EXPERMENTAL INVESTIGATION OF THE EFFECT OF WELDING PARAMETERS FOR METAL INERT GAS WELDING ON MILD STEEL

DIRIBA EJERSA ALEMU

A Thesis Submitted To

The Department of Mechanical Design and Manufacturing Engineering

School Of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of The Requirement for The Degree of Masters

in Mechanical Engineering (Manufacturing Engineering)

Office of Post Graduate Studies

Adama Science and Technology University

December, 2022

Adama, Ethiopia

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Advisor

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Adama, Ethiopia

DECLARATION

I declare that this thesis proposal entitled "**Experimental Investigation of The Effect of Welding Parameters for Metal Inert Gas Welding on Mild Steel**" Is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

<u>Diriba Ejersa Alemu</u> __________________ _________________

Name of student Signature Date

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Experimental Investigation of The Effect of Welding Parameters for Metal Inert Gas Welding on Mild Steel” prepared under my guidance Diriba Ejersa Alemu. Submitted in partial fulfillment for the degree of master’s science in manufacturing engineering.

Therefore, I recommend the submission of a revised version of the thesis to the department for following the applicable procedure.

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APPROVAL SHEET

I, the advisors of the thesis entitled "Experimental Investigation of The Effect of Welding Parameters for Metal Inert Gas Welding on Mild Steel" and developed by Diriba Ejersa Alemu hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Diriba Ejersa Alemu have read and evaluated the thesis entitled "Experimental Investigation of The Effect of Welding Parameters for Metal Inert Gas Welding on Mild Steel" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing engineering.

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TABLE OF CONTENTS

Contents **Page**

DECLARATION II
RECOMMENDATION III
APPROVAL SHEET IV
ACKNOWLEDGEMENT V
LIST OF ACRONYMS AND ABBREVIATIONS XII

ABSTRACT XIV

CHAPTER- 1 1

1. INTRODUCTION 1
1.1. Background of study 1
1.2. Statement of the Problem 2
1.3. Objective of the study 3
1.3.1. General objective 3
1.3.2. Specific Objectives 3
1.4. Significance of the study 3
1.5. Scope of study 4
1.6. Limitation of the Research Work 4
1.7. Importance of the thesis 4
1.8. ORGANIZATION OF THE THESIS 5

CHAPTER -2 6

2. LITERATURE REVIEW 6
2.1. Introduction 6
2.2. Effects of shielding gas on MIG welding quality 6
2.3.Different MIG Welding Processes parameters 7
2.4 Studies on mechanical properties 12
2.5. Weld bead 13
2.6. Research gap 14

CHAPTER-3 .... **15**
3. MATERIALS AND METHODOLOGY 15
3.1. Introduction 15
3.2 Research Methodology 15
3.3. Data Collection Methods 15
3.3.1. Primary Data Collection 15
3.3.2 Secondary Data Collection 17
3.4. Method of Data Analysis 17
3.4.1 Design of experiment methods 17
3.4.2 Steps of experiment 18
2.4.3 Practical methodology for Design of Experiment 19
3.4.4 Statistical Analysis of Experimental Data 22
3.5. Materials and Experimental Procedure 22
3.5.1 MATERIALS 23
3.5.1.1 Selection of Material 23
3.5.1.2 Materials Used: 23
3.5.1.3 Equipment's Used: 24
3.5.1.4 Technical Specification for MIG Welding Machine 24
3.5.2 MIG Welding Experimental Procedure 25
3.5.2.1 Cleaning the Welding Specimens: 25
3.5.2.2 Design for Experimental Set up: 25
3.6. Weld bed Geometry 26
3.7. Liquid Penetrant Testing (LPT) 27
3.8. EXPERIMENTAL PROCEDURE 27
3.9 Mechanical Property Testing For various mechanical tests 28
3.9.1 Tensile Strength 28
3.9.1.1. Specimen preparation and test procedures 28
3.9.2 Hardness Testing 31
3.10. Microhardness setup 31
3.11. MIG welding parameters 32
3.12.1. Welding current 32

3.12.2. Welding voltage 32
3.12.3. Welding arc gap (standoff distance) 33
3.12.4 Welding speed (arc speed) 33
3.13. Determine Parameter Design Using Orthogonal Array 33
3.14 Models Used in Calculating S/N Ratio Larger-the-better 36
3.15. For analysis quality of welding Mathematical Modeling 36

CHAPTER - 4 37

4. RESULT AND DISCUSSION 37
4.1 INTRODUCTION 37
4.2 NDT and DT 37
4.2.1 Liquid Penetrant Testing (LPT) 37
4.3. Micro hardness analysis 39
4.4. Mechanical properties 40
4.5. Tensile strength 41
4.6.1 S/N Ratios 42
4.6.2 Overall Mean S/N 44
4.6.2.1 Average S/N Ratio of Experiment for each Factor and Level 45
4.7.1 Performance of Level One Parameter 48
4.7.2 Performance of Optimal Levels 48
4.8. Sum of Squares for Mean of Sample Experiments 48
4.8.1 Total Sum of Squares 48
4.8.2 Sum of Squares 2 Level for each Factor 49
4.8.3 Mean Square (Variance) 49
4.8.4 Percentage Contribution; 49
4.8.5 Pooling 50
4.8.6 Degree of Freedom Error Term 50
4.8.7 Variances for Errors 50
4.8.8 New Percentage Contribution 51
4.9 ANOVA Terms Notation and Development Methods 51
4.9.1 Determination of ANOVA for Response (TS) 53
4.9.2 Sum of the Squares 53

4.9.3 Factor DOF for Response defects OA 53
4.9.4 Variance (Mean of the Squares) 54
4.9.5 F-Ratio 54
4.9.6 Percent..54
4.10. Regression Analysis of Response for Optimization 55
4.11. Mathematical Model for Regression Analysis for Predicted TS 55
4.11.1. Predicted Optimum Tensile Stress...57
4.12 Confirmation Experiment result based Tensile strengths 59
4.13. Tensile Strength Vs Strain Graph 60
4.14. Hardness test 61
4.14.1 Mean response for hardness analysis...62
4.13.2 Signal to noise ratio analysis for hardness 64
4.14.3. Effect of parameters on hardness 64
4.15. Analysis of variance (ANOVA) for hardness test 65
4.14. For best weld Bead 66
4.14.1 Mean response analysis of bead width 67
4.14.2. Signal to noise ratio analysis of bead width 68
4.15. Result Graphs for confirmation Setting in DOE 69
4.16 THE TOTAL CONFIRMATION RESULT...69
Chapter -5...**70**
5. Conclusion and Recommendation 70
5.1. Conclusion 70
5.2 Recommendation 71
REFERENCE **72**
APPENDIX “A”...I
APPENDIX “B” viii
APPENDIX C...ix
APPENDIXES “D” XVIII

LIST OF TABLES

Table **Page**

Table 2.1: Table 6. The Mean S/N ratio 7
Table 2.2. Analysis of variance (ANOVA). 8
Table 3.1 MIG Welding Technical Specification 24
Table 3.2 setting the welding parameter 25
Table 3.3: ASTM standard for tensile test specimen 29
Table 3.4 Standard RSM OA table. 34
Table 3.5 symbol, Parameters, units and their Values at Different Level 34
Table 3.6 L16 Coded Parameters in OA used for RSM 35
Table 3.7 L16 Un-Coded Parameters in OA used for RSM 36
Table 4.1 Defects distinguished in MIG Welding sixteen DOE samples 37
Table 4.2. Process parameters and levels selected 40
Table 4.3 Tensile Strength 41
Table 4.4 Experimental Results and S/N-Ratio for TS Experimental 46
Table 4.5 The Optimum Factor/Level Combination for TS & S/N-Ratio 46
Table 4.6 percentage contributions will be calculated after factor C is pooled out 51
Table 4.7 model is considered to be satisfactory 52
Table 4.8 ANOVA for Tensile Strength Predicted Numerical Calculation 54
Table 4.9. MINITAB Software ANOVA Result for Tensile Strength 55
Table 4.10 Coefficients of variance 55
Table 4.11 Estimated Regression Coefficients for TS for MIG Welding Parameters 58
Table 4.12 coefficient correlations 58
Table 4.13 Improved Setting and its response for tensile strength 59
Table 4.14: confidence level during tensile strength is optimum 60
Table 4.15 Improved Setting and its response 62
Table 4.16 Response table for means of Hardness S/n rations 62
Table 4.17 Response table for hardness (Larger is the better) 63
Table 4.*18*: Analysis of Variance for SN ratios 66
Table 4.20 response table for means best weld bead based on S/n rations 67
Table 4.21 Response table for best weld bead (Larger is the better) 68
Table 4.22 correlation analysis 69
Table 4. 24 conformation result 69

LIST OF FIGURES

Figure **Page**

Figure 2.1 Weld bead geometry....14
Figure 3.1 Thesis methodology flow charts....16
Figure 3.2 A 36 mild steel (100*30*3)....23
Figure 3.3 MIG BLUMIG 503S model machine and specimens for welding....24
Figure 3.4 welded sample for study....26
Figure 3.5 Photos of specimens during welding experiment....26
Figure 3.6 Liquid penetrant and developer used....27
Figure 3.7 Treated sample when liquid penetrant is processed....28
Figure 3.8 tensile test specimen standard dimension....29
Figure 3.9 sample prepared for tensile strength from mild steel specimens....30
Figure 3.10 Universal tensile testing machines during specimen is test....30
Figure 3.11 The result after tensile test at defense engineering collage....30
Figure 3.12 During hardness test on Brinell hardness testing machine at EEAMSMI....31
Figure 3.13 Vickers's HVS50 hardness testing machine....32
Figure 4.1 indetfication of defects....37
Figure 4.2 crack analysis during microscopy at ASTU material science lab....38
Figure 4.3 Indentation after test Samples....39
Figure 4. 4 Microhardness analysis graph based on high values....40
Figure 4.5 TS after MIG welding experiment from this graph TS....42
Figure 4.6 Main effect plot for S/N ratios for Tensile Strength....47
Figure 4.7 TS after MIG welding experiment....60
Figure 4.7 TS after MIG welding experiment for optimum S/N for sample 16....61
Figure 4.8 mean effects plots graph hardness test....64
Figure 4.9 main effect plot of means of means and mean of S/N ratios hardness test....65
Figure 4.10 main effects plot for SN ratios larger is the better for best weld bead....68

LIST OF ACRONYMS AND ABBREVIATIONS

List	Description
A	Current
ANOVA	Analysis of variance
ASTM	American society’s technology of manufacturing
B	Voltage
BHN	Brinell hardness in number
C	Travel speed
CCD	Central Composite Design
CI	Confidence interval
Coef	Coefficient for parameters
D	Standoff distance
Db	Decibel
DOE	Design of experiment
DT	Destructive test
EGBAMI	Ethio-Engineering Group Bishoftu Automotive Manufacturing Industry
EEAMSMI	Ethio-Engineering Group Addis Machinery Spare Manufacturing Industry
F	F –ratio
FEM	finite element model
L	Level
MIG	Metal inert gas
GMAW	Gas metal arc welding
GMI	Micro wave imager
GRA	Grey Relational Analysis
HRRR	High-Resolution Rapid Refresh
MS	Mean of the squares
NDT	Nondestructive test
N	Number of runs

OA	Orthogonal array
P	Probability
PDM	plasma discharge machines
PI	Probability interval
SS	Sum of the squares
S/N	Signal to noise ratio
T	T-test
Tbs	Calibrated brightness temperatures
TS	Tensile Stress
RSM	Response surface methodology
SE	Stand error
ηA	Average for signal-to-noise ratio for each factor
ηM	Mean for signal –to –noise ratio
ηOM	Overall mean for signal –to –noise ratio
ηOpt	Optimum for signal –to –noise ratio
3D	Three dimensional
5M	Man, machine, material, method, measurement

ABSTRACT

A good quality of welding focused had been required, when joining two pieces of metals were processed. The changing chemical, physical and thermal properties in order to made joint bond robust and rigid. The problem MIG welding on mild steel improved by controlling process welding parameters such as welding current, voltage, standoff distance and arc speed. The goal of this study was to see how significantly metal inert gas (MIG) welding process parameters affected mechanical properties of A36 mild steel. Method had been used Mathematical model parameters, OA, S/N- ratio, ANOVA, 95% confidence intervals level, Regression analysis for 16 sample. The result had been investigated optimal parameters S/N ratio current 31.37%, arc voltage 18.66%, travel speed 30% and standoff distance 19.97% used S/N ratio. For ANOVA 25% contribution for each factor and regression analysis maximum predicted tensile stress was 288.9MPa, minimum percent improvement for tensile stress was 2.87% maximum value of percent improvement. The percent difference was from 250MPa original material TS and regression analysis of process parameter optimum values combinations were 115, 27.5, 21.125, and 13 for current, voltage, travel speed and standoff distance respectively it was a better hardness and tensile strength. Confirmation tests were also carried out by the welded product tested on UVT machine for design of experiment after optimum parameter determination through destructive testing to proposed optimum parameter settings. The finding of this research work was optimal use of process parameters on weld bed products had been improved tensile stress was widely applicable and valuable in manufacturing industries. S/N ratio voltage was first, current second, travel speed third and standoff distance were the fourth contribution.

***Keywords*: -** ANOVA, Design of Experiment, Destructive Test, Metal Inert Gas, Regressions.

CHAPTER- 1

1. INTRODUCTION

1.1. Background of study

A weld is made when separate pieces of material to be joined combine and form one piece when heated to a temperature high enough to cause softening or melting. Filler material is used to added to strengthen the joint. Welding is a dependable, efficient and economic method for permanently joining similar metals (Thomas Henry et al., 2017). Welding is a permanent joining process, that means joining of different metal alloy with the help of number of processes in which heat is supplied by electric. Usually, metals or thermoplastics with or without application of heat, pressure and filler materials. As well as welding is the best economical process than other joining processes. There are much more methods of arc welding processes. From all of welding process the metal inert gas (MIG) welding is one of the arc welding processes and a capable of achieving the highest quality welds. Welding quality is a degree of perfection of one product which is produced by using welding operations as well as fabrications(Londhe & Inamdar, 2019).

According researchers' explanations welding is started around stone Age, since 2nd century Gas Metal Arc Welding (GMAW) was first developed by H. Kennedy from the Battelle Memorial Institute. At that time earlier GMAW, electrode is a smaller diameter and constant voltage is used. Because of it gave a high deposition rate, but the high cost of inert gases, its usage is limited to ferrous or non-ferrous materials and prevented cost savings.

Babu et al., (2020) were used in 1953 CO_2 as a welding atmosphere and in 1958, GMAW has been modified to short-arc variation. Due to this, welding was used in many industries and it became popular by making thin materials also suitable for weld. Today, GMAW is commonly used in many industrial welding processes. MIG (metal inert gas) is one of the gas metal arc welding processes. In case of the MIG welding process heat is generated by the transfer of electrons between continuous wire feed and base metal. This heat will melt the continuous wire, base plate metal and they will solidify together to form a sound joint. The shielding gases are allowed to flow from the weld gun along with wire feed to prevent the oxidization due to the atmospheric gases at the weld area (Vishnu et al. 2020).

MIG welding is one of the most widely used processes in industry areas, this process is used to weld a variety of ferrous and non-ferrous metals, and it can be used with virtually any weldable metals including similar and dissimilar metals, up to a thickness of metal from 0.5mm upwards. Based on this occasion the input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and there by the construction and manufacturing costs of aluminum structures and mechanical devices minimized. Due to this process the effect of welding parameters like, wire diameter, welding current, welding speed, and gas flow rate optimization based on bead geometry of welding joint(Consultant and Bridges, 2020).

The arc and the molten puddle are protected from contamination by the atmosphere likes oxygen and nitrogen. With an externally supplied gaseous shield of inert gas such as argon, carbon dioxide, helium or an argon-helium mixture. Since the metallic electrode provides the arc as well as the filler metal, during the MIG welding is operated the external filler metal is not necessary. It is often referred to in abbreviated form as MIG welding (Shah et al. 2018). The process uses a continuous consumable wire electrode and the molten weld puddle is completely covered with a shield gas, which was fed through the welding gun. The MIG welding process has been widely used as a metal joining technique because of its potential for increasing the productivity and quality of welding and is used by most arc welding robots(Ramanjaneyulut et al., 2018).

The MIG machine is used to weld any type metal, aluminum and metal alloy. In spray arc process an arc is introduced in between welding wire & work piece. The arc avoids spatters and it provides deep penetration in base material. In order to obtain spray arc, it is necessary to keep welding current above certain minimum value and the current level is depending on base metal, Arc voltage, shielding gas, welding positions & size of welding wire (Aher et al.,2019).

1.2. Statement of the Problem

In Ethio-engineering Group, Bishoftu Automotive Manufacturing Industry was producing deferent types of vehicles such as light and heavy-duty vehicles through welding process from mild steel material. MIG welding quality was the most problem in assembling areas on this company and welding involves a wide range of variables such as welding speed, Welding current, Welding voltage, temperature, wire electrode, power input, gas flow rate and gas combination that influence the eventual properties of the weld metal.

There is the need to select welding parameters for a given a good weld quality, unfortunately, a common problem that has faced the manufacturer is control of the process input parameters to obtain a good welded joint with the required bead geometry and weld quality with maximum tensile strength and hardness.

The reasons behind welding qualities are lack of proper optimized welding parameters, material microstructure, material type and also material properties. this study was address proper investigation on welding factors in order to produce quality product with good surface finish and addressing the current problem within improving the quality of product by increasing strength and durability of products.

1.3. Objective of the study

1.3.1. General objective

The general objective of this study was investigation of welding parameters on mechanical properties of the welded joint using MIG on A-36 mild steel.

1.3.2. Specific Objectives

To achieve the main objective of this thesis the following specific objectives were designed

1. To investigate welding process parameters on the quality of the welded joint
2. Optimization of welding parameters using DOE
3. Analysis of welding quality using liquid penetrant test
4. Studying mechanical properties (tensile strength and hardness) of welded joint at optimum welding parameters

1.4. Significance of the study

The defect parts were one of the most factors which determine the quality of the products**,** the several possible benefits from good welding quality such as improvement in manufacturing process, reduction in cost, reduction in lead time, and better utilization of vehicle products. Other industries that used good welding quality in manufacturing strategies experienced improvements in operational performance through eliminating welding defect and reworks, which provided these industries with cost saving and shortened lead times.

These benefits were particularly interesting for automotive industries as the industry faces increased global competition from lower-wage-structured nations and customers along the shorter delivery times within a good quality of products. This study helpful for vehicle production industries and society for better use of different vehicle with long duration without failurity.

1.5. Scope of study

This study was focused on experimental investigation effects of metal inert gas welding quality on mild steel**,** such as welding control factors and process parameters, conducting experiment, Destructive test (Tensile strength and hardness).

1.6. Limitation of the Research Work

The limitation of this study is listed as follows;

- Shortage of design of experiment software.
- Lack of ultrasonic and other confirmation testing machine related to this study.

1.7. Importance of the thesis

This study was been relevant to the management of Bishoftu automotive industry on the state of implementation of design of experiment of welding factors and parameters and its effects on quality of mild steel product by using metal inert gas welding technique. This study was offer in management for the opportunity to know how the welding factors and parameters affect the quality of mild steel products by using metal inert gas welding technique. The result of this study was providing a good insight about the current status of welding factors and parameters in the automotive manufacturing industries. It also provides the current welding factors and parameters in the factory and future researchers can study welding factors and parameters in industry level and can develop implementation framework that fit with the inherent quality culture of the industry.

1.8. Organization of the Thesis

The thesis consists of five chapters

Chapter one: - Begins with an intention to introduce the overall background of the study, an overview of MIG welding, in case of mild steel metals welding techniques, objectives, the problem statement, the significance of the study, scopes of the study and importance of the study.

Chapter two: - Addresses the detailed science behind MIG welding and rules followed during mild steel metals and different optimization techniques by reviewing different kinds of literature. Finally, the summary of the literature and the research gap is described

Chapter three: - The experimental specifics, such as the materials utilized for the experiment, the experimental protocols, the equipment used, and the methodology that fulfilled the study's aims, are briefly discussed in this chapter.

Chapter four: - The results and discussion of the experimental values are covered in this chapter. It investigates the effect of process parameters on the quality of MIG welds on mild steel. And keeping the parameters settings in optimum condition.

Chapter five: - It is the final chapter that summarizes the research done and proposed the recommendation and future work for further studies

CHAPTER -2

2. LITERATURE REVIEW

2.1. Introduction

The amount of literature reviews was quite healthy regarding to theoretical methodologies for process parameter setting in order to optimize the product responses, generally based on computer simulation. Many studies demonstrated that statistical tools and DOE for welding quality problem on MIG welding within a good quality can be successfully integrated for fine optimization. Many researchers were applied DOE methods to plan experiments and improve the quality of products in the past years for different industrial applications having different optimization approaches to process defects minimization with own parametric settings and levels.

2.2. Effects of shielding gas on MIG welding quality

At present Gas-shielded arc welding is widely used in practice, the techniques and various solutions constantly are widely used its applicability and fusion arc welding process is important part of shielding gas which used to cover the welding bead from the effects of the arc shape and material transfer mode and energy distribution, as well as the temperature distribution, in the arc welding process(Tusae and Suban, 2019).

In Addition, the primary function, of the shielding gases is significantly affect the shape of the welded parts, and the weld geometry, seam appearance and mechanical properties and fume emissions, almost exclusively mixtures of two, three or even more different gases are used to protect the arc and the molten pool (Map, 2012). The Shielding gases are considerable on the significance of the protection of the molten metal from atmospheric contamination during welding processes, these gases play the important role in a number of aspects of welding including arc characteristics and the microstructure of weldments(Mohanavel et al., 2018).
The Shielding gas can affect the transfer of the arc to the weld joint, which contributes to the efficiency of the welding process and the quality of the weld bed is determining by weld penetration profiles the results presented can be used as guidelines to achieve higher quality and efficiency in welding practices(Kah & Martikainen, 2014).

2.3 Different MIG Welding Processes parameters

Process parameter optimization is important in the welding process because it helps to determine the best process parameters for a high-quality weld while also reducing the number of trials and as a result, choosing the right MIG welding process parameters and setting them at the right values is critical for getting the best mechanical characteristics and bead shape (Ayoola et al., 2019; Choudhary et al., 2019)**.** The optimization of MIG welding process parameters were alloy steel work piece using grey relational analysis method and design of experimental runs based on an orthogonal array and Taguchi method were performed Arya et al., (2013)

Ikimi et al., (2021)focused investigate the effect of Metal Inert Gas (MIG) welding process parameters; welding current, welding voltage and welding speed on the tensile strength of mild steel AA10119 welded plates. The experiment was designed using Taguchi's L9 orthogonal array with three levels. Kaierda MIG MAG Inverter CO2 Welder Model E-180 welding machine was used to conduct the experiments with three repetitions. From the analysis carried out by applying Taguchi's method, the result shows that the welding speed and welding current have the most significant influence on tensile strength of the weld and an optimum parameter setting of A3B2C2 was suggested; welding current 240 A, welding voltage 25 V and welding speed 0.010 m/s. The mean tensile strength at this optimal setting A3B2C2 was predicted to be 442 N/mm2.

Table 2.1: Table 6. The Mean S/N ratio for tensile strength and their levels(Ikimi et al., 2021)

Mean S/N ratio(dB)						
Symbol	Process Parameter	Level 1	Level 2	Level 3	Max-Min	Rank
A	Welding Current(A)	51.53	51.88	52.39*	0.86	3
B	Welding Voltage(V)	51.73	52.16*	51.91	0.43	2
C	Welding Speed(m/s)	51.37	52.27*	`52.17	0.9	1

Pardeshi, (2020) used the DOE Taguchi technique to investigate the parametric study of the welding parameter for SS317L steel. Welding current, voltage, and gas flow rate are process parameters, whereas Bending and Tensile tests are response variables and the welding current was shown to be the most influential parameter in tensile strength, followed by voltage and GFR.

Table 2.2. Analysis of variance (ANOVA)(Jiru et al., 2022).

Source	DF	Seq SS	%Cont.	Adj MS	Adj SS	F	P
Welding Current(A)	3	6.88294	74.57	6.88294	2.29431	200.49	0.001
GFR(B)	3	0.75520	8.52	0.75520	0.25173	22.00	0.015
Root Gap (C)	3	1.14149	12.37	1.14149	0.25173	33.25	0.008
Filler type(D)	3	0.41515	4.5	0.41515	0.38050	12.09	0.035
Residual error	3	0.03433	0.04	0.03433	0.13838		
Total	15	9.22910	100		0.01144		
S=0.2276, R-Sq= 98.57%, R-Sq(adj) = 92.86%.							

Poolperm, Nakkiew, et al (2021) said the purpose is to investigate the forming characteristics of single-pass Metal Inert Gas (MIG) welding wire for multi-layer additive manufacturing parts and the effects of parameters, temperatures and heat analysis input on layer formation were analyzed, (Klobčar, Lindič, and Bušić 2018) the overview of additive Manufacturing technologies for production of metal parts and the most advantages of machine technology when compared to laser or electron beam technologies are lower investment cost and operational cost.

Kong et al., (2021) used a double-ellipsoidal volume heat source to simulate the gas metal arc welding (GMAW) heat input and a cylindrical volume heat source to simulate the laser beam heat as input was developed and to predict the temperature field and thermally induced residual stress in the hybrid laser gas metal arc (GMA) welding process (Arulraj & Barros, 2021) said the PDM is a Random Forest Classifier using GPM Microwave Imager (GMI) calibrated brightness temperatures (Tbs) and low-level precipitation mixing ratios from the High-Resolution Rapid Refresh (HRRR) analysis as inputs and the Plasma Cutting Machine is a Convolutional Neural Network which is the precipitation regime on this class, to defined the

Independently based on quantitative features by used ground-based radar reflectivity profiles, a series of experiments has been performed to verify the developed thermo-mechanical finite element model (FEM), and a qualitative agreement of residual stress distribution and weld geometrical size is shown to exist.

Ye et al. (2017) refund, a welding process of MIG-TIG double-sided arc welding-brazing (DSAWB) was introduced to used butt join AA5052 aluminum alloy and Q235 low-carbon steel of 3.0 mm thickness without any groove and the material microstructure and mechanical properties of the joints of material is investigated and compared with that improve from the traditional metal inert gas (MIG) joint in detail.

Rao & Deivanathan, (2014) used Taguchi Analysis and optimization of joining similar grades of mild steel by MIG welding, and this optimization which parameters was more affected the weld like current, voltage, arc speed, and arc gap are the variables.

In this study the material microstructure and mechanical properties of AISI1010 mild steel was discussed. Because it has higher tensile strength within achieved quality of welds by improve the current 120A and the weld has a littler defect.

Sonasale et al . (2016) studied on the Metal arc Welding (MIG) process finds wide application because all commercially important applicable metals such as carbon steel, high-strength, low-alloy steel, and stainless steel, aluminum, are considered. The welding parameters such as bead width, dilution and depth of HAZ have been considered. By using DOE method, the weld parameters were optimized.

Kumar et al. (2018) By selecting effects of process parameter of the Metal Inert Gas welding on the microstructural evolution, grain size variation of different zones, impact energy, micro-hardness analysis and depth of penetration in case of IS 2062 Grade B mild steel have been inspected (Rao and Deivanathan, 2014) the welding was carried out manually using different welding current and different sheet thickness value due to this the microscopic analysis of the weld cross-sections, were also conducted to observe and distinguish the microstructure of fusion zone and heat affected zones.

Patel et al. (2016) investigated the effect of welding parameters like wire diameter, wire feed rate and current on weld hardness in welding of AISI 1020 carbon steel plates by MIG welding. The input welding parameters were optimized by Grey Relational Analysis (GRA) and claimed that welding current is most influencing factor. (Mroziński and Piotrowski et al 2018) studied analyzes the impact of thermal cycle the basic strength parameters determined the tensile test.

On the basis of literature reports, it can be stated that in addition to changes in static strength and hardness, there is a significant reduction in impact strength and changes in fatigue strength. In the analyzed case, the change in properties was determined by the distance of the area from which the sample was taken from the heat source which was the weld.

Ghazvinloo et al. 2016 examined on the robust design technique for optimization in the field of engineering by using Taguchi method. Taguchi method is used to optimizes the input parameters on the basis of single response only. When the units in which response report's is measured data are different for different parameters as well as the effect of some parameters may be neglected. These kinds of responses lead to improper results in the evaluation. In this step the measured data is normalized from 0 to 1. Rajendran et al. (2017) has explained on the made to identify the combination of friction stir welding parameters such as tool rotational speed, welding speed, tool tilt angle and shoulder diameter to maximize tensile strength of butt joints of AA2014-T6 aluminum alloy. Statistical tools such as design of experiments; analysis of variance was used to develop the empirical relationship, to predict the ultimate tensile strength of the joint at the 95% confidence level.

Garg et al., (2017) used the Quality weld mainly depends on mechanical properties of the weld metal and heat affected zone (HAZ), which is in direct relation to the type of welding and its process parameters. and also, it plays an important role in determining the mechanical properties of the weld such as tensile strength, hardness etc. In this paper, effect of the various process parameters has been studied on welding of IS:2062 mild steel plate using gas metal arc welding process with a copper coated mild steel wire of 0.8 mm diameter. Nandi et al (2016) has examine on the welding based on visual inspection and X-ray radiographic test has been conducted in order to detect surface and sub-surface defects of weld specimens made of AISI 316L austenitic stainless steels. Effect of current, gas flow rate and nozzle to plate distance on quality of weld in metal inter gas arc welding of AISI 316L austenitic stainless steel has been studied in the present work through experiments and analyses. Chen et al.(2020) has studied model-based parameter optimization for simulating a metal-inert gas welding process. The computational model used in this study is based on computational fluid dynamics methods and implemented using the finite volume approach on a 3D com- mutational domain. The wire electrode, the arc plasma and the workpiece are treated as a self-consistent system

Aher et al (2019) has examined the Manufacturing process plays a very vital role in the product life management. The process parameters and its selection are important to achieve required outcomes. Welding is one of the critical manufacturing processes, which is affected by various process parameters involved. The outcomes of the welding process are measured in terms of strength, penetration, reinforcement, height and hardness.

Michael, (2015) has investigates the weld quality assurance practices in the metal welding industries in Ghana. The results of the analysis revealed that majority of the welding industries in the country lack weld quality assurance standards, weld quality testing equipment and materials as well as personnel to help assure weld quality practices in the metal welding industries. Also, equipment and materials for welding inspection and testing are not readily available in the welding hardware shops in the country. Moreover, even though most of the welders in the country have considerable years of working experience, they lack the skills of ensuring quality in their welding activities due to low levels of technical training.

Thakur and Gebrelibanos, (2019) has indenting methodology to compare three welding processes, namely SAW submerged arc welding, SMAW (shield metal arc welding) and GMAW (gas metal arc welding) and to select the best one for a given application. To instill professionalism into the welding industry, the suppliers should import the weld quality testing equipment into the country to be made available to the welders. The welders and the suppliers should take advantage of training programs offered by the training institutions in the country to enable them upgrade and update their knowledge and skills in weld quality assurance practices. The Government, the banks and other corporate organizations should help establish industries solely to produce more of the weld quality testing equipment locally in the country.

Pant et al., (2014) has discusses the effect of welding speed on the weld quality and microstructure of welded joints. The welding was performed using single and double wires and different speeds (16.93, 19.69, 25.4, 29.63 and 33.87mm/s). Vishnu et al (2020) studied on the application of Taguchi and Grey relational analysis methodologies to determining optimal process parameters for MIG Welding are presented. In the present work welding current, voltage, speed, bevel angle was considered as input parameters in joining two dissimilar metals (AISI1010 & AISI1018), as these influence the output characteristics like tensile strength and hardness, these parameters need to be optimized. (Pradesh and Pradesh et al.,2017) was studied to identifying the problem that has faced the manufacturer is the control of the process input parameters to obtain a good welded joint with the required weld quality. (Shah et al., 2018) is studied on MIG Welding is widely used by engineers and production personnel as a quick and effective welding process for joining metals. The above- mentioned parameters were optimized using Genetic Algorithm and suitable combinations of parameters were proposed for target quality using ANOVA.

A prediction model is also developed using Artificial Neural Network. The analysis provides significance of said process parameters and its effect on the quality and strength of joint. It is a powerful statistical technique used to study and analyze the effect of various process parameters upon the response and the analysis starts with the implementation concept of Design of Experiment (DOE), ANOVA and optimized by using genetic algorithm(Abrha, 2017). Traditionally, it has been necessary to study the weld input parameters for welded product to obtain a welded joint with the required quality, to do so, requires a time-consuming trial and error development method. (Shah et al., 2018)on weld strength, ultimate tensile strength and hardness of weld joint using design of experiments method. Then welds are examined whether they meet the requirement or not. Finally, the weld parameters can be chosen to produce a welded joint that closely meets the joint qualities and what is not achieved or often considered was an optimized parameters combination (kulkarni, 2017).

2.4 Studies on mechanical properties

The mechanical properties can easily be modified by heat treating to suit a particular design purpose and the present study, selected samples are heat-treated at different temperature above the austenitic region and quenched followed by tempering in order to investigate the effect of different tempering temperature on the mechanical properties of mild steel(Sultana et al., 2014) and the tensile strengths of the specimens were measured with Testo metric material testing machines, Prior to tensile test, the treated specimens were prepared according to the machine specification with length of 100 mm and diameter of 10 mm having a gauge length of 40 mm and in accordance to the BS standard and the test was conducted by gripping and pulling each specimen until catastrophic failure occurred, the load at which failure occurred was recorded(Ikpambese et al., 2022).

Bahar et al., (2018) studied the purpose of heat treating was to analyze the mechanical properties of iron, usually ductility, hardness, Yield strength, tensile strength and impact resistance, the heat treatment develops hardness, softness, and improves the mechanical properties such as tensile strength, yield strength, ductility, corrosion resistance and creep rupture and these processes also help to improve machining effect, and make them versatile.(Sultana et al.,2019) studied the mechanical behavior of the samples is investigated using universal tensile testing machine for tensile test, compression test and Rockwell hardness tester for hardness testing.

The samples revealed that with increasing temper temperatures: (a) hardness first increases to a maximum and then gradually decreases; (b) yield strength first decreases, then increases, and then increases again; (c) ultimate strength first increases to a maximum and then steadily decreases; and (d) ductility (% elongation) gradually decreases till 600ºC, and then increases rather sharply. (Singh & Goyal, 2017) Studies welded surfaces produced are smooth, neat, clean and spatter free which require no further cleaning so reduces total welding cost(Biswas et al., 2018).Singh and Goyal, 2017 they affect the weld quality in terms of mechanical properties and weld bead geometry.

2.5. Weld bead

The molten weld puddle and the arc zone are shielded by inert gases medium of argon or helium or carbon dioxide which used Metal inert gas (MIG) is also known as Gas Metal Arc Welding (GMAW) and this method is the most common technique used for mild steels and a smooth metal transfer is observed with low spatter loss and good weld penetrations can be achieved by a stable arc

A. Kumar et al., (2020).Studied bed geometry variables; heat affected zone, bead width, bead height, penetration and area of penetration are greatly influenced by welding process parameters; welding speed, welding current, shielding gas flow rate and gap distance and also it plays an important role in determining the mechanical properties of the weld such as Tensile load(Esme et al., 2009).

Figure **2.1** shows control of weld bead shape is indispensable as the mechanical properties of welds are affected by the weld bead shape. In 2005, Gunaraj and Murugan spread out their study and managed to found mathematical expressions to predict the penetration size ratio ‘PSR’ (the ratio of bead width to the height of penetration) and the reinforcement form factor ‘RFF’ (the ratio of bead width to the height of reinforcement)(Pant et al., 2014).

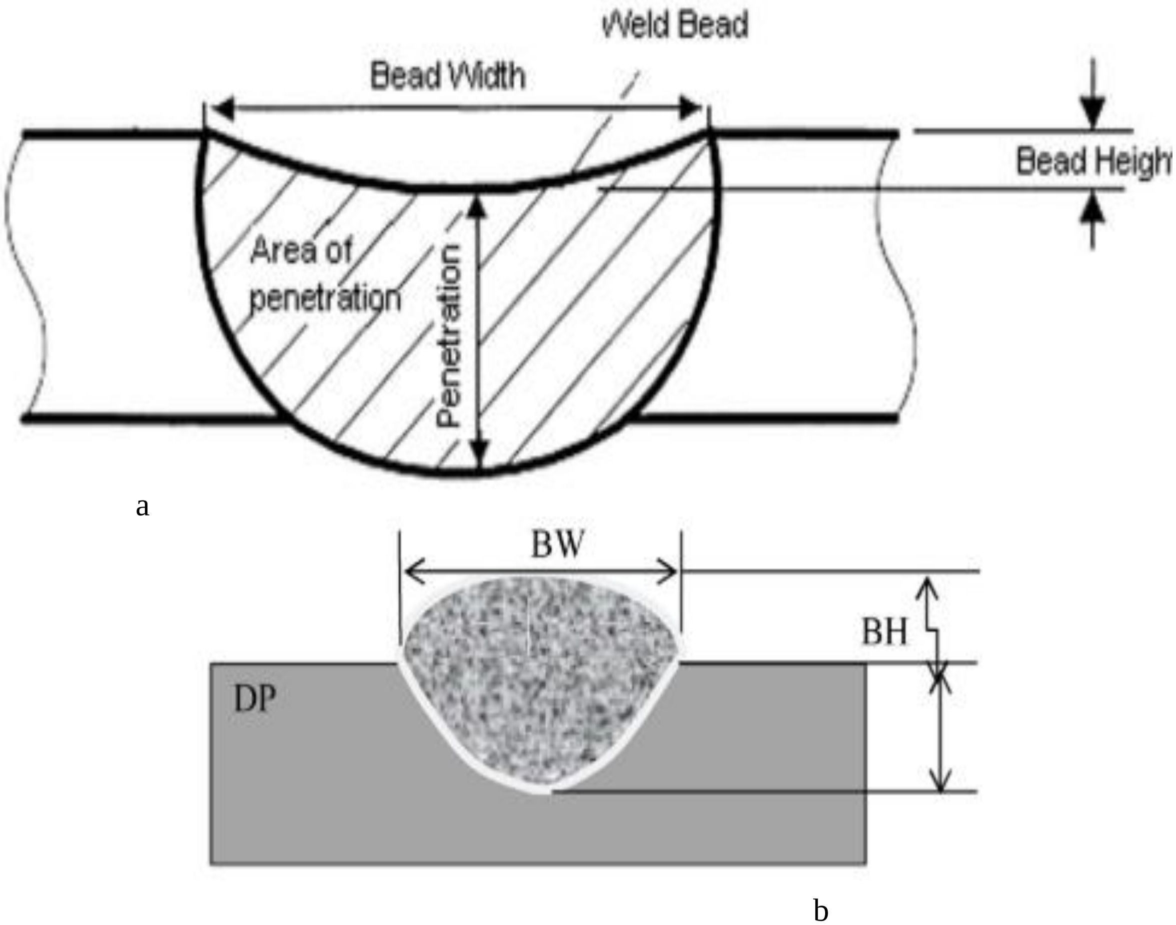


Figure 2.1 Weld bead geometry(Srivastava & Garg, 2017b)

2.6. Research gap

The revised study had not addressed with proper research work in order to produce good quality products based on mild steel welding process with good tensile strength, hardness, toughness and surface finish to minimize defective products. But some researcher was tries to solve those problem and proposed to minimize defects by using Taguchi method. However, investigation of metal inert gas welding process parameter needed more analysis within this work, design of experiment was used to optimize welding parameters to produce good quality of products.

CHAPTER-3

3. MATERIALS AND METHODOLOGY

3.1. Introduction

This chapter describes the research methodology undertaken and focus on objective investigation of a subject or problem in order to discover relevant information and principles and the best optimal level of design of experiment parameters has been selected and the final step is to predict and summaries the improvement of the welded quality and by using welding the optimal level of defects by experimental design parameters and proper materials selection.

3.2 Research Methodology

For this study, the first step is governing evidence and concepts about this thesis has obtained from various academic sources such as MIG welding books, research journal articles related to this thesis objective, previous studies, manual of the company related welding principle, and different types of websites. Second step of this study, experimental design based on the selected welding parameters has conducted and the process flow has indicated in figure 3.1, then problem analysis, welding parameters optimization have conducted and the process welding. The systematically organization of this study represents in this flow chart was a powerful statistical technique used to study and analyze the effect of various process parameters upon the response. This research analysis starts with the implementation concept of Design of Experiment (DOE), S/N-ratio, ANOVA, Correlation, Regression is optimized(Goundar and Universities, 2019).

3.3. Data Collection Methods

This research utilized data collected from both primary and secondary

3.3.1. Primary Data Collection

The first method of primary data collection was through direct observation by visual inspection in order to identify MIG welding defects; this activity has been done when the vehicle body was welding process conducted giving the equal chance for all factors and levels until to be got the optimum one for the next design of experiment. The existed data was collected during MIG welding fabrication asking the documented and recorded data for most practically known setting by welding technicians(Ajayi, 2017). The second method of primary data collection was through regular interview with concerned person about originated of the welding defects and the interview activity during collecting data was accomplished and conducted on supervisors and technicians as well as Engineers in MIG welding fabrication shop in EEGBAMI.

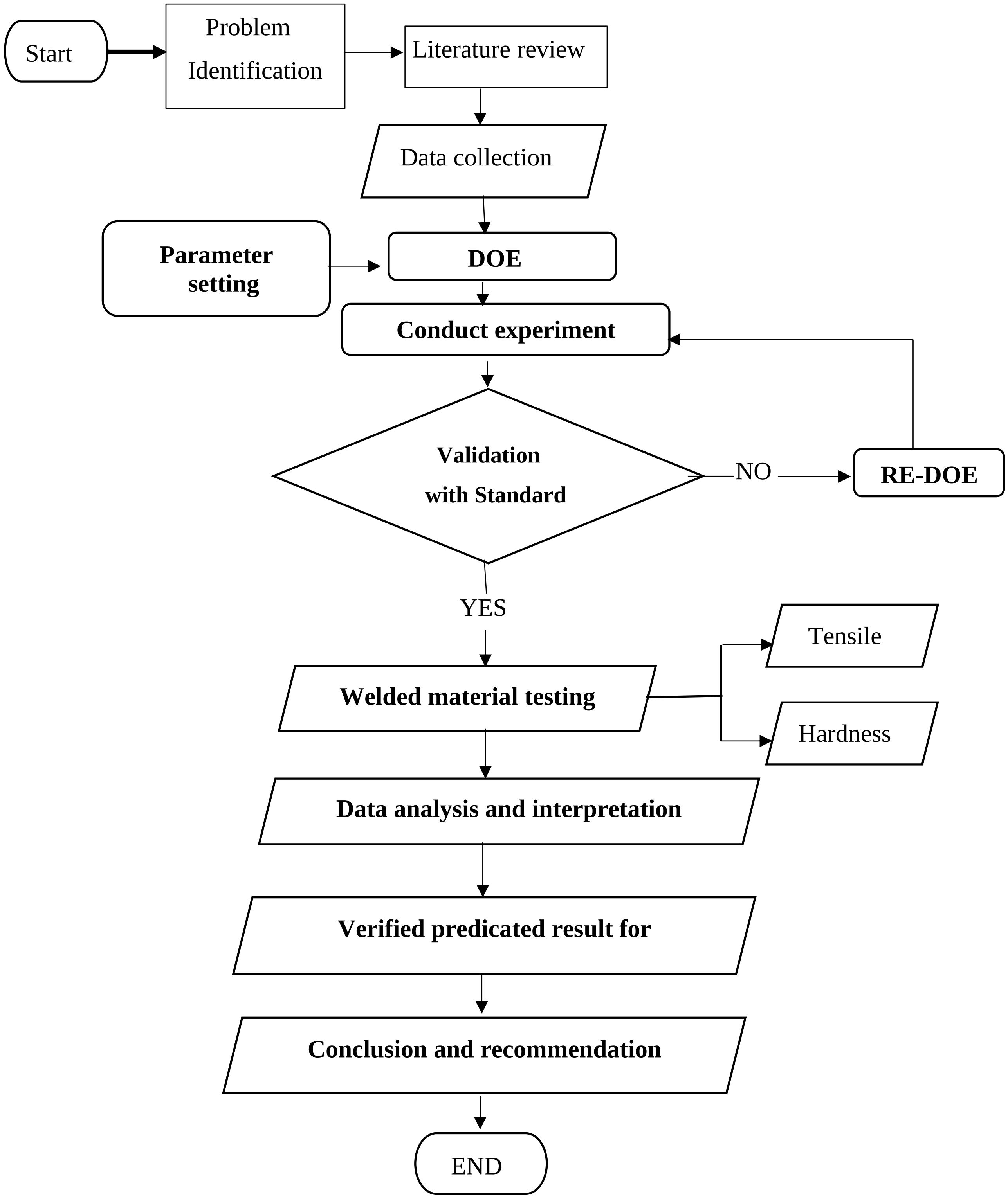


Figure 3.1 Thesis methodology flow charts

3.3.2 Secondary Data Collection

The secondary data collection was also collected from the company manual and recorded data and this data was used to distinguish which types of defects frequently happen in the data. The best collection Parameter Selection DOE (quality analysis) Conduct experiment validation with Standard RE-DOE welded material testing data analysis and interpretation verified predicated result for optimization conclusion and recommendation to the company. Particular product of automotive parts and from this recorded data collected some root cause of the defects. The other method of secondary data collection used in this thesis was from different types literature review like published journal and different types of welding books.

Therefore this reference used to know how each defects caused and their originated or their root cause of the defects as well as level of effects on the final MIG welding products, in addition to use, compare the data collected through primary with the secondary data, because the secondary data was more connected with the science than the data collected through regular interview(Goundar & Universities, 2019).

3.4. Method of Data Analysis

The study was using statistical analysis and the analysis tools were consisted of;

- Minitab software (for ANOVA and regression analysis), RSM (for prepare number of experiments using number of factor and their level) and for optimization parts. In addition, to this, the results have been verified using tools like, ANOVA, cause-and-effect diagram.
- Cause-and-effect diagram to identify the root cause of the defects.

3.4.1 Design of experiment methods

Design of experiments (DOE) is a systematic efficient method that enables scientists and engineers to study the relationship between multiple input variables (factors) and key output variables (responses). This is a structured approach to collected data and for making discoveries, the design Experimental was first introduced in the 1920s by R. A. Fischer working at the agricultural field station at Roth Amsted in England(Moulon et al., 1985). One of Fisher's responsibilities was to analyze agricultural field trials, during this period Fisher invented the factorial approach to designed experiments in the process reduced the calculations to comparisons of means and thus greatly simplifying the analysis, arranging trials on fertilizers on plots to protect against the underlying effect areas such as moisture, gradient, nature of soils, etc(Taylor et al., 2011).

Fischer developed the basic principles of factorial design and the associated data analysis known as ANOVA, during research in improving the yield of agricultural crops and classical experimental design was identified by b^a, where 'a' represents the number of variables and 'b' represents the levels (Alagumurthi et al., 2017). This encompasses the following

- ❖ Sequential experimentation to model process behavior.
- ❖ Prediction of future process behavior.
- ❖ Investigation and isolation of factors affecting mean and variation independently.
- ❖ Selection of experimental design from consideration of full fractional design.

3.4.2 Steps of experiment

Do the layout out of a detailed experimental plan in advance before doing the experiment so that experiment results are both objective and valid(*Design of Experiments* , 2019).

1. **Perform Experiment:** perform Design and experiment to test the hypothesis and the experiment has an independent and dependent variable. That means change or control the independent variable and record the effect. were the dependent variable was important to change, one variable for an experiment rather than the try to combined with an effects of variables in an experimental method (Shalabh, 2016).
2. **Data Analysis:** data analysis was record, observations and analyze the meaning of the data and by prepared a table or graph of the analyses which is nothing won't to throw out the data points that think bad or don't support the predictions. Because of the most incredible discoveries in science area, were made the data was looked wrong! and may need to perform a mathematical analysis to support or refute they hypothesis(Being, 2019.).
3. **Draw Conclusion and Recommendations:**
   Conclude whether to accept or reject hypothesis of the experiment there are not right or wrong outcome either result is better. because of Sometimes repeating an experiment may give a different result and in other cases the hypothesis may have alternative predict on outcome. Therefore the results compiled into a lab report or formally submitted whether its accepted or reject the hypothesis, likely learned something about the subject and revise the original hypothesis from a new one for a future experiment(Lammers and Babbie, 2005).

3.4.3 Practical methodology for Design of Experiment

The methodology of Design of Experiment is fundamentally divided into four phases (Jankovic et al., 2021). Those are:

- Planning phase;
- designing phase;
- conducting phase and analyzing phase.

Planning Phase: In planning phase the following steps are involved(Jankovic et al., 2021).

1. **Problem recognition and formulation:** A clear and succinct statement of the problem can create a better understanding of hat need to be done. The experiment contains a specific and measurable idea that can yield practical value on the company and some of the manufacturing problems that have addressed using an experimental approaches (Jankovic et al., 2021).
    - Development of new products: improvement of existing process or products
    - Improvement of the process/ product performance relative to the customers' needs
    - Reduction of the existed process spread which leads to poor capability
    - Having decided upon the objectives of the experiment and experimentation team can be formed.
2. **Quality characteristic selection**: the selection of a suitable response for the experiment is critical to the success of any industrial designed experiment and the experimental data can be a variable or attribute in nature. The variable responses during experimental such as length, thickness, diameter, viscosity, strength, etc. As the whole to provide more information about attribute responses such as good/bad, pass/fail or yes/no and the variable characteristics or responses require to the fewer samples than attributes require to achieve the same level of statistical significance. Experimental design be able to define the measurement system prior to performing the experiment in order to understand what to measure and what to do, where ever to measure, who is able to measurements, etc. It is very good to make too sure that the measurement system is capable, stable, robust and insensitive to environmental changes (Lammers & Babbie, 2005).

3. **The selection of process variables:** during some possible ways to identify potential process of getting variables are the method of engineering knowledge of the process, historical data, cause and effect analysis and brainstorming. If important factors left out of the experiment and the results was note accurate within useful for any improvement actions. It has a good practice to conduct the screening out of the experiment in the first phase of any experimental investigation to identify the variable and the most important of design process parameters (Lammers and Babbie, 2005).
4. **Classification of process variables:** due to identified the fact of process variables and classify them into controllable and uncontrollable variables. The Controllable variables are which controlled by process engineer/production engineer. Uncontrollable variables or noise variables are difficult for expensive to control in actual production environments times. The Uncontrollable Variables, such as ambient temperature fluctuations, humidity fluctuations, raw material variations, are examples of noise variables. These variables may have some immense impact on the process variables, therefore must be dealt for enhanced understanding of our process and the effect of nuisance variables which can be minimized by the effective application of DOE principles such as blocking, randomization and replication(Marlin, 1996).
5. **Determining the levels of process variables:** a process variable wait for an experiment level is the value of process parameters, these chosen process variable is qualitative such as type material e.g., mild steel, or quantitative such as current, speed, voltage, and arc gap(Silva, 2016).
6. **List all the interactions of interest:** interaction among variables is quite common in industry areas to order effectively interpret the data of the experiment as a result, it is highly desirable to have a good understanding about the interaction between two process variables(Silva et al., 2016). The best way to relate the interaction effect of a factor or process variable effects and an input control, unlike factors or process variables, interactions do not enter into descriptions of trial conditions and the number of two-order interactions within an experiment that can be easily obtained by using a simple equation(Shalabh, 2016)

$$N = n \times (n-1)/2 \quad (2.1)$$

Where N is the number of factors, n number of levels. For the four factors in an experiment, the number of two-order interactions can be equal to sixteen.

Designing phase: the design phase, one may select the most appropriate design for experiment the experiments can be analysis statistically designed using classical approach which is advocated by Sir Ronald fisher, orthogonal array approach advocated by Dr. Genichi Taguchi and the variables are search approach promoted by Dr. Dorian Shiann(Antony, 2006).

The size of the experiment is dependent on the number of factors and interaction to be studied, the number of levels of each factor, budget and resources allocated for carrying out the experiment etc and due to the design stage the Taguchi method is quite important to consider the confounding structure and resolution of the design(Shalabh, 2016).

Conducting phase: This a phase in which the planned experiment is carried out and the results are evaluated and the Several conditions are recognized as being recommended prior to executing an experiment, such as(Wulff, 2003):

- ✓ Selection of the better location for carrying out the experiment.
- ✓ Availability of materials/parts, operators, machines, etc.
- ✓ Assessment of the viability of an action in monetary terms by utilizing cost benefit analysis and monitor the experimental trials.
- ✓ Record the observed response of experiment values on the prepared data sheet or directly into the computer.

Analyzing phase

After performing the experiment, the next phase is to analyze and interpret the results so that valid and sound conclusion can be derived by DOE (Wulff, 2003).

- Determine the design parameters or process variables that contributed effect on the mean process performance.
- Determine the design parameters or process variables that influence performance variability.
- Determine the design parameter levels that to achieve the yield the optimum performance.

3.4.4 Statistical Analysis of Experimental Data

1. **Analysis of variance (ANOVA)**

Analysis of variance (ANOVA) is a statistical method which are used to detect differences between experimental trails. ANOVA is warranted in experimental designs with one dependent variable that is a continuous parametric numerical outcome measure, and multiple experimental groups within one or more independent variables and which is to compare the variance or variation between the experimental data. Yet, to identify the variation within each particular sample sizes when the variation is much larger that means; the different samples will not be equal(Sawyer, 2009).

2. **Assumptions of ANOVA**

Assumptions for ANOVA pertain to the underlying using mathematics of general linear models and specifically, a data set should meet the following criteria before being subjected to ANOVA(Asai, 1991).

- **Parametric data**: for ANOVA analysis parametric data (ratio or interval measures) are required
- **Normally distributed data within each group**: It follows that a fundamental assumption of parametric ANOVA is that each group of data level can be normally distributed and the normal distribution curve can be described by whether it has symmetry about the mean and the appropriate width and height (Pett, 2022).

3.5. Materials and Experimental Procedure

For this thesis the process parameters of welding defects were used to determine the MIG welding parameters that would produce an optimal weld bead quality. The welding process parameters were the TS input variables and output variables of the MIG welding process parameters are optimized. The base metal was low carbon steel (A36) with a square butt joint as much as, a single-pass welding process was used. When the welding Matrixes for 2*8, L16 orthogonal arrays was generated. For this study, a total number of specimens “16” sample was prepared & the combination DOE with optimization of welding control parameters to obtain the best results can be achieved with a good welding quality and shows in table 3.4, the selected MIG welding parameters and their levels for the DOE.

3.5.1 MATERIALS

For this study A-36 mild steel plates were used, it was a type of carbon steel and for specimens' mild steel plates in dimensions (100 x 100 x 3) mm length, width and thickness respectively and this type of material was used to perform the experiments. The material composition has tasted during spectrometer in Ethio-Engineering Group Addis Machine and Spare Part Manufacturing Industry. This steel possesses excellent size accuracy; easily shaped required shape, not too hard, carburizing can increase hardness and surface, its low-cost material. Generally, these carbon family strengthening is accomplished by cold work, relatively stress relieved and has toughness, easily fabricate with the least cost to produce, Yield Strength of 250MPa, ultimate tensile strengths between 550MPa, whereas ductility of 30%EL (Jiru et al., 2022). Chemical composition of welding plates metal sample for conducting design of experiment in this research work for obtaining optimum welding factor and parameter combinations and the specimens were cut according to the standard dimensions for each test (tensile, hardness, material microstructure, and toughness tests) using cutting tools

3.5.1.1 Selection of Material

Selection of material is mild steel were the thickness 3mm is used for the experiment and it has a carbon content 0.25%, hardness value 13.4HRN for the light vehicle body. At figure 3.2 mild steel Plate dimensions (100 x 100 x 3) mm length, width and thickness respectively was used for experiments analysis. An appendix "A" mild steel material characteristic that is used to perform the experiments and its composition was tested using spectrometer at Ethio Engineering Group Addis Machine and Spare Part Manufacturing Industry.

Figure 3.2 A 36 mild steel (100*30*3)

3.5.1.2 Materials Used:

A 36 mild steel plates of size 100 x 100 x 3mm which are used for each plate sample equal in the dimension as the welding material for DOE. During this welding experiment was conducted the used wire electrode materials called ER70s-6 electrodes.

3.5.1.3 Equipment's Used:

For this chapter DOE has conducted for MIG welding parameter optimization and equipment used such as; Welding Machine, Gloves, Shielding Gas Bottle (25% Carbon Dioxide and 75% argon), Protecting Helmets, Clothing, Pillars, Wire Brush, Anti Spatter, Chisels and Punches, Vice and Anvil, Scriber, Permanent Marker, Soapstone, Grinding Machine and the Figure 3.3 shows MIG welding specimens during welding operation to optimize the product quality.

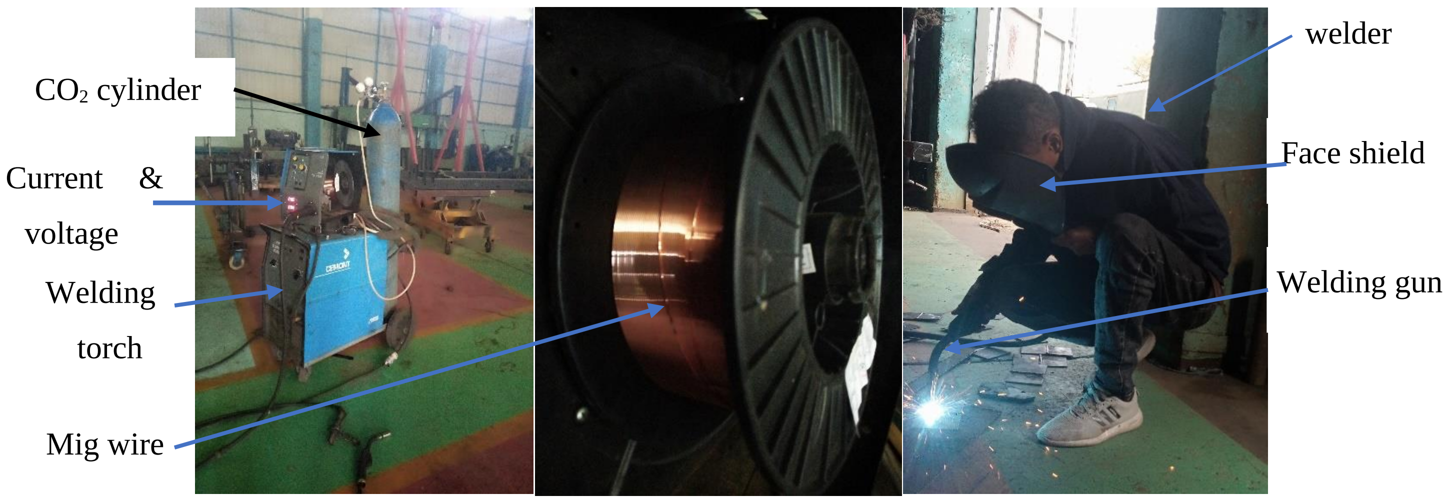


Figure 3.3 MIG BLUMIG 503S model machine and specimens for welding

3.5.1.4 Technical Specification for MIG Welding Machine

MIG welding is a type of an arc welding process in which used a continuous solid wire electrode in fed through a welding gun. The weld pool was joining the two base materials together by covering shielding gas from a weather contamination and sent through the welding gun and protects the weld pool from defect. In table 3.1 are discussed detail about MIG weld welding requires and generally three things was required, electricity to produce heat, an wire electrode to fill the joint, and shielding gas to protect the weld bead from the air contaminate and MIG welding is done using a very small electrode that is fed continuously, while the operator controls the amount of weld being done(Ascs, 2010).

Table 3.1 MIG Welding Technical Specification

Model	BLUMIG 503S
POWER	22.5-25 N
Current	45-450 ampere
Voltage	25-100 volt
Weight	182 kg
Wire range	0.6-1.2 mm
Dimension	863*483*1041 mm (H*W*D)
Wire speed	0.5-58 mm/sec

3.5.2 MIG Welding Experimental Procedure

3.5.2.1 Cleaning the Welding Specimens:

Before conducting welding experiment, the surface of the welding specimens should have to clean enough in order to get better surface finish, properly unit weld pool and reduce amount of porosity. Prepare welding equipment ready, Set the welding parameters, Wear protected safety equipment. Then weld the specimens. After welding stay it until to cooled down, grind the welding specimen and finally finish welding process.

3.5.2.2 Design for Experimental Set up:

For this study, specimen was prepared by welding process and the type of using specified material in dimension to fabricate MIG welding of square butt joints. Welding experiments have been carried out using MIG Welding process and an ER1100 wire electrode with 1.2mm diameter has been used as a consumable electrode. Figure 3.4 shows square butt joint and geometry welding specimen for welding settings. For this setting, the design of experiment welding operation was conducted by two phases.

Table 3.2 setting the welding parameter

S/N	Current (Amp)	Voltage(volt)	Speed(mm/s)	Distance(mm)
1	90	17	20	10
2	90	19	25	12
3	90	22.5	30	14
4	90	26	35	16
5	100	17	20	10
6	100	19	25	12
7	100	22.5	30	14
8	100	26	35	16
9	120	17	20	10
10	120	19	25	12
11	120	22.5	30	14
12	120	26	35	16
13	150	17	20	10
14	150	19	25	12
15	150	22.5	30	14
16	150	26	35	16

Figure 3.4 welded sample for study

3.6. Weld bed Geometry

Figure 3.5 was described the MIG welded bead material after the process parameters are optimized and the weld quality is mostly determined by the geometry of the weld bead(Esme et al., 2009) and Bed geometry is heavily influenced by welding process parameters, such as welding current, voltage rate, arc speed and arc gap (Esme et al., 2009) and other variables such as the heat-affected zone, bead width, bead height, penetration, and area of penetration, as well as the mechanical qualities of the weld, such as tensile strength, hardness, and bending strength, are all crucial in defining the mechanical properties of the weld(Jiru et al., 2022). The optimal weld bead geometry has a smaller-the-better quality characteristic for the front height, front width, back height, and back width of the weld bead (Tarng & Yang, 1998) and through the analysis of variance, it is seen that welding speed, welding current, and polarity ratio are the important welding process parameters for the determination of the weld bead geometry(Tarng et, al, 1998).

Figure 3.5 Photos of specimens during welding experiment

3.7. Liquid Penetrant Testing (LPT)

liquid penetrant test is a type of non-destructive test and this type of material-testing method that employs capillary forces to locate and see surface defects (Alexandria et,al 2000). This method for the detection of discontinuities that are open to surfaces such as cracks, fractures, laps, seams and may be affected by fatigue, applied impact loads, quenching hardening, machining, remove surface by grinding, forging, shrinkage or overload and as a result, it is often used on lots of machined parts, as well as weldments, manufactured products, castings, forgings and other items that will be placed into service(Afzal, 2000). The penetration of liquid penetrant open surface discontinuities is the basis of PT and Surface defects, such as surface cracks, porosity, absence of fusion, and intergranular corrosion, are detected using the dye penetrant method (Capabilities et al., 2003). Therefore, the Welds area and parent material were subjected to dye penetrant testing and among these methods of tests and this research work has done using LPT because of it identify the quality problem by detecting amount of crack, porosity on the surface of the welded specimens depend on thickness show in figure 3.6.

Figure 3.6 Liquid penetrant and developer used

3.8. Experimental Procedure

Before surface area of test piece is evaluated, then, using a multi-purpose cleaner, pre-clean the area to remove any superfluous material such as scale, slag, grease, oil, paint, water, and the like. Cleaning with chlorinated hydrocarbons, volatile petroleum distillates, or acetone. Some dwell time should be allowed for the evaporation of the volatile cleaner from discontinuities before the penetrant is applied(Capabilities et al., 2003). Then the penetrant is applied to the surface area of the test samples by spraying. After the penetrant is applied some dwell time was allowed until the capillary action allows this to permeate small fractures or pores(Afzal, 2000).

After carefully removing the remaining test media from the surface, a developer is used to draw the dye penetrant out of the pores and cracks, sufficient time should be allowed after the developer has been applied to permit it to draw or blot out the penetrant from any discontinuities which resulting in indications that may be analyzed as a defect. Finally, the test specimens were cleaned with solvents following the completion of the examination as shown in figure 3.7.

Penetrant adds

After developer adds

Figure 3.7 Treated sample when liquid penetrant is processed

3.9 Mechanical Property Testing For various mechanical tests

Metal inert gas-welded experimental specimens were created from A36 mild steel metals and machined using ASTM E-18 in order to determine the necessary dimensions for studying their properties.

3.9.1 Tensile Strength

The whole principles of deformation and fracture can be described through the use of a uniaxial tension loads (or tensile) test. Therefore, only a communiques description is presented for the purpose of introducing deformation and fracture mechanisms in metals. In general, the tensile tests are performed on A 36 mild steel specimens 3mm thickness plate shown in Fig. 3.9. The samples are loaded uniaxially, along the length of the specimen and the applied load and extension or change in length of the sample are simultaneously measure.

3.9.1.1. Specimen preparation and test procedures

The preparation of test specimens depends on the purposes of testing and the governing test method or specification. A tensile specimen usually has a standardized sample cross-section. As shown in Table 3.3 and Figure 3.8. It has two neck and a gauge (section) in between. The shoulders and grip section are generally larger than the gauge section by 33% so they can be easily gripped (Davis, 2004 and Jiru et al., 2022). The specimens prepared for testing were shown in figure 3.9.

Table 3.3: ASTM standard for tensile test specimen (Davis, 2004 volume 9).

All values in inches (1 in = 25mm)	Plate type (1.5 in. wide)	Sheet type (0.5 in. wide)	Sub-size specimen (0.25 in. wide)
Gauge length	8.00 ± 0.01	2.00 ± 0.005	1.000 ± 0.003
Width	1.5 + 0.125–0.25	0.500 ± 0.010	0.250 ± 0.005
Thickness	0.188 ≤ T	0.005 ≤ T ≤ 0.75	0.005 ≤ T ≤ 0.25
Fillet radius (min.)	1	0.25	0.25
Overall length (min.)	18	8	4
Length of reduced section (min.)	9	2.25	1.25
Length of grip section (min.)	3	2	1.25
Width of grip section (approx.)	2	0.75	3⁄8

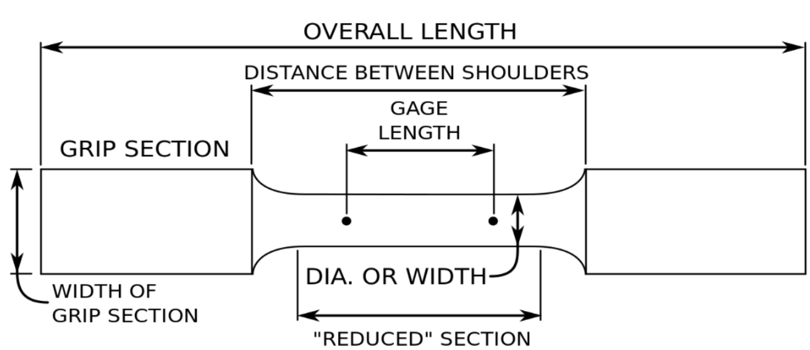
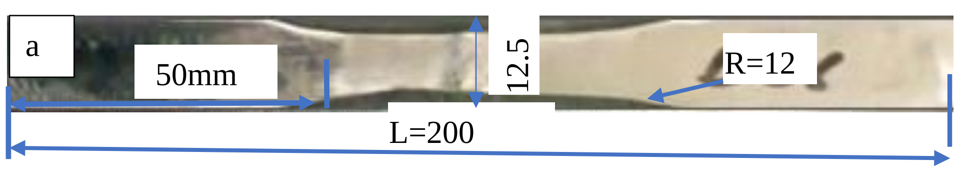


Figure 3.8 tensile test specimen standard dimension (Davis, 2004 and Jiru et al., 2022)



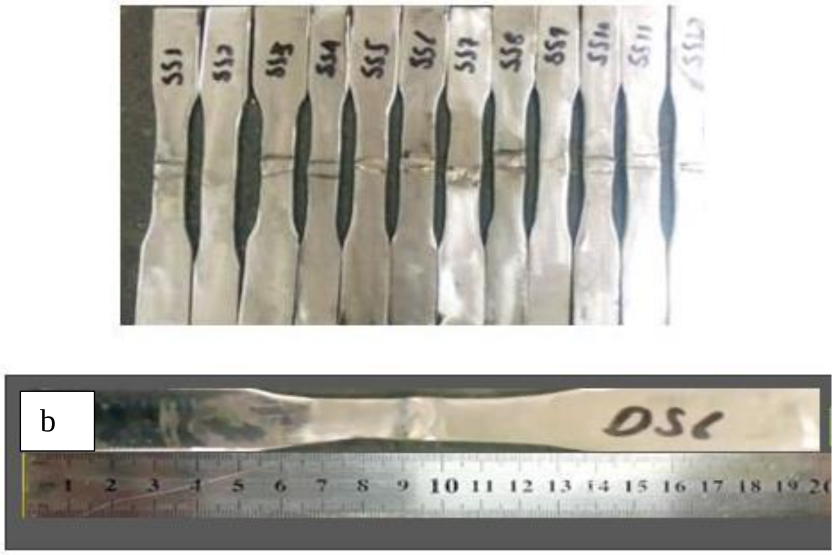


Figure 3.9 sample prepared for tensile strength from mild steel specimens.

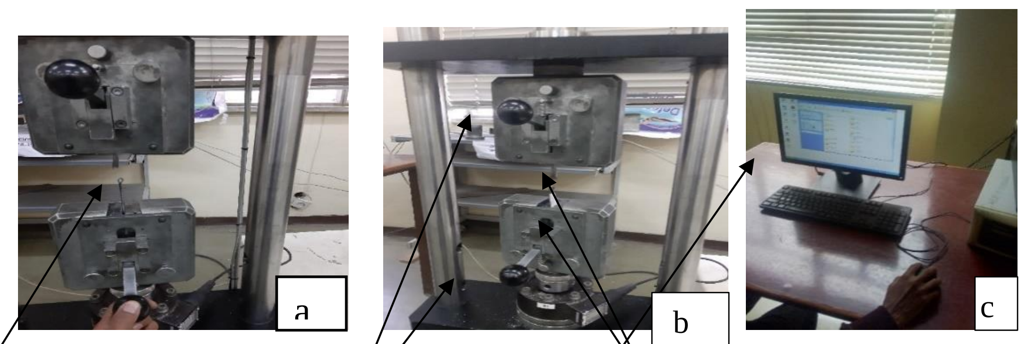


Figure 3.10 Universal tensile testing machines during specimen is test

Figure 3.11 The result after tensile test at defense engineering collage

3.9.2 Hardness Testing

In setting up of hardness-testing equipment, the hardness of a weldment or welded specimen is assessed by pushing a hardened steel ball or diamond point into a flat surface on the weldment or welded specimen with a prescribed load and then measuring the size of the resulting indentation(Jiru et al., 2022). The Vickers, Brinell, and Rockwell tests are the three most used hardness tests machines and the Brinell hardness testing is quick, cheaper, easily and largely used during destructive testing method, according to ASTM E-18, as shown in Figure 3.12, has three sample zones. As (Apts et al., 2019) the hardness of the welded area of samples was examined using BROOKS Brinell hardness testing equipment with a ball shape indenter at a force of 100 kg for a duration of 5 s and the weld's HBN hardness was assessed first with a standard Brinell hardness tester with a ball shape indenter, and then the material's hardness was determined with an EQUOTIP2 digital hardness tester that reads in HRB.

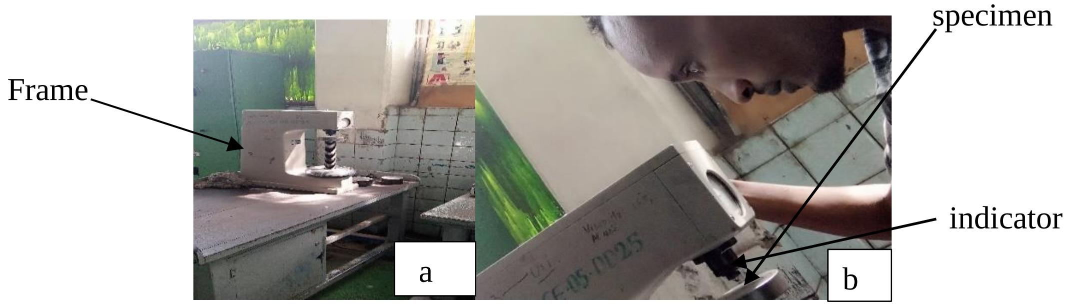


Figure 3.12 During hardness test on Brinell hardness testing machine at EEAMSMI

3.10. Microhardness setup

Microhardness testing was performed using a Vickers hardness testing machine at the material science engineering laboratory and the Vickers hardness test was used for each specimen's test and the resulting impression was measured and examined under a microscope before being turned into a hardness number (Hoboken, NJ, USA, 2007). Figure 3.13 were microhardness testing; the samples were sectioned using an abrasive cutter with a coolant to protect the properties of the metal for testing. Then, the material was mounted, after mounting, the specimens were grinded using silicon carbide grit papers: #220-6600-800-1200-2000. The cross-section of the samples was 20 mm × 20 mm × 3 mm. After this all the samples were mounted and observed.

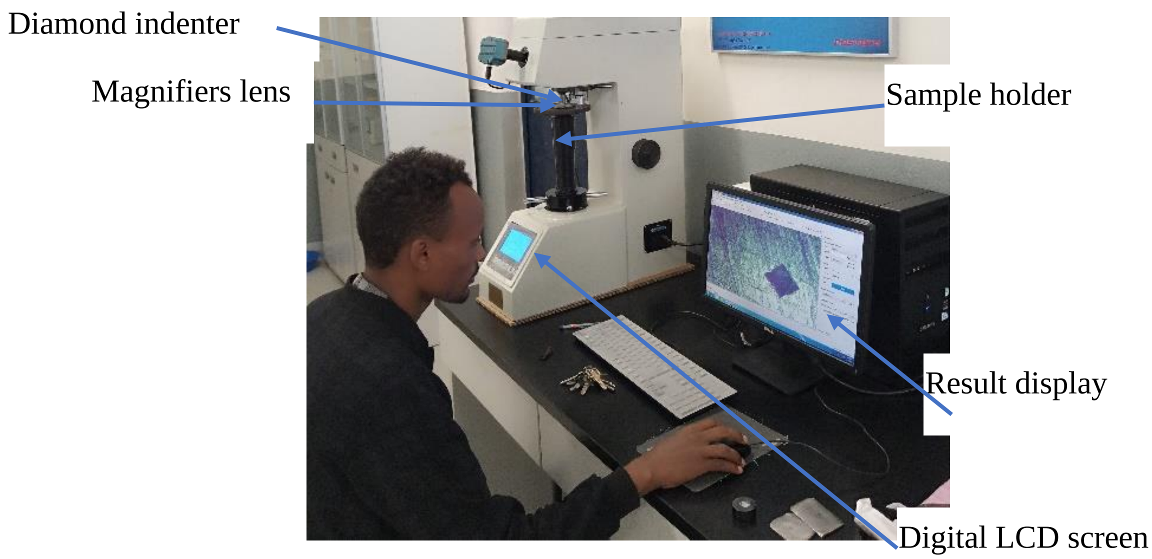


Figure 3.13 Vickers's HVS50 hardness testing machine (ASTU material laboratory)

3.11. MIG welding parameters

MIG welding is a process that uses copper alloy electrodes to concentrate welding current, into a welding bead and to simultaneously clamp the plates together, will melt the metal and form the weld. That permits the welding to occur without excessive heating to the rest of the steel plate. All provides an entire line of MIG welders both A.C. and D.C. for the entire metal-working industry.

3.12.1. Welding current

The welding current is the most important parameter in MIG welding which determines the heat generation by a power of square as shown $Q=I^{2}Rt$. The size of the weld bead increases rapidly with increasing welding current, but too high current will result in expulsions and material deteriorations(Srivastava & Garg, (2017b).

3.12.2. Welding voltage

The welding voltage primarily controls the arc length which is the distance between the molten weld pool and the wire electrode at the point of melting within the arc. As the voltage is increased, the weld bead will flatten out more and have an increasing width-to depth ratio(kumar et al, 2019).

3.12.3. Welding arc gap (standoff distance)

The arc length is one of the most important variables in MIG that must be held under control. Stick out of the electrodes affects the weld bead penetration and metal deposition rate because it changes the electrode heating due to electric resistance(S. V. A. Kumar & Gandhinathan, 2020). Increase in stick out increases the melting rate and reduces the penetration due to increased electrical resistive heating of the electrode itself and Selection of welding current is influenced by electrode stick out and electrode diameter and in general, high welding current is preferred for large diameter electrodes with small electrode extension in order to obtain optimal weld bead geometry as shown in figure 3.15 (S. V. A. Kumar & Gandhinathan, 2020).

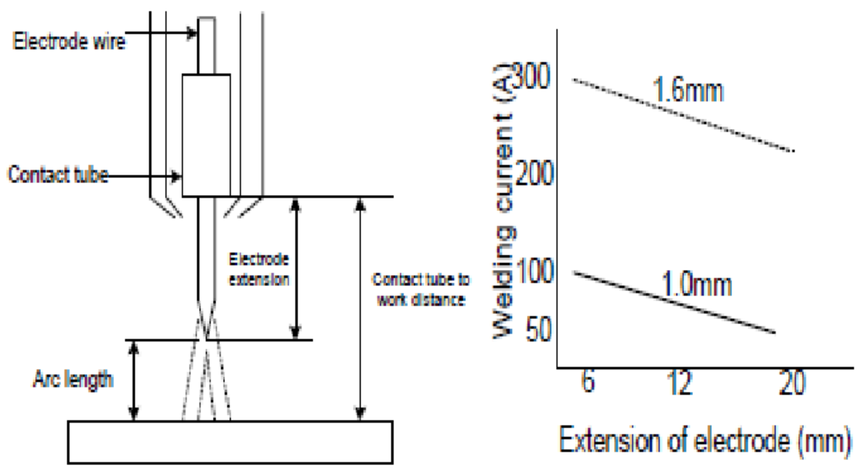


Figure 3.15 Schematic diagram showing electrode extension(S. V. A. Kumar et al., 2020)

3.12.4 Welding speed (arc speed)

The travel speed is the rate at which the arc travels along the work-piece and it is controlled by the welder in semiautomatic welding and by the machine in automatic welding. The effects of the travel speed are just about similar to the effects of the arc voltage. The penetration is maximum at a certain value and decreases as the arc speed is varied. (S. V. A. Kumar & Gandhinathan, 2020).

3.13. Determine Parameter Design Using Orthogonal Array

In order to determine the effect on response of use control factors during conducting an experiment. Factors can be categorized based on a continuous variable but only use four controlled values in the experiment(Shalabh, 2016).According to standard design of experiment, OA design is L16 (2^4) which shows the RSM orthogonal array selected the parameters and levels, four and two respectively.

The L16 orthogonal array was selected from the array selector of design of experiment in MINITAB software package. Table 3.4 shows the standard orthogonal array for design of experiment. From this table standard full factorial design numbers of runs are sixteen.

Table 3.4 Standard RSM OA table, (George E.P. Box and K. b. Wilson).

Design Model	Run Points	Number of Factors (K)			
		K=2	K=3	K=4	K=5
2^K CCD/ BBD	Factorial Points 2^K	4	8	16	32
	Axial Points 2^K	4	6	8	10
	Center Points Nc varies	5	5	6	6
	Total	13	19	20	48
3^K Design		9	27	81	243
Choice of α	Spherical Design	1.4	1.73	2	2.24
	Rotatable Design	1.4	1.68	2	2.38

There are many standard orthogonal arrays suitable for each of the arrays is meant for specific number of independent design variables and levels. To conduct an experiment in this research firstly understanding the influence of four different independent variables with each variable having two set values (level values) then L16 orthogonal array can be the right choice to conduct experiment. The L16 orthogonal array is meant for understanding the effect of 4 independent factors each having 2 factor level values. All the four factors have interaction with each other with in two level factorial designs; this typical case of interaction would be the interaction between all parameters shown on table 3.4, 3.5 and 3.6 shows un-coded parameters for design of conducting experiment which is selected for the experiment of all significant factors of MIG welding process.

Table 3.5 symbol, Parameters, units and their Values at Different Level

Symbol	Parameter Name	Units	Level	
			Low	High
A	Current	Ampere	90	150
B	Voltage	Voltage	20	35
C	Travel Speed	mm/min	17	26
D	Standoff distance	mm	10	15

In table 3.5 parameters and their levels are given each two-level parameter has 1 degree of freedom (DOF = n-1; where n= Number of levels-1) which is 2-1= 1, it has a degree of freedom of 1 and the total DOF required for four parameters each at two levels.

As per determine parameter design using orthogonal array method the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. So, a standard L8 ,2-level, OA having 7 DOF, mathematically 16-1= 15, which is calculated as difference between total no of DOF (15) and one DOF for experiment was selected for this analysis.

In determine parameter design using orthogonal array the word optimization implies determination of best levels of control factors for the best levels of control factors which maximize the Signal-to-Noise ratios and determine parameter design using orthogonal array has 30 runs as a desired output characteristic. The experiments that are conducted to determine the best combinations for welding parameter is based on OA are balanced with respect to all control factors.

This in turn implies that the resources (materials and time) required for the minimum experiments, Source: (MINITAB software design package). For data analysis the data are collected experimental by having machine record counts. In some reason, it mostly helpful to code data to simplify the recording process. Where current 90. Assign 1, 100 current assign 2, 120 current 3, 150 current assign 4. Voltage 1for 17, 2for 19. 3 for 22.5, 4 for 26, arc speed 20 assigned 1,25 assigned 2,30 assigned 3and arc speed 35 assigned 4 and the last stand off distance 10 assigned 1,12 assigned 2, 14assineg 3an 16 assigned 4 are discussed in table 3.6.

Table 3.6 L16 Coded Parameters in OA used for RSM, Source: (RSM in DoE)

	Controlled Parameter			
Experiment No	Current	Voltage	Travel Speed	Standoff distance
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	1	1
6	2	2	2	2
7	2	3	3	3
8	2	4	4	4
9	3	1	1	1
10	3	2	2	2
11	3	3	3	3
12	3	4	4	4
13	4	1	1	1
14	4	2	2	2
15	4	3	3	3
16	4	4	4	4
2^{k-1}	2^3	2^2	2^1	2^0

Table 3.6 coded parameters and the design matrix, where, k=4, 3, 2, 1 in DOE table for factors and the dynamic problems have a signal factor while the Static problems do not have

any signal factor. In static problems, optimization is achieved by using three Signal- to-Noise ratios which are smaller-the-better, larger-the-better and nominal-the-best. In dynamic problems, optimization is achieved by using Signal-to-Noise ratios of Slope and Linearity (data assess robust designs).

3.14 Models Used in Calculating S/N Ratio Larger-the-better

Suppose for n number of continuous experimental observations y_1, y_2, $y_3 \ldots y_n$ which represents multiple values of a response characteristics Y formulated in the design of experiments, then the following respective S/N ratios become the most significant choices for the optimization of design parameter settings be selected: Smaller-the-better, nominal- the best, larger-the-better. For i = 1 to no. parameters(Rezzoug et al., 2008).

Table 3.7 L16 Un-Coded Parameters in OA used for RSM

Experiment No	Controlled Parameter			
	Current	Voltage	Travel Speed	Standoff distance
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	1	1
6	2	2	2	2
7	2	3	3	3
8	2	4	4	4
9	3	1	1	1
10	3	2	2	2
11	3	3	3	3
12	3	4	4	4
13	4	1	1	1
14	4	2	2	2
15	4	3	3	3
16	4	4	4	4
2^{k-1}	2^4	2^3	2^2	2^1

In table 3.7 un-Coded Parameters in OA used for RSM in design of the experiment, Source: (MINITAB software design package).

S/N = -10 * log10 [(1/n) * Π (1/yi2)] 3.1

3.15. For analysis quality of welding Mathematical Modeling

Design of experiment for the control factors which is directly influence the effect of welding negate that affect the welding quality in the process. RSM Design = f (A, B, C, D) 3.2

CHAPTER - 4

4. RESULT AND DISCUSSION

4.1 Introduction

Result which to make the analysis of the experimental data from the lab to find out exactly optimum value of the problem including reason out and decision making is the process of reaches to conclusions about what now done and future actions to pursue given a set of objectives and limits. generally, result and decisions is used to find out the correct answers for our problem throughout experiments

4.2 NDT and DT

4.2.1 Liquid Penetrant Testing (LPT)

Among these methods of tests, this research work has done using LPT because of its quality for detecting amount of crack, porosity on the surface of the welded specimens depends on thickness. The NDT data was. "✓" put defects of welded specimen on the figure 4.1 to identified defects in MIG Welding from all sixteen specimens

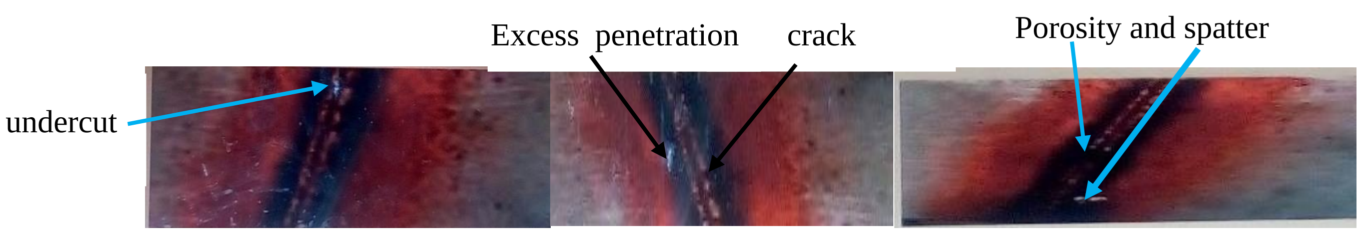


Figure 4.1 indetfication of defects

Table 4.1 Defects distinguished in MIG Welding sixteen DOE samples

Sample no	Porosity	Crack	Spatter	Excess penetration	Luck penetration	Luck fusion	Under cut
1	✓				✓		
2	Free						
3	✓		✓				
4	Free			✓			
5	Free					✓	
6						✓	
7					✓	✓	
8	✓						
9				Free			
10			✓				
11	✓						
12	✓						
13		Free					
14	✓						
15	✓						
16			✓				✓

Crack is microscopic or macroscopic scale which appears in the base metal, base metal weld metal boundary, or in the weld metal, weld surface or under the weld bead. The main cause of crack; inadequate pre-heat on high tensile and low alloys, incorrect composition of wire electrode, root pass too small in restrained joint, spray transfer welding with current too high, deep narrow weld bead, inadequate filling of crater. The fusion metals which are lacking at the root, side, or between two runs in a multi-run weld. It is due to voltage too low, current too low or too high, irregular surface, wrong torch angle. **Porosity** is a group of small voids; they occur mainly due to the entrapped shielding gases. The parent metal melted under the arc tends to absorb gases like hydrogen, carbon monoxide, nitrogen and oxygen they are present around the molten weld metal pool (Muhammed et al., 2016). Groove reduces the thickness of the plate and thus the area of the bead, which in turn weaken the weld and the main cause of **undercutting** is speed too fast, current too high, poor technique welding (Hekmatpanah, 2011).

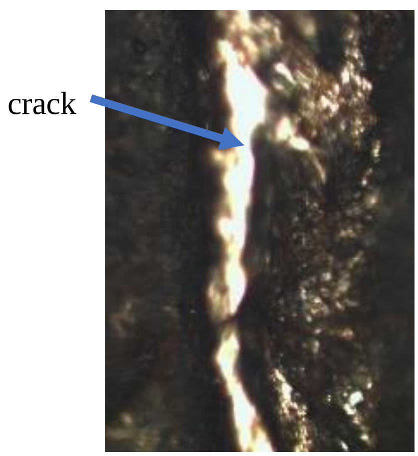


Figure 4.2 crack analysis during microscopy at ASTU material science lab

These gases get spread through the molten metal pool. Cause for porosity is gas flow too low or too high, blocked nozzle, leaking gas lines, draughty conditions, nozzles distance from work is too great, painted, wet or oily plate, wet or rusty wire electrode. **Spatter** is a small metal particles which are thrown out of the arc during welding and get deposited on the base metal around the weld bead along its length(Muhammed Raazick P K et al., 2016). Main reasons are current too low, preparation too narrow, root face too large, root gap too small, worn contact tip causing irregular are, incorrect alignment of plates MIG welding quality defects which is faced in EEGBAMI and Based on this each source of causes had highly affect the welding quality.

4.3. Micro hardness analysis

Based on result on Vickers microhardness values the welded part hardness are different in case of far from fusion areas indicated on Figure 4.3. from the selected sample 9, 5, and 3. The hardness values of all the weld areas were incisively higher than the hardness of the base metals. Welded fusions zone area has the highest hardness, and the average hardness value in the fusion zone of the welded metals was 370.6 HV. During test both sides of weld metal, HAZ and base metal hardness values of the base metals, the HAZ sides had higher hardness values. The hardness values in the HAZ of mild steel 257.66 Hv, and base metals was138HV. For the sample 5 selected because it seems a grater values of the average hardness value in fusion zone, heat affected zone, and base metal is respectively. 333.75, 227.6667, and 180.825. At the last the sample three (3) is more attractive than other so the fusions zone, heat affected zone, and base metals, 356.25, 243, 183.405 the result of Vickers hardness analysis.

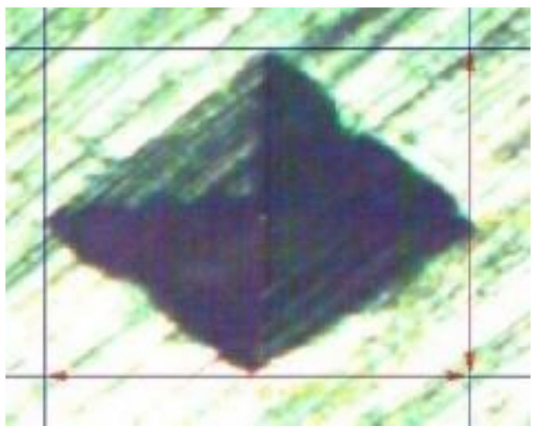


Figure 4.3 Indentation after test Samples

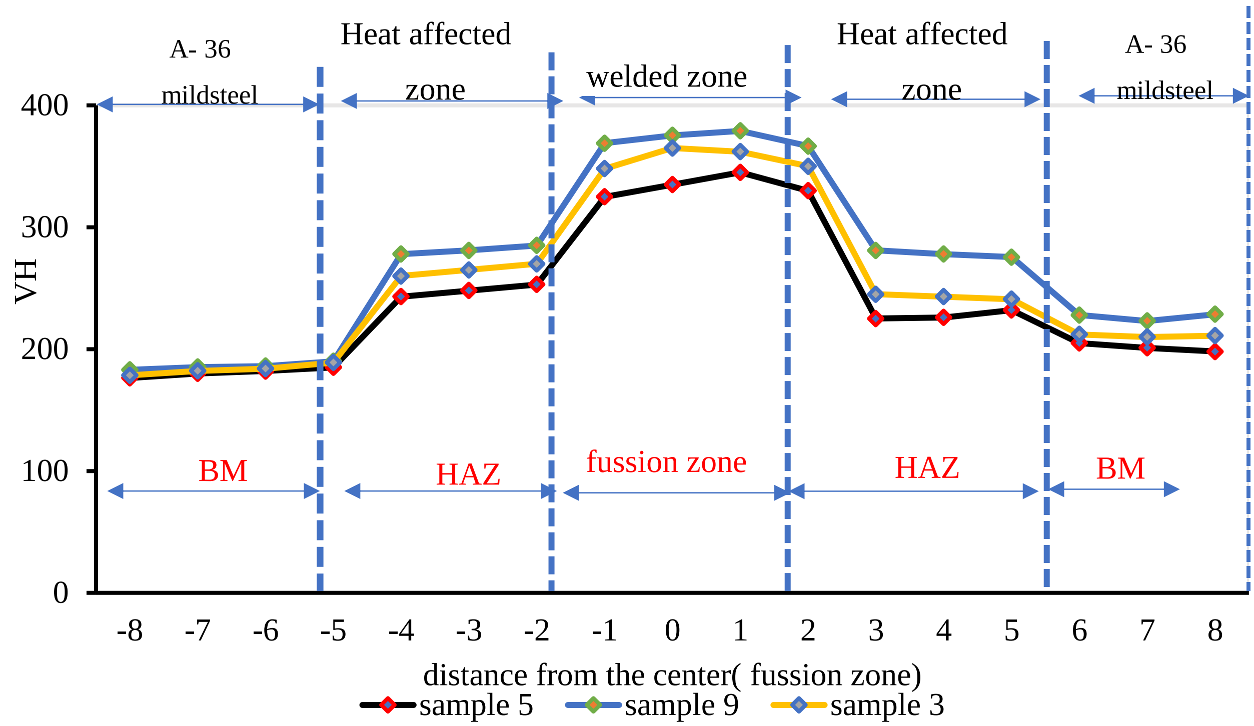


Figure 4. 4 Microhardness analysis graph based on high values.

Where, VH = Vickers hardness

4.4. Mechanical properties

The proposes of this study was to Investigated the effect of welding Parameters for Metal Inert Gas welding on mild Steel which are analysis the mechanical properties (tensile strength and hardness) and arrangement of welding bed width through welder hand motion techniques. For analysis this all techniques used DOE method and statical analysis software, the percentage contribution was determined by analysis of variance (ANOVA). Finally, the process parameters are optimized. The welding control parameters and levels utilized are shown in Table 4.2, below.

Table 4.2. Process parameters and levels selected

sample no	process parameter	unit	level			
			1	2	3	4
1	Current	Amp	90	100	120	150
2	Voltage	volt	17	19	22.5	26
3	Arc speed	mm/s	20	25	30	35
4	Arc gap	mm	1	12	14	16

4.5. Tensile strength

Tensile strength is the ability of resistance the load of a material throughout force is acting to pull on a part of material. At the whole, the most important mechanicals property in evaluating metal properties. Therefore, the metallurgists measure the tensile strength of a metal by determining the maximum load in pounds per square inch (abbreviated psi) it will be resist tensions before fail. This maximum load is also known as ultimate tensile strength because any additional load, no matter how small, will cause failure, like the last straw that broke the comes to back. These values for tensile strength and other properties of the more commonly used metals are also included in various own experiment.

Table 4.3 Tensile Strength All Response Data for Design Matrix Using 16 Runs Within Control Parameters.

Exp no	Control Parameter				Tensile Strength (N/mm^2) based on trails				
	Current	Voltage	Arc Speed	Arc gap	1st	2nd	3rd	4th	Average
1	90	17	20	10	353.09	348.77	350.213	355.45	351.8808
2	90	19	25	12	251.85	252.15	250.98	253.98	252.24
3	90	22.5	30	14	319.43	315	318.34	320.08	318.2125
4	90	26	35	16	203	203.72	201.56	199.78	202.015
5	100	17	20	10	116.25	116.03	115.89	118.67	116.71
6	100	19	25	12	80	79	81.78	83.67	81.1125
7	100	22.5	30	14	140	138.09	139.09	142.09	139.8175
8	100	26	35	16	184	186.73	185.07	188	185.95
9	120	17	20	10	366.66	365.18	368.78	369.56	367.545
10	120	19	25	12	258	255.31	257.34	259.09	257.435
11	120	22.5	30	14	187.13	188.09	186.78	188	187.5
12	120	26	35	16	366.32	363.78	365.09	369.543	366.4333
13	150	17	20	10	92	94.02	98.045	102.76	96.70625
14	150	19	25	12	363.69	365.45	362.78	367.09	364.3525
15	150	22.5	30	14	387.25	320.23	383.67	388.98	367.0325
16	150	26	35	16	333.09	328.77	330.213	325.45	329.380

According to this all analysis on Table 4.3 shows that the values of response for tensile strength. A 36 mild steel yield strength and ultimate strength are 367.545MPa respectively, to analyze in DEC metallurgy lab.

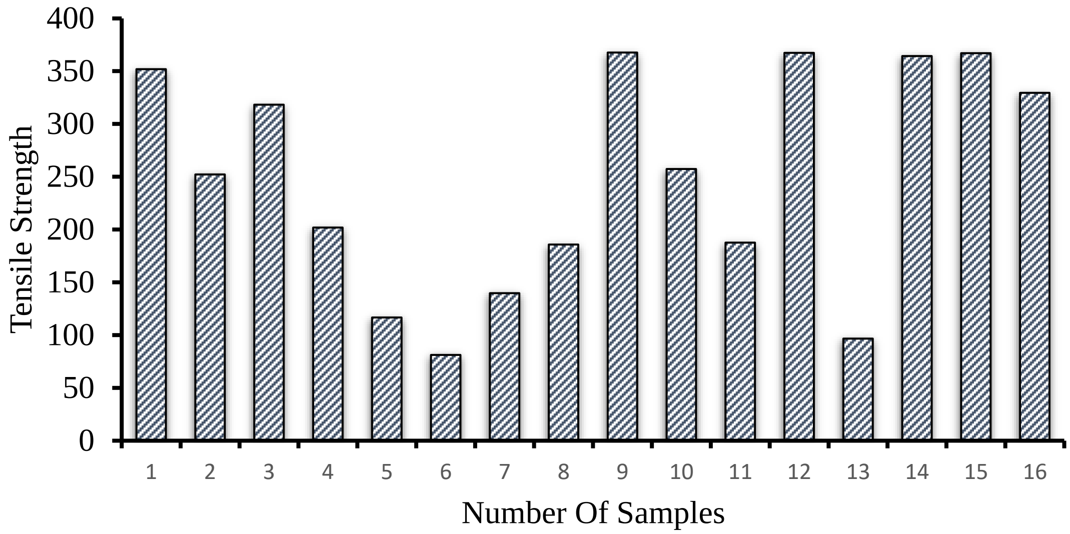


Figure 4.5 TS after MIG welding experiment from this graph TS

4.6.1 S/N Ratios

The quality of welded product is access by using weld bead strength and performances and the Noise factors are responsible for variation of response or functional characteristics from its target value. Signal-to-noise ratio basically reflects the variability in the response of system caused by noise factors Khoei et al., (2002).

The S/N ratios are calculated as given in Equation (4.1) and Response optimization method is used to analyze the result of response of welding bead strength for better criteria. For this study, three procedures are considered to determine the predicted and proposed for the final optimization. The first one is analyzing S/N ratio using larger the better concept; the second one analyzing using ANOVA; the third one is analyzing the result using regression analysis. Where η assign as the S/N ratios its was used to calculated from observed values, y_i represents the experimentally observed value of the i^{th} experiment and n is the repeated number of each experiment, $\boldsymbol{y}$is the average of observed data and $S_y 2$ is the variance of y. For each type of characteristics, with the above S/N transformation, the higher the S/N ratio the better is the result(Senthil and Rajasekaran, 2015).

For this study larger is the better has selected to analyze the effect of welding strength on the MIG welding experiment(Bahar et al., 2018). The sample tensile strength S/N (η) calculations are shown in equation (4.1). The control for variable of S/N-ratio has analyzed in numerical analysis. For this research study, three significant digits are implemented to reduce amount of error occurred in numerical analysis. Amount of confidence interval 5% (0.05) and confidence level 95% (0.95). If probability (P) value is less than the confidence interval 0.05 it is significant if the amount of P-value greater than 0.05 it is insignificant. Our objective is to predict maximum tensile stress. For all DOE Larger-the better characteristics is used. The following results are the modified design of experiment. Where "db." is Decibel.

$$\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{{y_1}^2}+\frac{1}{{y_2}^2}+\frac{1}{{y_3}^2}+\frac{1}{{y_4}^2})] = \tag{4.1}$$

EXP 1: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{353.09^2}+\frac{1}{348.77^2}+\frac{1}{350.213^2}+\frac{1}{355.45^2})] = 50.93db$

EXP 2: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{251.85^2}+\frac{1}{252.15^2}+\frac{1}{250.98^2}+\frac{1}{253.98^2})] = 49.30db$

EXP 3: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{319.43^2}+\frac{1}{315^2}+\frac{1}{318.34^2}+\frac{1}{320.08^2})] = 53.03672db$

EXP 4: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{203^2}+\frac{1}{203.72^2}+\frac{1}{199.78^2}+\frac{1}{202.015^2})] = 46.1118db$

EXP 5: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{116.25^2}+\frac{1}{116.03^2}+\frac{1}{115.89^2}+\frac{1}{118.67^2})] = 41.340db$

EXP 6: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{80^2}+\frac{1}{79^2}+\frac{1}{81.78^2}+\frac{1}{83.67^2})] = 48.17db$

EXP 7: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{140^2}+\frac{1}{138.09^2}+\frac{1}{139.09^2}+\frac{1}{142.09^2})] = 43.9596db$

EXP 8: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{184^2}+\frac{1}{186.73^2}+\frac{1}{185.07^2}+\frac{1}{188^2})] = 45.39db$

EXP 9: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{366.66^2}+\frac{1}{365.18^2}+\frac{1}{368.78^2}+\frac{1}{369.56^2})] = 51.323db$

EXP 10: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{258^2}+\frac{1}{255.31^2}+\frac{1}{257.34^2}+\frac{1}{259.09^2})] = 48.213db$

EXP 11: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{187.13^2}+\frac{1}{188.09^2}+\frac{1}{186.78^2}+\frac{1}{188^2})] = 45.46db$

EXP 12: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{366.32^2}+\frac{1}{368.78^2}+\frac{1}{365.09^2}+\frac{1}{369.543^2})] = 51.30db$

EXP 13: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{92^2}+\frac{1}{94.02^2}+\frac{1}{98.045^2}+\frac{1}{102.76^2})] = 49.686db$

EXP 14: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{363.69^2}+\frac{1}{365.45^2}+\frac{1}{383.67^2}+\frac{1}{367.09^2})] = 51.354db$

EXP 15: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{387.25^2}+\frac{1}{320.23^2}+\frac{1}{350.213^2}+\frac{1}{388.98^2})] = 51.08db$

EXP 16: $\eta_n = -10\log[\frac{1}{n}\sum_{i-1}^{16}\frac{1}{y_i^2}] = -10\log[\frac{1}{4}(\frac{1}{333.09^2}+\frac{1}{328.77^2}+\frac{1}{330.213^2}+\frac{1}{325.45^2})] = 50.35db$

But existed S/N-Ratio for each factor using one trail value of response same formula. η_1=49.925dB, η_2=48.135dB, η_3=50.197dB, η_4=40.354dB, η_5=48.278dB, η_6=45.238dB, η_7=40.070dB, η_8=49.900dB, η_9=50.054dB, η_{10}=43.046dB, η_{11}=49.930dB, η_{12}=50.144dB, η_{13}=49.827dB, η_{14}=50.72dB, η_{15}=50.883dB, η_{16}=51.73dB.

4.6.2 Overall Mean S/N

$\eta_{OM} = \frac{1}{16}$ [η1 + η2 + η3 + η4 + η5 + η6 + η7 + η8 + η9 + η10 + η11 + η12 + η13 + η14 + η15 + η16]

= $\frac{1}{16}$ [50.93 + 49.30 + 53.0367 + 46.1118 + 51.34 + 48.17 + 43.959 + 45.39 + 51.323 + 50.213 + 45.46 + 51.30 +49.686 +51.354 + 51.08 + 50.35] = 49.313d (4.2)

Similarly, for existed setting design of experiment overall mean η_{OM}= 45.926d. It is still smaller than the modified.

4.6.2.1 Average S/N Ratio of Experiment for each Factor and Level

$$\eta_{A\,A1} = \frac{1}{8} [\eta1 + \eta2 + \eta3 + \eta4 + \eta5 + \eta6 + \eta7 + \eta8] \quad (4.3)$$

$$\eta_{A\,A1} = \frac{1}{8}[50.93+49.30+53.0367+46.1118+51.34+48.17+43.959 + 45.39] = 48.52969d$$

$$\eta_{A\,A2} = \frac{1}{8} [\eta9 + \eta10 + \eta11 + \eta12 + \eta13 + \eta14 + \eta15 + \eta16] \quad (4.4)$$

$$\eta_{AA2} = \frac{1}{8} [51.323 + 50.213 + 45.46 + 51.30 + 49.686 + 51.354 + 51.08 +50.35] = 50.09575\ d$$

$$\eta_{BB1} = \frac{1}{8} [\eta1+ \eta2 + \eta3 + \eta4 + \eta9 + \eta10 + \eta11 + \eta12] \quad (4.5)$$

$$\eta_{BB1} = \frac{1}{8} [50.93 + 49.30 + 53.2+46.2 + 46.1118+ 51.3+ 48.213 + 45.46+ 51.3] = 55.25\ d$$

$$\eta_{BB2} = \frac{1}{8} [\eta5 + \eta6 + \eta7 + \eta8 + \eta13 + \eta14+ \eta15+ \eta16] \quad (4.6)$$

$$\eta_{BB2} = \frac{1}{8} [41.34+38.17+43.959+ 45.39+ 49.69 + 51.354 + 51.08 +50.35] =46.5db$$

$$\eta_{CC1} = \frac{1}{8} [\eta1 + \eta2 + \eta5 + \eta6 + \eta9+ \eta10 + \eta13+ \eta14] \quad (4.7)$$

$$\eta_{CC1} = \frac{1}{8} [50.93+ 49.3 + 41.34+48.17 + 51.32 + 48.23 + 49.686 + 51.354] =48.8db$$

$$\eta_{CC2} = \frac{1}{8} [\eta3 + \eta4 + \eta7 + \eta8 + \eta11 + \eta12 + \eta15 + \eta16] \quad (4.8)$$

$$\eta_{CC2} = \frac{1}{8} [53.03 +46.1118 + 43.959 + 45.39 + 45.46 + 51.3+51.08 + 50.35] =48.39db$$

$$\eta_{DD1} = \frac{1}{8} [\eta1+ \eta3 + \eta5 + \eta7 + \eta9+ \eta11 + \eta13 + \eta15] \quad (4.9)$$

$$\eta_{DD1} = \frac{1}{8} [50.93 + 53.0367+ 41.34+51.32+ 43.959 + 45.46 + 49.686+ 51.08] =48.35146db$$

$$\eta_{DD2} = \frac{1}{8} [\eta2 + \eta4 + \eta6+ \eta8 + \eta10 + \eta12 + \eta14 + \eta16] \quad (4.10)$$

$$\eta_{DD2} = \frac{1}{8} [49.3 +46.1118+48.17+45.39 + 48.213 + 51.3 + 51.354 + 50.356] =48.78db$$

Whereas, the existed average S/N Ratio of experiment for each factor and level are:

$\eta AA1$=49.925dB dB, $\eta AA2$=48.135dB, $\eta BB1$=50.054dB, $\eta BB2$=49.900db,

$\eta CC1$=49.930dB, $\eta CC2$=46.5dB, $\eta DD1$=48.35146dB, $\eta DD2$=50.081db

Table 4.4 Experimental Results and S/N-Ratio for TS Experimental

No sample	Tensile Strength (N/mm^2) based on number of trails					S/N (dB) From
	1st	2nd	3rd	4th	Average	
1	353.09	348.77	350.213	355.45	351.881	50.93
2	251.85	252.15	250.98	253.98	252.24	49.3
3	319.43	315	318.34	320.08	318.213	53.0367
4	203	203.72	201.56	199.78	202.015	46.1118
5	116.25	116.03	115.89	118.67	116.71	41.34
6	80	79	81.78	83.67	81.1125	48.17
7	140	138.09	139.09	142.09	139.818	43.959
8	184	186.73	185.07	188	185.95	45.39
9	366.66	365.18	368.78	369.56	367.545	51.323
10	258	255.31	257.34	259.09	257.435	48.213
11	187.13	188.09	186.78	188	187.5	45.4
12	366.32	368.78	365.09	369.543	367.433	51.3
13	92	94.02	98.045	102.76	96.7063	49.686
14	363.69	365.45	362.78	367.09	364.753	51.25
15	387.25	320.23	383.67	388.98	370.033	51.08
16	333.09	328.77	330.213	325.45	329.38	50.35
Total	4001.76	3925.32	4197.181	4032.193	3988.725	801.92
Mean	250.11	245.3325	262.3238	252.0121	249.2953	50.12

After S/N ratio values are calculated for each factor, level and range (delta). Delta= large S/N-small S/N of each parameter is calculated and is shown in Table 4.5. The larger the delta value for a parameter, the larger the effect the variable has on the process and its value is indicated. The signal causes a larger effect on the output variable being measured and voltage is first, current is the second, travel speed is the third and standoff distance is fourth are the significant parameter for maximum tensile strength .in the following table optimal parameter combination for larger-the-better concept 50.09, 55, 55,48.39 and 48.78 which is A2B1C1D2 respectively.

Table 4.5 The Optimum Factor/Level Combination for TS & S/N-Ratio

Level	Current	Voltage	Travel Speed	Standoff Distance
1	48.529	55	48.8	48.3515
2	50.0958	46.5	48.39	48.78
Delta	1.56675	8.5	0.41	0.42854
Rank	2	1	4	3
Optimum Combination	A1, B2, C1, D2			

General the effect of these factors on tensile strength is shown on Figure 4.5. The tensile strength increases dramatically as the current climbs from level one to level three, as shown in the graph above and the tensile strength decreases drastically as the current is increased from level three to level four. When the voltage increases from low level (1) to level three (3), the tensile strength value increases proportional.

4.7 Effect of parameters on tensile strength

The effect of welding parameters on tensile strength, as well as the optimum values based on their rank, are shown in Figure 4.5. The optimum values to maximize tensile strength, according to the analysis and the main effect plot graph for SN ratios, are current at level two (120A), the voltage level four (17), arc speed at level three (20mm), and standoff at level two (10), which has an initial parametric setting of A2B1C1D2. As seen from the graph above it was shown that the tensile strength was increased as the current raised from level 1(90A) to level 2 (100A). but the UTS significantly decreased from a higher value to a lower one at the current increased from level 2 to level 4 (150A)(Jiru et al., 2022). M. Naga Swapna et al., (2021) and Sanjay Kumar et al., (2019) also reported the same result that the current was the most significant welding parameter. As voltage increased from level 1 (17) to level 2 (19) the UTS was increased. When further GFR increased to level 3(22.5) the UTS started decreasing but when further the GFR raised to level four then the UTS was increased to a higher value, (Ghadi & S., 2016) also get the same experimental result. The arc speed at level 1 (20mm/s) was given minimum tensile strength, but the arc speed at level 3 (30mm) was given maximum tensile strength. Arc gap level two (12) was best for higher tensile strength and arc gap at level four (16) was given the minimum value of tensile strength

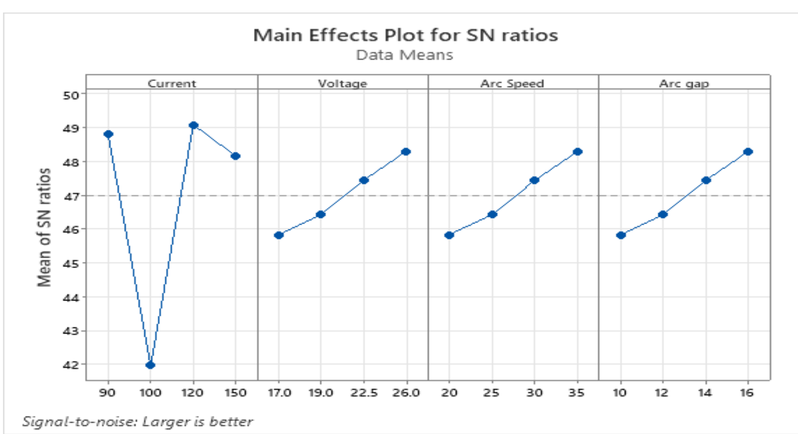


Figure 4.6 Main effect plot for S/N ratios for Tensile Strength.

4.7.1 Performance of Level One Parameter

The trial parameter combination for the tensile test A2B1C1D2 for mean is calculated as follows. Level one S/N ratios mean (ηM);

$H_{opt=}$ ηom + (ηom -ηAA1) + (ηom -ηBB2) + (ηom -ηCC1) + (ηom -ηDD2) (4.11)

$H_{opt=}$ 49.313+ (49.313-46.13) + (49.313-47.95) + (49.313-47.78) + (49.313-47.033) = 55.5db

For existed DOE η_M = 53.8, still lower than the modified one.

4.7.2 Performance of Optimal Levels

For the optimum response four factors are selected by high S/N ratio value. A2B1C1D2 is the optimum level of parameters having high S/N ratio the following equation is used.

$H_{opt=}$ ηom + (ηAA1- ηom) + (ηBB2- ηom) + (ηCC1- ηom) + (ηDD2- ηom) (4.12)

$H_{opt\ =}$ 50.12+ (50.0958 -50.12) + (55 -50.12) + (48.8-50.12) +(48.78-50.12) = 52.32db

For existed DOE η_{opt}=51.049dB, still smaller than the modified one.

4.8. Sum of Squares for Mean of Sample Experiments

SSM =1 6η_{OM}^2 (4.13)

= 16 *$(50.12)^2$ = 16*2512.0144= 40192.2304 db^2

For existed DOE SSM=40192.2304 db^2, still larger is the modified one

4.8.1 Total Sum of Squares

$$SST= \sum_{n=1}^{16}(\eta i - \eta om)^2 = (\eta 1-\eta om)^2+ (\eta 2-\eta om)^2+(\eta 3-\eta om)^2+(\eta 4-\eta om)^2+(\eta 5-\eta om)^2 + (\eta 6-\eta om)^2+(\eta 7-\eta om)^2+(\eta 8-\eta om)^2+(\eta 9-\eta om)^2+(\eta 10-\eta om)^2+(\eta 11-\eta om)^2 + (\eta 12-\eta om)^2+(\eta 13-\eta om)^2+(\eta 14-\eta om)^2+(\eta 15-\eta om)^2+(\eta 16-\eta om)^2 \quad (4.14)$$

$$SST= \sum_{n=1}^{16}(\eta i - \eta om)^2 = (50.93-52.32db)^2+ (49.3-52.32db)^2+(53.0367-52.32db)^2+(46.1118-52.32db)^2+(41.34-52.32db)^2 + (48.17-52.32db)^2+(44.959-52.32db)^2+(45.39-52.32db)^2+(51.323-52.32db)^2+(48.213-52.32db)^2+(47.4-52.32db)^2+ (51.3-52.32db)^2+ (49.686-52.32db)^2+ (51.25-52.32db)^2+(51.08-52.32db)^2+ (50.35-52.32db)^2 = 221.5$$

4.8.2 Sum of Squares 2 Level for each Factor

$SSA= 2[(\eta_{AA\ 1} - \eta_{OM})^2 + (\eta_{AA\ 2} - \eta_{OM})^2]$ (4.15)

$SSA= 2[(48.529 - 52.32)^2 + (49.5- 52.32)^2] = 44.44\ db^2$

$SSB= 2[(\eta_{BB1} - \eta_{OM})^2 + (\eta_{BB\ 2} - \eta_{OM})^2]$ (4.16)

$SSB= 2[(55 - 52.32)^2 + (46.5- 52.32)^2] = 41.05db^2$

$SSC= 2[(\eta_{CC1} - \eta_{OM})^2 + (\eta_{CC\ 2} - \eta_{OM})^2]$ (4.17)

$SSC= 2[(48.8 - 52.32)^2 + (48.39- 52.32)^2] = 27.85db^2$

$SSD= 2(\eta_{DD\ 1} - \eta_{OM})^2 + 2(\eta_{DD2} - \eta_{OM})^2]$ (4.18)

$SSD= 2[(48.3515- 52.32)^2 + (48.78 - 52.32)^2] = 28.28db^2$

The existed sum of the square values is SS_A=30.0, SS_B=49, SS_C=13, SSD =8dB2

4.8.3 Mean Square (Variance)

$$MSn = \frac{SSn}{DOFn} \text{, for n factors} \quad (4.19)$$

$MSA = \frac{SSA}{DOFA} = \frac{44.44}{1} = 44.44\ db^2$

$MSB = \frac{SSB}{DOFB} = \frac{41.05}{1} = 41.05db^2$

$MSC = \frac{SSC}{DOFC} = \frac{27.85}{1} = 27.85db^2$

$MSD = \frac{SSD}{DOFD} = \frac{28.28}{1} = 28.28db^2$

4.8.4 Percentage Contribution;

$$p_n = \frac{SSn}{SST} \quad (4.20)$$

$p_A = \frac{SSn}{SST}*100\% = \frac{44.44}{141.62}*100\% = 0.3137$

$p_B = \frac{SSn}{SST}*100\% = \frac{41.05}{141.62} * 100\% = 0.30$

$p_C = \frac{SSn}{SST}$ x $100\% = \frac{27.85}{141.62} * 100\% = 0.1967$

$p_D = \frac{SSn}{SST} *100\% = \frac{28.28}{141.62} * 100\% = 0.1997$

According to higher to lower percentage contribution value of the factors are, B, are first place, A next, D, the third, and finally, C, is the last percent contribution has comparatively less than the others. From the table at this stage time to avoid the error the value of f-ratio is also negligible effect on the process parameter are discussed in table 4.5.

According to table 4.5 the DOE percentage contribution was found that PA=31.37%, PB=30%, PC=19.67%, PD=19.97%, in this case percentage contribution of C is lower than the others so it was pooled out.

Table 4.5 Results of ANOVA for S/N-Ratio

Parameters	**DOF**	**Sum of Squares**	**Mean Squares**	**F-Ratio**	**Percent (%)**
Current	1	44.44	44.44	-	31.37%
Voltage	1	41.05	41.05	-	28.99%
Travel speed	1	27.85	27.85	-	19.67%
Standoff distance	1	28.28	28.28	-	19.97%
Error	4	-	-	-	
Total	7	141.62	141.62	-	100

4.8.5 Pooling

In Taguchi methods pooling is the variance of the factor effects with the lowest contributions to the total sum of squares provides an approximate estimate of error variance without the need for replicates an approximate estimate of error variance can be obtained by pooling the sum of squares corresponding to the factors having the lowest mean square the effect of factor C is small(Soltani et al., 2016). These factors are pooled to obtained new non- zero estimates of SS_E and DOF_E Sum of the squares of error (SS_E).

SS_E = SST – (SSA+SSB + SSD+) (4.21)

= 141.62 – (45.5+41.05+ 48.29) = 27.78

4.8.6 Degree of Freedom Error Term

For four factor and two-level total number of degrees of freedom is (two times four which is minus) one which is seven. So, degree of freedom for errors is (seven minus number of factors after pooled) which is four. The degree of freedom was equal.

DOFE = DOFT - DOFA+DOFB + DOFD (4.22)

DOFE = 7 - 1+1 + 1= 4

4.8.7 Variances for Errors

$MS_E = \frac{SSE}{DOFE}$ = 27.78/4 = 6.95 db^2 (4.23)

For the existed setting variance of error are

$FA = \frac{MSE}{MSE} = \frac{44.5}{6.95} = 6.40$ (4.24)

$FB = \frac{MSE}{MSE} = \frac{41.05}{6.95} = 5.90$

$FD = \frac{MSE}{MSE} = \frac{28.29}{6.95} = 4.07$

4.8.8 New Percentage Contribution

Using equation (4.20) percent contribution are determined as follows.

PA=$\frac{SSA}{SST}$

$p_A = \frac{SSn}{SST} * 100\% = \frac{44.44}{141.62} * 100\% = 0.3137$

$p_B = \frac{SSn}{SST} * 100\% = \frac{41.05}{141.62} * 100\% = 0.30$

$p_D = \frac{SSn}{SST} * 100\% = \frac{28.28}{141.62} * 100\% = 0.1997$

Table 4.8 shows that the factor A contributes i.e., 31.37%, B is 30% and D has contribution 19.97%. But the contribution of factor C is not relatively significance it is negligible effect. So, A is critical, B next and lastly D according to percent contribution. The ANOVA in Table 4.8 percentage contribution will be calculated after factor C is pooled out from the contribution of the experiment. From this numerical value A has more factor effect, B the next, D the third and finally C less factor effect.

Table 4.6 percentage contributions will be calculated after factor C is pooled out

Parameters	**DOF**	**Sum of Squares**	**Mean Squares**	**F ratio**	**Percent Contribution**
Current	1	44.44	44.44	6.40	35.27%
Travel speed	1	41.05	41.05	5.90	31.92%
Standoff distance	1	28.28	28.28	4.07	27.87%
Welding voltage Pooled factor					
Error	4+1=5	27.85	6.95	-	4.94
Total	8	11.6	96.5	73.97	95.06

4.9 ANOVA Terms Notation and Development Methods

ANOVA this technique enables to estimate relative contribution each control factor makes to the overall measured response that expresses its percentage. It has used to provide the measure of confidence. This method does not directly analyze the data, yet, rather determines the variability (variance) of the data. Confidence is measured from the variance. It uses sum of squares to quantitatively examine the deviation of the control factor effect response averages from the total experimental mean response. It has been employed to find the level of significance of each process parameters on performance measures for interrelationships and mathematical development these quantities are defined as.

CF. = correction factor, e = error (experimental), F = variance ratio, n = number of trials, r = number of repetitions, P = percent contribution, f = degree of freedom, DOF_E = degree of freedom of error, DOF_T= total degree of freedom, T = total of results, SS = sum of squares, MS = mean, F= F-ratio square (variance),(Soltani et al., 2016). From appendix-the satisfactoriness of the model is checked by using the analysis of variance (ANOVA) technique and this technique had calculated value of the P value of the developed model does not exceed the standard tabulated value of P for a desired level of confidence (say 95%), then the model is considered to be satisfactory within the confidence limit.

Table 4.7 model is considered to be satisfactory within the 95% confidence interval source; author SPSS software data analysis

Descriptive				
			Statistic	Std. Error
TS	Mean		337.6956	2.14035
	95% Confidence Interval for Mean	Lower Bound	333.1336	
		Upper Bound	342.2577	
	5% Trimmed Mean		337.7157	
	Median		335.4900	
	Variance		73.298	
	Std. Deviation		8.56142	
	Minimum		323.23	
	Maximum		351.80	
	Range		28.57	
	Interquartile Range		14.30	
	Skewness		.054	0.564
	Kurtosis		-.986	1.091

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
TS	16	96.1%	1	3.9%	16	100.0%

4.9.1 Determination of ANOVA for Response (TS)

According to maximum is the better concept of, $f$or N = 16 runs MIG welding to determine ANOVA for tensile strength. Factor (A) for the interaction effect of the Response for two level factors.

An = $\sum l\ ow\ level$ (4.25)

PA= $\frac{(A1-A2)2}{N}$ In case of error therefore c is our error (4.26)

A1= (350.213 + 318.39 +344.48 +334.38+343.33+318.81+313.04) = 2,322.643

A2= (368.78+257.34+186.78+365.09+98.09+362.78+383.67+330.213) = 2,254.653

PA= $\frac{(2{,}322.643-2{,}254.653)2}{16}$ = 288.9Mpa

Same calculation for all factors case of each factor lower and higher value determines the pure sum factor interaction effect.

Factor (B) = 3119.16, factor C= 289.8 and D= 347.126Mpa respectively.

Yi= a1+a2, =2322.643+2254.653= **4577.296**

SUM = $\sum yi2 - \frac{\sum yi2}{16}$, (4.27)

=$4577.296 - \frac{4577.296}{16}$ = 19642161.25464

Using equation 4.20 sum of error term calculated as follows

SS_E = Sum – (A + B + C + D) = 19642161.25464 - (3119.16 +1.507+ 289.8 + 347.126) = 19638403.67

4.9.2 Sum of the Squares

Calculating values of sum of the squares; using similar equation (4.20)

SS_A = A -SS_E = 288.9- 19642161.25464 = 19638114.77 M p a

SS_B = B -SS_E = 1.507-19642161.25464 = 19642159.74764M P a

SS_C = C -SS_E = 239.8 -19642161.25464 =19641921.45464M P a

SS $_D$ = D -SS_E = 347.126-19642161.25464 = 19641814.12844 M P a

SS_T = SS_A + SS_B + SS_C + SS_D =19638114.8+19642159.7+19641921.45464 +19641814.12844 = 78564010.13308 Mpa

4.9.3 Factor DOF for Response defects OA

DOF_T = total number of test run s minus 1 = n – 1 = 8 – 1 = 7, so DOF_A, DOF_B, DOF_C, DOF_D. Respectively found one for each factor.

DOF of the error (DOF $_E$) = DOF $_T$ – (DOF_A+ DOF_B + DOF_C + DOF_D) = 7-4 = 3

4.9.4 Variance (Mean of the Squares)

Using equation (4.19) mean of variance calculated as.

$$MSA=\frac{SSA}{DOFA} = MSA=\frac{19638114.77}{1} = 19638114.77$$

$$MSB=\frac{SSB}{DOFB} = MSA=\frac{19642159.74764}{1} = 19642159.74764$$

$$MSC=\frac{SSC}{DOFC} = MSA=\frac{19641921.45464}{1} = 19641921.45464$$

$$MSD=\frac{SSD}{DOFD} = MSA=\frac{19641814.12844}{1} = 19641814.12844$$

$$MSE=\frac{SSE}{DOFE} = MSA=\frac{19638403.67}{3} = 6{,}546{,}134.55667$$

4.9.5 F-Ratio

Using the above equation (4.22) $F_A= F_B=F_C=F_D=1.000$

4.9.6 Percent

According to ANOVA for response percent contribution for factors are exactly the expected theoretical value. So, it's safe design of experiment accordingly MIG welding process. Table 4.8 shows the result of predicted ANOVA table for response. Using equation (4.20) percent contribution for each factor found that $P_A= P_B=P_C=P_D=25\%$. Sum of the total percent contribution found as 100%. According to ANOVA for response percent contribution for factors are exactly the expected theoretical value. So, it's safe design of experiment accordingly MIG welding process. Table 4.9 shows the result of Minitab software analysis of ANOVA table for response and total DOF is summation of linear, square, interaction, residual error is 5.

Table 4.8 ANOVA for Tensile Strength Predicted Numerical Calculation

Source	Source of Variation	DOF	SS	MS	F ratio	%
1	Current (A)	1	19638114.77	19638114.77	1	25
2	Voltage (V)	1	19642159.74764	19642159.74764	1	25
3	Travel Speed (mm/sec)	1	19641921.45464	19641921.45464	1	25
4	Standoff Distance (mm)	1	19641814.12844	19641814.12844	1	25
All other/errors		3	6,546,134.55667			
Total		7	78564010.13308	78564010.13308		100%

Table 4.9. MINITAB Software ANOVA Result for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F-Ratio	P
Regression	10	2217.24	2217.24	221.724	2.19	0.2
Linear	4	964.07	1245.38	311.345	3.08	0.124
Interaction	6	1253.18	1253.18	208.863	2.07	0.222
Residual Error	5	505.4	505.4	101.079	-	-
Total						

Table 4.10 Coefficients of variance

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	St. Error	Beta			Lower Bound	Upper Bound	Zero order	Partial	Part	Tolerance	VIF
Constant	335.245	25.063		13.376	.000	280.638	389.852					
Current	-.091	.101	-.253	-.907	0.382	-.311	0.128	-.295	-.253	-.246	0.944	1.059
Voltage	.784	1.213	.290	.646	0.531	-1.860	3.427	.179	.183	.175	0.364	2.746
Arc Gap	-1.396	3.292	-.188	-.424	0.679	-8.569	5.778	.039	-.121	-.115	0.372	2.687
a. Dependent Variable: TS												

4.10. Regression Analysis of Response for Optimization

For this research work second order regression analysis of mathematical and analytical formula for the response of the output in case of TS for the welding specimens of the sixteen samples are used to improve the welding quality for the product.

Whereas, A_0, A_{34}, A_2, A_3, A_4, A_{11}, A_{22}, A_{33}, A_{44}, A_{12}, A_{13}, A_{14}, A_{23}, A_{24}, A_1 are coefficient of regression analysis for each parameter respectively. X_1 = welding current, X_2 = welding arc voltage, X_3 = welding travel speed, X_4 = welding standoff distance respectively.

4.11. Mathematical Model for Regression Analysis for Predicted TS

The correlation of in regression analysis Table 4.9 for the four parameters and the TS has used out to fit the mathematical model to the experimental data in order to get an optimal region for the response has studied. As (Rezzoug et al., 2008) the predicted model can be described by the X_1 = welding current, X_2 = welding arc voltage, X_3 = welding travel speed, X_4 = welding standoff distance respectively. Following second-order polynomial equation.

Regression analysis of the experimental data has showed that coefficient for four factors (welding current, welding arc voltage, welding travel speed and welding standoff distance) have coefficient for welded tensile stress. Weld strength regression equation can be represented by the following formula and the analysis has done using un-coded units(*shewangizaw Abu et al.*, 2021). Estimated regression coefficients for tensile strength (N/mm2) of the proposed response surface method for each response can be analyzed using un-coded significant variables to determine the predicted tensile strength;

$TS= A_0+A_1X_1+ A_2X_2+ A_3X_3+ A_4X_4- A_{12}X_1 X_2 - A_{14}X_1 X_4 - A_{23}X_2 X_3 - A_{24}X_2 X_4 - A_{34}X_3 X_4 - \varepsilon$ (*shewangizaw Abu et al.*, 2021).

TS=240.478+0.132X1+ 3.487X2+ 3.69X3+ 1.709X4 - 0.004 X1 X2- 0.001 X1 X4-0.104 X2 X3-0.106 X2 X4-0.005 X3 X4

TS_1= 240.478 +0.132*90 + 3.48*17+ 3.69*20+ 1.70*10- 0.004*90* 17 - 0.104*90* 10 - 0.106*17* 20 - 0.005*17* 10 = 264.528

TS_2=240.478 +0.132*90 + 3.48*19+ 3.69*25+ 1.70*12 - 0.004*90* 19- 0.104*90* 12- 0.106*19* 25 - 0.005*19* 12=266.274

TS_3=240.478 +0.132*90 + 3.48*22.5 + 3.69*30+ 1.70*14- 0.004*90* 22.5 - 0.104*90* 14- 0.106*22.5* 30 - 0.005*22.5* 14=252.813

TS_4=240.478 +0.132*90 + 3.48*26 + 3.69*35+ 1.70*16- 0.004*90* 26- 0.104*90* 16- 0.106*26* 35 - 0.005*26* 16=241.528

TS_5=240.478 +0.132*100 + 3.48*17+ 3.69*20+ 1.70*10- 0.004*100* 17 - 0.104*100* 10 - 0.106*17* 20 - 0.005*17* 10 = 255.948

TS_6=240.478 +0.132*100 + 3.48*19+ 3.69*25+ 1.70*12 - 0.004*100* 19- 0.104*100* 12- 0.106*19* 25-0.005*19* 12=248.558

TS_7=240.478 +0.132*100 + 3.48*22.5 + 3.69*30+ 1.70*14- 0.004*100* 22.5 - 0.104*100* 14- 0.106*22.5* 30 - 0.005*22.5* 14=238.753

TS_8=240.478 +0.132*100 + 3.48*26 + 3.69*35+ 1.70*16- 0.004*100* 26- 0.104*100* 16- 0.106*26* 35 - 0.005*26* 16=225.168

TS_9=240.478 +0.132*120 + 3.48*17+ 3.69*20+ 1.70*10- 0.004*120* 17 - 0.104*120* 10 - 0.106*17* 20 - 0.005*17* 10 = 236.428

TS_{10}=240.478 +0.132*120 + 3.48*19+ 3.69*25+ 1.70*12 - 0.004*120* 19- 0.104*120* 12- 0.106*19* 25 - 0.005*19* 12=224.718

TS_{11}=240.478 +0.132*120 + 3.48*22.5 + 3.69*30+ 1.70*14- 0.004*120* 22.5 - 0.104*120* 14- 0.106*22.5* 30 - 0.005*22.5* 14= 210.473

TS_{12}=240.478 +0.132*120 + 3.48*26 + 3.69*35+ 1.70*16- 0.004*120* 26- 0.104*120* 16- 0.106*26* 35 - 0.005*26* 16=192.448

TS_{13}=240.478 +0.132*150 + 3.48*17+ 3.69*20+ 1.70*10- 0.004*150* 17 - 0.104*150* 10 - 0.106*17* 20-0.005*17* 10 = 207.148

TS_{14}=240.478 +0.132*150 + 3.48*19+ 3.69*25+ 1.70*12 - 0.004*150* 19- 0.104*150* 12- 0.106*19* 25 - 0.005*19* 12=188.958

TS_{15}=240.478 +0.132*150 + 3.48*22.5 + 3.69*30+ 1.70*14- 0.004*150* 22.5 - 0.104*150* 14- 0.106*22.5* 30 - 0.005*22.5* 14= 168.053

TS_{16}=240.478 +0.132*150 + 3.48*26 + 3.69*35+ 1.70*16- 0.004*150* 26- 0.104*150* 16- 0.106*26* 35 - 0.005*26* 16= 143.368

4.11.1. Predicted Optimum Tensile Stress

Optimum output response value for TS of MIG welding parameter optimization then, solves the values for each optimum combinations parameter and determines the final optimum response of MIG welding TS value. The following equation 4.27.

$\frac{D\mathring{U}TS}{dxn}$= $A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_4+ A_2X_{12} + A_{13}X_3 + A_{14}X_4+ A_{23}X_3 + A_{24}X_4+ A_{34}X_4+ \varepsilon$ (*shewangizaw Abu et al.*, 2021).

$\frac{D\mathring{U}TS}{dx1}=A_1 + A_{12}X_2 + A_{13}X_3 + A_{14}X_4= 0.132-0.004X_2 - 0.001X_4 = 0$

$\frac{D\mathring{U}TS}{dx2}=A_2 + A_{12}X_1+A_{23}X_3 + A_{24}X_4= 3.487 - 0.004X_1 - 0.104X_3 - 0.106X4=0$

$\frac{D\mathring{U}TS}{dx3}=A_3 + A_{13}X_1 + A_{23}X_2 + A_{34}X_4= 3.691 - 0.104X_2 - 0.005X_4 = 0$

$\frac{D\mathring{U}TS}{dx4}=A_4 + A_{14}X_1 + A_{24}X_2 + A_{34}X_3= 1.709 - 0.001X_1 - 0.106X_2 - 0.005X_3 = 0$

The analysis has done using un-coded units for estimated regression coefficient for TS for MIG welding parameters. Simultaneously solve the four variables X_1= 115, X_2 =27.5, X_3 = 21.125, X_4 = 13. So, the optimum value of ultimate tensile stress is calculated as follows by substituting these optimum values of parameters respectively.

Ts Opt = $A_0+A_1X_1+ A_2X_2+ A_3X_3+ A_4X_4+ A_{12}X_1 X_2 + A_{13}X_1 X_4 + A_{14}X_2 X_3 + A_{23}X_2 X_4 + A_{24}X_3X_4 + A_{34}X_3X_4$

= 240.478 +0.132*115 + 3.48*27.5+ 3.69*20+ 1.70*27.5+ 0.004*115* 27.5 + 0.104*27.5* 21.125+ 0.106*27.5* 13 + 0.005*21.125* 13= **321.432**

According to 95% confidence level which means 0.05 probability (p) concept the model has reduced and according to Table 4.7 shows regression result.

$TSOrgional$ = 250MPa, TS_{Opt} = 321.432MPa, for regression after optimization

$TS_{\text{improvement t}} = \frac{338.4691-321.432}{321.430} * 100\%$ = 5%

From this analysis regression model after optimization is 5% difference more than regression model after optimization for MIG welding process parameter which indirectly minimize amount of defect on weld bead of low carbon sheet metal steel. For this study current are more critical effect and the combinations (interaction effect) of current with standoff distance is the next significant effect but factors and combinations have negligible effect on MIG welding process parameter.

Table 4.11 Estimated Regression Coefficients for TS for MIG Welding Parameters

Term	Coef	SE Coef	T	P
Constant(model)	240.478	74.996	3.205	0.024
Current	0.132	0.121	1.086	0.327
Voltage	3.487	1.84	1.896	0.116
Travel speed	3.691	1.993	1.852	0.123
Standoff distance	1.709	5.519	0.31	0.769
Current*Voltage	-0.004	0.002	-1.878	0.119
Current*Travel speed	0	0.009	0.211	0.0841
Current*Standoff distance	-0.001	0.007	-0.095	0.028
Voltage*Travel speed	-0.104	0.036	-2.862	0.035
Voltage*Standoff distance	-0.106	0.134	-0.789	0.466
Travel speed*Standoff distance	-0.005	0.109	-0.05	0.0962
S = 0.105	R-Sq = 98.98%	R-Sq (adj) =98.3%		

Table 4.12 coefficient correlations

Coefficient Correlations					
Model			Arc Gap	Current	Voltage
1	Correlations	Arc Gap	1.000	-0.187	-0.792
		Current	-0.187	1.000	0.236
		Voltage	-0.792	0.236	1.000
	Covariance	Arc Gap	10.840	-0.062	-3.165
		Current	-0.062	0.010	0.029
		Voltage	-3.165	0.029	1.472
a. Dependent Variable: TS					

4.12 Confirmation Experiment result based Tensile strengths

The above table 4.13 shows that the final optimized setting and its output for determining the optimum one to get best welding product and the confirmation test was required after the experimental optimization to validate the optimized parametric configuration and as a result, the confirmation was carried out at the Ethiopian Technical Institute's Engineering Center of Excellence at the welding training center. The results of the confirmation testing agreed with the predicted optimum parametric setting result with a very minimal positive validation error, so, according to this experiment the data was collected shown in Table 4.3. For confirmed setting design of experiment photo, distractive testing for modified experiment, specimen drawing and tensile specimens for tensile test.

From this Table 4.13 the Tensile strength were improved from the existed one. The tensile strength data has collected from universal testing machine and table 4.13 shows for each experiment output of TS for improved and confirmed design of experiment.

Table 4.13 Improved Setting and its response for tensile strength

No. sample	Current (Ampere)	Voltage (voltage)	Speed (mm/s)	Distance (mm)	TS (MPa) Average
1	115	27.5	21.125	13	343.44
2	115	27.5	21.125	13	327.29
3	115	27.5	21.125	13	347.54
4	115	27.5	21.125	13	335.94
5	115	27.5	21.125	13	350
6	115	27.5	21.125	13	341
7	115	27.5	21.125	13	323.23
8	115	27.5	21.125	13	334
9	115	27.5	21.125	13	351.8
10	115	27.5	21.125	13	328.39
11	115	27.5	21.125	13	334.48
12	115	27.5	21.125	13	344.38
13	115	27.5	21.125	13	343.33
14	115	27.5	21.125	13	328.46
15	115	27.5	21.125	13	334.81
16	115	27.5	21.125	13	335.04

So, from the mathematical analysis the result has found that percent improvement is 1.07, 5.766, and 0.280 existed, modified and improved design of experiment, Source: (Author's analysis using MINITAB software design package).

Table 4.14: confidence level during tensile strength is optimum

Sample	N	Mean	St Dev	SE Mean	95% CI for μ
Current	16	115	23.7	23.8	(68.5, 161.5)
Voltage	16	21.1	3.5	23.8	(-25.4, 67.7)
Arc Speed	16	2.8	0.6	23.8	(-43.8, 49.3)
Arc gap	16	1.3	0.2	23.8	(-45.2, 47.8)

Where μ: population mean of Current, Voltage, Arc Speed, Arc gap Known standard deviation = 95%

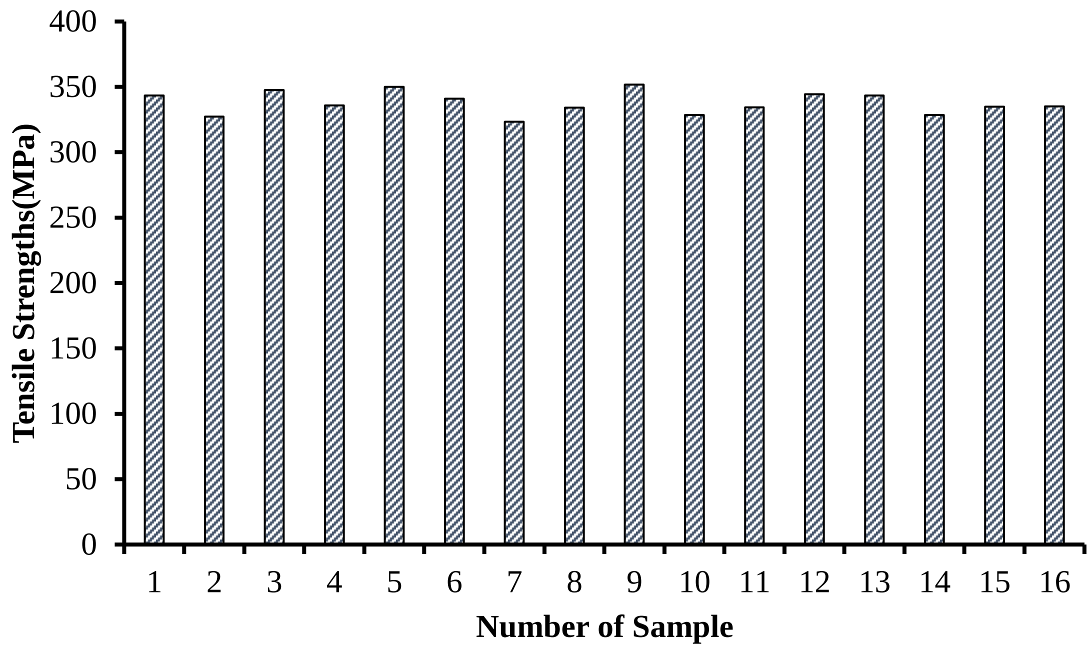


Figure 4.7 TS after MIG welding experiment from this graph TS increase improved comparing material, after DOE and after RSM regression analysis.

4.13. Tensile Strength Vs Strain Graph

In this thesis the optimum tensile stress to its strain value is plotted for the MIG welding product due to improve the weld bead tensile strength. Fig 4.8, tensile strength for MIG welding operation has relatively increased, for selected sample 9 with calculated tensile strength 351.8MPa with larger-the-better was determined.

Stress- strain graph for this sample six after conducting design of experiment which is compared to the material tensile strength value 250MPa, as strain value increases, tensile strength also increases for graph. For 50.868dB, factor combination current (115A), voltage (27V), travel speed (21.5mm/s), standoff distance (13mm) was selected using S/N-Ratio. For the following graph as strain value increases TS increases from DOE for the graph.

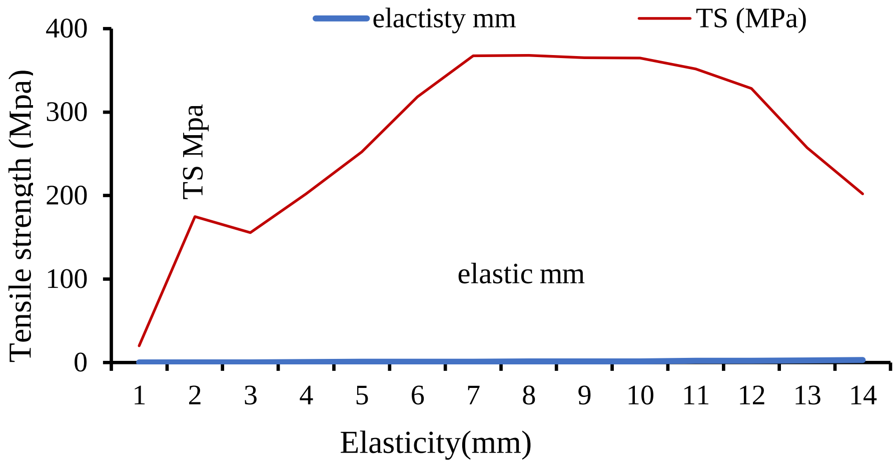


Figure 4.7 TS after MIG welding experiment for optimum S/N for sample 16

4.14. Hardness test

Hardness is the ability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation is measured (Smith et al., 2007). The most commonly used hardness tests are defined by the shape or type of indent, the size, and the amount of load applied (Jignesh Sabhadiya et al., 20220). Permanent deformation is also called plastic deformation while elastic deformation means that a material changes its shape through applied force, a resulting plastic deformation means that the material will not return to its original shape. Some materials are naturally hard. In case of hardness measurement data were collected by using a Brinell’s hardness testing machine, with each test performed on the base metal, Heat affected zone and those weld zone are determined by each at 3 mm from the weld zone’s means from center to last base metal. therefore, each zone data is recorded, that means three readings were selected, and the average value was calculated. Table 4.15 shows the measured experimental results of the mean hardness values for each trial experiment. Table 4.16 reveals that welding current (A) at level 1, voltage at level 2 .arc speed (C) at level 3, and arc gap(D) at level 4 have the maximum effect on hardness. These welding parameters (A4B1C1D1) were chosen as the first parametric setup for hardness when MIG-welding A36 mild steel with a thickness of 3 mm according to the response data means of the experiment.

As seen from the signal-to-noise ratio value in Table 4.16, the welding standoff distance weight percentage had the greatest impact (Delta = 0.45; Rank = 1st, welding voltage (Delta = 0.43; Rank = 2nd) and followed by arc speed (Delta = 0.41; Rank = 3rd), current had the smallest impact on the S/N ratio (Delta = 0.39; Rank = 4th).   Standoff distance (D), voltage (B), at the second level, arc speed (C) at the third level, and current (A)

Table 4.15 Improved Setting and its response

N. S	Applied load	Current (Amp)	Volt	Arc speed(mm/s)	Standoff distance	Hardness (BHN)
1	100	90	17	2	10	148
2	100	90	19	2.5	12	134
3	100	90	22.5	3	14	132
4	100	90	26	3.5	16	279
5	100	100	17	2	10	185
6	100	100	19	2.5	12	138
7	100	100	22.5	3	14	181
8	100	100	26	3.5	16	271
9	100	120	17	2	10	243
10	100	120	19	2.5	12	139
11	100	120	22.5	3	14	212
12	100	120	26	3.5	16	171
13	100	150	17	2	10	218
14	100	150	19	2.5	12	325
15	100	150	22.5	3	14	183
16	100	150	26	3.5	16	126

4.14.1 Mean response for hardness analysis

Standoff distance (D) was the highest value and were ranked first, followed by voltage (B), at the second level, arc speed (C) at the third level, and current (A) at the fourth level, as reveals in table 4.16. For MIG welding of mild steel with a thickness of 3mm, these welding settings (D1B1C1A4) were chosen as the initial parametric setting. For means of hardness value fluctuations, the main influence plot for control parameters is shown in Figure 4.8.

Table 4.16 Response table for means of Hardness S/n rations

Level	Current (Amp)	voltage	Arc speed (mm/s)	Standoff Distance (mm)
1	41.5	41.95	41.95	41.95
2	41.85	41.52	41.52	41.52
3	41.85	41.73	41.73	41.73
4	41.89	41.89	41.89	41.89
Delta	0.39	0.43	0.41	0.45
Rank	4	2	3	1

The parameter's best value at that level is shown by the maximum signifying point as numbered in each graph in the main effect plot figure 4.8. When compared to other welding variables, the welding current weight percent has the greatest impact on improving hardness, while the voltage has the least impact, (Moi et al., 2018) also reported the same result.
Welding current at level four (150A), voltage (17 volt) at level two, standoff distance(10mm) at level one, and arc speed (20mm/s) at level three were the optimum parameters. Fusion welding of mild steel alloys was very challenging mainly due to the formation of low melting eutectics by the constituent elements resulting in weld solidification yet hardness. Rapidly Solidification is gotten good hardness in mild steels alloys is extremely sensitive to weld metal composition, which depends on the composition of the weld wire and base metal composition of the base metal, and amount of dilution.

Table 4.17 are discussed on hardness larger is the better for good hardness of mild steel. Therefore, one must carefully choose the MIG welding wire composition and/or welding process parameters such that the resultant weld composition is not susceptible to solidification resist initial failure. The guidelines for selection of MIG wire, the type of exist base metals and uses for different classes and types of carbons steel. However, when it comes to fusion welding of mild steel, slow solidification is not easy to deal with easily fails in case of hardness. For many mild steels, there exist no filler metals that can produce MIG weld beads.

Based on the result of S/N ration and response the larger is the better. Which is the analysis result at the last for the optimum value is discussed on table 4.17 which means the more affected hardness. based on analysis the current is extremely affected the hardness and the second is voltage, third is standoff distance and at the last arc speed is respectively affected the hardness.

Table 4.17 Response table for hardness (Larger is the better)

Level	Current	Voltage	speed(mm/s)	Standoff
1	136.6	149.3	149.3	149
2	146.9	142	142	142
3	145.6	138.5	138.5	138.5
4	156.5	155.9	155.9	155.9
Delta	19.9	17.4	17.0	17.1
Rank	1	2	4	3

4.13.2 Signal to noise ratio analysis for hardness

From the S/N ratio analysis, it was observed that the welding current weight percentage has a higher effect (Delta = 19.9, Rank =,1st.) followed by Voltage (Delta =17.4, rank =,2nd) Standoff (Delta =17.1, rank 3rd) as shown in table 4.17 below. speed(mm/s) (Delta = 17.1, Rank =,4th) has the smallest effect on the (S/N) ratio. On larger the better, hardness character, the initial parameter combination is (A4B4C4D4) for enhancing the hardness of MIG-welded 3mm mild steel are selected.

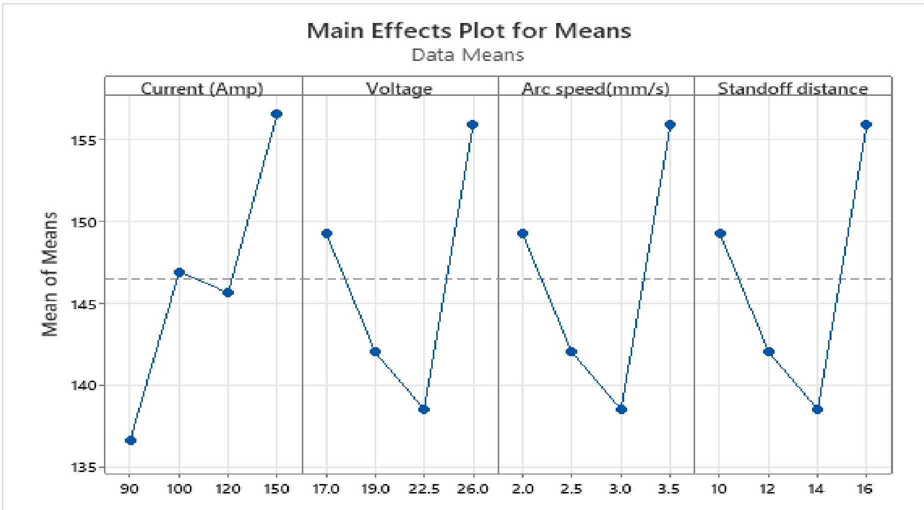


Figure 4.8 mean effects plots graph hardness test

When compared to other welding variables, the welding current weight percent has the greatest impact on improving hardness, while the arc speed has the least impact, (Moi et al., 2018) also reported the same result. Welding current at level four (150A), voltage (26volt) at level one, arc gap (16) at level two, and arc speed at level three (35mm/s) were the optimum parameters.

4.14.3. Effect of parameters on hardness

Figure 4.9 shows how welding parameters effect on hardness, as well as the ideal values depending on their rank. The optimal values for maximizing hardness, according to the analysis and the primary effect plot graph for SN ratios, are current at the first level (150A), the voltage at the second level (17volt), Standoff distance third level (10mm), and Arc Speed at for level (20), with an initial parametric setting of (A4B1C1D1). The hardness increases proportionally with standoff distance input as the arc gap is rise from level one to level three, as shown in the figure 4.8.

The hardness drops substantially as the arc speed is increased from level three to level four and as the standoff increases from level one to level three, the material's hardness is raised. The was the highly influential parameter; as the current increased from level one to two, the hardness fell from a higher value to a lower value. The hardness somewhat returns to growing as the game progresses from level two to three.

The hardness returns to growing as the game progresses from level two to three. However, when the gap is raised from level three to level four, the hardness decreases again. The voltage was the second important welding characteristic; when compared to other processes parameters, level one voltage had a lower hardness value. The voltage at level two has the highest hardness value, followed by the voltage at levels three and four, each having a higher hardness value. As seen from the graph shown below the hardness is minimum at a lower current (Salehpour et al., 2021) also got the same experimental result depending on the current.

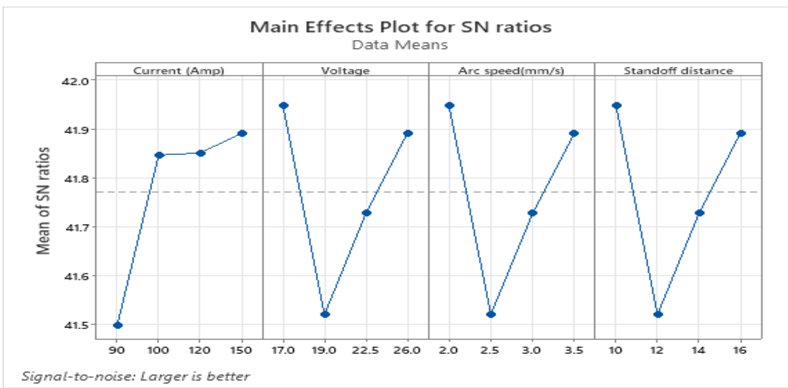


Figure 4.9 main effect plot of means of means and mean of S/N ratios hardness test

4.15. Analysis of variance (ANOVA) for hardness test

Based found the optimum value of hardness is using (ANOVA), and the most important characteristics (most significant parameters) that determine the hardness of MIG-welded steels are found and displayed in table 4.17. To determine the percentage contribution of each of the components, the study was conducted using their S/N ratios.

Table 4.*18*: Analysis of Variance for SN ratios

source	DF	Seq SS	%Contrib.	Adj SS	Adj MS	F	P
welding current (A)	3	5.7657	53	5.7657	1.92190	37.11	0.007
voltage (B)	3	0.2393	2	0.2393	0.07977	1.54	0.366
Arc gap (c)	3	0.9621	9	0.9621	0.32071	6.19	0.084
Arc speed (D)	3	3.7661	35	3.7661	1.25538	24.24	0.013
Residual Error	3	0.1554	1	0.1554	0.05180		
Total	15	10.8887	100				

S= 0.2276 R-Sq = 98.57% R-Sq (adj) = 92.86%

F-Value=3.49 < F-ratio so the parameters were significant, and as shown in the percentage graph in figure 4.9, the welding current weight percentage (53%), voltage (2%), arc gap (35%), and arc speed (9%) all have a significant impact on the hardness of MIG-welded Mild steel with a thickness of 3mm. As a result, the welding current and arc speed has a highly significant impact on the hardness.

4.14. For best weld Bead

The width welded parts are depended on the thickness of material for this propose must be consider the arc speed, welding power and diameter of electrode. So, it was determined by measuring the width of the welded material deposited rate area and the gap between base metals with a vernier caliper with a 0.01 precision (kulkarni et al., 2017). In each welded specimen, three readings were collected, and the average value was calculated Table 4.19 shows the measured experimental results of the mean bead width geometry and the parameter used through at that bead weld, current (A) at level two, followed by arc gap (C) at level three, voltage (D) at level two, and arc speed (B) at level four and the S/N value on table 4.20 welding settings (A2B4C4D4) were chosen as the initial parametric setup to A36 steel with a thickness of 3 mm. These implications are using to development the parameter combination to create smaller the better results are viable.

Table 4.19weld bed length for all specimen

No Sample	Current (Amp)	Distance(mm)	Voltage	Arc speed(cm/s)	Width bead(mm)
1	90	10	17	2	6.5
2	90	12	19	2.5	7.25
3	90	14	22.5	3	6
4	90	16	26	3.5	8
5	100	10	17	2	7.5
6	100	12	19	2.5	7
7	100	14	22.5	3	9
8	100	16	26	3.5	10
9	120	10	17	2	6.5
10	120	12	19	2.5	7.25
11	120	14	22.5	3	6
12	120	16	26	3.5	8
13	150	10	17	2	7.5
14	150	12	19	2.5	7
15	150	14	22.5	3	9
16	150	16	26	3.5	10

Table 4.20 response table for means best weld bead based on S/n rations

Level	current	Arc gap	voltage	Arc Speed
1	16.77	16.89	16.88	16.88
2	18.37	17.05	17.05	17.05
3	16.77	17.32	17.32	17.32
4	18.37	19.03	19.0	19.03
Delta	1.6	2.14	2.12	2.15
Rank	4	2	3	1

4.14.1 Mean response analysis of bead width

Table 4.21 shows that standoff distance (D) at the first level has the highest value, followed by voltage (B) at the second level, arc speed (C) at the third level, and Current (A) at the fourth level. For MIG welding of mild steel with a thickness of 3mm, these welding parameters (A4B4C4D4) were chosen as the initial parametric setup. Figure 4.10 shows the main influence plot for control parameters for the mean bead width value. From the means graph, the numerical number at the minimum point in each graph in the main effect plot graph shows the parameter's best value at that level.

They also show the best settings within the parameters of the experiment. When compared to other welding variables, the welding arc speed weight percent has the greatest impact on improving bead width, followed by the arc gap. Welding current (150A) at level one, voltage (26volt) at level two, arc gap (16mm) at level three, and arc speed (35) at level four and at the were the optimum parameters (A3B3C2D3)

Table 4.21 Response table for best weld bead (Larger is the better)

Level	Current	Distance(mm)	Voltage	Arc speed(mm/s)
1	6.938	7.03	7	7
2	8.375	7.125	7.125	7.125
3	6.938	7.5	7.5	7.5
4	8.375	9	9	8.9
Delta	1.438	2.03	2	1.9
Rank	4	1	2	3

4.14.2. Signal to noise ratio analysis of bead width

The standoff distance weight percentage has the major influence, according to the signal to noise ratio value indicated in table 4.21 (Delta = 2.03, Rank =,$1st$) followed by voltage (Delta =2 Rank =,$2nd$) arc speed, (Delta =1.9, Rank =,$3rd$). The current has the smallest impact on the (S/N) ratio (Delta = 1.4, Rank =, $4th$.) The parameter combinations A1B4C4D4 based on the smaller the better, weld width character is the first optimum parameter combination for enhancing the bead width with the smallest the better response.

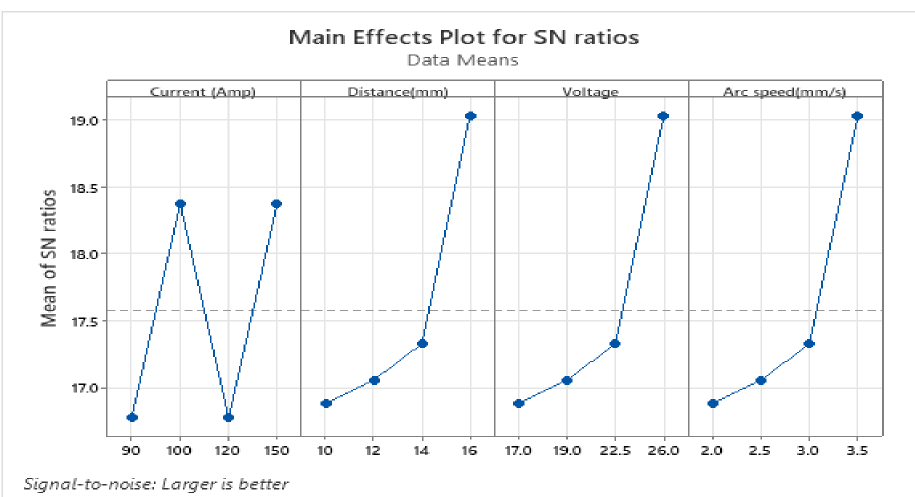


Figure 4.10 main effects plot for SN ratios larger is the better for best weld bead

4.15. Result Graphs for confirmation Setting in DOE

Table 4.22 are discussed on the correlation analysis in conformation test and the result for existed setting in the factory area. Due to the reason of these table effect on weld quality in the factory the individual treatment and influence for each factor new design of experiment were studied for final output. For mechanical properties of the improved setting of factory numerical analysis predicted TS, Hardness, Weld bead is lower than the modified one which is 351.8, and 138BHN within produce 5.9 mm weld beads. But the optimal setting process parameter are 115, 27.5, 21.12, and 13 for current, voltage, travel speed and standoff distance respectively.

S = 0.282 R-Sq = 99.3% R-Sq (adj) = 98.9%.

Table 4.22 correlation analysis

Correlations						
		TS	Current	Voltage	Speed	Arc Gap
Pearson Correlation	TS	1	-0.295	0.179	0.039	0.039
	Current	-0.295	1	-0.147	0	0
	Voltage	0.179	-0.147	1	0.784	0.784
	Speed	0.039	0	0.784	1	1
	Arc Gap	0.039	0	0.784	1	1
Sig. (1-tailed)	TS	.	0.133	0.253	0.443	0.443
	Current	0.133	.	0.294	0.5	0.5
	Voltage	0.253	0.294	.	0	0
	Speed	0.443	0.5	0	.	0
	Arc Gap	0.443	0.5	0	0	.
N	TS	16	16	16	16	16
	Current	16	16	16	16	16
	Voltage	16	16	16	16	16
	Speed	16	16	16	16	16
	Arc Gap	16	16	16	16	16

4.16 THE TOTAL CONFIRMATION RESULT

The confirmation test was conducted after the experimental result was analyzed through optimization to validate the hypothesis due to process parametric configuration. As a result, the confirmation was carried out in the Ethiopian Technical Institute's Engineering Center of Excellence at the welding training center. After these all the results of the confirmation testing agreed with the predicted optimum parametric setting with a very minimal positive validation error, as shown in Table 4.24.

Table 4. 24 conformation result

types of samples	optimum setting	Tensile Strength (Mpa)	Hardness (BHN)	Bed width	Error
A36 mild steel	A2 B2 C4 D3	351.8	138	5.9	4.9%
	Exp setting				
	A2 B2 C4 D3	321.8	118	6.14	

Chapter -5

5. Conclusion and Recommendation

5.1. Conclusion

The complete result of 16 sample was performed as per the experimental plan was shown in table 4.3, 4.4 and 4.13, modified and improved design of experiment respectively analyzed for the result with run order selected at standard OA. These results were input into the Minitab, SPSS, RSM design expert software for further analysis. After the examination result was summary, output revealed that the quadratic model significant for responses. This study was based on the parameter optimization process to find the optimum Tensile strength and hardness. For those experiment, 100mm x 100mm x 3mm length, width and thickness respectively A36 mild steel was used.

The hardness and TS material was less-than the hardness and TS after welding, MIG welding parameters impact on quality characteristics are analyzed by S/N-Ratio and ANOVA finally confirmed by RSM regression analysis. Based on the three concepts which mean S/N-Ratio, ANOVA, RSM regression analysis the hardness and TS numerical calculation was analyzed using with four parameters. This study used four factors and two levels L8 (OA) design of experiment and analyze the factor effect on MIG welding first for S/N-Ratio overall, average S/N-Ratio for each factor, optimum factor combinations, ANOVA, Sum Squares, Mean Squares, Degree of Freedom, F-ratio, percentage contributions, and critical factors on MIG welding was determined. Similarly, ANOVA for response were predicted using analytical calculation with larger-the-better S/N-Ratio, factor standoff distance percentage contribution (19.854%), critical factor; current (31.847%), travel speed lowest (28.9%) and factor voltage was almost negligible effect according to percentage contribution which was showed on table 4.5. According to ANOVA calculation factor effect on MIG welding factor percentage contribution is 25% for each factor. In regression analysis design model, tensile stress, hardness, weld bead optimum output and percent improvement for new model was determined and optimum and improved tensile stress, hardness respectively 351.8Mpa and 138BHN with the percent improvement after regression analysis 4.9%.

Generally, from these five concepts process parameter regression analysis was acceptable method in determination factor contribution without biasing the four factors.

From the analysis the results using the conceptual signal-to-noise (S/N) ratio approach, analysis of variance (ANOVA), by using SPSS and Minitab software regression analysis for optimization method to conclude as the below from the present study.

- It was found that the parameter design MIG welding bead quality in case of provides a simple, systematic and efficient methodology for the optimization the process parameters.
- The existed DOE design of parameter combination current setting 90A, voltage 22.1, speed 20 mm/sec and standoff distance 10 mm with optimum bead width 6.14mm, hardness 118BHN and TS 321.433MPa.
- For modified DOE setting, the travel speed increases the strength of the welded part increases from 321.433to 351.8MPa, when the optimal values of the above parameters are experimentally increasing found attain an optimal point.
- For improved (optimized) current as 115A, voltage 27.5V, travel speed 21.12mm/sec and standoff distance 13mm with result of 351.8MPa.
- According to regression analysis optimum process parameter was 5%TS improvement. So, regression 351.8MPa was better than S/N-ratio 321.43 MPa result.

5.2 Recommendation

According to this study the following recommendations are advice to the factory.

- For 3 mm thickness, low carbon steel should be used in order to attain optimal welding parameter combination.
- During the operation welding current should be set at 115amperes, arc voltage 27.5volt, travel speed 21.125cm/sec and standoff distance 1.3cm to achieve 351.8MPa and above weld bead tensile strength with bead width 5.9mm and hardness 138BHN
- Update the skill and knowledge of welder by taking a training program awareness to achieve good quality products.
- Welding operation manual should be prepared for all process parameters to increase quality and decrease defects.

5.3 Future Work

The analysis which has done gives the optimum condition for MIG welding i.e. Only four welding parameters were studied in this study: welding current, voltage, Arc gap, and Arc speed. Future research could investigate the effects and analyses of shear stress, fatigue stress, compressive strength and impact load during MIG welding of mild steel

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APPENDIX "A"

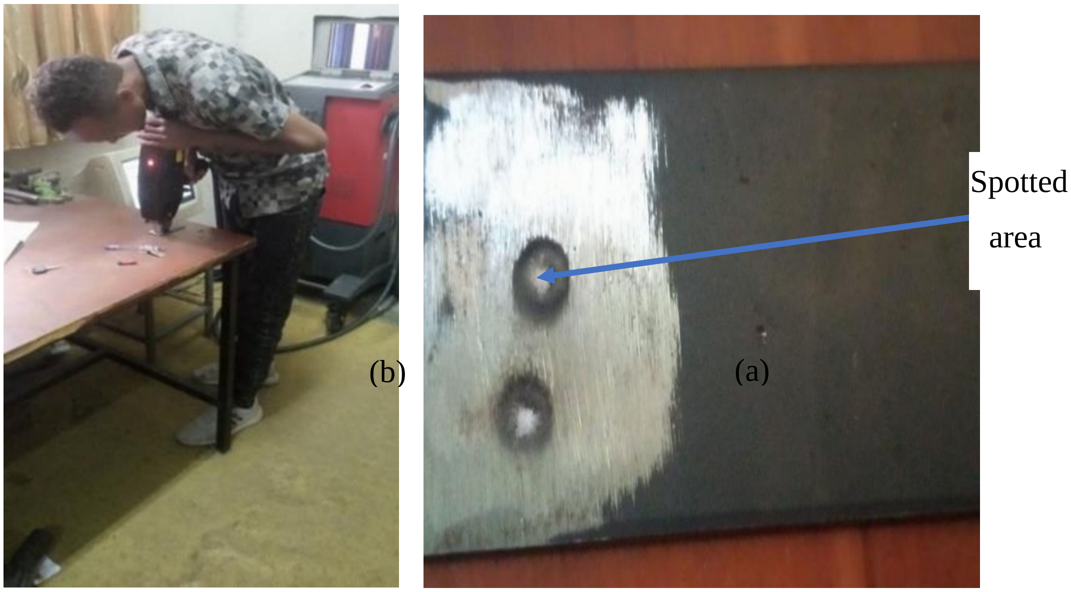

Figure: (a) Chemical composition testing and (b) Spot marks after testing

Table: Chemical composition of A 36 mild steel

Element	Content (%)	Element	Content (%)
C	0.25	Mo	0.003
Si	0.006	Ni	0.013
Mn	0.28	Cu	0.014
P	0.05	W	0.040
S	0.097	Fe	99.202
Cr	0.045		

Table: Typical copper electrode compositions, Source: EEGAMSMI

Value	Elements (%)						
	Cu	Pb	Sn	As	Zr	Zn	Fe
	99.6	< 0.004	< 0.002	< 0.003	0.002	0.045	0.23
Tensile strength	6205-775N/mm^2						

በኢትዮ-ኢንጂነሪንግ ግሩፕ
የአዲስ ማሽንና መለዋወጫ ማምረቻ ኢንዱስትሪ
Ethio-engineering Group
Addis Machine and Spare Part Manufacturing Industry

ቁጥር ኢግ/አማመ/ [illegible] 20 — 13/215/14
ቀን 23/09/2014

Date: 23/09/2014

Requested by: ADAMA SCIENCE &TECHNOLOGY UNIVERSITY

Sample type: STEEL

Purpose: IDENTIFICATION

S/N	Sample Name	Chemical Composition											
		C	Si	Mn	P	S	Cr	Mo	Ni	Cu	W	Fe	CSN
1	PLATE	0.18	0.006	0.28	0.050	0.097	0.045	0.003	0.013	0.014	0.040	99.3	12024

Prepared by: [illegible]
Sign: [illegible]
Date: 23/09/14

Checked by: [illegible]
Sign: [illegible]
Date: 23/09/14

Approved by: [illegible]
Sign: [illegible]
Date: 23/9/2014

Ethio-Engineering Group
Addis Machine and Spare Part Manufacturing Industry

ስልክ ቁጥር Tell +251 115 508 685 /ዋና ሥራ አስኪያጅ/
+251 115 508 690 /ሀብት አስ..መምሪያ/
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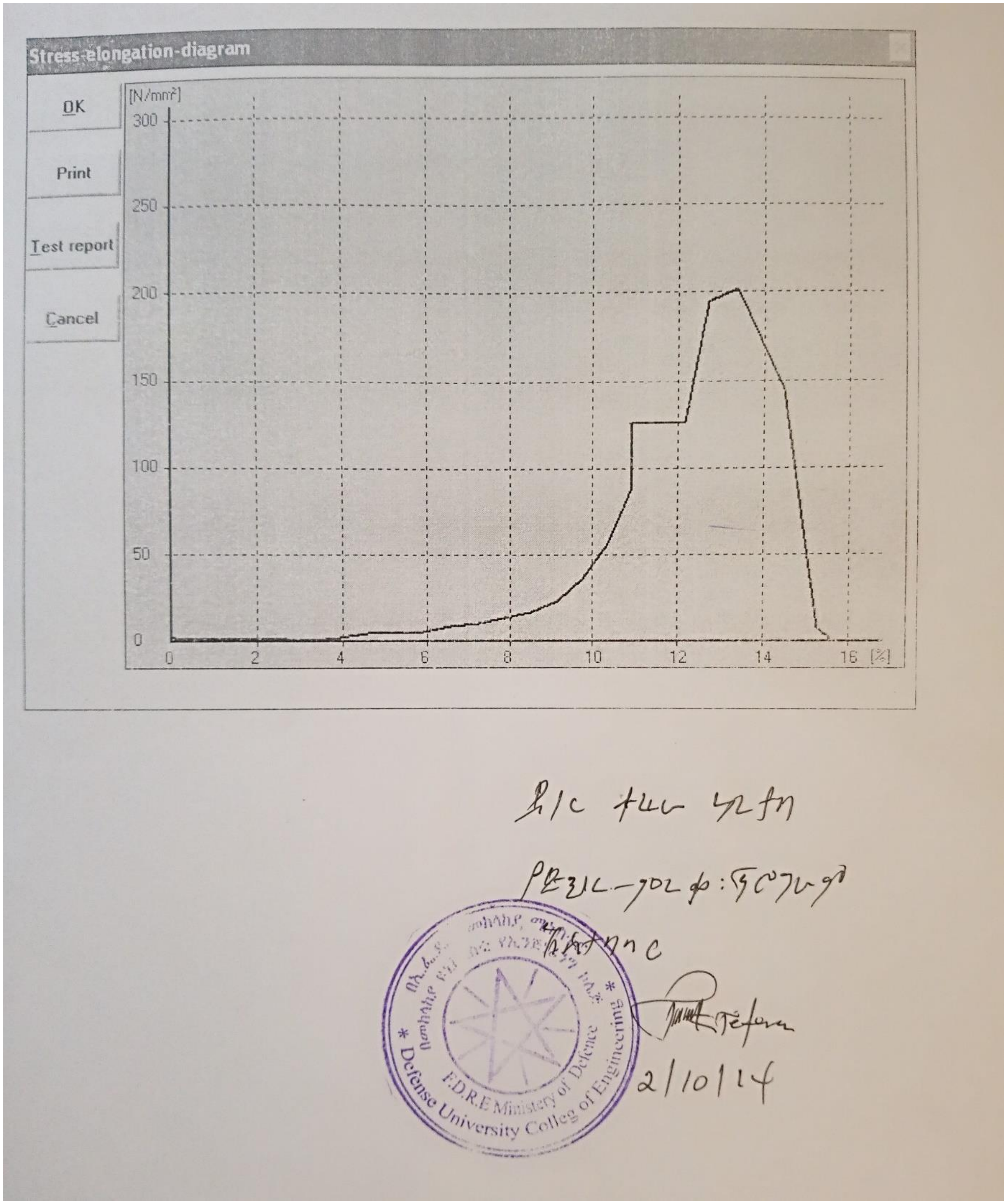
ኢ-ሜይል e-mail egaddismfgindustry@gmail.com


Stress-elongation-diagram
OK
Print
Test report
Cancel
[N/mm²]
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16 [%]
F.D.R.E Ministry of Defence
* Defense University College of Engineering
2/10/14

EXP.

Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	m.steel
Dimensions of specimen:	Tension specimen B12 x 100 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	256.94 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	09.06.2022
Name of tester:	Mintesnot Tsegaw
Signature:	

EXP.

Output force-elongation-table

Material:	m.steel
Free Text:	
Initial measurement length:	100mm
Specimen diameter:	12mm
Date:	09.06.2022

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	12.49
2	0.00	0.00
3	0.01	0.33
4	0.02	1.68
5	0.02	2.26
6	0.02	2.92
7	0.02	3.60
8	0.02	4.26
9	0.00	4.92
10	0.06	5.57
11	0.27	6.22
12	0.52	6.86
13	0.95	7.47
14	1.68	8.07
15	2.78	8.66
16	4.06	9.26
17	5.57	9.84
18	7.17	9.81
19	7.17	11.10
20	9.25	11.67
21	6.65	12.79
22	0.33	13.60
23	0.02	14.19
24	0.00	14.29

Exp.

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	1.67	1.32
2	0.28	1.86
3	5.83	2.45
4	10.83	3.05
5	16.94	3.65
6	26.67	4.22
7	40.00	4.79
8	56.94	5.35
9	77.78	5.91
10	106.11	6.46
11	135.56	7.02
12	167.50	7.58
13	203.06	8.12
14	240.56	8.66
15	275.00	8.63
16	275.00	9.87

OK

Print

Cancel

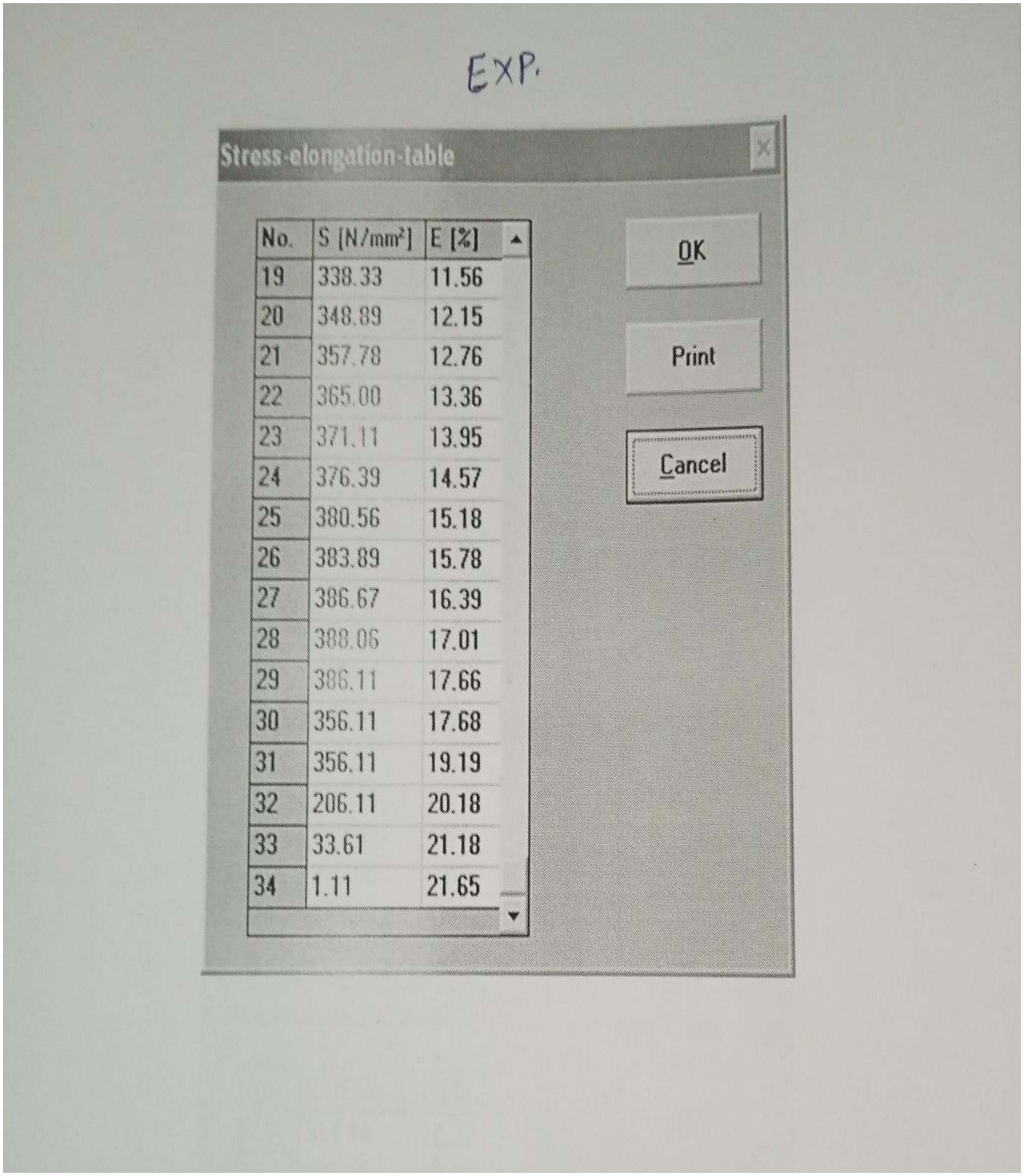
Stress-elongation-table

No.	S [N/mm²]	E [%]
17	314.44	10.37
18	326.11	10.97
19	338.33	11.56
20	348.89	12.15
21	357.78	12.76
22	365.00	13.36
23	371.11	13.95
24	376.39	14.57
25	380.56	15.18
26	383.89	15.78
27	386.67	16.39
28	388.06	17.01
29	386.11	17.66
30	356.11	17.68
31	356.11	19.19
32	206.11	20.18
33	33.61	21.18

OK

Print

Cancel



No.	S [N/mm²]	E [%]
19	338.33	11.56
20	348.89	12.15
21	357.78	12.76
22	365.00	13.36
23	371.11	13.95
24	376.39	14.57
25	380.56	15.18
26	383.89	15.78
27	386.67	16.39
28	388.06	17.01
29	386.11	17.66
30	356.11	17.68
31	356.11	19.19
32	206.11	20.18
33	33.61	21.18
34	1.11	21.65

APPENDIX “B”

		Correlations				
		TS	Current	Voltage	Speed	Arc Gap
Pearson Correlation	TS	1	-0.295	0.179	0.039	0.039
	Current	-0.295	1	-0.147	0	0
	Voltage	0.179	-0.147	1	0.784	0.784
	Speed	0.039	0	0.784	1	1
	Arc Gap	0.039	0	0.784	1	1
Sig. (1-tailed)	TS	.	0.133	0.253	0.443	0.443
	Current	0.133	.	0.294	0.5	0.5
	Voltage	0.253	0.294	.	0	0
	Speed	0.443	0.5	0	.	0
	Arc Gap	0.443	0.5	0	0	.
N	TS	16	16	16	16	16
	Current	16	16	16	16	16
	Voltage	16	16	16	16	16
	Speed	16	16	16	16	16
	Arc Gap	16	16	16	16	16

Descriptive Statistics			
	Mean	Std. Deviation	N
TS	337.696	8.56142	16
Current	115	23.6643	16
Voltage	21	3.16754	16
Speed	2.5	1.1547	16
Arc Gap	2.5	1.1547	16

APPENDIX C

Current

Case Processing Summary								
		Cases						
		Valid		Missing		Total		
Current		N	Percent	N	Percent	N	Percent	
TS	90.00	4	100.0%	0	0.0%	4	100.0%	
	100.00	4	100.0%	0	0.0%	4	100.0%	
	120.00	4	100.0%	0	0.0%	4	100.0%	
	150.00	4	100.0%	0	0.0%	4	100.0%	

Descriptive					
Current				Statistic	Std. Error
TS	90.00	Mean		338.5525	4.45657
		95% Confidence Interval for Mean	Lower Bound	324.3697	
			Upper Bound	352.7353	
		5% Trimmed Mean		338.6789	
		Median		339.6900	
		Variance		79.444	
		Std. Deviation		8.91313	
		Minimum		327.29	
		Maximum		347.54	
		Range		20.25	
		Interquartile Range		17.06	
		Skewness		-.568	1.014
		Kurtosis		-1.230	2.619
	100.00	Mean		344.2000	4.14005
		95% Confidence Interval for Mean	Lower Bound	331.0245	
			Upper Bound	357.3755	
		5% Trimmed Mean		344.3444	
		Median		345.5000	
		Variance		68.560	
		Std. Deviation		8.28010	
		Minimum		334.00	
		Maximum		351.80	
		Range		17.80	
		Interquartile Range		15.60	
		Skewness		-.540	1.014
		Kurtosis		-2.581	2.619
	120.00	Mean		332.6200	4.54443
		95% Confidence	Lower Bound	318.1576	

		Interval for Mean	Upper Bound	347.0824	
		5% Trimmed Mean		332.4883	
		Median		331.4350	
		Variance		82.607	
		Std. Deviation		9.08886	
		Minimum		323.23	
		Maximum		344.38	
		Range		21.15	
		Interquartile Range		17.39	
		Skewness		0.647	1.014
		Kurtosis		-0.198	2.619
	150.00	Mean		335.4100	3.04858
		95% Confidence Interval for Mean	Lower Bound	325.7081	
			Upper Bound	345.1119	
		5% Trimmed Mean		335.3561	
		Median		334.9250	
		Variance		37.175	
		Std. Deviation		6.09715	
		Minimum		328.46	
		Maximum		343.33	
		Range		14.87	
		Interquartile Range		11.21	
		Skewness		0.473	1.014
		Kurtosis		1.618	2.619

Percentiles

Current			Percentiles						
			5	10	25	50	75	90	95
Weighted Average	TS	90.00	327.2900	327.2900	329.4525	339.6900	346.5150		
		100.00	334.0000	334.0000	335.7500	345.5000	351.3500		
		120.00	323.2300	323.2300	324.5200	331.4350	341.9050		
		150.00	328.4600	328.4600	330.0475	334.9250	341.2575		
Tukey's Hinges	TS	90.00			331.6150	339.6900	345.4900		
		100.00			337.5000	345.5000	350.9000		
		120.00			325.8100	331.4350	339.4300		
		150.00			331.6350	334.9250	339.1850		

Extreme Values[a]

Current				Case Number	Value
TS	90.00	Highest	1	3	347.54
			2	1	343.44
		Lowest	1	2	327.29
			2	4	335.94
	100.00	Highest	1	7	351.80
			2	5	350.00

		Lowest	1	8	334.00
			2	6	341.00
	120.00	Highest	1	12	344.38
			2	11	334.48
		Lowest	1	9	323.23
			2	10	328.39
	150.00	Highest	1	13	343.33
			2	16	335.04
		Lowest	1	14	328.46
			2	15	334.81
a. The requested number of extreme values exceeds the number of data points. A smaller number of extremes is displayed.					

Voltage

Case Processing Summary							
	Voltage	Cases Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
TS	17	1	100.00%	0	0.00%	1	100.00%
	17.5	1	100.00%	0	0.00%	1	100.00%
	18	3	100.00%	0	0.00%	3	100.00%
	19	2	100.00%	0	0.00%	2	100.00%
	20	1	100.00%	0	0.00%	1	100.00%
	21	1	100.00%	0	0.00%	1	100.00%
	22	1	100.00%	0	0.00%	1	100.00%
	22.5	1	100.00%	0	0.00%	1	100.00%

Descriptivism, b, c, d, e, f					
Voltage				Statistic	Std. Error
TS	18.00	Mean		337.8100	6.39017
		95% Confidence Interval for Mean	Lower Bound	310.3153	
			Upper Bound	365.3047	
		5% Trimmed Mean			
		Median		335.0400	
		Variance		122.503	
		Std. Deviation		11.06809	
		Minimum		328.39	
		Maximum		350.00	
		Range		21.61	
		Interquartile Range			
		Skewness		1.056	1.225
		Kurtosis			
	19.00	Mean		335.3100	8.02000
		95% Confidence Interval for Mean	Lower Bound	233.4062	
			Upper Bound	437.2138	
		5% Trimmed Mean			
		Median		335.3100	

		Variance		128.641	
		Std. Deviation		11.34199	
		Minimum		327.29	
		Maximum		343.33	
		Range		16.04	
		Interquartile Range			
		Skewness			
		Kurtosis			
	23.00	Mean		343.3050	8.49500
		95% Confidence Interval for Mean	Lower Bound	235.3658	
			Upper Bound	451.2442	
		5% Trimmed Mean			
		Median		343.3050	
		Variance		144.330	
		Std. Deviation		12.01374	
		Minimum		334.81	
		Maximum		351.80	
		Range		16.99	
		Interquartile Range			
		Skewness			
		Kurtosis			
	26.00	Mean		338.1067	3.18627
		95% Confidence Interval for Mean	Lower Bound	324.3973	
			Upper Bound	351.8161	
		5% Trimmed Mean			
		Median		335.9400	
		Variance		30.457	
		Std. Deviation		5.51878	
		Minimum		334.00	
		Maximum		344.38	
		Range		10.38	
		Interquartile Range			
		Skewness		1.494	1.225
		Kurtosis			
a. TS is constant when Voltage = 17.00. It has been omitted.					
b. TS is constant when Voltage = 17.50. It has been omitted.					
c. TS is constant when Voltage = 20.00. It has been omitted.					
d. TS is constant when Voltage = 21.00. It has been omitted.					
e. TS is constant when Voltage = 22.00. It has been omitted.					
f. TS is constant when Voltage = 22.50. It has been omitted.					

Percentiles[a, b, c, d, e, f]									
Voltage			Percentiles 5	10	25	50	75	90	95
Weighted Average (Definition 1)	TS	18.00	328.3900	328.3900	328.3900	335.0400			
		19.00	327.2900	327.2900	327.2900	335.3100			
		23.00	334.8100	334.8100	334.8100	343.3050			
		26.00	334.0000	334.0000	334.0000	335.9400			
Tukey's Hinges	TS	18.00			331.7150	335.0400	342.5200		
		19.00			327.2900	335.3100	343.3300		
		23.00			334.8100	343.3050	351.8000		
		26.00			334.9700	335.9400	340.1600		
a. TS is constant when Voltage = 17.00. It has been omitted.									
b. TS is constant when Voltage = 17.50. It has been omitted.									
c. TS is constant when Voltage = 20.00. It has been omitted.									
d. TS is constant when Voltage = 21.00. It has been omitted.									
e. TS is constant when Voltage = 22.00. It has been omitted.									
f. TS is constant when Voltage = 22.50. It has been omitted.									

Extreme Values[’, b, c,d,e,f,g]						
Voltage				Case Number	Value	
TS	18.00	Highest	1	5	350.00	
		Lowest	1	10	328.39	
	19.00	Highest	1	13	343.33	
		Lowest	1	2	327.29	
	23.00	Highest	1	7	351.80	
		Lowest	1	15	334.81	
	26.00	Highest	1	12	344.38	
		Lowest	1	8	334.00	
a. TS is constant when Voltage = 17.00. It has been omitted.						
b. TS is constant when Voltage = 17.50. It has been omitted.						
c. The requested number of extreme values exceeds the number of data points. A smaller number of extremes is displayed.						
d. TS is constant when Voltage = 20.00. It has been omitted.						
e. TS is constant when Voltage = 21.00. It has been omitted.						
f. TS is constant when Voltage = 22.00. It has been omitted.						
g. TS is constant when Voltage = 22.50. It has been omitted.						

Speed

Case Processing Summary							
Speed		Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
TS	2	4	100.0%	0	0.0%	4	100.0%
	2.5	4	100.0%	0	0.0%	4	100.0%
	3	4	100.0%	0	0.0%	4	100.0%
	3.5	4	100.0%	0	0.0%	4	100.0%

Descriptive					
Speed				Statistic	Std. Error
TS	2	Mean		340.0000	5.80341
		95% Confidence Interval for Mean	Lower Bound	321.5309	
			Upper Bound	358.4691	
		5% Trimmed Mean		340.3761	
		Median		343.3850	
		Variance		134.718	
		Std. Deviation		11.60683	
		Minimum		323.23	
		Maximum		350.00	
		Range		26.77	
		Interquartile Range		20.11	
		Skewness		-1.551	1.014
		Kurtosis		2.911	2.619
	2.5	Mean		331.2850	3.24940
		95% Confidence Interval for Mean	Lower Bound	320.9440	
			Upper Bound	341.6260	
		5% Trimmed Mean		330.9672	
		Median		328.4250	
		Variance		42.234	
		Std. Deviation		6.49879	
		Minimum		327.29	
		Maximum		341.00	
		Range		13.71	
		Interquartile Range		10.30	
		Skewness		1.959	1.014
		Kurtosis		3.873	2.619
	3	Mean		342.1575	4.42417
			Lower Bound	328.0778	

		95% Confidence Interval for Mean	Upper Bound	356.2372	
		5% Trimmed Mean		342.0483	
		Median		341.1750	
		Variance		78.293	
		Std. Deviation		8.84833	
		Minimum		334.48	
		Maximum		351.80	
		Range		17.32	
		Interquartile Range		16.17	
		Skewness		.196	1.014
		Kurtosis		-4.868	2.619
	3.5	Mean		337.3400	2.37990
		95% Confidence Interval for Mean	Lower Bound	329.7661	
			Upper Bound	344.9139	
		5% Trimmed Mean		337.1344	
		Median		335.4900	
		Variance		22.656	
		Std. Deviation		4.75980	
		Minimum		334.00	
		Maximum		344.38	
		Range		10.38	
		Interquartile Range		8.01	
		Skewness		1.835	1.014
		Kurtosis		3.467	2.619

Percentiles

Speed			Percentiles 5	10	25	50	75	90	95
Weighted Average	TS	2	323.2300	323.2300	328.2550	343.3850	348.3600		
		2.5	327.2900	327.2900	327.5650	328.4250	337.8650		
		3	334.4800	334.4800	334.5625	341.1750	350.7350		
		3.5	334.0000	334.0000	334.2600	335.4900	342.2700		
Tukey's Hinges	TS	2			333.2800	343.3850	346.7200		
		2.5			327.8400	328.4250	334.7300		
		3			334.6450	341.1750	349.6700		
		3.5			334.5200	335.4900	340.1600		

Extreme values [a]

Speed				Case Number	Value
TS	2	Highest	1	5	350.00
			2	1	343.44
		Lowest	1	9	323.23
			2	13	343.33
	2.5	Highest	1	6	341.00
			2	14	328.46
		Lowest	1	2	327.29

			2	10	328.39
	3	Highest	1	7	351.80
			2	3	347.54
		Lowest	1	11	334.48
			2	15	334.81
	3.5	Highest	1	12	344.38
			2	4	335.94
		Lowest	1	8	334.00
			2	16	335.04
a. The requested number of extreme values exceeds the number of data points. A smaller number of extremes is displayed.					

ARC GAP (STAND OFF DISTANCE)

Case Processing Summary

Arc Gap		Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
TS	1	4	100.0%	0	0.0%	4	100.0%
	1.2	4	100.0%	0	0.0%	4	100.0%
	1.4	4	100.0%	0	0.0%	4	100.0%
	1.6	4	100.0%	0	0.0%	4	100.0%

Descriptive

Arc Gap				Statistic	Std. Error
TS	1	Mean		340.0000	5.80341
		95% Confidence Interval for Mean	Lower Bound	321.5309	
			Upper Bound	358.4691	
		5% Trimmed Mean		340.3761	
		Median		343.3850	
		Variance		134.718	
		Std. Deviation		11.60683	
		Minimum		323.23	
		Maximum		350.00	
		Range		26.77	
		Interquartile Range		20.11	
		Skewness		-1.551	1.014
		Kurtosis		2.911	2.619
	1.2	Mean		331.2850	3.24940
		95% Confidence Interval for Mean	Lower Bound	320.9440	
			Upper Bound	341.6260	
		5% Trimmed Mean		330.9672	
		Median		328.4250	
		Variance		42.234	
		Std. Deviation		6.49879	
		Minimum		327.29	
		Maximum		341.00	
		Range		13.71	

		Interquartile Range		10.30	
		Skewness		1.959	1.014
		Kurtosis		3.873	2.619
	1.4	Mean		342.1575	4.42417
		95% Confidence Interval for Mean	Lower Bound	328.0778	
			Upper Bound	356.2372	
		5% Trimmed Mean		342.0483	
		Median		341.1750	
		Variance		78.293	
		Std. Deviation		8.84833	
		Minimum		334.48	
		Maximum		351.80	
		Range		17.32	
		Interquartile Range		16.17	
		Skewness		.196	1.014
		Kurtosis		-4.868	2.619
	1.6	Mean		337.3400	2.37990
		95% Confidence Interval for Mean	Lower Bound	329.7661	
			Upper Bound	344.9139	
		5% Trimmed Mean		337.1344	
		Median		335.4900	
		Variance		22.656	
		Std. Deviation		4.75980	
		Minimum		334.00	
		Maximum		344.38	
		Range		10.38	
		Interquartile Range		8.01	
		Skewness		1.835	1.014
		Kurtosis		3.467	2.619

Percentiles

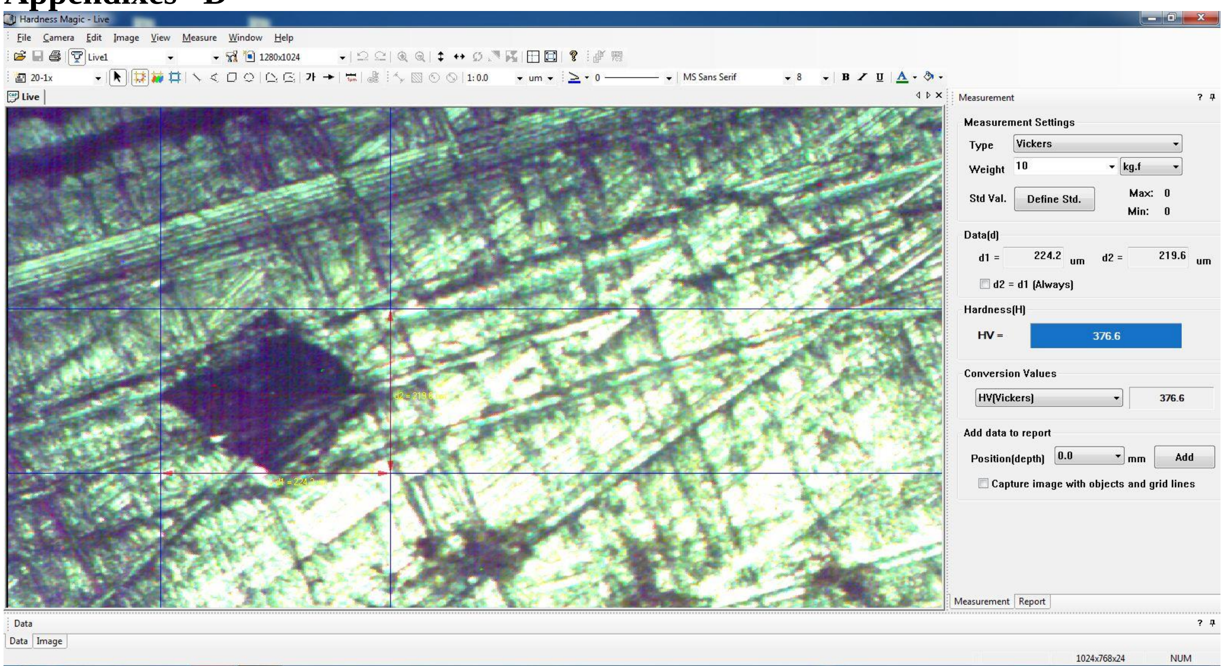
Arc Gap			Percentiles 5	10	25	50	75	90	95
Weighted Average	TS	1	323.2300	323.2300	328.2550	343.3850	348.3600		
		1.2	327.2900	327.2900	327.5650	328.4250	337.8650		
		1.4	334.4800	334.4800	334.5625	341.1750	350.7350		
		1.6	334.0000	334.0000	334.2600	335.4900	342.2700		
Tukey's Hinges	TS	1			333.2800	343.3850	346.7200		
		1.2			327.8400	328.4250	334.7300		
		1.4			334.6450	341.1750	349.6700		
		1.6			334.5200	335.4900	340.1600		

Extreme Values [a]

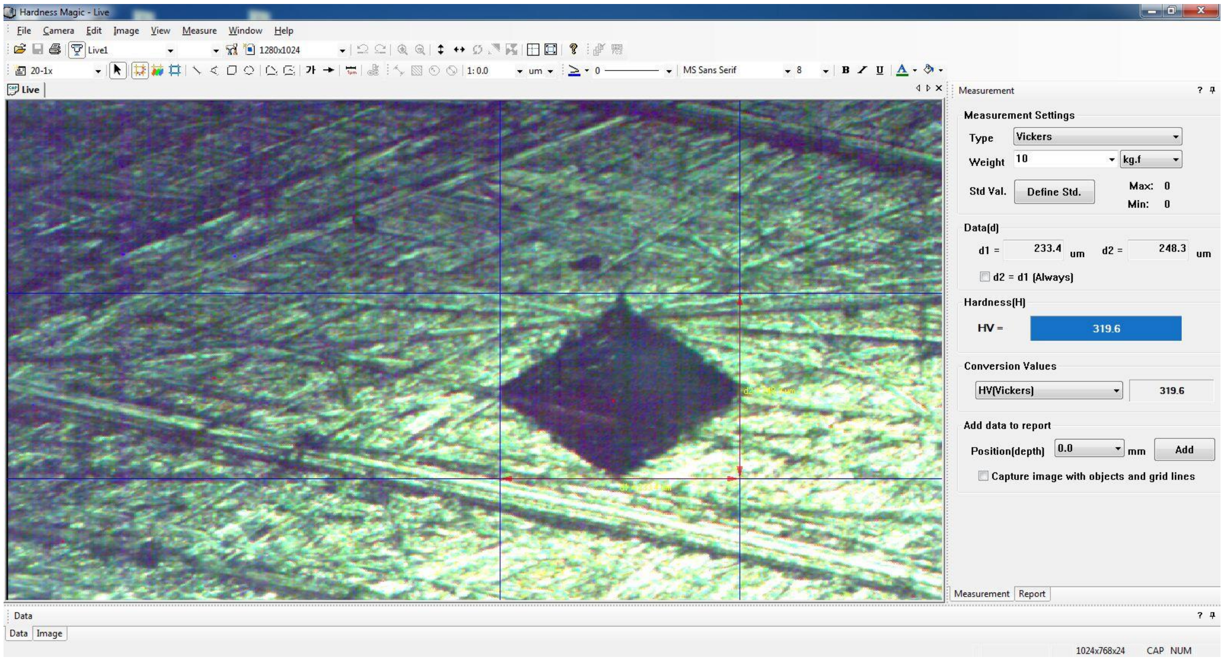
Arc Gap				Case Number	Value
TS	1	Highest	1	5	350.00
			2	1	343.44
		Lowest	1	9	323.23
			2	13	343.33
	1.2	Highest	1	6	341.00

			2	14	328.46
		Lowest	1	2	327.29
			2	10	328.39
	1.4	Highest	1	7	351.80
			2	3	347.54
		Lowest	1	11	334.48
			2	15	334.81
	1.6	Highest	1	12	344.38
			2	4	335.94
		Lowest	1	8	334.00
			2	16	335.04
a. The requested number of extreme values exceeds the number of data points. A smaller number of extremes is displayed.					

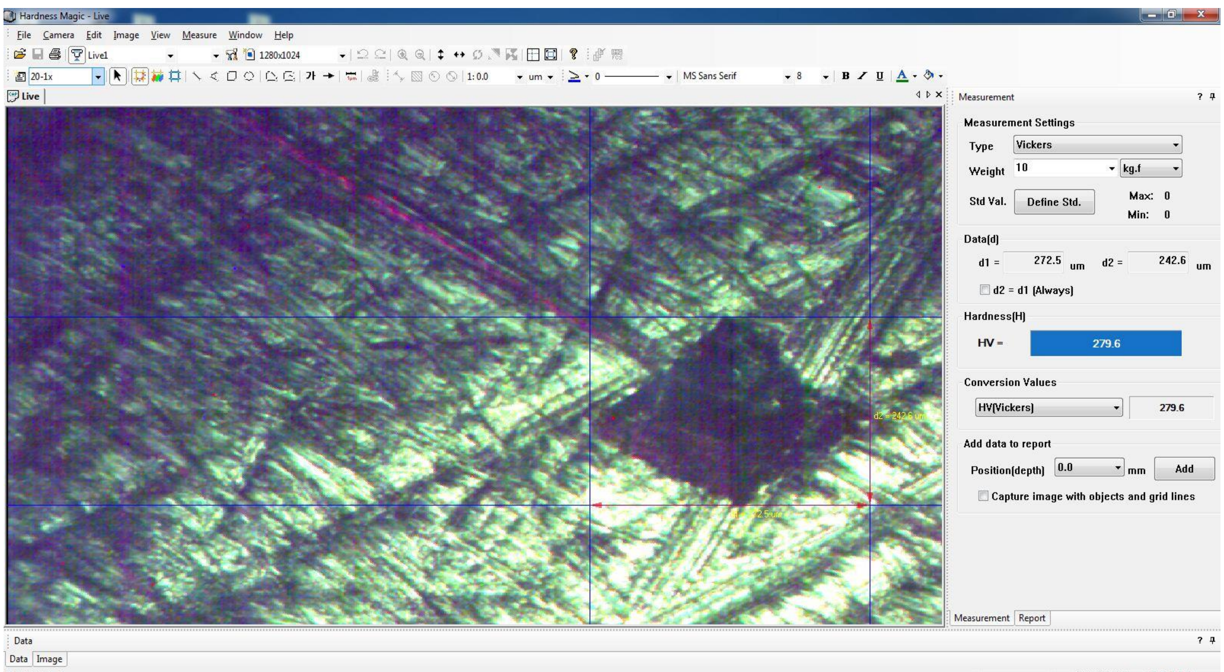
Appendixes “D”



Sample 9 Vickers micro hardness



Sample 5 Vickers micro hardness



Sample 3 Vickers micro hardness