associated levels for each control factor for OA $L_{27}(3^7)$.

Table 16: Taguchi design experiment $L_{27}(3^7)$ orthogonal array by using Minitab 18 software

Run Order	Control parameters (Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature)						
	Feed speed	vacuum pressure	Take-off speed	screw speed	Temperature-1	Temperature-2	Temperature-3
1	0.9	150	1.2	65	155	170	185
2	0.9	150	1.2	65	160	175	190
3	0.9	150	1.2	65	165	180	195
4	0.9	160	1.8	75	155	170	185
5	0.9	160	1.8	75	160	175	190
6	0.9	160	1.8	75	165	180	195
7	0.9	175	2.6	90	155	170	185
8	0.9	175	2.6	90	160	175	190
9	0.9	175	2.6	90	165	180	195
10	1.6	150	1.8	90	155	175	195
11	1.6	150	1.8	90	160	180	185
12	1.6	150	1.8	90	165	170	190
13	1.6	160	2.6	65	155	175	195
14	1.6	160	2.6	65	160	180	185
15	1.6	160	2.6	65	165	170	190
16	1.6	175	1.2	75	155	175	195
17	1.6	175	1.2	75	160	180	185
18	1.6	175	1.2	75	165	170	190
19	2.0	150	2.6	75	155	180	190
20	2.0	150	2.6	75	160	170	195
21	2.0	150	2.6	75	165	175	185
22	2.0	160	1.2	90	155	180	190
23	2.0	160	1.2	90	160	170	195
24	2.0	160	1.2	90	165	175	185
25	2.0	175	1.8	65	155	180	190
26	2.0	175	1.8	65	160	170	195
27	2.0	175	1.8	65	165	175	185

A total of twenty-seven runs must be conducted while using Taguchi design, using the combination of levels for each control factor.

5.4.3. RSM Experimental Design

The process of production starts by cleaning extruder sections, dismantling the die component, mandrel, adaptor, preparation of vacuum chamber, puller, and cutter. The machine takes at least a startup time of 4 hours for production. It is governed by different factors.

Extruder and die-section:

- By using high jet air compressor (with its hose attached in the machine itself) the internal part of extruder section is cleaned.
- The hopper would have fill with a dry white cleaner, Ca(Co)3 that allow any residuals which remains in the wall to be staked, and removed together. The cleaner helps to make sure any unwanted materials have not missed and present in the extruder container, or barrel wall.
- A Feed speed of 28 mm/min is allowed to quickly take away the residuals from the barrel well as a perforated extrude with mixed striped color of white, gray and/ or black.

Vacuum chamber:

- Adjustment on vacuum chamber is beginning by changing the appropriate calibrator that was suited to maintain the desired outer diameter of the pipe.
- Checking and cleaning rubber hose as it is used for spraying water for cooling the hot extrude sufficiently before passing to the next station.
- To support a steady, continuous and smooth movement of pipe inside the chamber and letting it safely in and out, the Nylon rollers are loose tightened to accommodate differences in size of the processed pipe than the previous one.

Die:

- An appropriate die with desired cross section transported by fork lift, and set in position at the end of the extruder machine. Activities like loosening and tightening bolts, screw knobs, connecting heater pads, sitting thermocouples etc.., are performed.
- Placing mandrel in position at the center of the die opening, which determines the desired thickness of the pipe being produced. To avoid any misalignment, vibration etc.., the

mandrel strongly tightened and holding in place by longitudinally screwed bar using a bolt at its center.

From the above different factors, the machine takes at least a startup time of 4 hours for production. Then Response surface methodology (RSM) is an analytical method that is commonly used to statistically justify the significance of the relationship between input variables (independent variables) to output variables (response). Statistical branch revolves around deriving information about the properties of random processes from sets of observed samples (Arce et al.., 2005).

The selected independent experimental factors for this study:

- Feed drum, vacuum chamber, rotational screw speed and barrel temperature.

The dependent response parameters for this study include:

- Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature.

Immediately after manufacturing each pipe, sample are taken and its thickness and width was measured with the help of digital micrometer and calibration instrument. The difference between their targeted value and the actual value dimension indicated the amount of variation that took place in the pipe. So, the dependent response parameters can occur thickness and width variation disused on the above.

Measuring thickness, diameter, length and width pipes in three shifts because EPI works in three shifts (1-9 shift one, 9-1, shift two and 1-1 shift three) the data is arbitrarily tick a mark at any point in the circumference of the pipe and then continuously ticking by making the string straightly stretched from point where initially the pipe was ticked up until the end of string tip lay on pipe section. And follow the same procedure until the pipe fully divided in to eight measurement positions. For all this case temperature set-points for each factor were identified and their corresponding level was selected and recorded below the table:

Table 17: Orthogonal array for their associated response output

Run Order	Control parameters (Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature)							Response Value	
	Feed speed	vacuum pressure	Take-off speed	screw speed	Temperature-1	Temperature-2	Temperature-3	Thickness	Width
1	0.9	150	1.2	65	155	170	185	0.002	0.00223
2	0.9	150	1.2	65	160	175	190	0.003	0.0043
3	0.9	150	1.2	65	165	180	195	0.045	0.0063
4	0.9	160	1.8	75	155	170	185	2.456	2.545
5	0.9	160	1.8	75	160	175	190	2.456	2.478
6	0.9	160	1.8	75	165	180	195	2.557	2.535
7	0.9	175	2.6	90	155	170	185	2.570	2.506
8	0.9	175	2.6	90	160	175	190	2.551	2.443
9	0.9	175	2.6	90	165	180	195	2.555	2.470
10	1.6	150	1.8	90	155	175	195	2.565	2.532
11	1.6	150	1.8	90	160	180	185	2.559	2.510
12	1.6	150	1.8	90	165	170	190	2.624	2.526
13	1.6	160	2.6	65	155	175	195	2.684	2.482
14	1.6	160	2.6	65	160	180	185	2.669	2.601
15	1.6	160	2.6	65	165	170	190	2.441	2.468
16	1.6	175	1.2	75	155	175	195	2.574	2.508
17	1.6	175	1.2	75	160	180	185	2.525	2.540
18	1.6	175	1.2	75	165	170	190	2.53	2.498
19	2.0	150	2.6	75	155	180	190	2.541	2.443
20	2.0	150	2.6	75	160	170	195	2.673	2.526
21	2.0	150	2.6	75	165	175	185	2.567	2.531
22	2.0	160	1.2	90	155	180	190	2.660	2.488
23	2.0	160	1.2	90	160	170	195	2.599	2.450
24	2.0	160	1.2	90	165	175	185	2.396	2.456
25	2.0	175	1.8	65	155	180	190	2.513	2.348
26	2.0	175	1.8	65	160	170	195	2.453	2.764
27	2.0	175	1.8	65	165	175	185	2.555	2.543

The S/N ratio for each level of the parameters is summarized and called the S/N response table for total thickness and width variation (Table 18). 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 (Table 19). By using Minitab software, each values of the response output are 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 18: Response Table for Signal to Noise Ratios

Nominal is best (10×Log10(Ybar^2/s^2))

Level	A (Feed speed)	B (Vacuum pressure)	C (Take-off speed)	D (Screw speed)	E (Temperature-1)	F (Temperature-2)	G (Temperature-3)
1	27.96	26.92	27.35	25.91	30.43	31.20	37.06
2	37.19	34.62	36.35	38.06	31.44	34.62	31.64
3	31.75	35.37	33.21	32.93	35.04	31.08	28.20
Delta	9.23	8.45	9.00	12.15	4.61	3.54	8.86
Rank	2	5	3	1	6	7	4

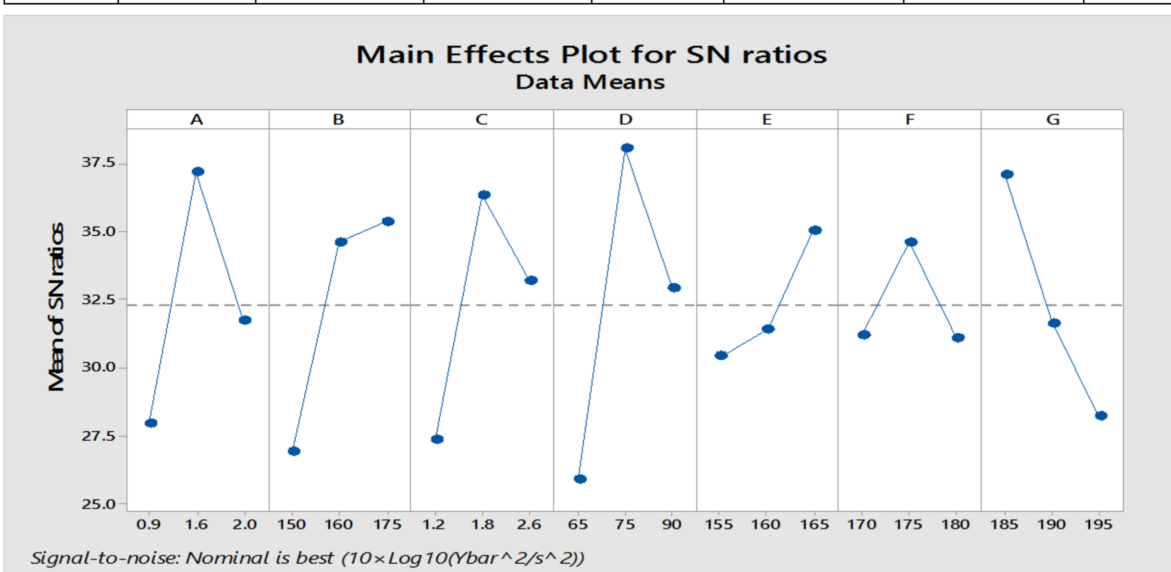


Figure 18: Main effect plot for Signal to Noise Ratios

Table 19: Response Table for Means

Level	A (Feed speed)	B (Vacuum pressure)	C (Take-off speed)	D (Screw speed)	E (Temperature-1)	F (Temperature-2)	G (Temperature-3)
1	1.677	1.703	1.683	1.699	2.246	2.257	2.252
2	2.546	2.523	2.529	2.527	2.267	2.240	2.223
3	2.528	2.525	2.540	2.526	2.239	2.254	2.277
Delta	0.870	0.821	0.857	0.828	0.028	0.017	0.053
Rank	1	4	2	3	6	7	5

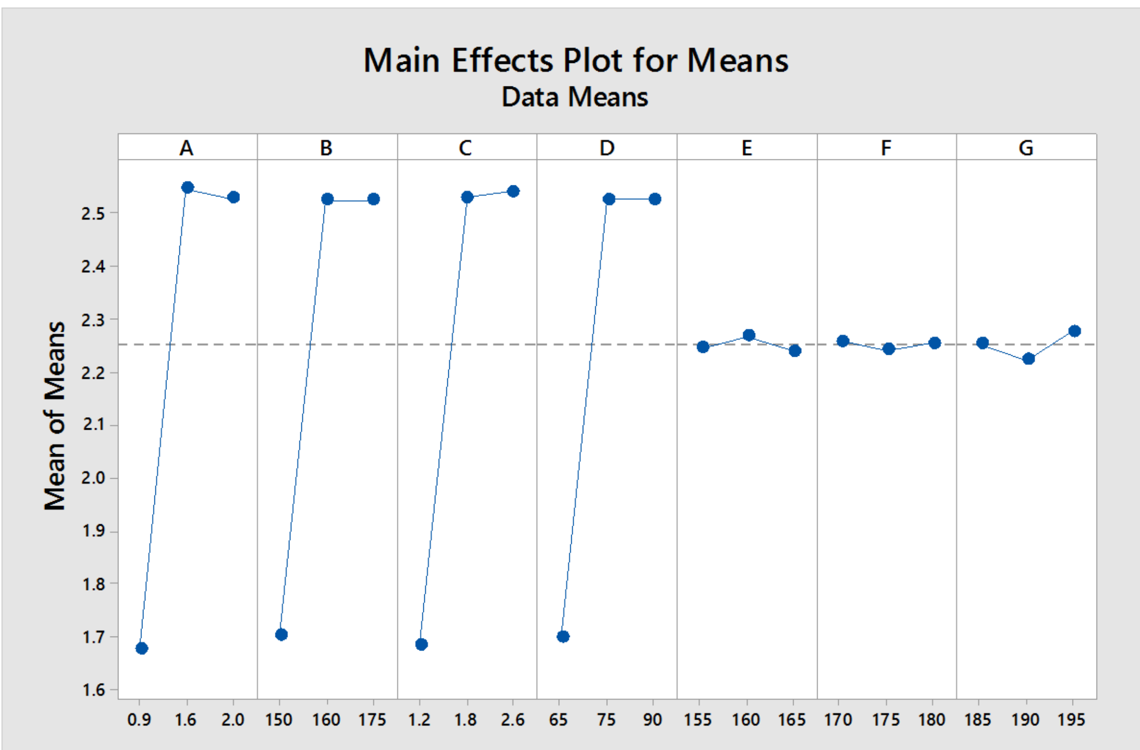


Figure 19: Main effect plot for means

Using main effects plots to help us visualize the relative value of the effects of different factors. Figure 19 shows the S/N response graph for total thickness and width variation. As shown in the figure, the greater the S/N ratio, the smaller is the variance of total thickness and width variation around the desired (the-Nominal-The-Better) value. However, the relative importance amongst the parameters for total thickness variation still needs to be known so that optimal combinations of the parameter levels can be determined more accurately.

<u>Interpreting the results signal to noise and means:</u>

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 Nominal-is-best is used. In this case, the factor with the biggest impact on the S/N ratio is Screw speed (Delta = 12.15, Rank = 1). And the factor with the least effect on S/N ratio Temperature-2 (Delta = 3.54, Rank = 7). In order to reduce the impact of noise on response (i.e., reducing around the thickness and width variation of the pipe), 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 thickness and width variation of the pipe is Feed speed-1, vacuum pressure-2, Take-off speed-1, screw speed-1, temperature one-3, temperature two-1 and temperature three-2 (A1, B2, C1, D1, E3, F1, G2). And for response table and main effects plots for mean both show that the factor with the greatest effect on the mean is Feed speed (Delta = 0.870, Rank = 1). And the factor with the least effect on the mean is Temperature-2 (Delta = 0.017, Rank = 7). The main effect plots for means is helpful for adjusting the mean on target value, those parameter levels with near or close to the desired target thickness and width of pipe that means optimum parameter level for minimum value of thickness and width variation of the pipe is Feed speed-1, vacuum pressure-1, Take-off speed-1, screw speed-1, temperature one-2, temperature two-3 and temperature three-3 (A1, B1, C1, D1, E2, F3, G3) can be replaced.

5.5. 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. The total variability of the S/N ratio was measured by the sum of the squared deviations from the total mean S/N ratio. 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. Whereas, P values was ≤ 0.05, then we go for validation of the result in either of three cases. I.e., Normality, Constant Variance, and Independence Test.

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 - 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 (Silva et al.., 2011).

After this go for validation of the result of P value to put values in ANOVA for thickness and width versus with control parameters.

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

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
A	Fixed	3	0.9, 1.6, 2.0
B	Fixed	3	150, 160, 175
C	Fixed	3	1.2, 1.8, 2.6
D	Fixed	3	65, 75, 90
E	Fixed	3	155, 160, 165
F	Fixed	3	170, 175, 180
G	Fixed	3	185, 190, 195

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	2	4.5893	2.29465	343.57	0.000
B	2	3.9403	1.97016	294.98	0.000
C	2	4.3615	2.18076	326.52	0.000
D	2	4.2965	2.14826	321.65	0.000
E	2	0.0052	0.00260	0.39	0.686
F	2	0.0056	0.00279	0.42	0.668
G	2	0.0116	0.00582	0.87	0.443
Error	12	0.0801	0.00668		
Total	26	17.2902			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0817246	99.54%	99.00%	97.65%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.2712	0.0157	144.41	0.000	
A					
0.9	-0.5829	0.0222	-26.21	0.000	1.33
1.6	0.3033	0.0222	13.64	0.000	1.33
B					
150	-0.5402	0.0222	-24.29	0.000	1.33
160	0.2752	0.0222	12.37	0.000	1.33
C					
1.2	-0.5674	0.0222	-25.51	0.000	1.33
1.8	0.2552	0.0222	11.47	0.000	1.33
D					
65	-0.5640	0.0222	-25.36	0.000	1.33
75	0.2709	0.0222	12.18	0.000	1.33
E					
155	0.0138	0.0222	0.62	0.547	1.33
160	0.0052	0.0222	0.23	0.818	1.33
F					
170	-0.0103	0.0222	-0.46	0.651	1.33
175	-0.0100	0.0222	-0.45	0.661	1.33
G					

185	-0.0158	0.0222	-0.71	0.492	1.33
190	-0.0136	0.0222	-0.61	0.554	1.33

Regression Equation

Thickness = 2.2712 - 0.5829 A_0.9 + 0.3033 A_1.6 + 0.2796 A_2.0 - 0.5402 B_150 + 0.2752 B_160 + 0.2650 B_175 - 0.5674 C_1.2 + 0.2552 C_1.8 + 0.3122 C_2.6 - 0.5640 D_65 + 0.2709 D_75 + 0.2931 D_90 + 0.0138 E_155 + 0.0052 E_160 - 0.0190 E_165 - 0.0103 F_170 - 0.0100 F_175 + 0.0203 F_180 - 0.0158 G_185 - 0.0136 G_190 + 0.0293 G_195

Fits and Diagnostics for Unusual Observations

Obs	Thickness	Fit	Resid	Std Resid	
15	2.4410	2.5551	-0.1141	-2.09	R
24	2.3960	2.5069	-0.1109	-2.04	R

Note: R for Large residual

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

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
A	Fixed	3	0.9, 1.6, 2.0
B	Fixed	3	150, 160, 175
C	Fixed	3	1.2, 1.8, 2.6
D	Fixed	3	65, 75, 90
E	Fixed	3	155, 160, 165
F	Fixed	3	170, 175, 180
G	Fixed	3	185, 190, 195

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	2	4.2986	2.14931	392.11	0.000
B	2	4.1460	2.07299	378.19	0.000
C	2	4.3661	2.18305	398.27	0.000
D	2	3.9217	1.96087	357.73	0.000
E	2	0.0121	0.00603	1.10	0.364
F	2	0.0079	0.00397	0.72	0.505
G	2	0.0231	0.01155	2.11	0.164
Error	12	0.0658	0.00548		
Total	26	16.8413			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0740363	99.61%	99.15%	98.02%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.2298	0.0142	156.49	0.000	
A					
0.9	-0.5642	0.0202	-28.00	0.000	1.33
1.6	0.2886	0.0202	14.32	0.000	1.33
B					
150	-0.5541	0.0202	-27.50	0.000	1.33
160	0.2706	0.0202	13.43	0.000	1.33
C					
1.2	-0.5683	0.0202	-28.21	0.000	1.33
1.8	0.3015	0.0202	14.96	0.000	1.33
D					
65	-0.5388	0.0202	-26.74	0.000	1.33
75	0.2818	0.0202	13.98	0.000	1.33
E					
155	-0.0237	0.0202	-1.18	0.261	1.33
160	0.0276	0.0202	1.37	0.196	1.33
F					
170	0.0241	0.0202	1.20	0.254	1.33
175	-0.0101	0.0202	-0.50	0.626	1.33
G					
185	0.0185	0.0202	0.92	0.377	1.33
190	-0.0413	0.0202	-2.05	0.063	1.33

Regression Equation

Width = 2.2298 - 0.5642 A_0.9 + 0.2886 A_1.6 + 0.2757 A_2.0 - 0.5541 B_150 + 0.2706 B_160
+ 0.2836 B_175 - 0.5683 C_1.2 + 0.3015 C_1.8 + 0.2669 C_2.6 - 0.5388 D_65
+ 0.2818 D_75 + 0.2570 D_90 - 0.0237 E_155 + 0.0276 E_160 - 0.0038 E_165
+ 0.0241 F_170 - 0.0101 F_175 - 0.0141 F_180 + 0.0185 G_185 - 0.0413 G_190
+ 0.0228 G_195

Fits and Diagnostics for Unusual Observations

Obs	Width	Fit	Resid	Std Resid	
22	2.4880	2.3856	0.1024	2.08	R
25	2.3480	2.4726	-0.1246	-2.52	R
26	2.7640	2.6262	0.1378	2.79	R

Note: R for Large residual

For the Response Surface Analysis information for both thickness and width control parameters (Feed speed, vacuum pressure, Take-off speed, screw speed) A, B, C and D, P values was ≤ 0.05, then we go for validation of the result in either of three cases. I.e., Normality, Constant Variance, and Independence Test. So, P value is 0.000, it is residuals on both sides of 0, validation of the result is Constant Variance. And (Temperature-1, Temperature-2 and Temperature-3) E, F and G, P value for both thickness and width control parameters a factor is > 0.05, the related design parameter appears to have a significant effect on the quality characteristic.

CHAPTER SIX

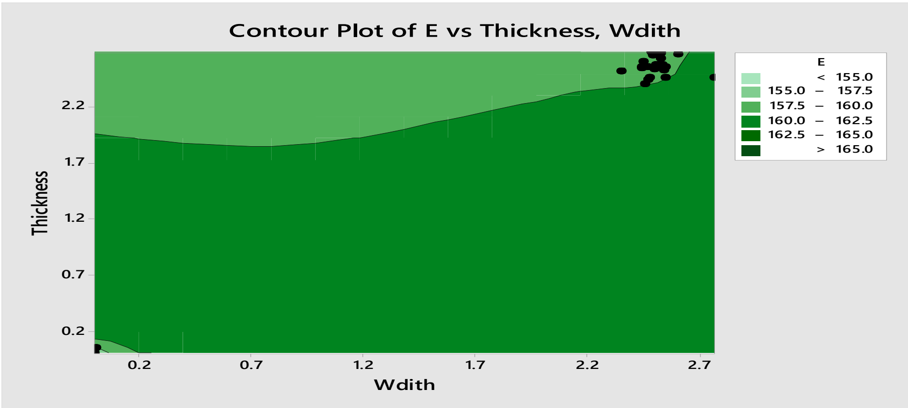
SUMMARY OF FINDINGS, RESULTS AND DISCUSSIONS

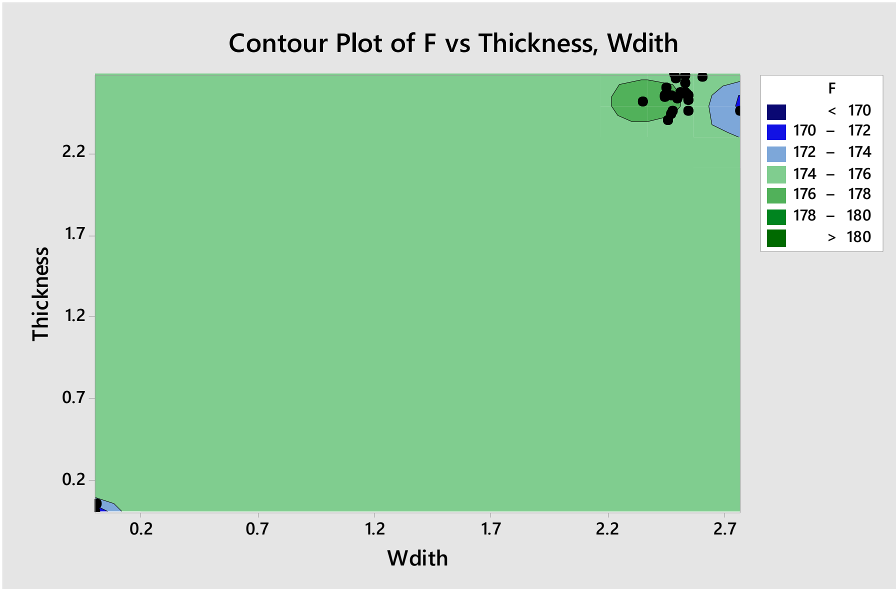
In this study, an extrusion process that is used for production of PVC pipes at EPI was studied to optimize process parameters that have significant effect on reducing pipe thickness and width variation problems and bringing them to the desired targeted thickness and width. The study begins: By identifying possible product quality problems that adversely affect rate of rework or recyclability; then prioritizing those quality problems which needs company top management intervention to minimize as much as possible; and performing cause and effect analysis using cause and effect diagram to strengthen and diagnose causes corresponding to the identified, prioritized quality problems. Finally, Taguchi and RSM design of experiment is systematically approached from the existing EPI extrusion machine set points to identify the possible response output values that is approaching or nearest to the Taguchi Design; L_{27} OA and RSM independent and response factor. Also, Taguchi's loss function discussed.

In general output of this study, one method of reducing such PVC pipes thickness and width variation problem is by applying Taguchi and RSM method. And the optimum combination of parameters was found with an intension of bringing the pipe to its desired nominal thickness, that is "Nominal-The-Better" approach is selected for both S/N Ratio and loss function analysis in the study.

6.1. Fitting Results of RSM

Surface plot and contour plot shows the interaction of (Temperature-1, Temperature-2 and Temperature-3) E, F and G value for both thickness and width control parameters in next figure.





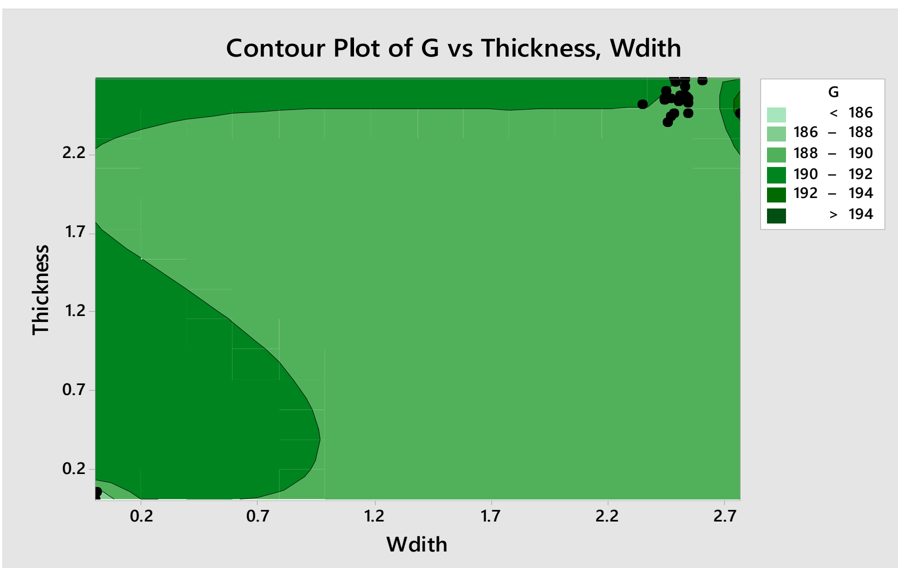


Figure 20: Surface plot and contour plot shows the interaction of (Temperature-1, Temperature-2 and Temperature-3) E, F and G with thickness and width

6.2. Taguchi and Response Surface Methodology tests

Taguchi design experiment select control parameters (were: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature) and $L_{27}(3^7)$ orthogonal array by using Minitab and know Response factor: Thickness and Width variation.

RSM design experiment for the selected response factor from Taguchi design experiment selected independent experimental factors: Feed drum, vacuum chamber, rotational screw speed and barrel temperature. The dependent response parameters: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature. After this, Analysis of Variance (ANOVA) used to integrate Taguchi and Response Surface Methodology design experiments.

6.3. Summary of results

In this study, an extrusion process that is used for production of PVC pipes at EPI was studied process parameter optimization of extrusion process that have significant effect on reducing pipe thickness and width variation problems to bringing them to the desired targeted thickness and width of the PVC pipe. This study begins: to identifying possible product quality problems that adversely affect rate of rework or recyclability; then prioritizing those quality problems which needs company top management intervention to minimize as much as possible; and performing cause and effect analysis using cause and effect diagram to strengthen and diagnose causes corresponding to the identified, prioritized quality problems. Finally, Taguchi and RSM design of experiment is systematically approached from the existing EPI extrusion machine temperature set points to identify the possible response output values that is approaching or nearest to the L_{27} orthogonal array. Additionally, how the EPI loss of rework or recyclability by Taguchi's loss function was also discussed.

From the above discussion of the highlight of the study, a general output of this study was one method of reducing such PVC pipes thickness and width variation problem is by applying and using to integrating the Taguchi and Response Surface Methodology method. And the optimum combination of parameters was found with an intension of bringing the pipe to its desired nominal thickness, that is "Nominal-The-Better" approach is selected for both S/N Ratio and loss function analysis in the study.

This study to reduce the impact of noise on response is for reducing variation around the thickness and width of pipe, 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 thickness and width variation of the pipe is Feed speed-1, vacuum pressure-2, Take-off speed-1, screw speed-1, temperature one-3, temperature two-1 and temperature three-2 (A1, B2, C1, D1, E3, F1, G2) from response table for Signal to Noise Ratios are the possible parameter combinations for reducing the variation around thickness and width variation of the pipe.

Table 20:The recommended possible parameter combinations for reducing the variation around thickness and width variation of the PVC pipe

Control parameters (were: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature)		Unit	Optimum parameter level for S/N ratio
A	Feed speed	rpm	0.9 (Min)
B	Vacuum pressure	Mpa	160 (Nom)
C	Take-off speed	m/mi	1.2 (Min)
D	Screw speed	rpm	65 (Min)
E	Temperature-1	^{o}C	165 (Max)
F	Temperature-2	^{o}C	170 (Min)
G	Temperature-3	^{o}C	190 (Nom)

The recommended possible parameter combinations and to reduce variation around thickness and width pipe, and control the factor with the biggest impact on the S/N ratio is Screw speed (Delta = 12.15, Rank = 1). And the factor with the least effect on S/N ratio Temperature-2 (Delta = 3.54, Rank = 7). And for response table and main effects plots for mean both show that the factor with the greatest effect on the mean is Feed speed (Delta = 0.870, Rank = 1). And the factor with the least effect on the mean is Temperature-2 (Delta = 0.017, Rank = 7). The main effect plots for means is helpful for adjusting the mean on target value, those parameter levels with near or close to the desired target thickness and width of pipe that means optimum parameter level for minimum value of thickness and width variation of the pipe is Feed speed-1, vacuum pressure-1, Take-off speed-1, screw speed-1, temperature one-2, temperature two-3 and temperature three-3 (A1, B1, C1, D1, E2, F3, G3).

Table 21: The recommended means for adjusting the mean on target value, those parameter levels with near or close to the desired target thickness and width of the pipe

Control parameters (were: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature)		Unit	Optimum parameter level recommended for
A	Feed speed	rpm	0.9 (Min)
B	Vacuum pressure	Mpa	150 (Min)
C	Take-off speed	m/min	1.2 (Min)
D	Screw speed	rpm	65 (Min)
E	Temperature-1	^{o}C	160 (Nom)
F	Temperature-2	^{o}C	180 (Max)
G	Temperature-3	^{o}C	195 (Max)

The response variable selected in this study is thickness and width variation. Feed speed, vacuum pressure, take-off speed, screw speed and die-temperature are root factor together with other dependent factors like feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature and the independent factors are feed drum, vacuum chamber, rotational screw speed and barrel temperature. This has a significant contribution towards all PVC pipes to get quality problems. In this case study, the above factors associated impacts on production of defected pipe were investigated. This study, after identifying above factors by integrating the Taguchi method and Response Surface Methodology, optimization process parameter applied in extrusion process

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

When to conclude this study, the outcome, the followings are the conclusions that can be drawn from the analyses made in this research:

- ↔ Integrating the Taguchi and Response Surface Methodology in plastic extrusion process most of the previous literatures not considered for to optimizing the process parameter.
- ↔ Taguchi experimental design was found to be effective technique to optimize the performance characteristics within the combination of design parameters and Response Surface Methodology design experiment for the selected response factor from Taguchi design experiment selected independent experimental factors: Feed drum, vacuum chamber, rotational screw speed and barrel temperature. The dependent response parameters: Feed speed, vacuum pressure, Take-off speed, screw speed and die-temperature. Then integrating this two experimental design by Analysis of Variance (ANOVA) the main effect plots for means is helpful for adjusting the mean on target value, those parameter levels with near or close to the desired target thickness and width of pipe that means optimum parameter level for minimum value of thickness and width variation of the pipe is Feed speed-1, vacuum pressure-1, Take-off speed-1, screw speed-1, temperature one-2, temperature two-3 and temperature three-3 (A1, B1, C1, D1, E2, F3, G3). And to reduce the impact of noise on response is for reducing variation around the thickness and width of pipe, 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 thickness and width variation of the pipe is Feed speed-1, vacuum pressure-2, Take-off speed-1, screw speed-1, temperature one-3, temperature two-1 and temperature three-2 (A1, B2, C1, D1, E3, F1, G2) from response table for Signal to Noise Ratios are the possible parameter combinations for reducing the variation around thickness and width variation of the pipe.
- ↔ Taguchi and Response Surface Methodology plays a vital role in any industries, whether engaged in manufacturing of tangible output or service rendering to satisfy their customer

needs, expectations by producing quality product or delivering services in a manner through reduction of unnecessary costs either prior to production or after the item was shipped to customers.

- ↔ Taguchi and Response Surface Methodology is helpful for reduction of unit manufacturing cost (UMC) and quality loss respectively through incorporating ideas either at the product development or process design stage and also identifying optimum control parameter combinations. And, rather than directly choosing the response output, Pareto chart analysis and cause and effect diagram needs to be incorporated to make the study visible so as it creates worth for the company profitability.

7.2 Recommendations

The need to conduct this research arose from the fact that the defect plastic product occurs in when applied drinking water. For water supplies above ground, both inside and outside buildings comes from pipe. From this fact, as an industrial engineer how can I optimize process parameter of extrusion process of the PVC pipe for this defect plastic product. Therefore, this research was carried out to distinguish the inherent and scientific characteristics by Integrating the Taguchi and Response Surface Methodology for process parameter optimization of extrusion process applied for this study. Consequently, the following recommendations should be taken into account when trying to optimization process parameter for extrusion process:

- ℜ EPI and other plastics can continuously measure its factories' process quality and produced in accordance with the recommendation of ISO standards (Tolerances on outside diameter and wall thickness, are as per ISO 11922-1 or Grade C tolerance and Grade W tolerance, respectively).
- ℜ Every quality controller, mechanical and electrical engineers must participate working process with the help of operators in order to optimize the process parameter for extrusion process for the product can minimizing the scrap or rework of pipe.
- ℜ To increase the production of the pipe and decrease the amount of scrap or rework from extrusion process must adjust the following things:

- ✓ The vacuum of the pump/air pressure/
- ✓ The raw material feeding speed
- ✓ The raw material screw speed
- ✓ The triano (haul or take off) speed
- ✓ The temperature of the heating zone (adjust temperature-die)
- ✓ Appropriate mixing ratio of raw material
- ✓ The measuring (metering) device with standard length

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APPENDIX

Appendix A: For PVC-pipe raw material company specifications

A. Poly Vinyl Chloride Resin

No.	Quality description	Company specification
1	K-value	66±1
2	Specific gravity	1.4
3	Particle size (% retained on 45 mesh sieve)	Max. 0.2
4	Apparent bulk density (gm/cm^3)	0.54±0.04
5	Volatile matter (%)	<0.3
6	Degree of polymerization	1000±50

B. Stabilizer

No.	Quality description	Company specification
1	Appearance	Cream flake
2	Lead content (%)	≤32
3	Specific gravity	1.4-1.8
4	Moisture (%)	Max. 1%

C. Filler (Calcium carbonate)

No	Quality description	Company specification
1	Calcium carbonate	>97%
2	Density (gm/cm3)	2.7
3	Oil absorption (gm per 100 gm powder)	13-18.
4	Particle size (µm)	≤ 10
5	Moisture (%)	0.01

D. Titanium Di Oxide

No.	Quality description	Company specification
1	Titanium Dioxide (TiO_2)	Min.93%
2	Crystal form	Rutile Type
3	Specific gravity	4.0
4	Bulk density(kg/L)	0.76
4	Moisture (%)	0.2%
5	Oil absorption (gm oil/100gm pigment)	20.3
6	Average Particle size (µm)	0.22
7	Hiding power	5.90
8	PH	7.75

E. Carbon Black

No.	Quality description	Company specification
1	Ash	0.5% Max.
2	Heating loss	2.5% Max.
3	Color intensity	105-125%

F. Stearic acid (lubricant)

No.	Quality description	Company specification
1	Acid Value	200 - 208
2	Iodine Value	1% Max.
3	Titer, ºC	58 - 62

Appendix B: table for Taguchi Standard Orthogonal Array

Orthogonal Array	Number of rows	Maximum number of factors	Maximum number of columns at this level			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4		-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L'_{16}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	-	13	-	-
L_{32}	32	31	31	-	-	-
L'_{32}	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L'_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L'_{64}	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

Appendix C: How to identified approached recorded data, and their associated response output

Run	Recorded data	Each difference= Run value – recorded data	Selected data	Corresponding Avg. Response Value	
				Thickness	Width
1	8,9,10	37	10	0.002	0.00223
2	5	More than one result	8	0.003	0.0043
	8, 9, 10	4			
3	33	0	33	0.045	0.0063
4	8, 9, 10	21	9	2.456	2.545
5	26	0	26	2.456	2.478
6	11	0	11	2.557	2.535
7	6	2	6	2.570	2.506
8	21, 23, 36, 64	0	21	2.551	2.443
9	60	0	60	2.555	2.470
10	12, 44, 45	1	44	2.565	2.532
11	14, 40, 42	0	14	2.559	2.510
12	16	0	16	2.624	2.526
13	26, 39	1	39	2.684	2.482
14	7	More than one result	6	2.669	2.601
	6	2			
15	5	More than one result	38	2.441	2.468
	8, 9, 10	More than one result			
	38	12			
16	1, 3, 47, 63	0	1	2.574	2.508
17	7	0	7	2.525	2.540
18	13, 27, 41	0	13	2.53	2.498
19	11	0	19	2.541	2.443
	18, 19, 22, 33, 35	More than one result			
20	16	0	16	2.673	2.526
21	12	0	12	2.567	2.531
22	18, 19, 22, 35	0	18	2.660	2.488
23	12, 44, 45	1	45	2.599	2.450
24	5	0	5	2.396	2.456
25	2, 32, 46	0	2	2.513	2.348
26	26, 39	1	26	2.453	2.764
27	55	0	55	2.555	2.543