

Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding

By

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A Thesis Submitted to Department of Mechanical Design and

Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

September, 2021

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**Presented in Partial Fulfillment of the Requirement for the Degree of
Master's in Manufacturing Engineering**

Office of Graduate Studies

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September, 2021

APPROVED BY BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by **Behredin Kedir Beyene** have read and evaluated his thesis entitled “***Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding***” and Examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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Subject: Thesis Submission

This is to certify that the thesis entitled “***Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding***” submitted in partial fulfillment of the requirement for the degree of Master’s in Manufacturing Engineering, the Graduate program of the department of Design and Manufacturing Engineering and has been carried out by Behredin Kedir Beyene (ID PGR/18392/11), under my supervision. Therefore, i recommend that the student has fulfilled the requirement and hence here by he can submit the thesis to the department.

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DECLARATION

I hereby declare that the work, which is being presented in thesis, entitled ***“Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding”*** In partial fulfillment of the requirement for the award of the Degree of Masters of Science in Manufacturing Engineering is my own work.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree or Diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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ACKNOWLEDGEMENT

All praise to the **ALMIGHTY ALLAH** whose knowledge and compassion extends to all His creations. This work would not have been completed without His endless grace and kindness upon me.

I want to express special thanks and gratitude to my Advisor **Dr. Perumalla Janaki Ramulu**, for his continuous support, guidance, comment and suggestions throughout the thesis work time from starting up to end. His extreme energy, creativity and excellent skills have always been a constant source of motivation for me. He is a great person and one of the best mentors; without his endless support it may not be possible for me to complete my thesis work

Dr. Habtamu Beri, Co-Advisor, for his valuable advising, inspiration, trust and vision to me to struggle the completeness of this work. I am thankful to him for his support.

I am also grateful to **Mengistu Gelaw**, Program Chair, Mechanical Design and Manufacturing Engineering Program, for his support and contribution to the success of my thesis work.

I would like to thank **Mr Kamil**, Lecturer And Lab Assistant of Material's and Chemical Engineering during hardness and microstructure testing, **Mr Fantahun**, The vice head of Ethiopian welding training center at ETU, who facilitates my welding work, **Mr Muluken**, workshop coordinator at ETU, Ethiopian welding training center for his help during my welding operation, **Mr Nelson**, Lecturer And Lab Assistant at ETU, during tensile testing operation, **Mr Tedi**, from MIDI, they help me in NDT testing.

I am also thankful for those people who supported and supervised my work. I thank my friend's and parents for constant encouragement to pursue my dreams. Without the support of my spouse, **Dr. Zeyneb I.**, I would not have successfully reached this goal. I am very grateful for her enduring love throughout the whole process and for her patience, encouragement and support for not only me but my sons. I also thank my mother **Fedila M.**, Brother **Dr. Nesrudin K.**, **Yasu K.** and **Buser M.** for their endless support in my life.

Finally, my thanks go to all the people who have supported me to complete the research work directly or indirectly.

Abstract

Welding is one of the secondary manufacturing methods, for joining similar or dissimilar materials with different joint configurations using various materials. There are many welding processes existed to join the metals, in which MIG welding is one of the most widely used processes in industries to weld materials thickness from 2mm to 12mm sheet and plate respectively. The MIG welding process has many process parameters which are responsible for the productivity, quality and cost of welded joints. Advanced High Strength Steels (AHSS) are multiphase steels that contain various concentrations of ferrite, bainite, martensite and retained austenite phases. The unique physical characteristics of AHSS present some challenges to welding and bonding processes. AHSS has tendency to change micro-structure and mechanical properties by any welding process like other steels. Based on the significant applications in various industries, the experimental works are carried out on one of AHSS materials EN-10149-2 S700MC of thickness 2mm steel sheet metal by MIG welding process parameters such as (current, voltage, welding speed). For all combinations of process parameters, the butt joints are fabricated. The butt joints are inspected through different non-destructive testing for defects detection. All the defect free joints are characterized through micro-structure (at different zones of joint), hardness and tensile tests. The analysis from DoE method used to identify which parameter is the most significant among all parameters. Confirmatory test was also done by taking the optimal parameters and the results show that the improvement of the response variables was acceptable and the method that was used to optimize was valid. Finally, by using optimum parameters in-terms of current, voltage and welding speed the tensile strength was increased from 765MPa to 780MPa, the hardness of weld zone was increased from 150VHN to 157VHN and the hardness of HAZ increased from 145.1 VHN to 166.47 VHN.

Keywords: MIG welding, welding parameter, Taguchi, ANOVA, S/N ratio microstructure, tensile strength, hardness

ABBREVIATIONS

AC	Alternating Current
Adj MS	Mean of Square of Variance
AHSS	Advanced High strength steel
AISI	American Institute of Steel Industry
ANOVA	Analysis of Variance
ASTM	American Society for Testing Material
AWS	American Welding Society
BM	Base Metal
DC	Direct Current
DCEN	Direct Current Electrode Negative
DCEP	Direct Current Electrode Positive
DCRP	Direct Current Revers polarity
DE	Degree of Freedom
EDS	Energy Dispersive Spectroscope
FZ	Fusion Zone
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
MIG	Metal Inert Gas Welding
MPa	Mega Pascal
MSD	Mean Square Deviation
OA	Orthogonal Array
RSM	Response Surface Methodology
S/N	Signal to Noise ratio
Seq SS	Sum of Square of Variance
UTM	Universal Tensile Testing Machine
UTS	Ultimate Tensile Strength
WM	Weld Metal
WPS	Welding procedure specification
WZ	Weld Zone
YS	Yield Strength

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CHAPTER ONE

INTRODUCTION

1.1 Introduction to Metal Inert Gas Welding

Metal Inert Gas (MIG) welding is one of the extensively used joining processes in manufacturing industries. The input parameters of MIG welding play a significant role in determining the quality of welded joints. Weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices get affected. The weld quality depends on the process parameters, so, the selection of the best parameters is necessary to get optimum results. Earlier in most of researches MIG parameters considered were welding current, arc voltage and welding speed. These parameters affect the weld characteristics remarkably. Because which can be varied over a large range, so that it was considered the primary adjustments of parameters in any welding operation. During MIG welding process, the electrode melts within the arc and becomes deposited as filler material. The shielding gas, that is used prevents atmospheric contamination and protects the weld during solidification. The shielding gas also assists with stabilizing the arc which provides a smooth transfer of metal from the weld wire to the molten weld pool.

Gas metal arc welding(GMAW) commonly referred to by its slang name “MIG” (metal inert gas welding) uses a continuously fed bare wire electrode through a nozzle, that delivers a proper flow of shielding gas to protect the molten and hot metal as it cools. Because the wire is fed automatically by a wire feed system, GMAW is one of the arc welding processes considered to be semiautomatic. The wire feeder pushes the electrode through the welding torch, where it makes electrical contact with the contact tube, which delivers the electrical power from the power supply and through the cable to the electrode. The basic equipment components are the welding gun and cable assembly; electrode feed unit, power supply, and source of shielding gas. This setup includes a water cooling system for the welding gun, which is typically necessary when welding with high duty cycles and high current. GMAW is self-regulating, which refers the ability of the machine to maintain a constant arc length at

all times. This is usually achieved using a constant-voltage power supply, although some modern machines are now capable of achieving self-regulation in other ways. This self-regulation feature results in a process that is ideal for mechanized and robotic applications.

1.2 Background of the Study

Metal inert gas (MIG) welding is also known as Gas metal arc welding (GMAW). The MIG welding process was developed and made commercially available in 1948, whereas the basic concept was actually introduced in the 1920's. Metal inert gas welding is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal causing them to melt and join. Along with the wire electrode, a shielding gas is supplied through the welding gun which shields the process from contaminants in the air. MIG welding is versatile and having less loss of alloying elements during the process and can be operated as semi-automatic and fully automatic welding.

Metal inert gas welding melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals. *Ar* and *He* are used as inert shielding gases to protect the molten weld pool. Mixture of CO₂ with *Ar* or *He* in ratio of (25%) *Ar*, (75%) *He* and (2%) CO₂ with *Ar* (98%) are used for non-ferrous (mostly Al) as well as stainless and alloy steels. The Argon arc plasma is stable and beneficial for transferring metal droplets through the arc plasma.

Metal inert gas welding is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. There, the method is often used for arc spot welding, thereby replacing riveting or resistance spot welding. It is also popular for automated welding, in which robots handle the work pieces and the welding gun to quicken the manufacturing process. Generally, it is not suitable for welding outdoors, because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld.

Gas metal arc welding is one of the conventional and traditional methods to join materials. A wide range of materials can be joined by gas metal arc welding; similar metals, dissimilar metals, alloys, and nonmetals.

Design of Experiment (DOE) and statistical techniques are widely used for optimization of process parameters. In the present study, the welding process parameters of MIG welding have been optimized to maximize the tensile strength, hardness and study the micro-structure of the work piece also reducing the number of experiments without affecting the results. The optimization of process parameters can improve quality of the product and minimize the cost of performing lots of experiments and also reduces the wastage of the resources.

The properties such as weld-bead geometry, mechanical properties, and distortion can define the joint quality. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. In order to determine the welding input parameters that lead to the desired weld quality, application of Design of Experiment (DOE), evolutionary algorithms and computational network are widely used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint.

1.3 Advanced High Strength Steels

AHSS are multiphase steels that contain various concentrations of ferrite, bainite, martensite and retained austenite phases. AHSSs were developed to support Fuel efficient, lower carbon emission and passenger safety were the main driving strategic requirements in designing automobiles. A recent report from World Steel Dynamics projected that by 2025 the usage of AHSSs would reach 23.7 million tons. This means that a significant part of the low-carbon steel parts would be replaced by AHSSs. Reductions in automotive mass and government regulations on crash requirements seem to have mutually opposing directions; fuel economy is ensured but safety can seemingly be endangered by lighter vehicles. However, studies to date using AHSSs for automobile designs have shown that reducing the weight of vehicles can be achieved without compromising passenger safety. AHSSs are extensively used in the automobile industry for manufacturing several body-in-white parts of vehicles. Auto designers have introduced these steels in critical structural parts such as the A, B and C pillars; the roof rails and bow; cross-members; door beams; front and side members; and as bumper reinforcement. They are also extensively used in internal panels made of tailor-welded blanks. AHSSs exhibit ultimate tensile strengths of 600 MPa or

higher, allowing vehicle manufacturers to make major strides in terms of the strength and rigidity of thinner-gauge sheets. In addition to high tensile properties these steels have good ductility, the capacity for high energy absorption and a high work-hardening coefficient over the uniform elongation regime. Advanced high-strength steel (AHSS) grades contain significant alloying and two or more phases. The multiple phases provide increased strength and ductility not attainable with single phase steels, such as high strength, low alloy (HSLA) grades. HSLA materials achieve their strength through alloying and solid solution hardening, whereas AHSS are produced by using specific alloys and precise thermo mechanical processing. Dual-phase (DP), complex-phase (CP), transformation-induced plasticity (TRIP) and martensitic steels are the prevalent AHSS grades, that are currently in commercial use. These grades are referred to as first-generation AHSSs. The relationship between the strength and ductility (as measured by elongation) of these steel grades is shown in Figure 1.1.

Advanced high strength steels are complex, sophisticated materials; with selected chemical compositions and multiphase microstructures resulting from precisely controlled heating and cooling processes. Various strengthening mechanisms are employed to achieve a range of strength, ductility, toughness, and fatigue properties. The AHSS family includes Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). These 1st and 2nd Generation AHSS grades are uniquely qualified to meet the functional performance demands of certain parts. For example, DP and TRIP steels are excellent in the crash zones of the car for their high energy absorption. For structural elements of the passenger compartment, extremely high-strength steels, such as Martensitic and boron-based Press Hardened Steels (PHS) result in improved safety performance. Recently there has been increased finding and research for the development of the “3rd Generation” of AHSS. These are steels with special alloying and thermo-mechanical processing to achieve improved strength-ductility combinations compared to present grades, with potential for more efficient joining capabilities, at lower costs.

The unique physical characteristics of Advanced High Strength Steels (AHSS) present some challenges to welding and bonding processes. AHSS differ from mild steels by chemical composition and microstructure, and it's important to note, that their microstructures will

change from welding operations. For example, intensive localized heat associated with some welding processes causes a significant change in the local microstructure, and hence affect properties. Due to fast Cooling Rates (CR) typical in welding, it is normal to see martensite and/or bainite microstructures in the weld metal and in the Heat-Affected Zone (HAZ). When joining AHSS, production process control is important for successful assembly. Manufacturers with highly developed joining control methodology will experience no major change in their operations. Others may require additional checks and maintenance. In certain instances, modifications to equipment or processing methodologies may be required for successful joining of AHSS.

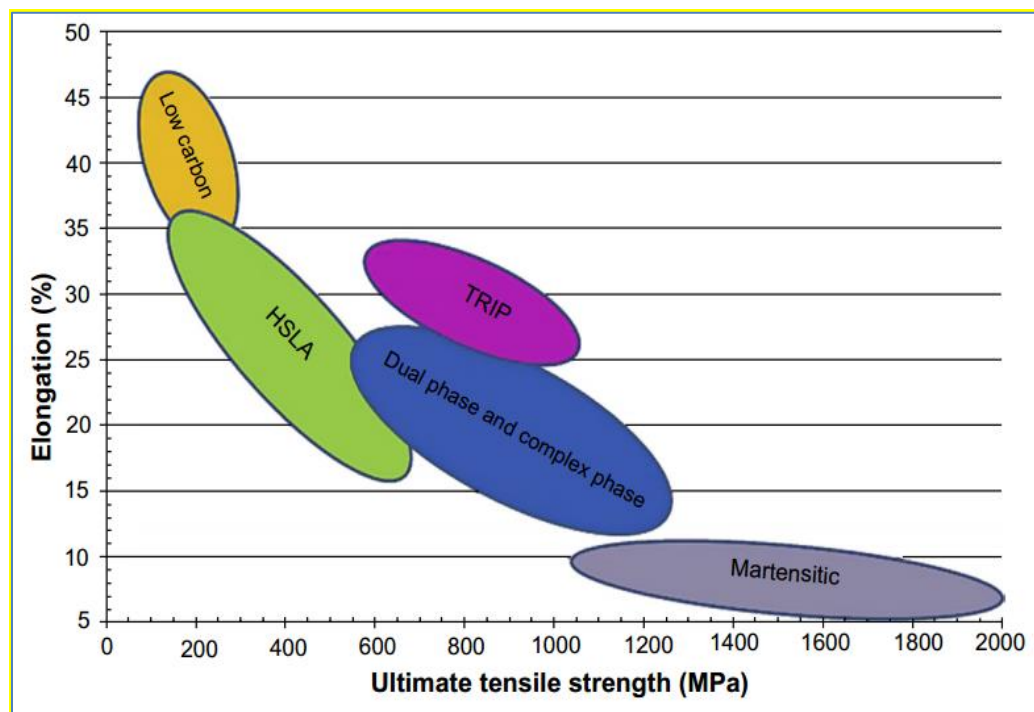


Figure 1.1 The strength versus elongation relationship for first-generation advanced high strength steels. (Shome and Tumuluru 2015)

The coating methods for AHSS are similar to those for mild steels. Welding of either AHSS or mild steels with coatings will generate fumes. The amount and nature of fumes will depend on the coating thickness, coating composition, joining method, and fillers used to join these materials. The fumes may contain some pollutants. The chemical composition of fumes and the relevant exhaust equipment must meet appropriate regulatory standards. Thicker coatings and higher heat inputs cause more fumes. Additional exhaust systems should be installed.

1.3.1 Welding processes for AHSS

Gas metal arc welding (GMAW) is mostly applied in chassis parts, where it is important to secure the strength and rigidity of the joint. The process also has the freedom to join parts of various shapes to structural members such as pipes and brackets. Long fatigue life of the weld joint is a prerequisite. Spatter, fit-up and gap issues need to be dealt with in parts formed during welding.

The GMAW process is also known as metal inert gas or metal active gas welding. Carbon dioxide is the active shielding gas in the latter process. Consumables with matching strengths are preferred to meet the mechanical property requirements of the joint, but lower-strength wires have been used to attain mechanical properties by depositing extra material. Consumable ER70S3 wires and shielding gas comprising 90% argon and 10% carbon dioxide produced acceptable welds. Higher heat input GMAW causes the HAZ to soften in DP steels, which in turn affects the fatigue properties. Studies have been carried out to correlate the effect of weld geometry and microstructure on the fatigue properties of AHSS butt welds. Some showed that the bead geometry and microstructure could act as a notch for the initiation and propagation of cracks under fatigue conditions.

The lowest hardness point is in the subcritical HAZ of DP590 steel, and most samples fail in this location during tensile testing, regardless of the bead geometry. Specimens with large beads (convex profile with higher height to width ratio) show a significantly shorter fatigue life, with fractures initiated at the toe of the weld. A shallow bead, that is, lower height/width ratio, with appropriate microstructure can improve fatigue performance in GMAW welds. The weld pool flows in the direction of the arc and prevents the formation of blow holes and porosities, which is a major issue during arc welding of zinc-coated sheets. The beads are flatter with a smooth curvature at the toe region. In fact, a welding wire with low silicon content and a base metal with higher silicon content give the best bead profile.

1.3.2 Application areas of EN-10149-2 steel material

EN-10149-2 steel sheet metal sheet has many application areas in modern manufacturing industries. It has also good mechanical properties and light weight that increase the

application in automotive, aerospace, and industrial structural design compared to other metals. Main applications of EN-10149-2 S700MC steel sheet metal are;

- Body and chassis components for the automotive and truck industry, bumper brackets, engine mounting brackets and passenger car components.
- Crane jibs and booms heavy-duty highway and off-road vehicles,
- A wide variety of uses for rolling stock and cold formed sections.
- Oil and gas pipelines,
- Construction and farm machinery, industrial equipment, storage tanks, mine and railroad cars, barges and dredges,
- Power transmission towers, light poles, and building beams and panels are additional uses of these steels.

1.4 Statement of Problem

The findings of optimum parameters in MIG welding processes for welding similar joints of advanced high strength steels are very important due to challenges in welding activities now a days. Many researchers have studied optimization and characterization of different MIG welded joints process parameters made of different materials having different thicknesses. From the observation of the various researches work, it is found that there were limited experiments performed on advanced high strength steels. Therefore, studying the optimization and characterization of AHSS's with experimental work on MIG welding process in order to know, which parameters more significantly affect welded joints strength, hardness and microstructure have highly necessary. The research work has been done on semi-automatic MIG welding machine in welding steel grade of EN-10149-2 S700MC of thickness 2mm high tensile and yield strength steel.

1.5 Research Gap

From literature survey welding parameters on the conventional MIG welding machines like welding current, welding voltage, welding speed, arc length, angle of welding, air gap, welding position, stick length, shielding gas and work piece material weld-ability, which affects the desired outputs like strength, hardness, and micro-structure for different material like mild steel, carbon steel, aluminum alloys etc. were studied. But the optimization of

welding parameters and characterization of AHSS steel sheets material welded by MIG welding process needs more research in detail. Therefore, it is vital to study the optimization and characterization of welding parameters for AHSS of EN-10149-2 S700MC of thickness 2mm.

Based on the literatures surveyed major challenges identified, and it was decided to experimentally investigate the following aspects of the welding process input parameter optimization in this thesis as a research gap.

- The difficulties in welding operation of AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal on MIG welding process and how to over-come those challenges by selecting optimal welding parameters .
- Identifying significant factors (welding current, welding voltage and welding speed) that affect the surface quality of MIG welding process for AHSS of EN-10149-2 S700MC of thickness 2mm.

1.6 Objective

1.6.1 General Objective

The general objective of this research is characterization and parametric optimization of EN-10149-2 S700MC steel butt welded joints made by MIG welding.

1.6.2 Specific Objectives

The specific objectives of this research are to:

- Investigate and identify the MIG welding process input parameters range for welding S700MC of thickness 2mm steel sheet metal.
- Join defect free butt joints using MIG welding process with different parameters.
- Perform non- destructive testing and distractive testing test.
- Distinguish the microstructural analysis at different weld zones.
- Evaluate the significant process parameters using Taguchi and ANOVA techniques.

1.7 Significance of Study

Studying the MIG welded joints on AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal with different welding process parameters was used to identify the most significant factors that affect the strength and quality of welded material and joints. Welding

parameters like welding current, welding voltage, welding speed, arc length, air gap and welding position are the main parameters that determine weld strength and quality. Hence, we need to optimize process parameters and characterize the microstructure of MIG welding process. Since this AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal material is used in bridges and buildings, articulated dump trucks, Mechanical handling, waste compaction equipment, petrochemical industries, oil gas industries, food processing industries and others are the application areas of the material. So the study of welding behavior of it will be very useful. From this research customers who use MIG welding operations viz. manufacturing industries, automotive industries, metal working workshops and any other welding operations takes place in and around the factories will be benefited.

1.8 Scope and limitations

MIG welding has so many welding parameters and is possible to weld in all welding positions. Parameters viz. welding current, welding voltage, welding speed, arc length, angle of welding, air gap and welding position, stick length, shielding gas. However, scope of this study will mainly focuses on the most significant parameters viz. welding current, welding voltage and welding speed and the other scope of this research is to study and know the tensile strength, hardness and micro-structure of MIG welded butt joints on AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal.

1.9 Structure of the Thesis

This thesis entitled as “*Characterization and Parametric Optimization of EN-10149-2 Steel Welded Joints Made by MIG Welding*” have five chapters.

- Chapter one presents introduction to welding, MIG welding and welding of AHSS, background of the study, significance of study, research gap, scope of study and others.
- The second chapter presents the Literature survey on different topics.
- The third chapter elaborates on the experimental details including the design of the experiment, material preparation, the experimental procedures, equipment used, materials used for the study, and methodology. The methodology of

measurement and analysis of Tensile strength, Hardness, and Microstructure also explained.

- The fourth chapter deals with the result and discussion of the major findings of the experiment work. It discusses the effects of welding parameters on mechanical properties and microstructure of the material.
- The fifth chapter presents conclusion from the overall study, recommendation and future research directions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Literatures surveyed

This literature review explores the dominant themes which include study and research of published materials like journals, thesis, case study, technical document, and online library. Generally, the purpose of a review is to analyze critical segment of a published body of knowledge through summary, classification and comparison of prior research studies, reviews of literature, and theoretical articles. This chapter describes literatures reviewed that are related to MIG welding process and optimization methods applied by the scientific society across the globe.

A research was done by Manoj Singla *et.al* (2010) aiming to optimizing various Gas Metal Arc welding parameters including welding voltage, welding current, welding speed and nozzle to plate distance (NPD) by developing a mathematical model for sound weld deposit area of a mild steel specimen. Factorial design approach applied for finding the relationship between the various process parameters and weld deposit area. The study revealed that the welding voltage and NPD varies directly with weld deposit area and inverse relationship is found between welding current and speed with weld deposit area.

An investigation on welding parameter effects was done by Izzatul Aini Ibrahim *et.al* (2012) on welding penetration, microstructural and hardness measurement in mild steel that having the 6mm thickness of base metal by using the robotic gas metal arc welding are investigated. The variables that choose in this study are arc voltage, welding current and welding speed. The arc voltage and welding current were chosen as 22, 26 and 30V and 90, 150 and 210A respectively. The welding speed was chosen as 20, 40 and 60cm/min. The penetration, microstructure and hardness were measured for each specimen after the welding process and the effect of it was studied. As a result, it obvious that increasing the parameters value of welding current increased the value of depth of penetration. Other than that, arc voltage and welding speed is another factor that influenced the value of depth of penetration. The microstructure shown the different grain boundaries of each parameters that affected of the welding parameters.

To identify the main influencing factors on welding process was done by Sapakal and Telsang (2012) presented the influence of welding parameters like welding current, welding voltage, welding speed on penetration depth of MS C20 material during welding. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) were employed and investigated the welding characteristics of MS C20 material and optimize the welding parameters. Finally the confirmatory tests carried out to compare the predicted values with the experimental values confirm its effectiveness in the analysis of penetration. Welded joint qualities such as bead width, bead penetration and weld reinforcement on butt joint was investigated Rati Saluja and Moeed (2012) by the developing a mathematical model. And adopted the factorial design approach to examine the Metal Inert Gas welding variables viz. current of welding, welding speed, and welding arc voltage and stick-out distance of electrode on aluminum by measuring geometry of weld bead and penetration of weld. For sound quality it was found that welding current to be the most influencing parameter on the weld geometry.

By developing a response surface model to predict tensile strength of inert gas metal arc welded AISI 1040 medium carbon steel joints a research was performed by Ajit Hooda *et.al* (2012) to optimize input process parameters chosen as welding voltage, current, and wire speed and gas flow rate. They applied Response Surface Methodology (RSM) for MIG welding process to attain the maximum yield strength of the joint. The effects of MIG welding parameters on the weld bead and shape factor characteristic of bright drawn mild steel specimen was studied by Abbasi *et.al* (2012). They used input parameter of welding current, arc voltage, and welding speed, heat input rate and studied effect on depth of penetration and weld width.

Biswajit Das *et.al* (2013) investigated the effect of various welding process parameters on the weld ability of Mild Steel specimens of grade EN-3A having dimensions 150mm×100mm×6mm, welded by metal inert gas welding. The welding current, arc voltage and welding speed are chosen as welding parameters. The depth of penetrations were measured for each specimen after the welding operation was done on closed butt joint and the effects of welding speed, current, voltage parameters on depth of penetration were investigated. The influence of welding parameters like wire diameter, welding current, arc voltage, welding speed, and gas flow rate optimization based on bead geometry of welding joint was studied

by Arya *et.al* (2013). The objective function was chosen in relation to parameters of MIG welding bead geometry, tensile strength, bead width, bead height, penetration and heat affected zone for quality target. Optimal parameters contribution of the MIG operation was obtained via grey relational analysis. Experiment with the optimized parameter setting, which obtained from the analysis, validated the results. The influence of welding parameters like welding current, welding voltage, welding speed on ultimate tensile strength (UTS) of AISI 1030 mild steel material during welding was studied by Patil and Waghmare (2013). And an Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) were employed on the welding characteristics of material and optimize the welding parameters. The result computed is in form of contribution from each parameter, through which optimal parameters were identified for maximum tensile strength. It observed that welding current and welding speed were major parameters which influence on the tensile strength of welded joint. Rajkumar Duhan and Rajesh Nandal (2013) aimed at making an attempt to develop a response surface model to predict tensile strength of inert gas metal arc welded AISI 50110 (EN31) high carbon steel joints. The process parameters such as arc voltage and welding current were studied. The experiments conducted based on a two-factor, three-level, and face centered composite design matrix. The empirical relationship used to predict and study the effects and behavior of processing parameters on tensile strength of inert gas metal arc welded EN31 high carbon steel joints. Response surface methodology (RSM) applied on MIG welding process parameters and attained the maximum tensile strength of the joint.

Ramazani *et.al* (2014) studied the mechanical properties of the welded joint, taking into account the effect of features of all regions, such as microstructure, chemical composition and the area fraction, of the welded joint. Hot rolled DP 600 steel was welded by GMAW and tensile tests were made on welded joint. In the heat-affected zone, the microstructure varied from bainite to coarse grained ferrite and tempered martensite. Chemical composition of every quantified region in the welded specimen was also identified using electron probe microanalysis (EPMA). Macro mechanical FE modeling was employed to simulate the mechanical properties of the tensile specimen. 2D representative volume elements (RVE) for different parts of the welded region were constructed from real microstructure. 2D simulated flow curves were corrected to 3Ds using a developed correlation factor. Finally,

the tensile test of welded material with inhomogeneous morphology was simulated and good agreement between experimental and predicted flow curve was achieved. The influence of welding parameters like welding current, welding voltage, welding speed etc., on mechanical were presented by Pipavat *et.al* (2014) on austenitic stainless steel AISI 316. A plan of experiments based on Taguchi technique was used to acquire the data. An Orthogonal array and analysis of variance (ANOVA) were employed and investigated the welding characteristics of austenitic stainless steel AISI 316 material and optimize the welding parameters. The technique used for obtaining optimal process parameters with the use of experimental data was reviewed. The success of MIG welding process in terms of providing weld joints of good quality and high strength depends on the process conditions used in the setup.

Analyzing the effect of GMAW parameters such as current, voltage, gas flow rate and speed on UTS of ST-37 low alloy steel material was studied by researchers Utkarsh *et.al* (2014). Experiment were designed using L9 orthogonal array and found UTS and also performed confirmatory experiment for optimal run set of current, voltage speed and gas flow rate. by doing a case study Mohan and Shelke (2014) found the design optimization for special purpose MIG welding operation. The effect of welding parameters like welding current, welding voltage, welding speed, gas flow rate, rotational speed of work piece, filler wire feed rate on MIG welding was recorded. An Orthogonal Array, Signal to Noise (S/N) ratio and analysis of variance (ANOVA) were used and determined the welding characteristics and optimization parameters. Finally the confirmations tests have been carried out to compare the predicted values with the experimental values.

Predicted and experimental values of effects of welding parameters was studied by Satyaduttsinh *et.al*(2014), and presented the influence of welding parameters like welding current, welding voltage, gas flow rate and wire feed rate on weld strength and weld pool geometry of Medium Carbon Steel material during welding. Orthogonal array and analysis of variance were employed and investigated the welding characteristics of Medium Carbon Steel material and optimize the welding parameters. Finally, the conformations tests were carried out and compared the predicated values with the experimental values.

The weld bead geometry on mechanical properties of MS 5986 Fe 410 was investigated by Rakesh Sharma and Jagdeep Singh (2014) bead-on plate welds were carried out on MS 5986 Fe 410 carbon steel sheets using GMAW process. ER70S-6 solid wire having 1.2mm diameter was used as an electrode with direct current electrode positive polarity. A mixture of argon-carbon dioxide was employed for shielding purposes.

The weld bead geometry played an important role in determining the mechanical properties of a weld joint. Amit Pal (2015) on his research presented the effect of different welding parameters like welding voltage, filler wire rate and v-butt angle on the strength of the weld joint and elongation produced during the tensile test. In order to optimize these parameters for better weld quality Taguchi Orthogonal array was used. The medium carbon steel slabs had used as welding material. The ANOVA also employed to predict the percentage effect of each parameter on results.

The effect of post-weld heat treatments (PWHT's) performed at 760°C on the microstructure and hardness of ASTM A335 P91 steel welded joints studied by Nilthon Zavaleta Gutiérrez *et.al* (2015). The welding process used was GMAW and the filler material was a solid wire of the type AWS ER90S-B9. The analysis of cross sections of the welds revealed a narrow heat-affected zone (HAZ) 4mm wide, composed by a thin (0.2mm) coarse-grained layer with high hardness, a fine-grained region exhibiting grains up to 4µm in size, and a soft inter critical region with low hardness, located 3 to 4mm away from the fusion line. The results of hardness measurements suggest that a PWHT of 2h at 760°C is enough to reestablish the strength of the P91 steel after the welding process.

A review done on optimization techniques and analysis tools used by researchers Pranesh B. Bamankar *et.al* (2015) to optimize the parameters. Also many researches were carried out on various response parameters like depth of penetration, bead width, bead height, micro-hardness, microstructural study etc. Kornél Májlinger *et.al* (2016), Conducted research on investigating the use of austenitic steel filler, of a new advanced high strength TWIP sheet steel and TRIP sheet steel is investigated in this research. Quality of butt weld beads being examined in terms of processing, microstructure, and mechanical properties. The grain coarsening and microstructural changes, as well as volumetric fraction of each phase, in the

heat affected zone at the TWIP and TRIP side of the joint were also determined. The optimal heat input range needed to obtain good quality joints was determined; achieving ultimate tensile strengths over 585MPa and fracture elongations over 9%. Analytical methods for the prediction of mechanical properties of welded joints made of S355 steel were presented Wiesława Piekarska and Dorota (2016). Formulas determining characteristic temperatures and times for corresponding phase transformations used in order to build computational CCT diagrams.

These empirical relationships are presented in correlation with corresponding cooling rates $v_8/5$ ($t_8/5$). Additionally, volume fractions of each phase determined as function of cooling rate using analytical models. Mechanical properties of welded joints made of S355 steel are predicted on the basis of obtained phase fractions. Vinay Kumar *et.al* (2016) made an attempt to understand various welding techniques and found the best welding technique for steel. Special focuses was put on TIG, MIG, and ARC welding. On hardness testing machine and UTM various characteristics such as ultimate tensile load, ultimate tensile stress, breaking point, % elongation etc. were analyzed. Abhishek Prakash *et.al* (2016) determined the welding process parameters which influence the mechanical properties by using the Taguchi method and produced a result that welding current had the greatest influence on tensile and hardness in the weld ability of welded joint followed by wire feed speed and arc voltage.

Influence of process parameters was investigated the optimized process parameters for GMAW by using Taguchi technique by researcher Piyush Sarin *et.al* (2016). Welding input parameters such as material, welding current, wire feed rate, and gas flow rate on heat affected zone (HAZ) as output quality parameter. Feed Wire ER70S-6 was used to weld three different ferrous base metals of EN Series 3, EN Series 8 and EN Series 31 by using CO₂ as shielding gas. Experimental layout was formulated using L9 orthogonal array of Taguchi technique. ANOVA was also applied to predict the percentage contribution of each parameter on results. It was found that material (41.95%) is the most contributing parameters which affect HAZ. A research conducted on NDT by Nabendu Ghosh *et.al* (2016) indicated that visual inspection and X-ray radiographic test 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 welding of AISI316L austenitic stainless steel, through mathematical and experimental analyses. Butt welded joints were made by using several levels of current, gas flow rate and nozzle to plate distance. The quality of the weld has been evaluated in terms of yield strength, ultimate tensile strength and percentage of elongation of the welded specimens. The observed data interpreted, discussed and analyzed by using Grey-Taguchi methodology.

The effect of Post weld heat treatment pulsed current welding, hybrid welding and vibratory assisted welding in the weld quality, residual stresses and mechanical properties of welded joints was studied by research's Kalpana *et.al* (2017). At last, vibratory assisted welding has been suggested to enhance the mechanical properties of welded joints by overcoming the drawbacks in the above stated techniques. Past results showed that the welded test specimens under vibratory conditions exhibited improvements in mechanical properties than the arc welding without vibrations. Chaudhari *et.al* (2017) conducted research to investigate the influence of different single component oxide flux in Activated Metal Inert gas (MIG) welding of AISI 316L. Two different fluxes SiO_2 , Cr_2O_3 were used to bead on plate welding. 6 mm thick plate of stainless steel weld with MIG welding, Carried out under some process parameter. The process parameters such as welding speed, current, Arc voltage and response are welding dimension such as depth of penetration, Bead width were studied.

The Welding experiments were conducted with L9 orthogonal array using MINITAB16 software. A Same Nine set of parameter used for the without flux, With SiO_2 and with Cr_2O_3 flux. Total 27 experiments had done at work. AHP-MOORA and ASRS method was applied to optimizing the MIG welding process parameters and result indicated the enhanced penetration in weld achieved with use of fluxes SiO_2 , Cr_2O_3 . On the basis of present result it is considered that the centripetal Marangoni convection & Constricted arc as a mechanism in increasing the penetration of activated MIG welding. The metallurgical characteristic Hardness of weldment was evaluated using Vickers-Hardness. The purpose of this work to investigate the effect of oxide fluxes on weld morphology & welding parameter. The optimization of Parameter was done by using AHP-MOORA and ASRS method.

By using DOE method, weld strength, weld pool geometry of steel material how it influence of during welding the welding parameters were studied by Labesh kumar(2017) to optimize and suggest the best parameters combination for target quality. The results were computed in form of contribution from each parameter, through which optimal parameters identified for maximum tensile strength. The optimization of welding input process parameters for obtaining greater weld strength in the Gas Metal Arc Welding of Mild Steel (1018).

By applying Taguchi method to analyze the effect of welding process parameter on the weld strength, and considered process parameters are optimized to achieve greater weld strength a research was performed by Monika and Jagdip Chauhan (2017). L9 Orthogonal array was selected for analysis of data. From the investigation found that the influence of current, voltage and gas flow rate (GFR) on tensile strength, and hardness of weld zone and heat affected zone during welding process was validated by ANOVA for each response. Experimental results were provided to represent the proposed approach. From the investigation, found that when increases the current, voltage and GFR tensile strength decreases but in case of hardness, the value of hardness increases due to high input rate.

The effects of welding parameters: welding current, gas flow rate and nozzle to plate distance, on ultimate tensile strength (UTS) and percentage elongation (PE) in MIG welding of AISI409 ferritic stainless steel materials was presented by Nabendu Ghosh *et.al* (2017). Experiments were conducted as per L9 orthogonal array of Taguchi method. The visual inspection and X-ray radiographic test conducted in order to detect surface and sub-surface defects of welded specimens. The observed data of UTS and PE interpreted, discussed and analyzed with use of Taguchi methodology and analysis of signal to noise ratio. Jogiet.*et.al* (2018) studied on optimization parameters for Metal Inert Gas (MIG) welding on AISI 1018 mild steel by Teaching-Learning Based Optimization (TLBO) algorithm. The input parameters considered are welding current, workpiece thickness, voltage and wire feed rate. Taguchi's L27 orthogonal array has been used for design of experiment (DoE) and the mathematical models have been developed for output response using MINITAB16. Results show that welding current and voltage are statistical significance on overall MIG welding performance. Experimental investigation was done by Nabendu Ghosh *et.al* (2018) on AISI 316L stainless steel samples have been welded by MIG welding.

Some important parameters have been varied during welding. Thus several butt-welded joints have been made. Each sample of the joints has been prepared under certain combination of welding parameters. The parameters considered for variation, in the present work have been welding current, gas flow rate and nozzle to plate distance. The influence of the process parameters (mainly current, gas flow rate and nozzle to plate distance) has been examined visually and also through X-ray radiographic tests. Next, samples have been cut, machined to conform to some specified dimensions for tensile testing. The quality of the weld has been evaluated in terms of ultimate strength, yield strength and percentage of elongation of the welded specimens. The observed data have been interpreted, discussed and analyzed by using principal component analyses (PCA). Optimum parametric setting has been predicted and validated as well. Useful interpretations of the experimental results and subsequent analysis have been made to draw some meaningful conclusions.

The influence of welding parameters such as welding current, welding voltage and welding speed on a welded joint investigated by Labesh Kumar *et al* (2018). By using design of experiment method, the parameters were optimized and made the best parameter combination for target quality. An orthogonal array and Signal to Noise (S/N) ratio were employed to study the welding characteristics of material and optimize the welding parameter. The results were computed using the form of contribution from each parameter, through which optimal parameters identified for maximum tensile strength. The chosen parameters and obtained tensile strength results were analyzed.

Hussein and Sultan (2018) also carried out research on Weldox700MC high strength steel welded by the mixed gas arc welding process. The microstructure and chemical composition as well as the impact toughness of the weld line, fusion area and heat affected zone metal were analyzed, which provided a theoretical guidance to the physical properties of the welding different parts. The results showed that weldox700MC low alloy high strength steel welds formed the uniform microstructure distribution of a circular ferrite in different welded regions which increased the impact toughness.

By performing MIG welding operation on the mild steel pieces By taking Different mild steel pieces were welded by varying the currents, 180amp, 200amp and 230amps and weld

speeds 3mm/sec, 3.5mm/sec and 4mm/sec, Ramanjaneyulu *et.al* (2018) suggested the hardness and tensile tests were performed to determine the optimal welding currents and weld speeds. Taguchi method was used to determine the optimal process parameters for high tensile strength and hardness. Thermal analysis and structural analysis also performed and determined the heat transfer rates and the strength of the welds at the applied load.

Ahsan Jameel Ansari, *et.al* (2019) conducted investigation for optimization of MIG welding of EN-31 and established the influence of MIG welding process parameters on hardness and surface roughness. From the results, concluded that welding speed become the main influencing parameter for hardness while welding current least influencing. For the case of surface roughness, welding current had major dominance while other parameters were less effective. Saurabh Gandhe *et.al* (2019) measured the welding process in terms of strength, penetration, reinforcement, height and hardness. These outcomes were affected by different process input variables like current, voltage, welding speed, wire feed rate, etc. The values of weld current, welding voltage and welding speed were set by experimentation in terms of DOE.

Vyavahare *et.al* (2019) studied the influence of parameters like welding current, welding voltage, feed rate, gas flow rate, etc., on the factors like weld strength, weld pool geometry of medium carbon steel material by using Taguchi's DOE method. Parameters were optimized, and the best parameters obtained for target quality. They had performed conformation test and compared the predicted values with experimental values. Sudhir Kumar and Rajender Singh (2019) welded AISI 1018 mild steel samples in V-butt joint configuration using MIG welding. The design of experiment was Taguchi based Orthogonal Array (L9). Effect of process parameters such as current, voltage and preheat temperature was studied and welds examined using X-ray-radiographic tests. Weld quality had assessed in terms of tensile properties of weldments such as ultimate tensile strength and percentage elongation. Process parameters were optimized using grey based Taguchi methodology.

2.2 Summary of literature review

Generally different researchers done allot on MIG welding process with different input and output variables, using different methods and optimization mechanisms. It was obviously

seen that the researches on AHSS of EN-10149-2 S700MC of 2mm sheet metal material were limited. The need for scientifically suggesting the optimum working parameters for MIG welding process of AHSS of EN-10149-2 S700MC 2mm thickness sheet metal material is highly needed. Because of these and other reasons this work aimed to put value by analyzing on the effects of welding parameters on the mechanical property and microstructural analysis for AHSS of EN-10149-2 S700MC of 2mm thickness sheet metal joints using MIG process.

CHAPTER THREE

MATERIALS AND METHODOLOGY

Figure 3.1 shows the flow chart of entire procedure of the thesis work.

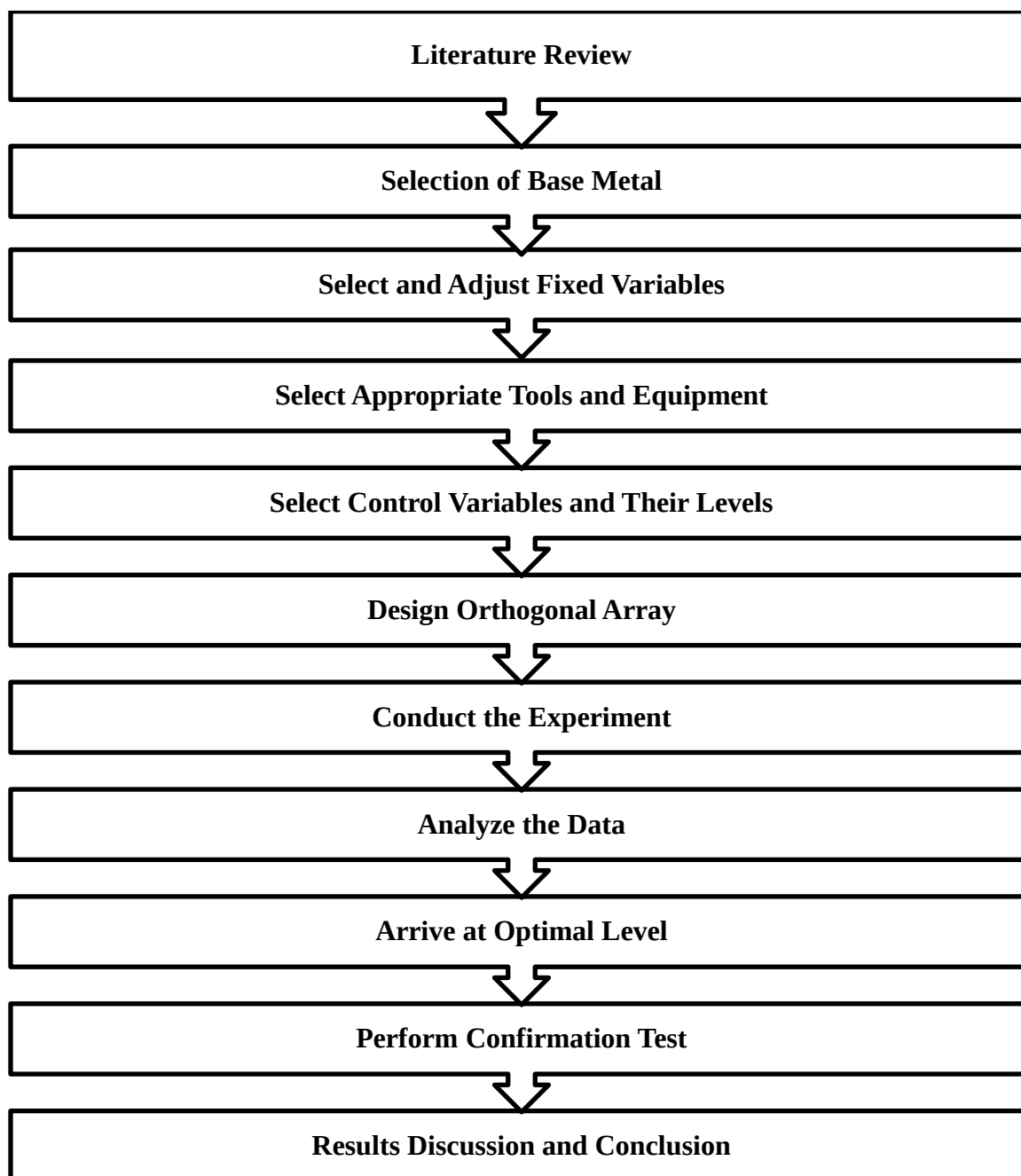


Figure 3.1 The flow chart of entire thesis work

3.1 Materials

This experimental works were carried out on AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal butt welded joints by different MIG welding process parameters.

For this thesis work to perform experiments, MIG welding machine, optical microscopy, universal testing machine and Vickers's hardness testing were required. The optima values of working parameters and effects of the welded joints of EN-10149-2 were analyzed for all the experiments.

3.2 Parent Material

An advanced high strength AHSS of EN-10149-2 S700MC of thickness 2mm steel sheet metal Figure 3.2 below was used for the welding experiments. This material is mainly used in automotive industries. The need for low weight, high strength material in automotive industries made this material the first choice. The experiments were conducted by MIG welding machine with different combinations of welding parameters.



Figure 3.2 Base metal samples

Parent metal details

The following Tables 3.1 and 3.2 show the chemical compositions and mechanical property of parent metal.

Table 3.1 Chemical Composition of base metal (S700MC) (Dereje H/Georgi *et.al* 2019)

Chemical composition of the parent material													
C	Si	Mn	P	S	Cr	Mo	Ni	Cu	W	Al	Nb	Ti	Fe
0.06	0.04	1.46	0.003	0.002	0.01	0.02	0.03	0.01	0.04	0.05	0.03	0.10	98.15

Table 3.2 Mechanical property of the parent metal (Saani Shakil *et.al* 2020)

Mechanical property of the base metal S700MC			
Tensile Strength MPa	Yield Strength MPa	Elongation mm	Hardness VHN
750	700	19	140

Details of filler material

The chemical composition and the mechanical properties of the wire electrode used to weld the material should be in accordance with the selected material described in Tables 3.3 and 3.4 below. The yield strength and tensile strength of the base metal must be equal or greater than the yield strength and tensile strength of the filler electrode to get proper welding joints.

Table 3.3 Chemical Composition of Filler Electrode ER70S

C	Si	Mn	Cr	Ni	Mo	V	Ti	Al	Zr	P	S	Cu
0.05	0.55	11.15	0.04	0.15	0.005	0.008	0.10	0.10	0.07	0.012	0.006	0.010

Table 3.4 Mechanical Property of Filler Electrode

Mechanical property of the filler electrode ER70S-6			
Tensile Strength MPa	Yield Strength MPa	Elongation	Hardness(HV)
483	583	26	140-158

3.2.1 MIG Welding Machine

Metal Inert Gas (MIG) welding embraces a group of arc welding processes in which a continuous electrode (the wire) is fed by powered feed rolls (wire feeder) into the weld pool. An electric arc is created between the tip of the wire and the weld pool. The wire is progressively melted at the same speed at which it is being fed and forms part of the weld pool. In order to protect the arc from the reactive oxygen and other gases from surroundings, a “shielding gas” also flows through the gas nozzle. This suppresses the oxygen during welding and therefore prevents oxidation on the arc and on the weld pool.

MIG welding is usually carried out with a handheld gun as a semiautomatic process. The MIG process can be suited to a variety of job requirements by choosing the correct shielding gas, electrode (wire) size and welding parameters.

The basic elements of MIG welding equipment are given in Figure 3.3 below. (1) Mains connection, (2) Power source, (3) Hose pack, (4) Grounding cable, (5) Welding torch, (6) Ground terminal, (7) Workpiece, (8) Filler metal, (9) Shielding gas. In MIG welding, a filler metal or welding wire ignites the arc when it touches the component.

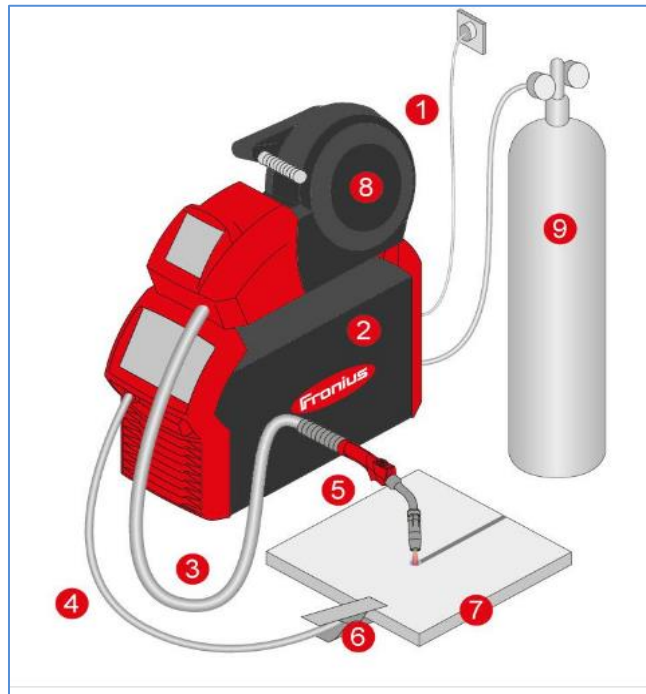


Figure 3.3 MIG welding machine (Telwin MIG-MAG welding machine)

3.2.2 Non-Destructive Testing

Nondestructive testing (NDT) is a method of testing that does not destroy or impair the usefulness of a welded item. These tests disclose all of the common internal and surface defects that can occur when improper welding procedures are used. The common NDT testing methods are visual inspection, dye penetrant, Ultrasonic testing, Magnetic particle testing, X-ray testing etc.

3.2.2.1 Visual inspection

The integrity of most welds is verified principally by visual examination. Even for weldments with joints specified for examination throughout by other nondestructive examination methods, visual examination still constitutes an important part of practical quality control. Therefore, visual examination is of the first order of importance. Many codes and other standards require welds to be accepted by visual examination prior to the

performance of any other nondestructive examinations. Many standards require its use before other methods because there is no point in submitting an obviously bad weld to sophisticated inspection techniques. The ANSI/AWS Structural Welding Code states, "All welds shall be visually inspected" Visual inspection requires little equipment. Good eyesight and sufficient light, a pocket rule, a weld size gauge, a magnifying glass, and possibly a straight edge and square for checking straightness, alignment and perpendicularity are all that is needed for a sufficient visual inspection. For visual inspection, the weld surface is observed with the naked eye, in order to detect the surface defects of the weldment.

The most extensively used nondestructive examination, visual examination is easy to apply, quick, and often requires no special equipment other than good eyesight and some relatively simple and inexpensive tools. Extensive review of visual examination is contained in AWS B1.11, Guide for the Visual inspection of Welds.

3.2.2.2 Dye Penetrant Testing

Liquid penetrant processes are non-destructive testing methods for detecting discontinuities that are open to surface. It is also called liquid penetrant inspection (LPI) or Penetrant Testing (PT) is a method used to locate the surface-cracking defects in all non-porous materials. The method is effectively used in the inspection of both ferrous and non-ferrous metals and on non-porous, non-metallic materials, such as ceramics, plastics and glass. Surface discontinuities, such as cracks, seams, laps, cold shuts and laminations are indicated by these methods. Liquid penetrant inspection is used to detect welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on the products. In this method, a red colored dye penetrant is applied on the surface of the component by dipping, spraying, or brushing. This dye enters crack interfaces through capillary action. After some times the excess penetrant is removed and a developer is applied to detect the weld defects. The stages to apply Dye Penetrant are Pre-cleaning, application of penetrant, excess penetrant removal, application of developer and inspection of welded part as of ASTM E 433 for dye penetrant testing.

The material required to do liquid penetrant testing are dye penetrant, developer and cleaner, shown in Figure 3.4.



Figure 3.4 Dye Penetration Test (MIDI lab)

3.2.2.3 Ultrasonic Testing

Ultrasonic inspection is a family of nondestructive methods in which beams of high frequency mechanical waves are introduced into materials. Response signals are detected, displayed, and then analyzed to give signatures that are used to define the presence, location, and characteristics of flaws or other discontinuities. This is potentially the most valuable technique because it can detect Defects throughout the volume of the joint and offers the possibility of locating and sizing cracks; as of ASTM E 164 for Ultrasonic Examination of Weldments.

Ultrasonic testing uses high frequency sound waves of a range between 0.5 to 15 MHz to conduct testing figure 3.5. The basic principle and applications of ultrasonic testing techniques are enormous use under the domain of mechanical engineering applications. Importance of ultrasonic testing of rails, train wheels, carbon fiber reinforced plastic, aeronautical defects in steel structures, testing of welds, and others.

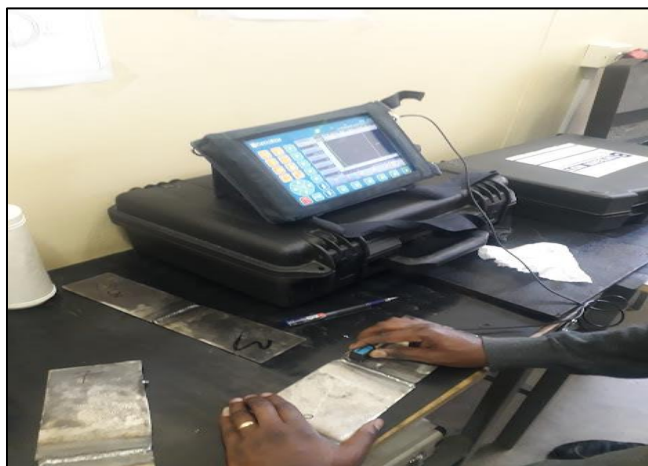


Figure 3.5 Ultra sonic testing operations (MIDI lab)

3.2.3 Optical Microscope

The microstructure of the specimen was observed by using Optical Microscope of model: Huvitz HR-300 series, magnification: 50X, 100X, 200X, 500X, 1000X, scanning area: 104x102mm, illumination system: 12v, 1000W halogen lamp below Figure 3.7. First, samples were cut from the base metal and welded samples. Then, these specimens were mounted in phenolic resins by hot mounting press machine shown in Figure 3.6. The machine has upper ram, lower ram, cylinder, heating chamber, cooling process and mold parts. After that grinding with silicon carbide paper with grid size of 220, 800, 1200 and 2000 respectively and polished by using high performance diamond suspension on rotating polishing machine as shown in Figure 3.8. All, samples are seen at 100x magnification.



Figure 3.6 Mounting machine (ASTU)



Figure 3.7 Optical Microscopy (ASTU)



Figure 3.8 Grinder/polisher (ASTU material lab)

3.2.4 Vickers Hardness Testing Machine

Hardness tests are one of the faster and less expensive methods for definition of mechanical properties of materials. The Vickers hardness test uses a square base diamond pyramid as the indenter Figure 3.9. The included angle between the opposite faces of the pyramid is 136° .degrees between opposite faces subjected to a test force of between 1gf and 100kgf. The area of the sloping surfaces of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. The hardness of the specimen was observed by using Vickers hardness testing machine of model: HVS 50 with capable force of 1, 5, 10, 20, 30, 50 kgf. The tests were measured on three trials for each sample and take an average.



Figure 3.9 Vickers hardness testing machine (ASTU material lab)

3.2.5 Universal Tensile Testing Machine

The tensile test is used widely to determine the characteristics of metals and plastics materials. Properties are usually determined by doing tensile test are Young's modulus, E ; yield stress or proof stress; tensile strength, percentage elongation on gauge length; percentage reduction in area. Universal tensile testing machine was used to measure the tensile strength of the weld joint. The test was carried out using Bairoe computer controlled electro-hydraulic universal testing machine of model HUT-600 shown in Figure 3.10. The tests were measured three times for each sample and take an average.



Figure 3.10 Universal tensile testing machines (ETU Material LAB)

3.3 Methodology

The materials mentioned above were used to perform the experiment in the following method. Defining sample size, specimen preparation, design of experiment procedure, selection of orthogonal array, MIG welding process, microstructural analysis, hardness testing, tensile testing, selection of optimum parameter by Taguchi and ANOVA method were the methodologies used.

3.3.1 Sample size

For this research twenty seven samples were taken for experimentation from the welded metal. The Methodology for this study was simple random sampling from the mechanical properties of the welded base metal. From the universe of properties AHSS of S700MC weld joint, population has been developed as mechanical properties of S700MC AHSS weld joint.

The mechanical properties of EN-10149-2 of S700MC AHSS weld joint has been taken as population of the research and the sample was taken from these mechanical properties. Tensile strength, hardness, and microstructure of the welded metal were studied.

3.3.2 Specimen Preparation

The sample of advanced high strength steel EN-10149-2 as a base metal was taken and prepared to the required dimensions of 300mm length, 90mm width and 2mm thickness as shown in Figure 3.11 below used as the workpiece. These specimens were prepared with a

'V'shaped groove, where the groove angle, the root face, and the root gap were 15° , 1mm and 0.5mm respectively. There after 27 pairs of such specimen with constant groove angle, and root face were prepared, and faces were cleaned by a surface polisher. To make a butt joint, two sheets were tacked at the two ends along the width, with a constant root gap of 0.9 mm. Copper coated mild steel wire of 0.8mm diameter was used. The wire was fed through the welding gun by a roller drive system. The shielding gas used was mixture of 98% Ar and 2% CO_2 , supplied in a regulated manner at a constant flow rate and pressure. The work piece surface and edge were properly cleaned and prepared for welding using wire brush, Power saw and grinder. To produce good quality welds, the surfaces of the weld joint was cleaned of rust, scale, dirt, oil and grease and irregular shape.

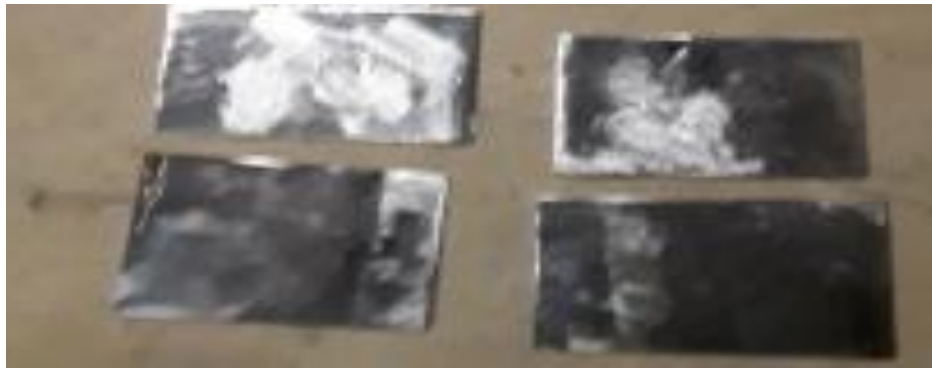


Figure 3.11 Specimens prepared for welding operation

3.3.3 Operations carried to prepare the experimental samples

- Cutting: cutting the parent metal from the base metal and sectioning with size of length = 300mm, width = 90mm and thickness = 2mm
- Cleaning: These metal sheets are thoroughly cleaned using metal wire brush for removing rust and mud formed on it, this cleaning process should be carried out on both sides.
- Grinding: Then each piece is grinded for obtaining a good surface finish using grinding machine to required edge angle. In this process surface gets smoothened to most extent.
- Polishing: After filing, pieces are polished using polisher machine and emery papers to make grains uniform. Welding: After polishing operation sample sheets

metal, by following proper steps and materials by taking combination of parameters welding operation is performed.

- Chipping: Welded sheets are chipped for removing slag. Chipping is process of removing excessive slag formed during the process of welding due to molten metal flow.

3.3.4 Data collection

Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes. In this work data collection was done through experimentation method. The task of data collection begins after a research problem has been defined. During experimentation the primary data were recorded according to the required task. Tensile strength reading on tensile strength machine, the hardness of the base metal, weld zone and hardness of HAZ were recorded by using Vickers hardness testing machine and microstructure of the welded material using optical microscope.

3.3.5 Processing and Data Analysis

The data, after collection, has to be processed and analyzed in accordance with the outline laid down for the purpose at the time of developing the research plan. Technically speaking, processing implies editing, coding, classification and tabulation of collected data so that they are amenable to analysis.

3.4 Welding Input Parameters Selection

MIG welding process has many working parameters and variables. Selecting those parameters is based on general knowledge and literature's surveyed. The fixed or preselected welding variables were those, which were set before the actual welding takes. These were items such as electrode type, electrode size, type of current (DC) and etc.

The primary adjustable variables were the major variables used to control the welding process once the fixed variables have been selected. The primary welding variables those were considered in this research includes: welding current (I), arc voltage (V), and travel speed (S). These can be easily adjusted and measured so they can be used effectively to control the welding process. The secondary adjustable variables were the minor adjustable

variables that were used to control the welding process. Secondary adjustable variables those were considered in this work includes: the work angle and the travel angle of the electrode.

The travel angle of the electrode is the angle between the joint and the electrode in the longitudinal plane. The work angle is the angle between the electrode and the perpendicular plane to the direction of travel.

The power source could be constant voltage DC power source with electrode positive, which yields a stable arc and smooth metal transfer with fewer spatters for the entire current range. The gas shield around it does not ionize, which prevents weld against atmospheric contamination and surface oxidation.

Mixture of 98% *Ar* with 2% *CO*₂ used as shielding gas. The main function of shielding gas is to protect the arc and molten weld pool from atmospheric gases (oxygen and nitrogen). If weld pool is not protected properly then formation of oxides and nitrites will takes place which are responsible for weld deficiencies such as porosity, slag inclusion and weld embrittlement.

After conducting related literature survey, it was found that among the most important parameters welding voltage, welding current and welding speed were most influencing parameters, while keeping other input parameters constant.

3.4.1 Welding current

The welding current is the most important factor in determining the characteristics of the weld. The welding current is controlled by a knob on the welding machine. The amount of current used is determined by the type of electrode, size of electrode, position and joint design. The welding current is the best variable to be used. it controls the burn off rate of electrode, fusion depth and weld geometry.

The level of welding current used in MIG has the highest effect on the deposition rate, the weld bead size, shape and penetration. In MIG welding, metals are usually welded with direct current electrode positive (DCEP), to facilitates the maximum heat input to the electrode results in to high deposition rate.

3.4.2 Welding voltage

The arc voltage is one of the most crucial parameter in MIG welding. When all other variables: electrode composition and sizes, the type of shielding gas and the welding technique are same, arc length is directly related to the arc voltage. Excessively high and low voltage causes an unstable arc. Excessive voltage causes the formation of spatter and porosity. On the other hand low voltage causes porosity and overlapping at the edges of the weld bead. Value of welding voltage to be used, depends on base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position.

3.4.3 Welding speed

The welding speed is the rate at which arc travels along the workpiece. For a constant given current, slower welding speed proportionally provides larger bead and higher heat input to the base metal owing to longer heating time. The welding speed is a crucial parameter in MIG welding was decided by the operator in accordance with the joint fit up, thickness of the metal being welded and welding position.

The travel speed is determined by the welder, who manually controls the rate that the arc travels along the work. There is an optimum travel speed where the penetration is maximum. Increasing the travel speed beyond this point will decrease the penetration.

3.5 Design of experiment

Design of experiment is a powerful statistical technique introduced by R.A.Fisher in England in the 1920's to study the effect of multiple variables simultaneously. DOE is a technique of defining and investing all possible combinations in an experiment involving multiple factors and to identify the best combination. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance of products. Thus Design of experiment (DOE) is a method to identify the important factors in a process.

One of the main advantages of DOE is that it shows the relationship between parameters and responses. DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. it is extremely

helpful in discovering the key variables influencing the quality characteristics of interest in the process. Minitab18 tool is a software package that has been used to analyze data in this work.

3.5.1 Application of Design of Experiments in Welding

In the present day fabrication industry, welding has become one of the major manufacturing processes frequently used in all types of works. Quality of a weld joint is influenced by welding input parameters that are to be controlled to establish a proper weld. The selected input parameters vary with the type of welding process, thickness and type of base material used. In order to establish the correct combination of input weld parameters trial experiments are to be performed which consumes lot of time and manufacturing cost.

In this research the Taguchi method was used arrange orthogonal arrays to study entire parameter space with only minimized number of experiments to analyze the effect of parameters on mechanical and microstructural property.

3.5.2 Taguchi Technique

The Taguchi method was developed by Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost.

Taguchi determines the minimum number of experiments to be conducted in the overall experiment based on the formula below.

$$N = L^P \dots\dots\dots (3.1)$$

Where:

N= Number of experiments to be conducted

P=Number of parameters

L=Number of levels

Before selecting the particular orthogonal array (OA); it is necessary to set the number of controlled parameters and the number of levels for these parameters. The estimation of the selected parameters level was done by doing weld bead joint geometry.

In this work there were three variables (welding current, welding voltage and welding speed) and three levels for each parameter as described in Table 3.5.

Table 3.5 Process Parameters and their levels

S.No	Process Parameter	Unit	Levels		
			Level 1	Level 2	Level 3
1	Current(I)	A	60	65	70
2	Voltage(V)	V	16	17	18
3	Welding Speed(S)	mm/s	2	4	6

3.5.3 Selection of orthogonal array

Orthogonal arrays (OA) is a standard design by which simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a process characteristic / output response can be done in a minimum number of tests.

In this work there are three variables and three levels .The general experiment that would be done will be given by factorial design formula given in equation 3.2. The interaction between the welding parameters is neglected.

$$N = 3^3 = 27 \dots\dots\dots (3.2)$$

$$N = L^{P-1} \dots\dots\dots (3.3)$$

$$N = 3^{3-1} = 9 \dots\dots\dots (3.4)$$

Table 3.6 L9 orthogonal arrays for number of experiments

Experimental runs	Experimental Variables		
	Current (A)	Voltage (V)	Speed (mm/s)
1	60	16	2
2	60	17	4
3	60	18	6
4	65	16	4
5	65	17	6
6	65	18	2
7	70	16	6
8	70	17	2
9	70	18	4

According to full factorial design; there would require a total of 27 experiments to optimize the parameters. Taguchi experimental design suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters, so that it was selected as indicated in equation 3.3. The orthogonal array matrices of experimental setup are given in Table 3.6 which was organized by using Minitab18 software. This setup allows the testing of all three variables without having to run 27 (3^3) experiments as shown in Table 3.6 above.

3.5.4 Signal to Noise Analysis

Taguchi transformed several repeated data to another value in which the measure of the variation is present and this process is called as signal-to-noise (S/N) ratio. This technique helps in data analysis and prediction of optimum results. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise).

Signal-to-noise (S/N) ratio consolidate several repeated data in to one value and reflects the amount of variations present.

The standard S/N ratios generally used are as follows:

Smaller is better (SB): This signal to noise ratio is used when there is a condition to minimize value. For example to minimize defect.

$$S/N = -10 \log(MSD \text{ SB}) \dots \dots \dots (3.5)$$

$$MSD \text{ SB} = 1/R \sum_{j=1}^R \left(\frac{y}{s^2} \right)^2 \dots \dots \dots (3.6)$$

Nominal is best (NB): is used when there is neither minimization nor maximization of value

$$S/N = 10 \log(MSD \text{ NB}) \dots \dots \dots (3.7)$$

$$MSD \text{ NB} = 1/R \sum_{j=1}^R (Y_j^2) \dots \dots \dots (3.8)$$

Larger is better (LB): This type of signal to noise ratio is used when the research wants to maximize the value.

$$S/N = -10 \log(MSD \text{ LB}) \dots \dots \dots (3.9)$$

$$MSD \text{ LB} = 1/R \sum_{j=1}^R \left(\frac{1}{Y_j} \right)^2 \dots \dots \dots (3.10)$$

Where:-

MSD=mean square deviation (which presents the average of square of all deviation from the target value rather than around the average value.)

R=number of repetition for each experiment

YJ= measured data

Y= mean of measured data

S= variance

S/N=Signal/Noise=Mean/Standard deviation

The optimal setting is the parameter combination, which has the highest S/N ratio.

The S/N ratios for the individual control factors are calculated.

$$IL1 = (n1 + n2 + n3), IL2 = (n4 + n5 + n6), IL3 = (n7 + n8 + n9)$$

$$VL1 = (n1 + n4 + n7), VL2 = (n2 + n5 + n8), VL3 = (n3 + n6 + n9)$$

$$SL1 = (n1 + n5 + n9), SL2 = (n2 + n6 + n7), SL3 = (n3 + n4 + n8)$$

For selecting the values of n1, n2, n3 etc. and to calculate IL1, IL2, IL3 use S/N ratio value.

Nk is the S/N ratio corresponding to experiment n.

$$\text{Average S/N ratio corresponding to current at level 1} = IL1/3$$

$$\text{Average S/N ratio corresponding to current at level 2} = IL2/3$$

$$\text{Average S/N ratio corresponding to current at level 3} = IL3/3$$

J is the corresponding level for each factor. Similarly VIJ and SIJ are calculated for Voltage and speed. Similarly S/N ratios can be calculated for other factors.

3.5.5 Analysis of Variance

The purpose of ANOVA is to investigate, which welding process parameter significantly affects the quality characteristics. This is accomplished by separating the total variability of the Signal to noise Ratios, which is measured by the sum of squared deviations from the total mean of the Signal to noise ratio, into contributions by each welding process parameter.

Taguchi recommended a logarithmic transformation of mean square deviation (S/N ratio) for the analysis of results. ANOVA separates the overall variation from the average S/N ratio into contribution by each of the parameters and the errors.

Confidence level is how likely the value will fall within the experimental confidence interval. Confidence interval is a range of values that are expected to include an unknown experimental parameter based on the samples.

If the p-value is less than the significance level, the factor is then regarded to be statistically significant. The relative significance of factors is often represented in terms of F-ratio or in percentage contribution. Greater the F-ratio indicates that the variation of the process parameter makes a big change on the performance.

In order to analyze the ANOVA; the following terms are calculated using MINITAB 18 software: Degree of Freedom, Sequential sums of squares, Percent of contribution, Adjusted sums of squares, Adjusted Mean of squares , Probability of Variance and Fisher value.

$$\text{Total (AdjSS = SeqSS)} = \text{SeqSS}_i + \text{SeqSS}_v + \text{SeqSS}_s + \text{SeqSS}_e \dots\dots\dots (3.11)$$

For single parameter SeqSS_k is calculated using

$$\text{SeqSS}_k = \sum_{j=1}^n \left(\frac{sy_j}{n} \right)^2 - G^2/n \dots\dots\dots (3.12)$$

$$\text{Total Error} = (\text{Error}/\text{Total SeqSS}) * 100\% \dots\dots\dots (3.13)$$

$$\text{AdjMS} = \text{AdjSS}/\text{DF} \dots\dots\dots (3.14)$$

$$\text{Percentage Cotribution (\%)} = (\text{SeqSS}/\text{Total}) * 100\% \dots\dots\dots (3.15)$$

$$\% \text{ error} = \frac{EV - TV}{TV} * 100 \dots\dots\dots (3.16)$$

Where:

(% Error)= Percentage error

Ev= Experimental value

Tv = Theoretical value

G= The sum of resulting data of all trials

n=Total number of runs

K= Represent one of the tested parameters

J=Level number of this parameter

Sy_j=Sum of all trials involving this parameter at level j

SeqSS_i = Sum of Square of variance of current

SeqSS_v = Sum of Square of variance of voltage

SeqSS_s = Sum of Square of variance of speed

SeqSS_e = Sum of Square of variance of error

3.5.6 Degrees of freedom

The total degrees of freedom (DF) are the amount of information in the research data that is determined by the number of observations in the sample. The analysis uses that information to estimate the values of unknown population parameters.

$$DF = Level - 1 \dots\dots\dots (3.17)$$

3.5.7 Adjusted sums of squares (Adj SS)

Adjusted sums of squares are measures of variation for different components of the model. The order of the predictors in the model does not affect the calculation of the adjusted sums of squares. In the Analysis of Variance table, Minitab separates the sums of squares into different components that describe the variation due to different sources.

3.5.8 Sequential sums of squares (Seq SS)

Sequential sums of squares are measures of variation for different components of the model. Unlike the adjusted sums of squares, the sequential sums of squares depend on the order the terms are entered into the model. In the Analysis of Variance table, Minitab separates the sequential sums of squares into different components that describe the variation due to different sources.

3.5.9 Adjusted mean of squares (Adj MS)

Adjusted mean squares measure how much variation a term or a model explains, assuming that all other terms are in the model, regardless of the order they were entered. Unlike the adjusted sums of squares, the adjusted mean squares consider the degrees of freedom.

3.5.10 F-value

The F-value is the test statistic used to determine whether the model is missing higher order terms that include the predictors in the current model. With a higher fisher “F” value; there will be higher performance change. A sufficiently large F-value indicates that the term or model is significant. Fisher value (F) depends on the probability obtained from probability table at 95% confidence level. This value of F was compared to the F-limit (F_{cr}) for given degrees of freedom. If the F value we work out is equal or exceeds the F-limit (F_{cr}) value from F tables, we may say that there are significant differences between the sample means.

3.5.11 P-value

The p-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis. The null hypothesis for the overall regression is that the model does not explain any of the variation in the response. Usually, a significance level (denoted as α or alpha) of 0.05 works well.

If the p-value is less than or equal to the significance level, it can be concluded that there is a statistically significant association between the response variable and the term. If p value is greater than the significance level, it cannot conclude that there is a statistically significant association between the response variable and the term.

Significance level of 0.05 indicates 5% risk of concluding that the model does not correctly specify the relationship between the response and predictors. If 'p' value is less than 0.05% it shows that; the parameter has greater influence on the performance and 95% degree of confidence is allowable for the given parameter.

3.6 EXPERIMENTAL PROCEDURE

For the research purpose on MIG welding we have chosen the material En 10149-2. We made 27 pieces with a dimensions of 300x90x2mm by shearing machine.

3.6.1 Welding operation

The welding operation is performed using MIG welding machine. It was done after preparing all samples according to proposed dimensions. Continuous wire welding is a process in which the heat required to carry out the weld is supplied by an electric arc that is maintained between the piece to be welded and the wire electrode. The welding zone is constantly fed with the welding material (the wire electrode) by means of a special torch, which also supplies the flow of gas (or gas mixture) whose purpose is to shield the wire electrode, the weld pool, the arc and the area surrounding the base material from atmospheric contamination. After welding operation is done the cooling process has been done by air, then the slag formed is removed by wire brush.

3.6.2 Microstructure Study

Microstructure is very useful to study the characterization of materials. This analysis is commonly made on a cross section of the weld, often perpendicular to welding direction shown in Figure 3.12. Metallographic measurement is an effective technique to characterize the microstructural details of the various metals or alloys in cross section. In comparison with electron microscopy, the etching method is fast and inexpensive; Keller's etchant used for microstructure observation shown in Table 3.7 below is used for etching purpose. Microstructure tests were performed according to standard ASTM E45.

Table 3.7 Keller's etchant used for microstructure observation

Keller's etchant	Concentration	Condition
Methanol	25ml	15 seconds
Hydro-chloric acid	25ml	
Nitric acid	25ml	
Hydrofluoric acid	1 drop	



Figure 3.12 Sample for microstructural test

3.6.3 Destructive Testing

Destructive testing is usually a cheaper method of inspection. It lends its self to mass produced parts, where sacrificing one or two component for testing is acceptable. It is quite useful for setting up welding equipment. In destructive testing, sample portions of welded

structures were taken and subjected to loads until they fail. Failure property studied and compared with known standards to determine quality of weld.

3.6.3.1 Hardness

Hardness is defined as a resistance to plastic deformation or it is the ability of the material to localize plastic deformation. The samples for hardness test are taken by cutting small pieces from different zones of each welded sample as shown in Fig 3.13 below. Changes in the microstructure and hardness after welding will influence the quality of the weld. In order to examine the influence of the welding process a hardness test is performed. In this work the hardness number of the welded sample was calculated using Vickers hardness tester machine. The diagonals of the impression are measured and calculated automatically used to obtain a hardness number (VHN). Hardness tests were performed according to standard ASTM E92.

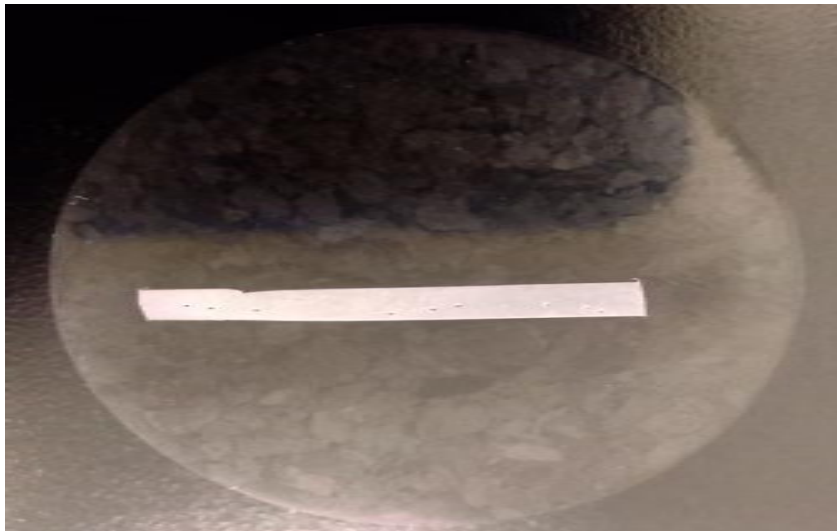


Figure 3.13 Sample for Vickers hardness testing

3.6.3.2 Tensile strength

Tensile strength is the maximum stress that a material can sustain in tension. In other words we can say the amount of applied load per cross sectional area that a material can withstand before failure. It is the resistance offered by a material when subjected to external loading. So, stronger the material the greater the load it can withstand. The load up to which the

materials remain elastic is the elastic limit. The deformation or strain produced within the elastic limit is proportional to the load or stress.

In this work the samples were prepared in standard form (dog bone) with dimensions total length 300 mm, gauge length 100mm, grip length of 95mm thickness 2mm and width 20mm as shown in Figures 3.14 and 3.15. For all experiments, three trial samples were tested. Tensile tests were performed according to the ASTM standard E-8M

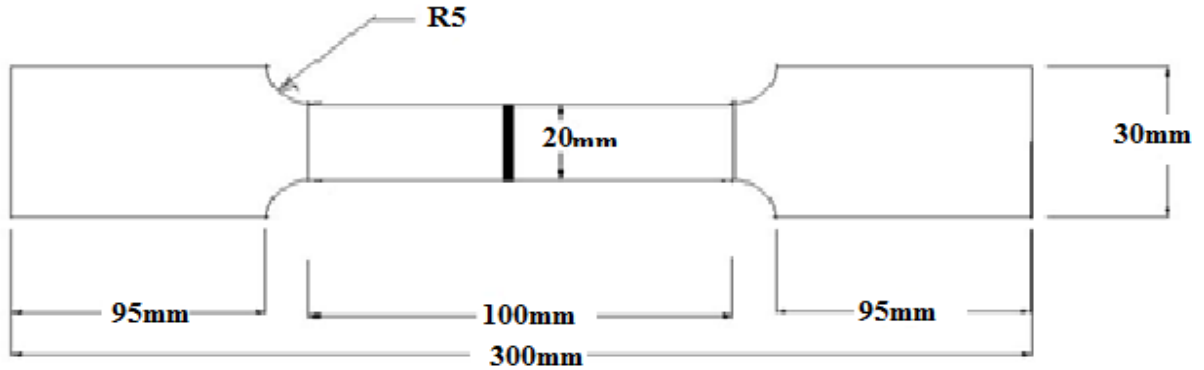


Figure 3. 14 Sample for tensile test



Figure 3.15 Samples for tensile testing

The tensile test specimens, prepared corresponding to L9 Taguchi Orthogonal Array experiments, have been tested for tensile strengths and the results obtained are discussed in chapter four.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Experimental study was conducted to evaluate the effect of welding parameters namely welding current, welding voltage and welding speed on the welding material property of tensile strength, hardness and microstructure of base material, fusion zone and heat affected zone. The results for each experiment are discussed under this chapter. Design of experiment was used to identify the optimum welding parameters and to identify the most influential parameters.

4.2 Formation of different Weld zones of the welded sample

In a welding process, different weld zones are formed due to the addition of new materials at the weld joint and the solidification process. Those are: fusion zone, HAZ and parent metal as shown in Figure 4.1.

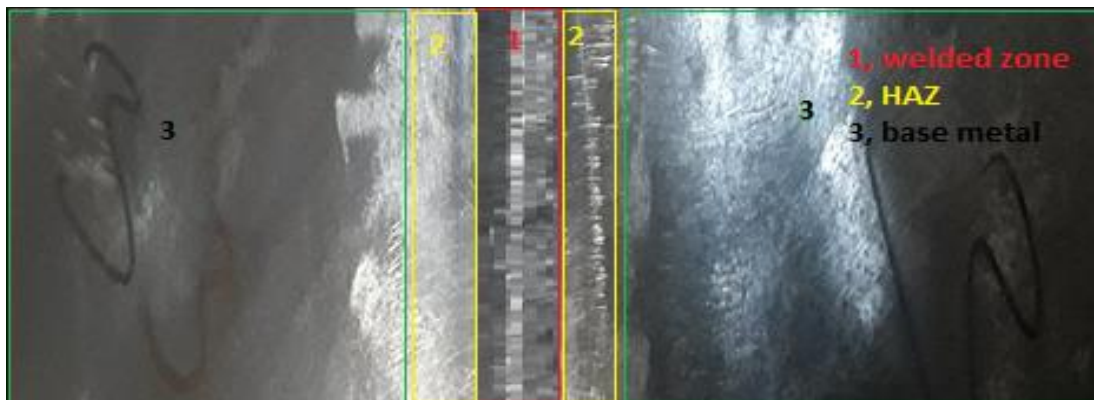


Figure 4.1 Formation of different weld zones

4.2.1 Weld zone

The central zone is the fusion zone changes as shown in figure 4.1, which comprises the filler metal and part of the base metal and it is termed the weld bead. It is due to the purpose of the welding process, which forms the actual weld joint. It is formed by the addition of filler metal and the melting of the parts of the base metal. Under high welding temperature,

it forms a pool of molten metals, which on solidification becomes strong joint and the strength of this fusion zone was analyzed in this work.

4.2.2 Heat affected zone

The area adjacent to the fusion zone on either side is termed as the Heat Affected Zone (HAZ). This zone is not the fused zone, but subjected to high temperature for a short duration by the central fusion zone.

The heat-affected zone is the area of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by welding or intensive cutting operation. The thermal diffusivity plays an important role. If the diffusivity is high, the material cooling rate is also high and HAZ is alternatively small.

4.2.3 Parent Metal Zone

The last zone in the welded metal is the parent metal shown in Figure 4.1. That is the original base metal itself. This zone is adjacent to the HAZ, but being away and having not experienced high temperatures, it will not have structural and mechanical property changes.

4.3 Results of non-destructive testing

Nondestructive testing (NDT) is a method of testing that does not destroy or impair the usefulness of a welded item. These tests disclose all of the common internal and surface defects that occur when improper welding procedures are used.

4.3.1 Visual inspection

From visual inspection it was found that for certain welding conditions; no defect has been observed. These are for the samples 3, 4, 5, and 6. Test samples 2 and 3 were under penetration and over bead have been found, which might have been caused by improper joint geometry or because of incorrect combination of current, voltage or speed.

Spatter, Slag inclusion, undercut, and uneven penetrations are the types of defects which are found on samples 8 and 9 are caused possibly due to damp filler rod or arc blow or bubble of gas being entrapped in the molten globule of metal expanding with great violence and projecting small drops of metal outside the arc seam.

4.3.2 Ultrasonic inspection

Ultrasonic inspection is one of the most widely used families of methods employed for nondestructive testing (NDT). Ultrasonic testing uses high frequency sound waves of a range between 0.5 to 15 MHz to conduct testing.

Its primary application in the inspection of metals is the detection and characterization of internal flaws. It also is used to detect surface flaws, to define bond characteristics, to measure the thickness and extent of corrosion, structure, grain size, and elastic constants.

The propagation of ultrasonic waves in welding is influenced by crystallographic orientation and size of grains. The number and the positions of the peaks of echo dynamic curve are good indicators of beam deviation and the beam splitting.

4.3.3 Liquid Penetrant Testing

Liquid penetrant examination is a sensitive method of detecting and locating discontinuities, provided the discontinuities are clean and open to the surface. The method employs a penetrating liquid dye which is applied to the properly cleaned surface to be examined and which enters the discontinuity by capillary action. After a suitable dwell time, the excess penetrant is carefully removed from the surface and the part is dried. A developer is then applied which acts as a blotter, drawing the penetrant out of the discontinuity. The penetrant, drawn from an opening on the surface, indicates the presence and location of a discontinuity.

Table 4.1 Summary of observed results on NDT tests

Samples	Visual inspection	Liquid penetrant	Ultrasonic
1	Low Penetration, Over Bead	Defect Free	Defect Free
2		Internal Cracks	Slag Inclusion And Internal Cracks
3, 4, 5	No Defects	Defect Free	Defect Free
6	Defect Free	Internal Cracks	Slag Inclusion And Internal Cracks
7		Defect Free	Defect Free
8	Spatter ,Excessive Deposition,	Molten metal inclusion.	Un melted Metal Inclusion
9			

4.4 Microstructural Analysis

Microstructures determine the mechanical, physical, and chemical properties of materials. For example, the strength and hardness of materials are determined by the number of phases and their grain sizes.

The focus on the analysis of the microstructure in the weld is to examine, if it is possible to see any similarities in the microstructure according to parent material especially near the face of the weld bead and the toe of the weld. Microstructural study of weld joint includes analysis of solidified molten zone, heat-affected-zone (HAZ) and parent material region. Slow cooling rate reduce the interfacial energy between the austenite and ferrite, which results in formation of acicular ferrite. An acicular ferrite microstructure has the potential of combining high tensile strength, high hardness and high toughness of the welded sample. Microstructural stability is more in acicular ferrite compared to bainite in higher temperatures.

4.4.1 Microstructure of Parent Metal

Figure 4.2 shows the microstructure images of the advanced high-strength AHSS of EN-10149-2 S700MC of thickness 2mm steel. According to optical microscopy; this sample contains 60% area fraction ferrite and 40% area fraction Martensite as shown in figure 4.2. The microstructure shown by Metallurgical microscopy demonstrates the dispersed islands of the tempered Martensite (bright-dark phase) at the boundary of the ferrite phase (dark phase) in as shown in fig below. The presence of Martensite in the DP steels determines its resistance, and the amount of this phase can be controlled in such steels. The structure of these steels is a soft ferrite phase in which the martensitic islands are scattered; by increasing the amount of Martensite in the structure, the strength is raised. The behavior of these two-phase steels depends on the volume fraction of phases, morphology, grain size, and the carbon content.

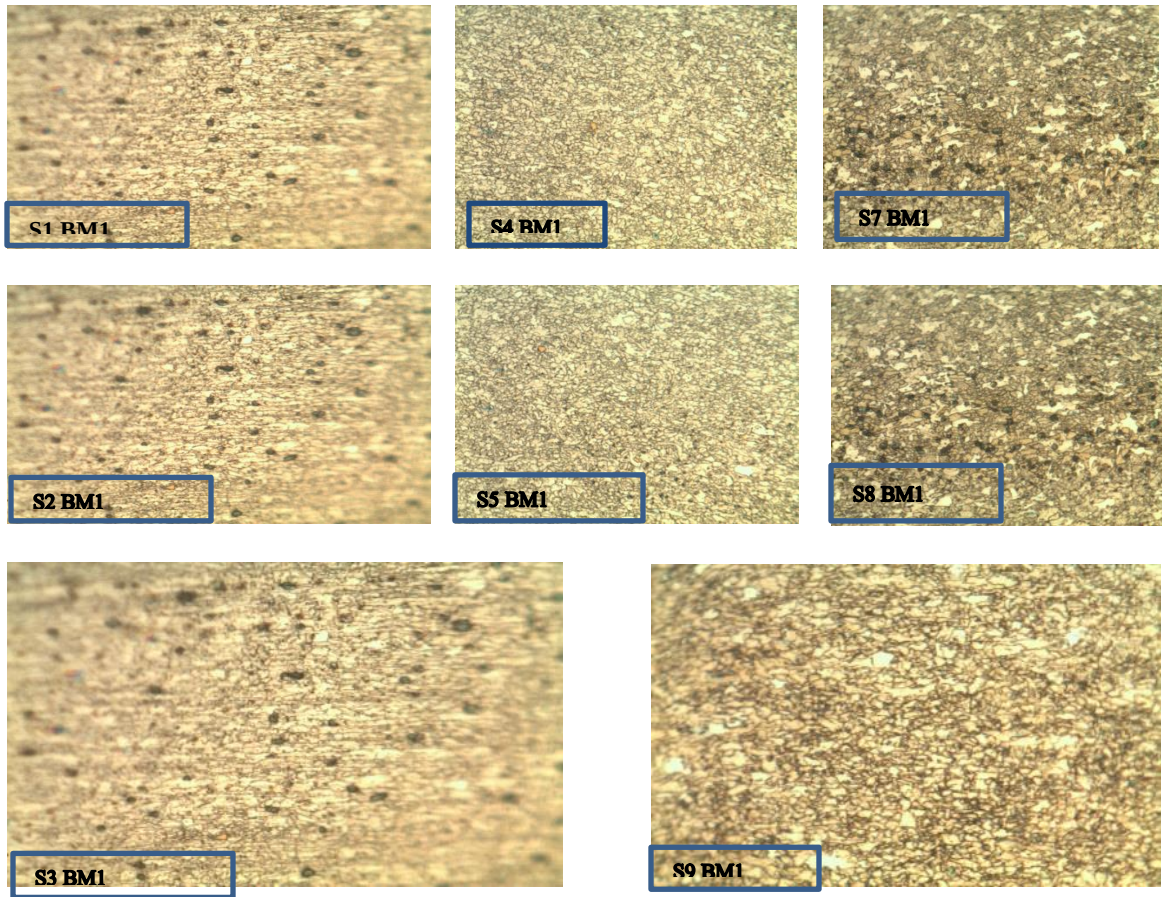


Figure 4.2 Micro structural analysis of parent material (100x)

4.4.2 Microstructure of weld zone

The weld metal microstructure of fusion welded joints is greatly influenced by the chemical composition of filler metal and the heat input ($V \times I \times t$) of the process. When higher heat input, phase transformation occurred in the GMAW. For example due to the addition of filler metal and high heat input, the quite increase in molybdenum and chromium may result in formation of ferrite with martensite and retained austenite and this leads to increase the hardness of weld zone as shown in figure 4.3.

In general, higher heat input leads to slower cooling rate, which results in the coarse grains in weld metal. Due to high heat input and intensity of GMAW process, the coarse grains in weld metal and HAZ were formed as shown in Figure.4.3. The relatively slow cooling rate of GMAW process led to the formation of martensite and acicular ferrite with some retained austenite in weld metal region. It is not possible to produce homogeneous weld metal by

fusion welding process, which is why the hardness of weld zone and heat affected zone were varied at the same heat input.

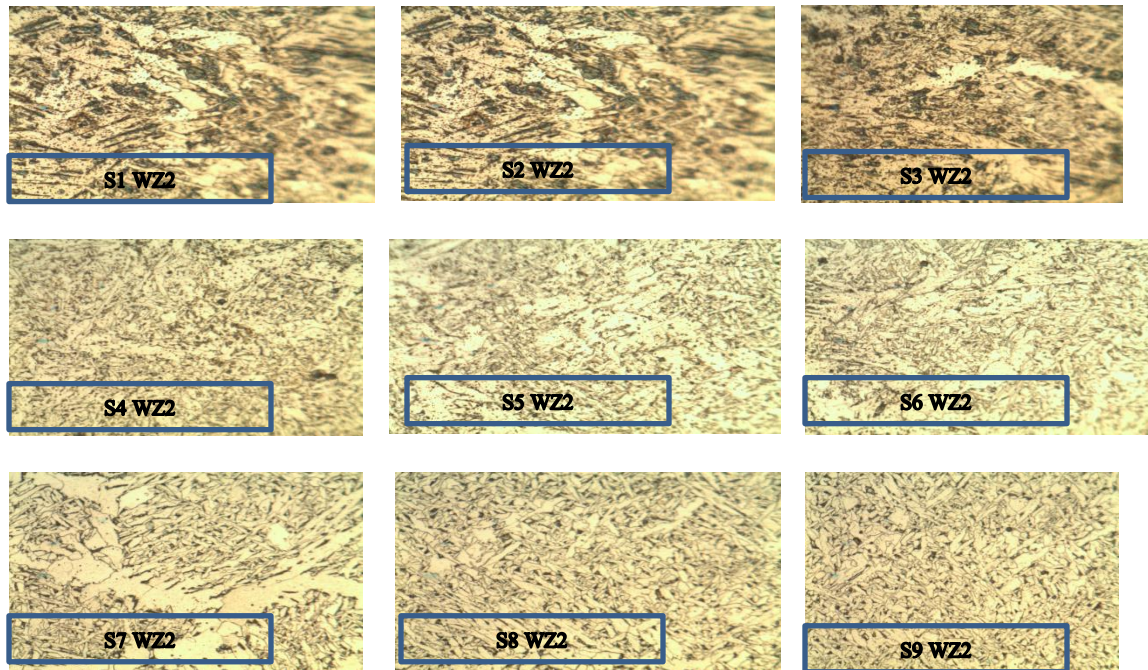


Figure 4.3 Microstructural analysis of WZ(100x)

Since welding involves high temperature, the diffusion of atoms is better promoted. Transition zone formed along the fusion boundary which is chemically discrete compared to both the parent metal.

4.4.3 Microstructure of heat affected zone

The rate of solidification is different compared to the technique followed during the fabrication of the base metal. These results in a significant change in the size of the grains in the HAZ, coarser grains are observed along the fusion boundary as shown in Figure 4.4 below. However, lower heat input leads to fast cooling rate which results in fine microstructure. Though the lower heat input can produce finer grains compared to higher heat input, the intrinsic nature of the process also plays major role in refining the weld metal microstructure.

The major difference between convention AHSS and HSS is their microstructure. Conventional HSS are single phase ferrite steel whereas AHSS are multiphase steel that contains ferrite; martensite, bainite and/ or retained austenite the first generation of AHSS

derive their strength to a large extent from manipulation of microstructures and not from alloying.

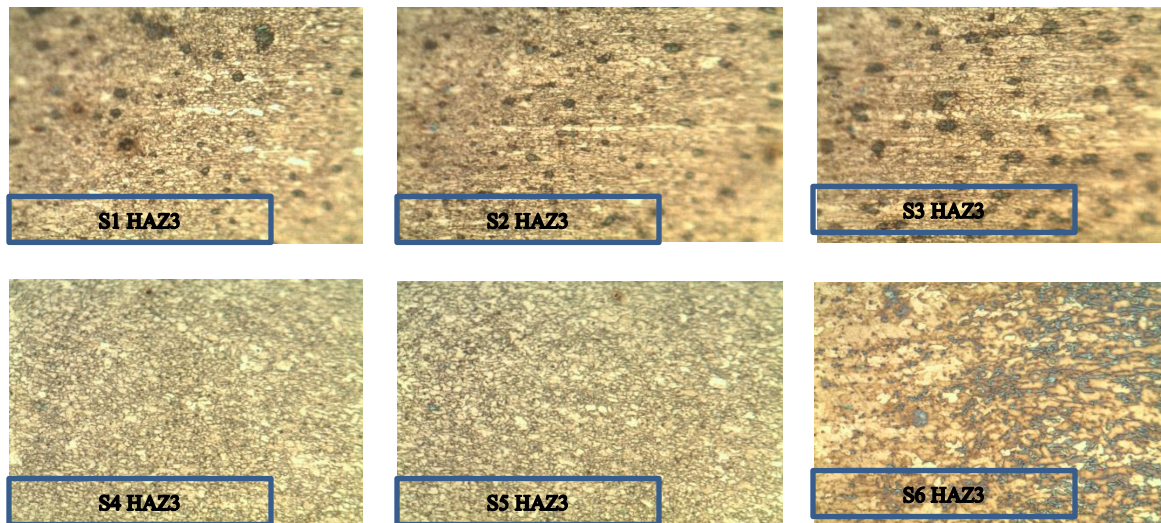


Figure 4.4 Microstructure Analysis of HAZ (100x)

4.5 Hardness analysis of Weld zone

The hardness of the sample material is measured using Vickers hardness machine. The results are recorded and analyzed. For each experiment done we took three samples and for each sample we recorded three trial data.



Figure 4.5 Hardness tested results

The signal to noise ratio has been calculated using MINITAB18 software for each single number of experiments and has been recorded in Table 4.2.

Table 4.2 Hardness of welded zone reading and S/N ratio

S.NO	Welding current	Welding voltage	Welding speed	Hardness of Weld zone	SNRA1	MEAN1
1	60	16	2	135	42.6067	135
2	60	17	4	152	43.6369	152
3	60	18	6	155	43.8066	155
4	65	16	4	140	42.9226	140
5	65	17	6	153	43.6938	153
6	65	18	2	150	43.5218	150
7	70	16	6	150	43.5218	150
8	70	17	2	158	43.9731	158
9	70	18	4	163	44.2438	163

As show in the Table 4.2 the signal to noise ratio of each experiment has been done using either MINITAB18 software or using mathematical equation of larger is better, which is explained in the methodology part. The input experimental values were measured by Vickers hardness testing machine.

By using this formula or the software the results of hardness of welded zone on different set of combination of parameters are shown in Table 4.2. On the basis of these results, the S/N ratio and ANOVA has been calculated separately for every single number of experiments with the help of Minitab software.

4.5.1 Response Table for hardness of weld zone

The response Tables 4.3 and 4.4 shows that the average of each response characteristics (S/N ratio, means) for each level of every variable. The table contains the rank of each variable according to the delta statistics reading which compares the relative magnitude of each variables effect.

Delta statistics can be calculated by subtracting the smallest value from the largest value of the averages of each variable. MINITAB18 software arranges the ranks of the variables according to the reading delta statistic. This software gives the first rank to the higher delta value, the second rank to the variable which has medium delta value and the third rank to the variable with low delta statistics.

In this experimental analysis the voltage has a greater influence followed by current and speed on the signal to noise ratio. According to Taguchi's experimental principle the S/N ratio must be larger. In this work the level averages in the response table shows that the greater S/N ratio and the mean were when the current at 70A, voltage 18V and speed 6mm/s as shown in Figures 4.6 and 4.7. Therefore these values are the proper or optimum welding variables on which maximum hardness of weld zone was occurred.

Larger is better

Table 4.3 Response table for signal to noise ratio for hardness of WZ

Level	Current(A)	Voltage(V)	Speed(mm/s)
1	43.35	43.02	43.37
2	43.38	43.77	43.60
3	43.91	43.86	43.67
Delta	0.56	0.84	0.31
Rank	2	1	3

Table 4.4 Response table for means for hardness of WZ

Level	Current(A)	Voltage(V)	Speed(mm/s)
1	147.3	141.7	147.7
2	147.7	154.3	151.7
3	157.0	156.0	152.7
Delta	9.7	14.3	5.0
Rank	2	1	3

The signal-to-noise ratio allows us to quantify the size of the applied or controlled signal relative to fluctuations that are outside experimental control.

Or in other words it is statistical method used to evaluate the ratio of mean of the required value to the standard deviation from the expected value .As shown in Table 4.3 and 4.4 the S/N of the optimum value of each parameter is almost similar, which means that each parameter in the welding process has equal chance to bring the performance change.

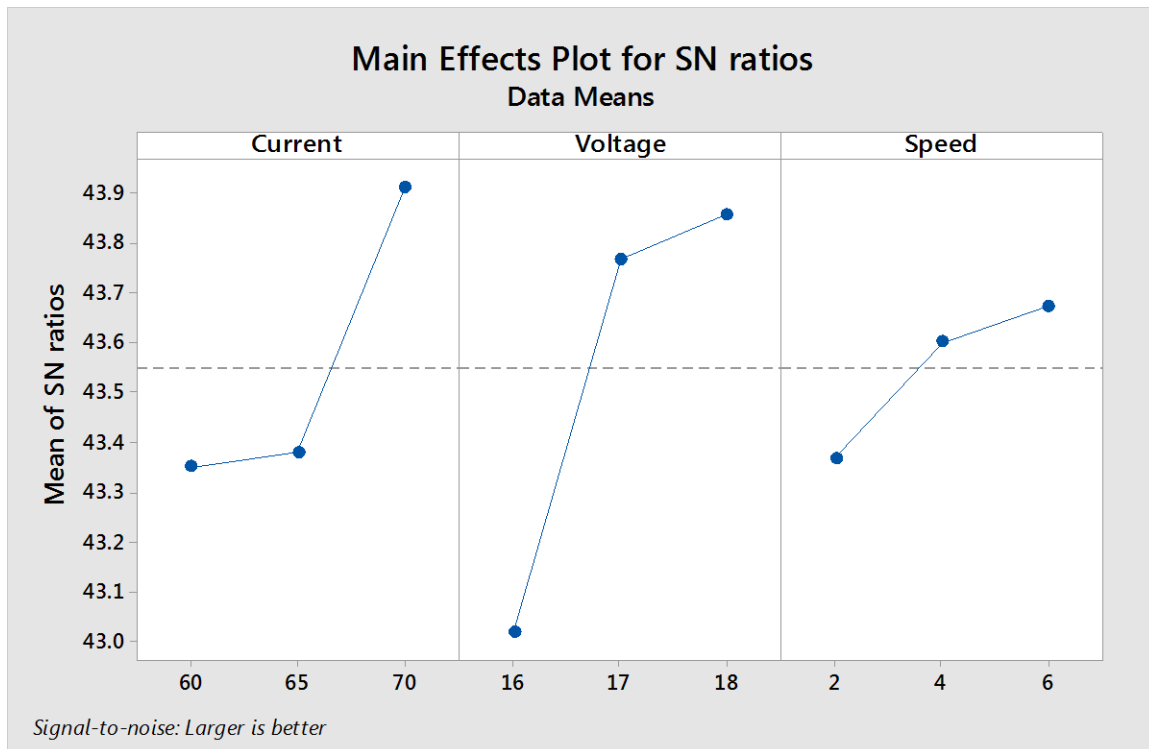


Figure 4.6 Main effect plot for S/N of hardness of welded zone

The adequacy of the model has been investigated by the examination of residuals. The difference between the respective observed response and the predicted response is called residuals.

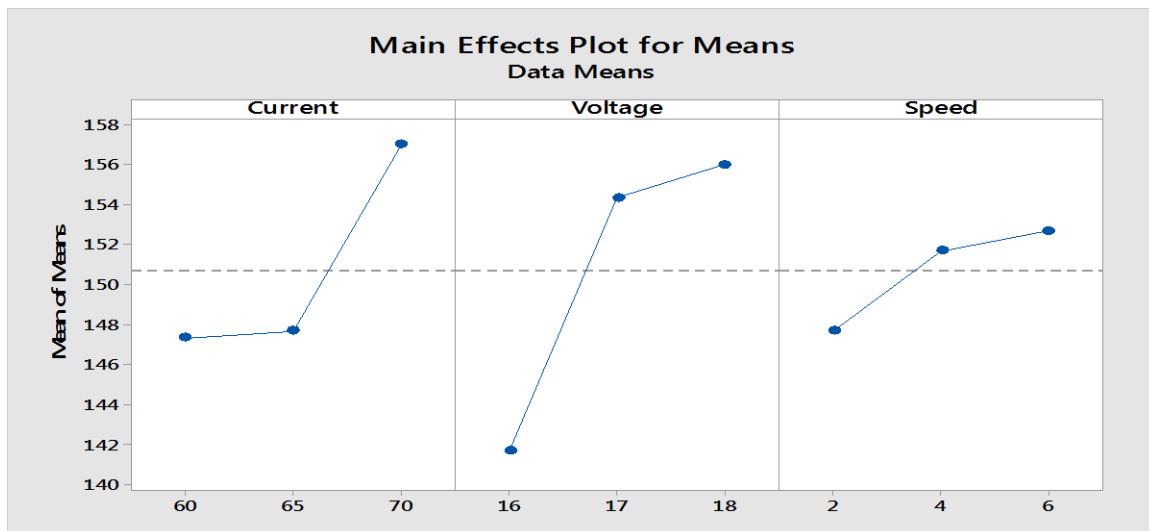


Figure 4.7 Main effects plot for Means of welded zone

Those are examined by using normal probability plot and plot of the residuals vs. predicted response. If the model is adequate, the residual points on the normal probability plot should form a straight line shown in Figure 4.8.

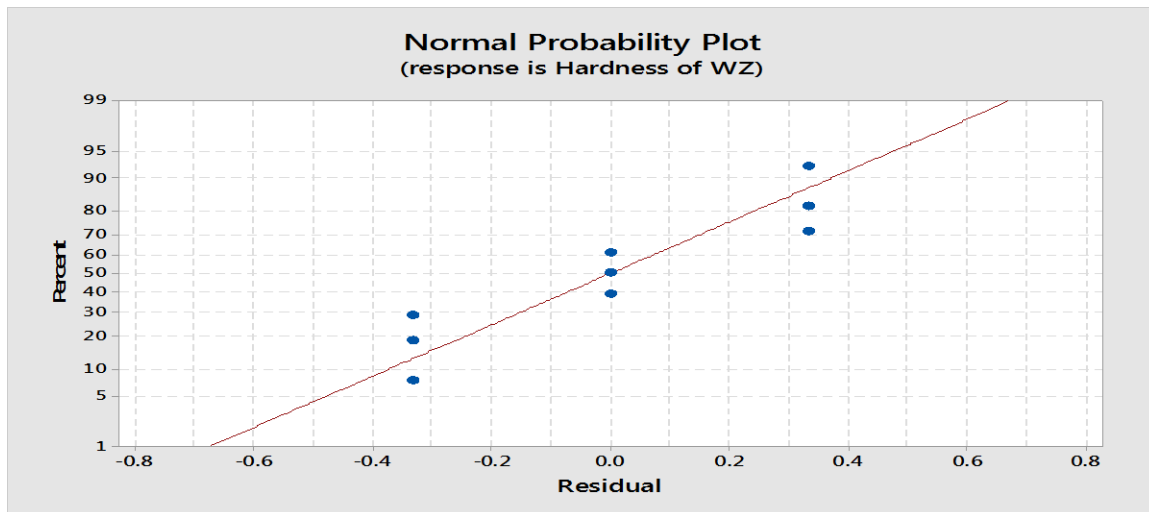


Figure 4.8 Normal probability plot of residual for hardness of weld zone

On the other hand the plot of residuals vs. predicted response should be structure less i.e. it should contain no obvious pattern shown in Figure 4.9. From the normal probability plot it is found that the residuals fall on a straight line; it implies that the errors are distributed normally. The plot of residual vs. predicted / fitted surface roughness values reveals there is no obvious pattern and unusual structure. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

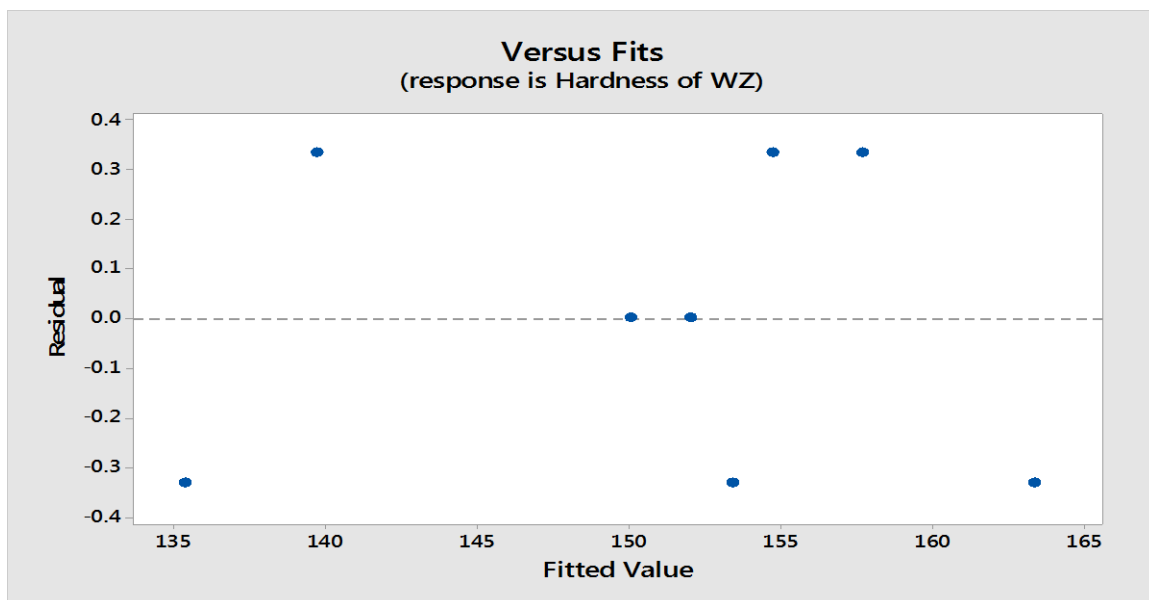


Figure 4.7 Plot of residual vs. fitted hardness of weld zone values

4.5.2 Analysis of Variance (ANOVA) of hardness for weld zone

In order to determine the significance of each variable it is necessary to know the critical 'F' value and comparing this critical 'F' value with the calculated 'F' value. If the calculated 'F' value is greater or equal to the critical 'F' value which is obtained from 0.05 significance level, then the variable is significant. But if it is less than critical value the parameter is non-significant. The critical Value can be obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significant level Table. Based on this principle 'Fcr' (0.05, 2, 8) =4.46 (appendices C) Critical values which is less than 'F' value of from Table 4.5.

In statistical hypothesis testing, a result has statistical significance when it is very unlikely to have occurred given the null hypothesis. More precisely, a study's defined significance level, α , is the probability of the study rejecting the null hypothesis, given that it were true and the p-value of a result, p, is the probability of obtaining a result at least as extreme, given that the null hypothesis were true.

Table 4.5 General linear model of hardness of weld zone

Source	DF	Seq SS	Percent of Contribution	Adj SS	Adj MS	F-value	P value	significance
Current	2	180.667	30.52%	180.667	90.333	271.00	0.004	Significant
Voltage	2	368.667	62.27%	368.667	184.333	553.00	0.002	Highly Significant
Speed	2	42.000	7.09%	42.000	21.000	63.00	0.016	Less Significant
Error	2	0.667	0.11%	0.667	0.333			
Total	8	592.000	100.00%					

The result is statistically significant, by the standards of the study, when $p < \alpha$. And effect of the significant feature can be determined according to 'F' and 'P' Values which is explained as follow. Table 4.5 shows that the parameters current and voltage have 'p' value less than 0.05% which means those variables have significant influence on the hardness of weld zone

of the weld sample using GMAW process. When we arrange their numerical value voltage has a greater influence with 'p' and 'f' values of 0.002 and 553, followed by current 0.004 and 271 and followed by speed 0.016 and 63.

Also percentage contribution is one way to know the influence of each parameter on the hardness of weld zone. Parameter with high percentage of contribution has high power to change the performance of the system. In this case voltage with 62.27%; current with 30.52% and speed with 7.07% have a rank of 1 to 3 respectively by their percentage of influence.

Total allowable Error= $(0.667/592) \times 100\% = 0.11\%$

4.6 Hardness Analysis for heat affected zone

Hardness of heat affected zone (HAZ) was recorded after the sample was measured using the hardness testing machine and the result of each experiment reading has been recorded and on the base of this reading the signal to noise ratio for each sample was calculated using Minitab18 software as shown in Table 4.6 below.

Table 4.6 Hardness of HAZ reading and S/N ratio

S.NO	Current(A)	Voltage(V)	Speed(mm/s)	Hardness of HAZ	SNRA1	MEAN1
1	60	16	2	129	42.2118	129
2	60	17	4	146	43.2871	146
3	60	18	6	149	43.4637	149
4	65	16	4	134	42.5421	134
5	65	17	6	147	43.3463	147
6	65	18	2	144	43.1672	144
7	70	16	6	143	43.1067	143
8	70	17	2	151	43.5795	151
9	70	18	4	157	43.9180	157

As show in the Table 4.6 the signal to noise ratio of each experiment has been done using MINITAB 18 software of Larger is better which is explained in the methodology part. The input experimental values were measured by Vickers hardness testing machine. By using the

software the results of hardness of HAZ on different set of combination of parameters are shown in the above Table 4.6. On the basis of these results, the S/N ratio has been calculated separately for every single no. of experiments with the help of Minitab software.

The heat input at the weld zone is greater than that of HAZ during welding, the welding process and welding technique both influence the energy input which is used to make a weld. The higher is the energy input, the slower use the cooling rate. Increasing Heat input tends to soften the weld zone, and its hardness level is reduced. From here we can compare that the hardness of heat affected zone is greater than the hardness of weld zone because of the effects of parameters. That means if optimal parameters are not selected the quality of the fusion zone is less than that of the HAZ due to the defect of the weld zone.

4.6.1 Response Table for Heat affected zone

In this experimental analysis the voltage has a greater influence followed by current and speed voltage on the signal to noise ratio. According to Taguchi's experiment principle the S/N ratio must be maximum. In this work the level averages in the response shows that the S/N ratio and the mean were maximum when the, voltage at 18V, current at 70A speed and at 6mm/s respectively as shown in Figures 4.10 and 4.11. Therefore these values are the proper or optimum welding variables on which maximum hardness of HAZ was occurred.

Larger is better

Table 4.7 Response table for Signal to Noise ratio of the hardness of HAZ

Level	Current(A)	Voltage(V)	Speed(mm/s)
1	42.99	42.62	42.99
2	43.02	43.40	43.25
3	43.53	43.52	43.31
Delta	0.55	0.90	0.32
Rank	2	1	3

The response Tables 4.7 and 4.8 shows that the average of each response characteristics (S/N ratio, means) for each level of every variable. The table contains the rank of each

variable according to the delta statistics reading which compares the relative magnitude of each variables effect. The signal-to-noise ratio allows us to quantify the size of the applied or controlled signal relative to fluctuations that are outside experimental control. As shown in the Tables the S/N of the optimum value of each parameter is almost similar, which means that each parameter in the welding process has equal chance to bring the performance change.

Delta statistics can be calculated by subtracting the smallest value from the largest value of the averages of each variable. MINITAB18 software arranges the ranks of the variables according to the reading delta statistic from Tables 4.7 and 4.8. This software gives the first rank to the higher delta value, the second rank to the variable which has medium delta value and the third rank to the variable which low delta statistics.

Response Table for Means

Table 4.8 Response table for means of the hardness of HAZ

Level	Current(A)	Voltage(V)	Speed(mm/s)
1	141.3	135.3	141.3
2	141.7	148.0	145.7
3	150.3	150.0	146.3
Delta	9.0	14.7	5.0
Rank	2	1	3

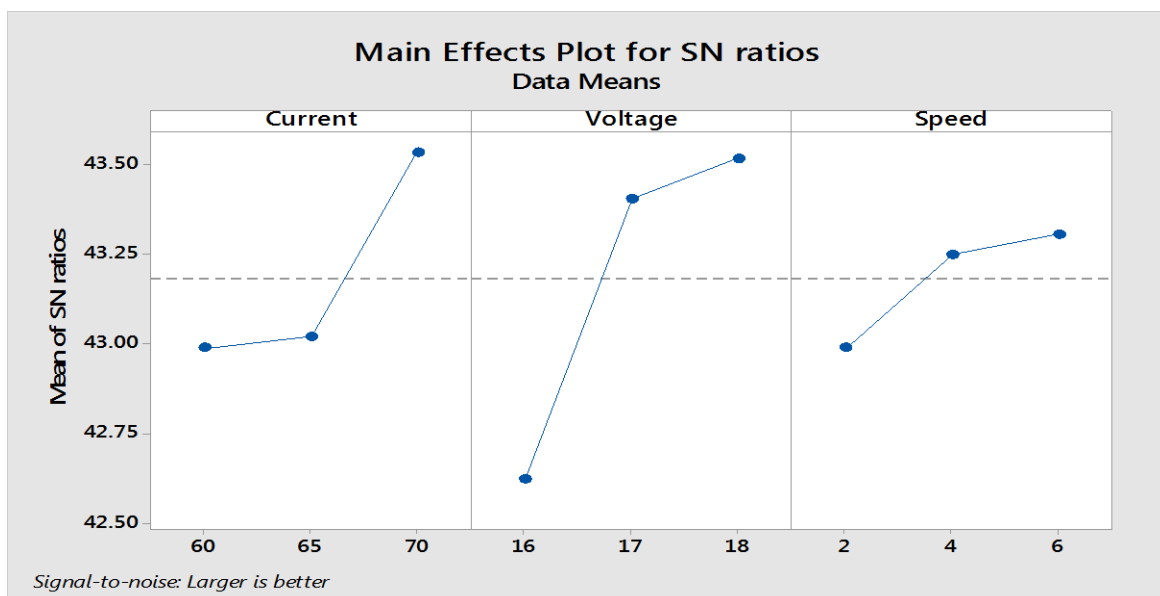


Figure 4.8 Main effect plot for S/N of hardness of Heat Affected zone

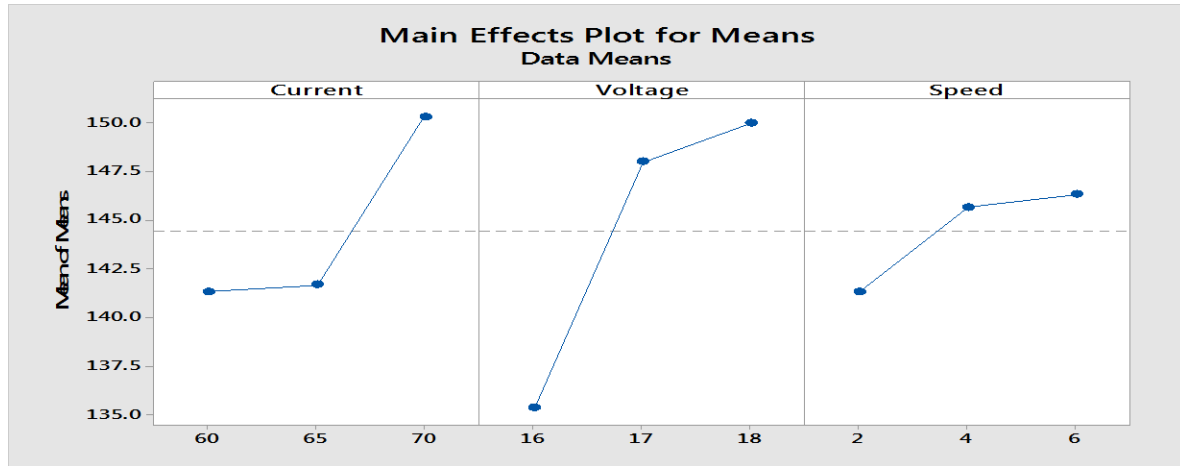


Figure 4.9 Main effects plot for Means of HAZ

4.6.2 Analysis of Variance (ANOVA) for HAZ

In order to determine the significance of each variable it is necessary to know the critical 'F' value and comparing this critical 'F' value with the calculated 'F' value. If the calculated 'F' value is greater or equal to the critical 'F' value which is obtained from 0.05 significance level, then the variable is significant. But if it is less than critical value the parameter is non-significant.

Table 4.9 General linear model of hardness of HAZ ANOVA table

Source	DF	Seq SS	% Contribution	Adj SS	Adj MS	F-Value	P-Value	significance
Current	2	156.222	26.92%	156.222	78.111	703.00	0.001	Significant
Voltage	2	379.556	65.42%	379.556	189.778	1708.00	0.001	Highly Significant
Speed	2	44.222	7.62%	44.222	22.111	199.00	0.005	Less Significant
Error	2	0.222	0.04%	0.222	0.111			
Total	8	580.222	100.00%					

The critical Value can be obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significant level Table. Based on this principle 'Fcr' (0.05, 2, 8) =4.46 (appendices C) Critical values which is less than 'F' value of from table 4.9 above. When we arrange their numerical value voltage has a greater influence with 'p' and

'f' value of 1708 and 0.001, followed by current with 'p' and 'f' value of 703 and 0.001 and speed with 'p' and 'f' value of 199 and 0.005 respectively.

Also percentage contribution is one way to know the influence of each parameter on the hardness. Parameter with high percentage of contribution has high power to change the performance of the system. In this case voltage with 65.42%, current with 26.92%; and speed with 7.62% have a rank of 1 to 3 respectively by their percentage of influence.

Total allowable Error= $(0.222/580.22)*100 = 0.04\%$

The adequacy of the model has been investigated by the examination of residuals. The difference between the respective observed response and the predicted response is called residuals. Those are examined by using normal probability plot and plot of the residuals vs. predicted response. If the model is adequate, the residual points on the normal probability plot should form a straight line.

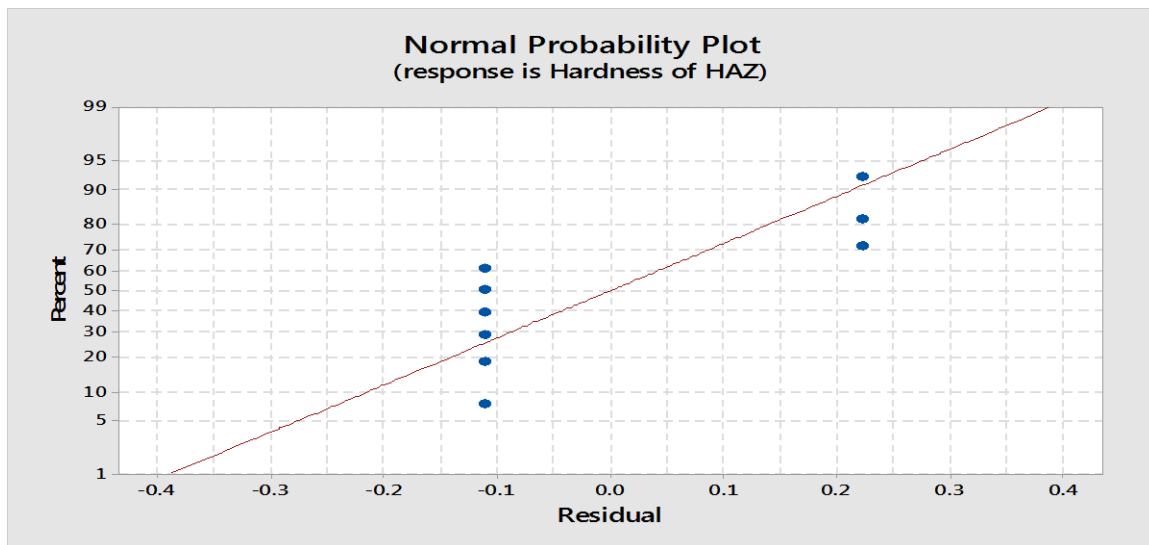


Figure4. 10 Normal probability plot of residual for hardness of weld zone

On the other hand the plot of residuals vs. predicted response should be structure less i.e. it should contain no obvious pattern. From the normal probability plot it is found that the residuals fall on a straight line; it implies that the errors are distributed normally. The plot of residual vs. predicted / fitted surface roughness values reveals there is no obvious pattern and unusual structure. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption as it is shown in Figures 4.12 and 4.13.

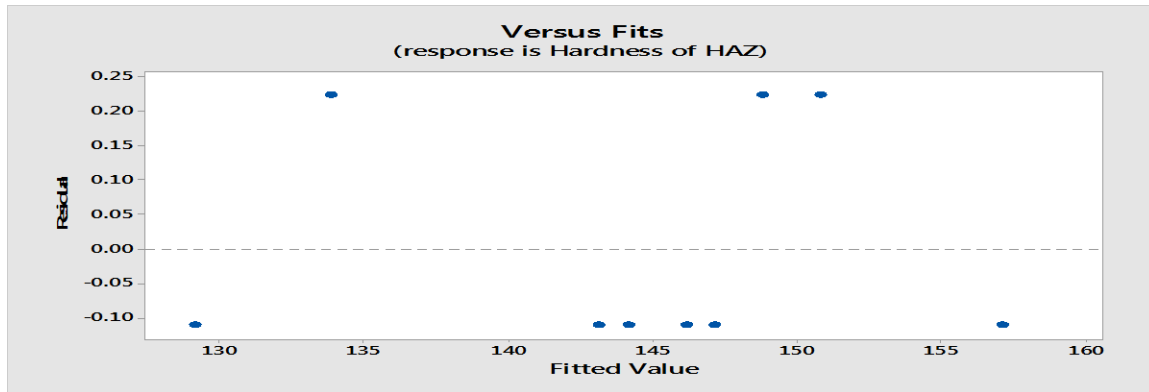


Figure4. 11 Plot of residual vs. fitted hardness of weld zone values

4.7 Analysis of Hardness of parent metal

The microstructure image 100X of EN-10492-2 steel sheet metal material tested by Vickers hardness (VHR) tester, for samples there are three trials performed with 10kg load. Figure 4.14 indicate the surface of sample on which hardness test was performed. The average hardness number of the sample is 158.70. Table 4.10 below shows the trials of test data's for samples.

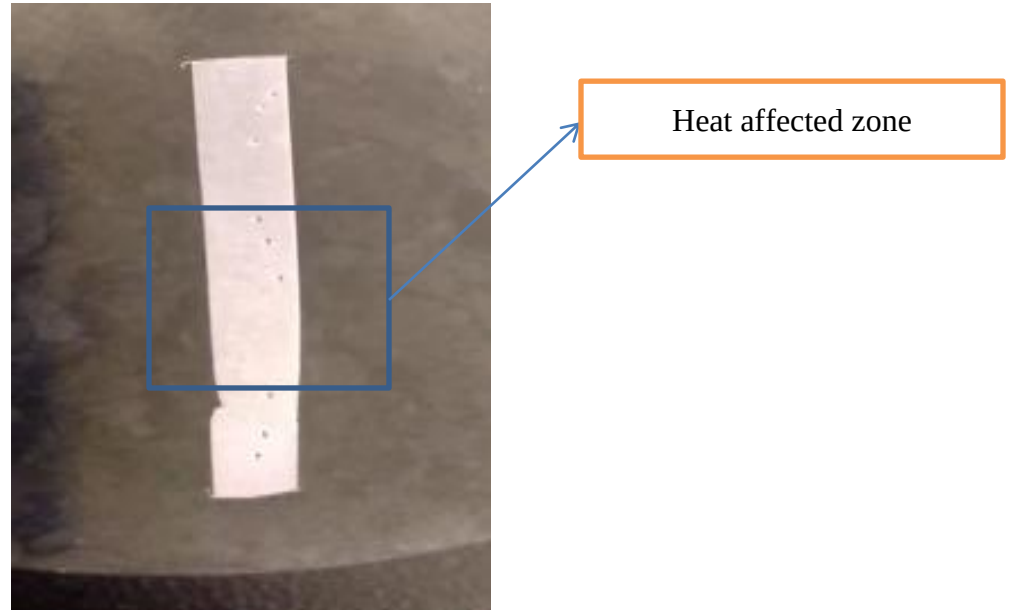


Figure 4.12 Hardness Tested for parent metal

Table 4.10 Vickers Hardness test value

Sample	Parent metal			
	Trial 1	Trial 2	Trial 3	Average Value
sample no 1	166	153	159	159
sample no 2	168	160	170	166
sample no 3	165	150	156	157
sample no 4	140	155	158	151
sample no 5	150	154	162	155
sample no 6	155	168	170	164
sample no 7	171	166	154.3	164
sample no 8	158	157	146.3	154
sample no 9	166	158	149.1	158
average value	160	158	158	158.70

4.8 Tensile strength analysis

After doing tensile testing operation on prepared samples as shown Fig 4.15, the result of the tensile strength on different combination of parameters the data's were recorded and organized to calculate the signal to noise ratio of each sample. The input experimental values were measured using universal tensile testing machine as described in chapter 3.



Figure 4.13 Tensile tested samples

The signal to noise ratio was done using MINITAB 18 software as shown in Table 4.11.

Table 4.11 Tensile strength reading and signal to Noise ratio

S.No	Current (A)	Voltage (V)	Speed (mm/s)	Tensile strength (MPa)	S/N Ratio	MEAN1
1	60	16	2	745	57.4431	745
2	60	17	4	762	57.6391	762
3	60	18	6	775	57.7860	775
4	65	16	4	762	57.6391	762
5	65	17	6	768	57.7072	768
6	65	18	2	785	57.8974	785
7	70	16	6	750	57.5012	750
8	70	17	2	759	57.6048	759
9	70	18	4	782	57.8641	782

As show in the above table the signal to noise ratio of each experiment has been done using MINITAB18 software by selecting the larger is better which is explained in the methodology part. By using this formula or the software the results of tensile strength on different set of combination of parameters are shown in the Table 4.11 above. On the basis of these results, the S/N ratio has been calculated separately for every single number of experiments with the help of Minitab software.

4.8.1 Response Table for tensile strength

The response Table 4.12 below shows that the average of each response characteristics (S/N ratio, means) for each level of every variable. The table contains the rank of each variable according to the delta statistics reading which compares the relative magnitude of each variables effect.

Table 4.12 Response Table for S/N ratio of tensile strength, Larger is better

Level	Current (A)	Voltage (V)	Speed (mm/s)
1	57.62	57.53	57.65
2	57.75	57.65	57.71
3	57.66	57.85	57.66
DELTA	0.13	0.32	0.07
RANK	2	1	3

Delta statistics can be calculated by subtracting the smallest value from the largest value of the averages of each variable. MINITAB18 software arranges the ranks of the variables

according to the reading delta statistic. This software gives the first rank to the higher delta value, the second rank to the variable which has medium delta value and the third rank to the variable which has low delta statistics.

Table 4.13 Response Table for Means tensile strength

LEVEL	Current(A)	Voltage(V)	Speed(mm/s)
1	760.7	752.3	763.0
2	771.7	763.0	768.7
3	763.7	780.7	764.3
DELTA	11.0	28.3	5.7
RANK	2	1	3

This also indicates which level of each factor provides the best result by using the level averages in the response Table 4.12 and 4.13 above.

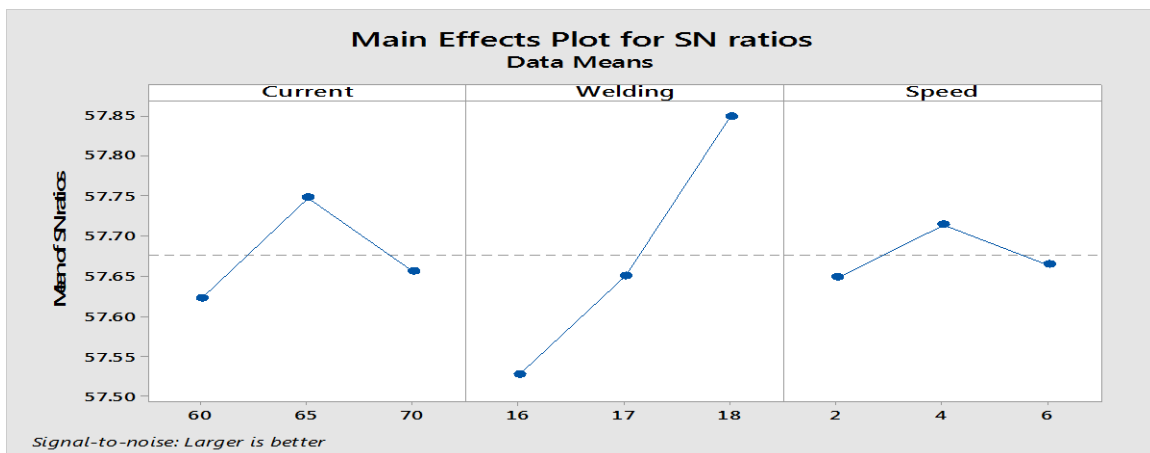


Figure 4.14 Main effect plot for S/N of tensile strength

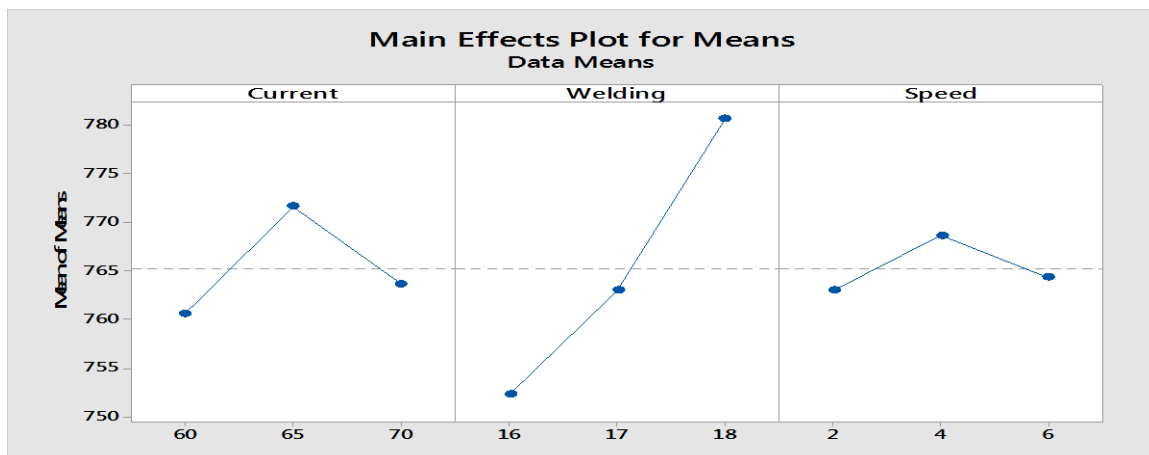


Figure 4. 15 Main effects plot for Means of tensile strength

In this experimental analysis the voltage has a greater influence followed by current and speed on the signal to noise ratio and means analysis. The level averages in the response Tables above 4.11 and 4.12 shows that the S/N ratio and mean are high when voltage, current and speed, were at 18volt, 65A and 4mm/sec, respectively as shown in Figures 4.16 and 4.17. Therefore these values are the proper or optimum welding variables on which maximum tensile strength was achieved.

4.8.2 Analysis of Variance (ANOVA) for Tensile strength

In order to determine the significance of each variable, it is necessary to know the critical F value and comparing this critical F value with the calculated F value. If the calculated F value is greater or equal to the critical F value which is obtained from the 0.05 significance level, then the variable is significant. But if it is less than critical value the parameter is non-significant. The critical F_{cr} value can be obtained by using degree of freedom of each parameter and degree of freedom of the error from 0.05 significant level tables. Based on this principle $F_{cr}(0.05, 2, 8) = 4.46$.

Table 4.14 General linear model of Tensile strength versus current, voltage and speed

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value	significant
Current	2	194.00	13.14%	194.00	97.000	291.00	0.003	significant
Voltage	2	1228.67	83.24%	1228.67	614.333	1843.00	0.001	H. significant
Speed	2	52.67	3.57%	52.67	26.333	79.00	0.012	L. significant
Error	2	0.67	0.05%	0.67	0.333			
Total	8	1476.00	100.00%					

In statistical hypothesis testing, a result has statistical significance, when it is very unlikely to have occurred given the null hypothesis. More precisely, a study's defined significance level, α , is the probability of the study rejecting the null hypothesis, given that it were true and the p-value of a result. p, is the probability of obtaining a result at least as extreme, given that the null hypothesis were true. The result is statistically significant, by the standards of the study, when $p < \alpha$.

And effect of the significant feature can be determined according to F and p Values which is explained as follow.

As shown in Table 4.14 all factors have p value less than 0.05% which means the variables have their own influence on the tensile strength of the weld sample using GMAW process. However their numerical value is different. When we arrange their value voltage, current and speed have p and f of 1843 and 0.001, p and f of 291 and 0.003 and p and f of 79 and 0.012 respectively. From this it was obvious that voltage followed by current and speed have significant effect on tensile strength on welded sample of EN-10149-2 S700MC sheet metal of 2mm thickness.

Also percentage contribution is one way to know the influence of each parameter on the response. Parameter with high percentage of contribution has high power to change the performance of the system. So that voltage with 83.24 %; current with 13.14% and speed with 3.57%; have a rank of 1 to 3 respectively by their percentage of influence.

Total Error= $(0.67/1476)*100=0.05\%$

The adequacy of the model has been investigated by the examination of residuals. The difference between the respective observed response and the predicted response is called residuals. Those are examined by using normal probability plot and plot of the residuals vs. predicted response.

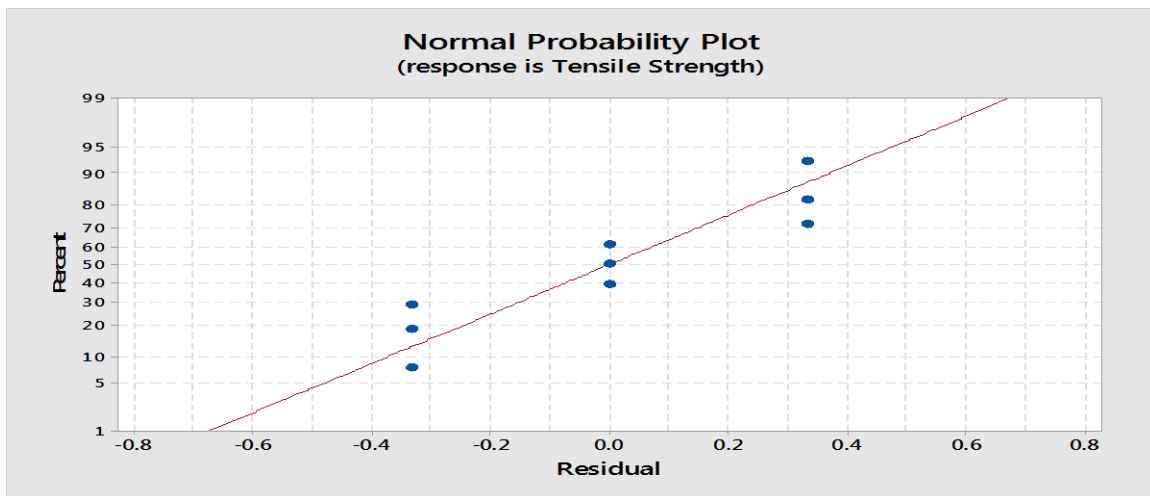


Figure 4.16 Normal probability plot of residual for Tensile strength

If the model is adequate, the residual points on the normal probability plot should form a straight line Figure 4.18. On the other hand the plot of residuals vs. predicted response should be structure less i.e. it should contain no obvious pattern Figure 4.19.

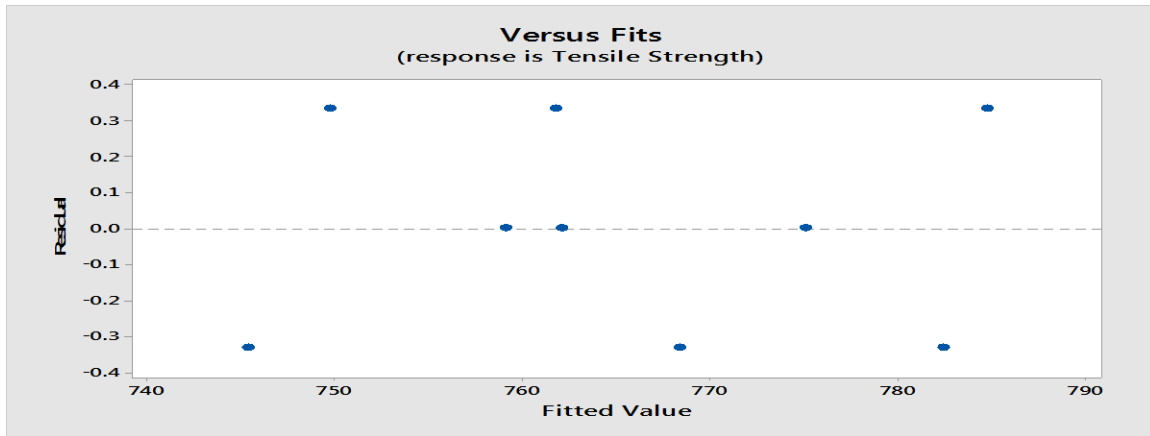


Figure 4.17 Plot of residual vs. fitted tensile strength values

From the normal probability plot it is found that the residuals fall on a straight line; it implies that the errors are distributed normally. The plot of residual vs. predicted / fitted surface roughness values reveals there is no obvious pattern and unusual structure. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

4.9 Effect of Welding Current

Melting rate is directly proportional to the energy (current and voltage) used for a given electrode and polarity used in DC welding. Welding current is most important variable affecting melting rate, the deposition rate, the depth of penetration and the amount of base and filler metal melted.

If the current (for a given welding speed) is too high, it will result in:

- Excessive penetration (Thinner plates will melt through)
- Excessive melting of electrode excessive reinforcement
- More heat input to sheets being joined increased distortions

If the welding current is too low, it will result in; inadequate penetration, lack of fusion. Due to this reason the quality of the welded sample also vary and that leads to the variation of the strength and hardness of the weldments.

4.10 Effect of welding voltage

The arc voltage depends on arc length and type of electrode. As arc length increases, arc resistance increases, resulting in higher voltage drop i.e., arc-voltage increases and arc

current decreases. This decrease in current depends upon the slope of volt ampere curve. As the metal droplet transfers through the arc there is a variation in instantaneous arc voltage. Therefore the variation of the power sources also brings the variation of the weld bead geometry and that brings in mechanical property and microstructural change.

4.11 Effect of Welding Speed

Welding speed is the linear rate at which the arc moves with respect to plate along the weld joint. Welding speed generally conforms to a given combination of welding current and arc voltage.

If welding speed is more than required

- Heat input to the joint decreases.
- Less filler metal is deposited than requires, less weld reinforcement height
- Undercut, arc blow, porosity and uneven bead shape may result.

If welding speed is slow

- Filler metal deposition rate increases, more weld reinforcement
- Heat input rate increases
- Weld width increases and reinforcement height also increases more convexity.
- Penetration decreases beyond a certain decrease in speed.
- A large weld pool, rough bead and possible slag inclusion.

With excessively high welding speeds, there is substantial drop in thermal energy per unit length of welded joint resulting in undercutting along the edges of the weld bead because of insufficient backflow of filler metal to fill the path melted by the arc. This indicates that the mechanical property of the welded sample is directly affected by the variation of the speed. Generally each variable has its own influence on the performance change of the welded sample. But the intensity of the influence for each parameter depends upon their level. Sometimes current creates influence and sometimes voltage and speed. It depends on their orthogonal array matrix combination and based on their level.

4.12 Taguchi parameter optimization formula for confirmatory test

$$P_{opt} = X + (C - X) + (V - X) + (S - X) \dots \dots \dots (4.1)$$

Where:-

P_{opt} = Optimal condition

X = is the overall mean of S/N data

C = mean of S/N data for welding current at optimal level

V = mean of S/N data for welding voltage at optimal level

S = mean of S/N data for welding travel speed at optimal level

4.12.1 Parameter optimization of hardness of weld zone

The optimal condition for maximum hardness of weld zone was obtained using Minitab18 software.

From Table 4.3 the following data are taken.

The optimum working parameters are I3 V3 S3 (i.e. I=70A, V=18V and S=6 mm/s)

Current at I3 = 70A, voltage at V3 = 18V and speed at S3 = 6 mm/s

X =is the overall mean of S/N data=43.54

$I1$ =mean of S/N data for welding current at level1 = 43.54

$V1$ =mean of S/N data for welding voltage at level1 = 43.55

$S3$ =mean of S/N data for welding travel speed at level3 = 43.54

Then;

Optimal condition for hardness of WZ

$$P_{opt} = (X + (I3 - X) + (V3 - X) + (S3 - X)) \dots\dots\dots (4.2)$$

$$P_{opt} = (43.54 + (43.54 - 43.54) + (43.55 - 43.54) + (43.54 - 43.54))$$

$$P_{opt} = 43.55$$

Predicted performance of WZ hardness

$$y^{2opt cond} = 10^{(P_{opt}/10)} \dots\dots\dots (4.3)$$

$$y^{2opt cond} = 10^{(43.55/10)}$$

$$y^{2opt cond} = 10^{(4.355)}$$

$$y^{2opt cond} = 22646.44$$

$$y = \sqrt{22646.44}$$

$$=150.48 \text{ VHN}$$

Therefore the optimal value for weld zone hardness is 150.48 VHN

From this the researcher concludes that the optimal value for of weld zone hardness is at parameters of current at 70A, voltage at 18V and speed at 6mm/s is **150 VHN**

4.12.2 Parameter optimization of hardness of HAZ

The optimal condition for maximum hardness of HAZ was obtained using MINITAB18 software From Table: 4.7 the following data are taken.

Current at I3 = 70A, voltage at V3 = 18V and speed at S3 = 6 mm/s

X= is the overall mean of S/N data=43.18

I1=mean of S/N data for welding current at level1 = 43.18

V1=mean of S/N data for welding voltage at level1 = 43.18

S3=mean of S/N data for welding travel speed at level3 = 43.18

Then;

Optimal condition for hardness of HAZ

$$P_{opt} = (X + (I3 - X) + (V3 - X) + (S3 - X)) \dots\dots\dots (4.4)$$

$$P_{opt} = (43.18 + (43.18 - 43.18) + (43.18 - 43.18) + (43.18 - 43.18))$$

$$P_{opt} = 43.18$$

Predicted performance hardness of HAZ

$$y^{2opt cond} = 10^{(p_{opt}/10)} \dots\dots\dots (4.5)$$

$$y^{2opt cond} = 10^{(43.18/10)}$$

$$y^{2opt cond} = 10^{(4.318)}$$

$$y^{2opt cond} = 20796.96$$

$$y = \sqrt{20796.96}$$

$$=144.21 \text{ VHN}$$

Therefore the optimal value for HAZ hardness is 144.21VHN

From this the researcher concludes that the optimal value for of HAZ hardness is at parameters of current at 70A, voltage at 18V and speed at 6 mm/s is **144 VHN**.

4.12.3 Taguchi parameter optimization formula for tensile strength

The optimal condition for maximum tensile strength was obtained using MINITAB18 software as;

From Table: 4.12 the following data's were taken.

Current at I2 = 65A, voltage at V3 = 18V and speed at S2 = 4 mm/s

X= is the overall mean of S/N data=57.6757

I2=mean of S/N data for welding current at level2 = 57.6766

V3=mean of S/N data for welding voltage at level3 = 57.6766

S2=mean of S/N data for welding travel speed at level3 = 57.6633

Then;

Optimal condition for tensile strength

$$P_{opt} = (X + (I3 - X) + (V3 - X) + (S3 - X)) \dots \dots \dots (4.6)$$

$$P_{opt} = (57.6757 + (57.6766 - 57.6757) + (57.6766 - 57.6757) + (57.6733 - 57.6757))$$

$$P_{opt} = 57.6751$$

Predicted performance (tensile strength);

$$y^{2opt cond} = 10^{(p_{opt}/10)} \dots \dots \dots (4.7)$$

$$y^{2opt cond} = 10^{(57.6751/10)}$$

$$y^{2opt cond} = 10^{(5.76751)}$$

$$= y^{2opt cond} = 10^{(5.76751)}$$

$$= y^{2opt cond} = 585477.21$$

$$y = \sqrt{585477.21}$$

$$= 765.16 \text{ MPa}$$

Therefore the optimal value for tensile strength is 765.16 MPa.

From this the researcher concludes that the optimal value for tensile strength is at parameters of current 65A, voltage, 18V and speed 4 mm/s is **765 MPa**.

Generally Hardness is a resistance to plastic deformation or it is the ability of the material to localize plastic deformation. That means as the hardness number increase it will have high ability to resist to easily deformation. Therefore welding structural members and other functional joints need proper parameter selection to obtain good weld joint. While we can say Tensile strength is the resistance offered by a material when subjected to external loading. So, stronger the material or increasing the tensile strength, the greater the load it

can withstand and it is reliable to use it in high load carrying member or structure when it is welded using optimal welding parameters.

4.12.4 Confidence Interval vs. Confidence Level

Confidence interval is a range of values that is expected to include an unknown population parameter based on the experiment sample. And Confidence level is how likely the value will fall within the experiment confidence interval. Interval is a range but Confidence level is a percentage. In this work 95% confidence level was used. Probability for 95% (0.95) confidence interval is calculated as

$$\text{Probability} = \text{Confidence interval} + \text{Alpha}/2$$

Where

Alpha is just a shorter word for level of significance. Alpha is the complement of Confidence Level.

$$\text{Alpha} = 1 - \text{confidence level} \quad \dots\dots\dots (4.8)$$

For 95% confidence level, Alpha = 1 - 0.95 = 0.05

$$\text{Probability} = \text{Confidence interval} + \text{Alpha}/2 \quad \dots\dots\dots (4.9)$$

Probability is (0.95 + 0.05/2) = 0.9750

Z value, for probability 0.9750 = 1.96 from probability Table for 95% confidence interval

$$z = 1.96$$

Calculating Margin of Error (E)

$$\text{Margin of Error (E)} = \text{Standard error} \times Z \quad \dots\dots\dots (4.10)$$

$$\text{But Standard error} = \text{Standard deviation} / \text{Square root sample size} \quad \dots\dots\dots (4.11)$$

Standard deviation can be calculated using the following formula

$$SD = \sum_{i=1}^n \frac{(\text{Reading } i - \text{Average})^2}{n-1} \quad \dots\dots\dots (4.12)$$

Where, n is number of experiments

Average of the sample can be calculated as

$$\sum_{i=1}^n \frac{(x_1 + x_2 + \dots + x_n)}{n} \quad \dots\dots\dots (4.13)$$

Using (Eq4.13), average for hardness of weld zone, hardness of heat affected zone and tensile strength were, 150 VHN, 144 VHN and 765 MPa respectively.

And by using (Eq4.12) standard deviation for tensile strength, hardness of weld zone and hardness of heat affected zone were 23.12, 37.89 and 41.92 respectively.

Standard error was calculated using

$$Error = \frac{SD}{\sqrt{n}} \dots\dots\dots (4.14)$$

Where s error= Standard error

SD = Standard deviation

n = Number of experiments

Using (Eq24) standard error for tensile strength, hardness of weld zone and hardness of heat affected zone obtained as 7.70, 12.33 and 13.97 respectively.

$$\text{Margin of error} = \text{standard error} * Z \dots\dots\dots (4.15)$$

Margin of error (E) for tensile strength, hardness of weld zone and hardness of heat affected zone are: 15.08, 7.16 and 8.37 respectively.

Then confidence interval can be calculated as:

$$\text{Predicted value} \pm E \dots\dots\dots (4.16)$$

For hardness of welded zone

$$\text{Upper interval} = \text{predicted value} + E = 150 + 7.16 = 157.16 \text{ VHN.}$$

$$\text{Lower interval} = \text{predicted value} - E = 150 - 7.16 = 142.84 \text{ VHN.}$$

For hardness of HAZ zone

$$\text{Upper interval} = \text{predicted value} + E = 144 + 8.37 = 152.37 \text{ VHN.}$$

$$\text{Lower interval} = \text{predicted value} - E = 144 - 8.37 = 135.63 \text{ VHN.}$$

For tensile strength

$$\text{Upper interval} = \text{predicted value} + E = 765 \text{ MPa} + 15.08 = 780.08 \text{ MPa}$$

$$\text{Lower interval} = \text{predicted value} - E = 765 \text{ MPa} - 15.08 = 749.92 \text{ MPa}$$

4.12.5 Confirmatory test

After doing the experiment an optimal level of welding process parameter is selected. The final step is to predict and verify the improvement of the performance characteristics using the optimum level of the welding process parameters. The purpose of confirmation of experiment is to verify the optimum conditions so as to reduce the variation. Therefore confirmation experiment is conducted by using the levels of optimal setting parameters. This experimental combination of parameters resulted in substantial reduction in variation

of performance characteristics and shows that the factors or parameters and levels chosen from the experiment do provide the desired results. This is done by welding the same base metal by using the same material and selected optimal welding parameters. In this study the experiment has been done three times and the final result was recorded from the average of them. If the predicted and the observed values are close to each other, then the used model is adequate for describing the effect of Parameters on quality characteristics and if there is a large difference in observed values and predicted values then the used model is not adequate.

Table 4.15 Compression between actual (experimental value) and theoretical (expected value) of tensile strength, hardness of weld zone and hardness of HAZ

Optimum parameter obtained by Taguchi method		Result obtained by confirmatory test	Results obtained by Prediction	% Error
		Maximum tensile strength		
Current	65 A	765 MPa	780 MPa	0.9 8%
Voltage	17V			
Speed	4 mm/s			
		Maximum hardness of weld zone		
Current	70 A	150 HVN	157.38 HVN	0.95 %
Voltage	18 V			
Speed	6 mm/s			
		Maximum hardness of HAZ		
Current	70 A	145.1 HVN	166.47 HVN	0.86 %
Voltage	18 V			
Speed	6 S			

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This research has described the use of Taguchi and ANOVA techniques for analyzing and optimizing the effect of welding parameters on the mechanical properties of AHSS of EN-10149-2 S700MC of thickness 2mm steel with MIG process. The process was performed using a specific set of controllable variables voltage, current and welding speed for the response variables of tensile strength, hardness microstructure of weld joint.

The study found that the controlled factors had significant influence on the response variables. The orders of the significant effect on the response variable are determined according to their percentage contribution. The result shows the comparison between the experimental and the theoretical values of the tensile strength and the hardness of weld zone.

Optimization is done for maintaining and increasing parent material mechanical and microstructural properties. The tensile strength was increased from 765MPa to 780MPa with a minimum error of 0.5 %.When we use optimum welding variable there is an increment of tensile strength as shown in the confirmatory test. This indicates that the weldment has high ability to resist when subjected to external load. But if tensile strength decreases below the expected value, we can say that the selected parameters were not proper. The hardness of weld zone has been increased from 150VHN to 157VHN and the hardness of HAZ increased from 144VHN to 166.47VHN. Increasing the hardness of weld zone and HAZ means increasing the resistivity of plastic deformation of welded joint and the opposite is true. The last zone in the welded metal is the parent metal zone, which is the original base metal itself. This zone is adjacent to the HAZ, but being away and having not experienced high temperatures, it will not have structural changes. The confirmatory test was done by taking the optimal parameters and the result show that the improvement of the response variables is acceptable and also shows that the method, which was used to optimize is valid. The contribution of the parameters on the change of tensile strength, hardness of weld zone and hardness of heat affected zone has been explains in terms of percentage. The parameter with higher percentage has a great contribution to the change and parameter with low

percentage has low contribution on the performance change. Based on this principle for tensile strength, voltage, current and speed have 83.24%, 13.14%, 3.57% percentage contribution respectively. For hardness of weld zone, voltage, current and speed have 62.27%, 30.52% and 7.07% percentage contribution respectively. And for hardness of heat affected zone, voltage, current and speed have 65.42%, 26.92%, 7.62% percentage contribution for the change. The Main scientific finding of this work is; using optimum MIG welding process parameters it is possible to weld AHSS of EN-10149-2 S700MC of thickness 2mm and get defect free high quality weld joint with maximum required mechanical and microstructural property.

5.2 Recommendations

If proper parameter selection has been done for GMAW process, it is possible to get good mechanical property of the weldment and that can be applicable in different industrial areas like: Automotive industries, construction industry, in shipbuilding industry, heavy equipment industry and in Maintenance and Repair application.

When using the optimal parameters, it is necessary to consider the effects of uncontrolled variables on the quality of the weld joint.

Recommended welding procedure specification for AHSS of EN-10149-2 S700MC of thickness 2mm, is as shown in Table 4.16 to acquire attractive mechanical and microstructural properties. Assuming all other input parameters constant.

Table 4.16 Recommended welding procedure specification

Property of material AHSS of En-10149-2 S700MC of thickness 2mm at room temperature	Parameter		
	Current	Voltage	Speed
Hardness	70amp	18v	6mm/S
Tensile Strength	65amp	17v	4mm/S

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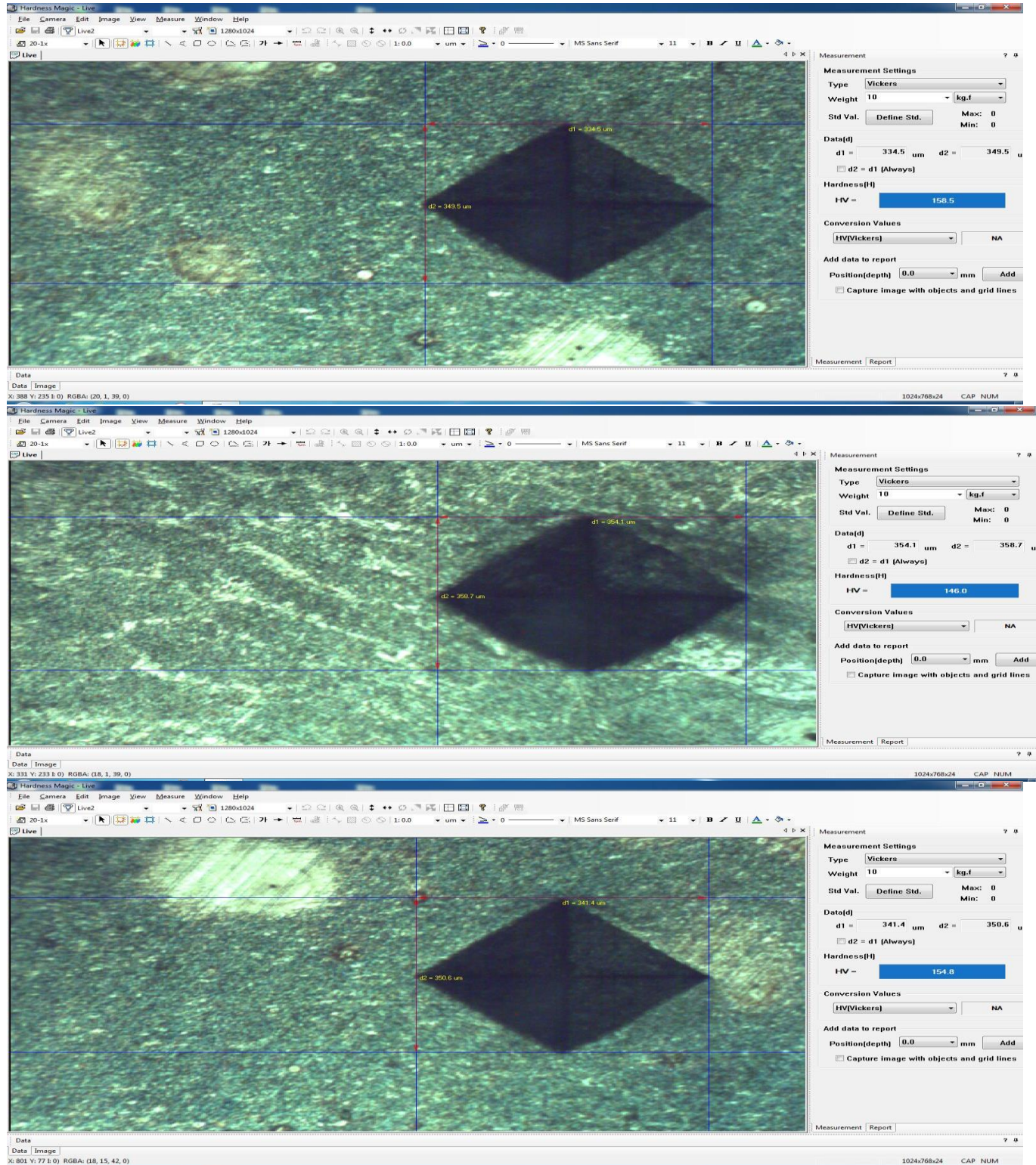
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APPENDICES

Appendices A: Data sheets for tensile test on UTM



Appendices B: Data sheets for hardness test



Appendices C: F critical values

TABLE E										
F critical values										
		Degrees of freedom in the numerator								
		1	2	3	4	5	6	7	8	9
Degrees of freedom in the denominator	p									
	.100	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86
	.050	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54
	.025	647.79	799.50	864.16	899.58	921.85	937.11	948.22	956.66	963.28
	.010	4052.2	4999.5	5403.4	5624.6	5763.6	5859.0	5928.4	5981.1	6022.5
	.001	405284	500000	540379	562500	576405	585937	592873	598144	602284
	.100	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38
	.050	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
	.025	38.51	39.00	39.17	39.25	39.30	39.33	39.36	39.37	39.39
	.010	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
	.001	998.50	999.00	999.17	999.25	999.30	999.33	999.36	999.37	999.39
	.100	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24
	.050	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
	.025	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47
	.010	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
	.001	167.03	148.50	141.11	137.10	134.58	132.85	131.58	130.62	129.86
	.100	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94
	.050	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
	.025	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90
	.010	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
	.001	74.14	61.25	56.18	53.44	51.71	50.53	49.66	49.00	48.47
	.100	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32
	.050	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
	.025	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68
	.010	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
	.001	47.18	37.12	33.20	31.09	29.75	28.83	28.16	27.65	27.24
	.100	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96
	.050	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
	.025	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52
	.010	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
	.001	35.51	27.00	23.70	21.92	20.80	20.03	19.46	19.03	18.69
	.100	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72
	.050	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
	.025	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82
	.010	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
	.001	29.25	21.69	18.77	17.20	16.21	15.52	15.02	14.63	14.33

TABLE E										
F critical values (continued)										
		Degrees of freedom in the numerator								
		1	2	3	4	5	6	7	8	9
Degrees of freedom in the denominator	p									
	.100	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56
	.050	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
	.025	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36
	.010	11.26	8.85	7.59	7.01	6.63	6.37	6.18	6.03	5.91
	.001	25.41	18.49	15.83	14.39	13.48	12.86	12.40	12.05	11.77
	.100	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44
	.050	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
	.025	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03
	.010	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
	.001	22.86	16.39	13.90	12.56	11.71	11.13	10.70	10.37	10.11
	.100	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35
	.050	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
	.025	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78
	.010	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
	.001	21.04	14.91	12.55	11.28	10.48	9.93	9.52	9.20	8.96
	.100	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27
	.050	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
	.025	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59
	.010	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
	.001	19.69	13.81	11.56	10.35	9.58	9.05	8.66	8.35	8.12
	.100	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21
	.050	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
	.025	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44
	.010	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
	.001	18.64	12.97	10.80	9.63	8.89	8.38	8.00	7.71	7.48
	.100	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16
	.050	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
	.025	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31
	.010	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
	.001	17.82	12.31	10.21	9.07	8.35	7.86	7.49	7.21	6.98
	.100	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12
	.050	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
	.025	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21
	.010	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
	.001	17.14	11.78	9.73	8.62	7.92	7.44	7.08	6.80	6.58
	.100	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09
	.050	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
	.025	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12
	.010	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
	.001	16.59	11.34	9.34	8.25	7.57	7.09	6.74	6.47	6.26
	.100	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06
	.050	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
	.025	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05
	.010	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
	.001	16.12	10.97	9.01	7.94	7.27	6.80	6.46	6.19	5.98
	.100	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03
	.050	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
	.025	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98
	.010	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68
	.001	15.72	10.66	8.73	7.68	7.02	6.56	6.22	5.96	5.75